SCALE THEORY

A Nondisciplinary Inquiry

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PART I

Algorithms for a Theory of Scale

Scale is not the exclusive purview of science or the technologies that produce any scalar observations. Rather, these modes of inquiry and extensions of observation (e.g., in microscopes, telescopes, and the many more complicated apparatuses) examine basic aspects of experience that already generate the basis for scalar observations or necessitate the introduction of scale for the understanding and comparing of empirical observations.

On this premise, the following algorithms are fractal unfoldings of principles and definitions that are derived first through three thought experiments that I call "experiential origins of scale." By this I mean basic phenomena that arise in experience that create the need for scale and the basis for producing it. These experiential origins are not produced by first creating an apparatus (as is the case with the creation of a map) or by attempts to understand pre-given objects, but rather through changes in one's approach to observation. These observations are then augmented and extended using technologies that permit us to comprehend this extension beyond typical human experience. This approach positions scale as an attempt to understand basic questions about experience and observation.

I then add three additional "thought experiments *in* scale" that assume the notion of scale laid out in the experiential origins. These thought experiments are more properly experiments in thinking in terms of scale, and they are meant to train the reader in scalar thinking. Along the way I propose some more speculative reconfigurings of some scientific assumptions and approaches. Thus, while the experiential origins are meant to follow a purposefully naive approach to inquiry and observation, the experiments in scale are meant to pave the way toward a more sophisticated and far-reaching extension of the power of scalar thinking.

To show the continuity and application of these points, throughout this work I will refer back to the points made here using the paragraph numbers.

1

Distance and Resolution

The First Experiential Origin of Scale

1.1—Let us start with a common observation. In front of me is an object: a tree. If I move away from the tree, the tree gets smaller. If I were to keep moving away from the tree while still keeping it in view—going to the top of a mountain, perhaps—I would find that the tree loses more and more detail until it merges into another object: the tree becomes part of a new entity called forest. The phrase "you can't see the forest for the trees" becomes more meaningful as a statement about how the entity "forest" is a larger phenomenon that is not perceptible from the same position that one sees "trees." The basic experience is that, in the view of trees, one does not discern this larger object, forest. This truism points to how this observation is not in any way new. Yet, if considered in its simplicity, it can unfold into a series of more significant observations about observation that generates the need for scale.

1.2—Clearly there is something fundamental about the brain's processing of a visual field that produces this shift. However, if we were to proceed through the science of optics, searching for aspects of the processing of visual signals that produces these shifts in appearance, we would only find a mechanism for producing this change.[1] But tracing such a mechanism does not change the fact that this visual shift occurs or explain its implications, but rather tempts us to dismiss it as an artifact of vision rather than a general phenomenon about all observation. (What follows applies to all perceptions, which must contain similar mechanisms for separating out thresholds of perceptibility according to the scale of relevance. Vision, however, makes the shift in scale easy to see [as the metaphor implies] and track with sufficient precision.) We must pause on this simple observation: the change in the relative position of observer and observed leads to an alteration in what is able to be distinguished as an object.

1.3—The view from the mountain already suggests a fundamental characteristic of this shift: that individual entities dissolve into different entities when we change the scale of our view. What on one scale appears separate, on a larger scale appears to be one. This is not just a set of entities considered together—a set of trees. Rather, we find a whole new entity—the forest. If we could imagine forgetting that trees exist and only consider these phenomena via the perception of forests, we might consider the nature of "forests" quite differently.

1.4—If we pause here on the mountain, we find it hard to forget, however, that these forests are made of trees. There are at least four reasons for this. First, we look around us and see trees close by and relate them to the forest in the distance. We depend on what is near to provide a perceptual premise to understand more distant perceptions. This amounts to a reassertion of the scale of proximity as a mode of interpreting distant objects on familiar terms.

1.5—Second, our memory and language encode these transformations of perspective in a way that often obscures the shift. For example, "grass" already implies an aggregate in the same way that "forest" implies an aggregate of trees (and other objects). Walt Whitman's famous "leaves of grass" is already a play on this kind of scalar encoding. Thus, in "A Song of Myself" he moves from an opening scalar identification ("I CELEBRATE myself, and sing myself / And what I assume you shall assume, / For every atom belonging to me as good belongs to you") to the image of grass ("I loafe and invite my soul, / I lean and loafe at my ease observing a spear of summer grass"). The awkwardness of singling out a "spear of grass" complements the opening scalar observation by highlighting the ease with which we speak and categorize certain things in aggregate and certain things in part.

1.6—Third, the object "forest" retains an intimate connection with the object "trees," such that, in viewing the forest, we don't think that we've lost sight of trees. Rather, we can retain the sense that in seeing the forest we are seeing many trees together, because the shift is not so great that the object "tree" is rendered completely unfamiliar. Indeed, if a tree is standing by itself, it might be perceived as a tree even from the mountain.

1.7—Finally, the consistency of the change in observation makes the shift seem trivial. The change in the appearance of objects is easily dismissed as a result of distance when we observe that moving away from an object creates this transformation in appearance.

1.8—If we remain at the mountain, our notion of scale will simply be the relation between these relatively familiar objects: the trees here and the forest in the distance. We arrive at what I am isolating here as a *scalar perspective* when we move even farther away from the objects at hand. If we continue to move away—perhaps now via a camera on a spaceship—we will find that even the forest disappears as a distinct entity to be discerned. The key is that, as you move farther away from an object, the familiar objects are entirely transformed, such that, if we were to experience wholly at this new perspective, the familiar objects (both tree and forest) would not be distinguishable at all. At the scale of the planet, as forests give way to colors on a landscape, trees are no longer observable in any way that could clearly be tied to the current observation except via a scalar shift (in this case, literally coming back to Earth).

The significance of this point is clearer if we, somewhat prematurely, go to smaller scales. The discovery of cells, microbes, atoms, and subatomic particles required the delineation of wholly new objects made available for observation at these different scales.

1.9—To mark this complete transformation of objects, we must introduce the notion of "threshold." A threshold is a discontinuity in what is observed, a change in the kind and quality of information that can be perceived as one alters the scale of observation. The need for scale arises when you observe this threshold shift whereby the whole experiential field transforms into new objects and need to make sense of what has happened. (We will arrive at these thresholds again in a different manner in 3.27 and continue to refine the notion of threshold throughout these experiments.)

1.10—Notably, this need for scale arises *before* measurement (the starting point for the second experiential origin); it is not measurement alone that produces scale, and scale is not itself simply a measuring process. Rather, scale arises first from an observational shift in the objects able to be perceived. Thus, scale relates first to observational thresholds rather than physical thresholds, since the first describes changes in what might be discerned while the second describes changes in the scale of an object (an object getting larger or smaller), which presumes that object in advance. While we might characterize this threshold as a phase transition in perception, we can reserve the term "phase transitions" for a later point (see 6.19).

1.11—Considering this observational shift in terms of distance highlights the continuity of the perceptual shift from one scale to another across any scalar threshold. Scale requires this continuity, since this permits us to trace the change in observation across this threshold. We will arrive at other reasons and implications for this continuity later (2.6, 6.6).

1.12—The continuity in the observing apparatus is met equally by the discontinuity in what is observed. This point cannot be emphasized too much: scale entails a consistent and accountable alteration of observation that produces radical changes in what appears in any observation.

1.13—Prior to the 1960s, continuing our experiment in distance via literal movement of the eye was not possible. This points to the essential relation between technology and scale: scale requires technological adjuncts, because scale is only produced when we move beyond the perceptual limits of the human body. Thus, we can rewrite the previous three points: the significance of scale emerges when the lifeworld of objects available to the *Homo sapiens* perceptual apparatus encounters a perception that exceeds these limits.

1.14—Even in going to space, you haven't physically switched scales. That is, the body of the *Homo sapiens* has not become as large as the Earth as if one has eaten the appropriate cake in *Alice in Wonderland*. Thus, you still have the same problems we noted above (1.4–7) at the top of the mountain: you can look around and see objects at the meter scale. However, once we have crossed a scalar threshold, one must ask: what is the relation between these two perspectives? Then one arrives at scale in the disorientation between two radically different perspectives. This is essential: in scaling, we are dealing with two very different experiences and putting them in relation. Scale is not either of these experiences alone but is an experience about two experiences (see 2.5).

1.15—Here, scale results from converting this observational movement into the concept of resolution. Resolution is the amount of detail one can discern within an observation. In relation to scale, resolution can be defined as the range of objects that are able to be taken as information for differentiation at a given observational range.[2] At different resolutions, different objects are discerned, so that one sees not merely small parts of a material but whole new objects. Shifts in resolution and shifts in scale go hand in hand: scale tracks the range of observation, while resolution points to the amount of detail able to be seen at that range.

Converting distance to resolution is truer to how scale moves beyond the human body (1.13). It also makes it possible to scale to the smaller, since simply moving physically closer to an object will not produce a revision of the world of objects unless accompanied by a change in resolution.

1.16—*Scale domains* can be defined as the ranges between thresholds of observation, where the field of objects revises into an entirely new set of objects. Within a scale domain, objects remain relatively recognizable, as the tree does even from the mountain. Thus, a forest remains within the same scale domain as the tree. It is only when we move farther, and the forest becomes a landscape, that we find ourselves shifting scale domains. In the remainder of this project, the phrase "change scales" indicates a shift across a scalar threshold into a new scale domain.

1.17—To change resolution is to change scales even if you don't move. Thus, if we were to remain in orbit and change our perceptual apparatus so that we resolve a singular tree, then we would be changing scales (scaling our perception via change in resolution). This meets the objection that better vision would allow one to view two scales at once or that certain parameters of the apparatus (e.g., the eyesight of a hawk who is able to see a mouse from the sky) cross thresholds of intelligibility.

1.18—The relationship between scale and resolution helps us understand the great innovation of the microscope. The microscope brings out an essential question of a threshold: do we conceptualize these objects in the terms of normal scale experience? We have arrived at a scalar perspective when we no longer consider the things in the microscope as simply really small objects within the same scale domain (cells as small compartments in the skin) but rather as a whole new set of objects (cells as units of their own).

1.19—In this scalar view, we can define objects as those differences that are able to make a difference at a particular range of observation.[3] By "differences" here we mean the grounds for separating objects available within a particular resolution. The tie between differentiation and resolution means that, to some extent, differentiation depends on the level of observation (i.e., scale). We should thus distinguish differentiation from division, since division implies an action taken on a pre-given object rather than a shift in observation. While any given scale provides grounds for differentiation, one must first select the resolution at which differentiation is to be produced.

1.20—Taking resolution (1.15) and the consistency of observation (1.11) together, we can state that scale produces multiple ways of looking at the same "thing" such that it will appear as different objects depending on the scale of observation.

1.21—The major premise implied by this shift in resolution is that any given differentiation might be rendered otherwise. Returning to 1.3, we can state the conclusion more generally: what appears differentiated on one scale is differentiated differently on another scale. That is, both differentiations and objects depend on the scale of observation. This implies that objects and differentiations are tentative or secondary delineations that depend first on the selection of the range of observation. At the same time, this does not mean that the observer creates the differences available for differentiation at any scale, but only that one must first designate the scale of relevance.

1.22—The unity of seemingly separated objects becomes available as a shift in perspective, not a bringing together of previously ontologically separated entities. As one moves to a larger scale, objects become a single unit as disparate things come together into a new object able to be discerned at that scale.

1.23—These units, however, are in turn inevitably parts of larger units. Scale to the largest possible scale imaginable. We can say that the "thing" that is being scaled is itself already "what is," or the Cosmos. By definition, one could not observe this "thing," since one is inside it and part of it. However, only such a unit that includes all units could be considered a "Whole." As a resolution, this Whole would be observationally One, since no second object could be distinguished apart from it.[4]

1.24—Multiplicity is the discovery of differences that one might resolve within a previously unified object.

1.25—Unity does not annihilate multiplicity but includes it within it as a function of a change in resolution (see also 3.39).

1.26—Scaling smaller reveals multiplicity (more units within a unit), while scaling larger reveals unity (a unit that encompasses given units). However, this logic breaks down at the scalar extremes: there is no reason to assume that reality must continue to produce discernible modes of differentiation at smaller and smaller resolutions. Likewise, the scale of the Whole does not produce a unity in the sense of an object able to be seen together. Thus, both ends of the scale are equivalent to substance in Spinoza's sense, a term already indicating that which underlies, that is, that out of which differentiations might be discovered to discern objects, and equivalent to the Bhagavad Gita's concept of *kūṭastham*, the unchanging, or "that which stands at the top or the highest position."[5]

1.27—The condition of possibility for redifferentiating this same "object" (whether the Whole or any object within that Whole) is that one might divide the world differently. This necessitates a kind of momentary and conceptual zeroing out of the mode of differentiating objects so that one might resolve them differently (see also 2.9). Thus, scale points to the inessentiality of objects and the unity of reality in three different senses via the Whole, the substance, and the negation of (which equals the openness of) differentiation.[6]

1.28—Only if we remain on one scale can we assume that an object discernible at that scale is contained and separate in itself. To adequately capture the paradoxical nature of this persistent habit, we can name this *the partial-whole problem*. The partial-whole problem includes all forms of distinctiveness taken as absolute or grounds for the distinction of objects as separate in and of themselves—in short, as "entities." This includes any kind of haecceity (Don Scotus), monads (Leibniz), holons

(Koestler), assemblages (Deleuze and Guattari), autopoietic systems (Maturana and Varela), and individuations (Simondon) that might be distinguished *insofar as they are considered distinct in and of themselves*.[7]

1.29—Because scale crosses us into thresholds beyond our human bodies, we need to be on guard for the ways we apply nonscalar experience to this scalar experience. Nonscalar experience leads us to persist in assuming the pre-given nature of the separation between objects able to be discerned at any given scale. It also tempts us to remain on one scale rather than being open to other possible scales.

1.30—The privileging of any given scale we can call *scalism*.[8] The first scalism is always going to be a privileging of this scale (around one meter), since it is the scale at which *Homo sapiens* live. This meter-scale reality is the nonscalar experience out of which our whole lifeworld, sense of reality, language, and culture is built. However, we can see how other scalisms are easily put into practice, for example, in strong reductionism's assumption that a smaller scale holds more explanatory power than a larger one or the reverse assumption that larger scales inherently control smaller scales.

1.31—This experiment permits us to distinguish what we are here calling "scale" from scaling in the sense of making objects bigger or smaller. I will call this *Gulliver's scaling*. Gulliver's scaling presupposes objects, keeps them intact, and considers making them larger or smaller. Thus, in *Gulliver's Travels* we find very small and very large versions of essentially the same lifeworld of human beings. We find similar operations in *Alice in Wonderland*, Godzilla, King Kong, and similar scalar distortions (more on the nature of these in 2.19). However, this notion of scaling also operates in biology in the idea that organisms have limits to size and scalar proportions in growth (see 3.30).[9] Scaling operations, in the business sense of making an operation function in a wider range of effect, are also a form of Gulliver's scaling.[10]

1.32—We can also separate out cartographic scaling. Cartographic scaling is about representation, while scale here has to do with specifying shifts in observation. As we will discuss later (2.15; chapter 11), these two are related, but to treat this larger apparatus of scale as the same as cartographic scaling is to obscure this essential relation between the transformation of observation and the transformation of reality.

1.33—I am separating out both Gulliver's scaling and cartographic scaling from what I am defining here as "scale itself." I'd argue that the notion of scale I provide here is more fundamental (and thus deserves the title "scale itself") because it extends beyond these changes in objects and underlies these representations. Scale has its own rules, conditions, and possibilities that are derived apart from any Gulliver's scaling and representations.

2

Measurement and Perspective

The Second Experiential Origin of Scale

2.1—Our trip up the mountain in chapter 1 suggests another experiential origin of scale. Given that this change of perspective generates two very different fields of objects, a need arises to compare and relate these two perspectives together. From the perspective of the mountain, how do I find a reference point for understanding the objects that are now in view? The answer: a measure. But how does this measure work, and why is it needed?

2.2—As we noted in our move up the mountain, my usual sense of size is formed by the physical proximity of the body to the structure called "house" (for the sake of quotidian variety, we'll switch from observing trees to houses). If I stand in front of the house, it can take up most, or even all, of the visual field. And yet, in moving away from it, that house takes up less and less of my view. From the top of the mountain, it is hardly noticeable. Our first experiential origin kept us moving further and permitted this horizon of difference whereby "house" could be distinguished to disappear. What if, instead, we take a more rational—literally, ratio-based—approach to this experience and provide a reference for the phenomenon's transformation?

2.3—Thus, we return back to the house and decide to insert a reference to help determine this thing we call "size." The selection of this reference is almost arbitrary—we could choose my hand, a car, a random stick, whatever—except that it will be more convenient if we can take it with us, hold it up to things, and, most importantly, see the object in our immediate experience. Thus, using the whole building as the measure would not be particularly useful, nor would choosing a speck of dust. Truly scalar objects are likewise useless—you can't use galaxies or cells as your base measure in this experiment. Likewise, the reference itself cannot change in length as we use it—so it needs to be a relatively stable object. Importantly, once the reference is chosen, *it is no longer arbitrary*. Now it has become a measure. For the sake of familiarity, let's use a meterstick.

2.4—If we want to measure the length of the house, we hold the meterstick up to the house and count the number of times it goes across the house. If we want, however, to then measure the house as it appears from the mountain, we have a problem. We can hold the meterstick up in front of the eye and find that it is useless for measuring the house. Since we can't put it up against the tactile boundaries of the house while this far away, this measure is completely reliant on how close the meterstick is to our eye. Suddenly the measure itself seems oddly variable despite being chosen for its consistency: if I bring the meterstick close to my eye, it appears that the whole landscape measures one meter and the house perhaps a centimeter, but if I pull it away from my eye, suddenly the house will measure several centimeters. Of course this is absurd, because it is not how we produce a measurement. What has happened? The distance from the house has produced a change in the way the house has appeared. We can thus approach the reference another way, measuring not the object as it appears for us, but *the eye's distance from it*.

2.5—Measuring the eye's distance from the object will produce a reference point for a ratio between the way the object appears and the size of that object depending on the distance from the object.[1] This is, in fact, a somewhat simple mathematical maneuver that is essential to the work of astronomy.[2] What we have done in this operation is move back and forth between the two positions as a function of distance in order to determine the comparative size as it will appear in a visual field. Here it becomes clearer that scale is created only by the relationship between these two very different perspectives (1.14).

2.6—What has changed in the scaling operation? Not the meterstick, the perceptual apparatus, nor the object. Rather, the *position* of the eye has changed. In other words, the *perspectival shift* creates the change (see 1.11).

2.7—What, then, is the measure measuring? As a function of distance, it is measuring the position of the viewing apparatus relative to the object (the eye to the house). But as a function of ratio, we are measuring the relationship between one view (from the mountain) and another view (from in front of the house). In scale, one is *not measuring objects, but perspectives*.

2.8—Furthermore, one of these experiences or perspectives will always be inaccessible or atypical in some way. From the mountain, the house is "over there," and the view of it is different from the usual way of interacting with it. If we went back down to the house, the experience of viewing it from the mountain would now be "over there." In each case, the "here" remains the same, based on the immediate domain of proximal objects, which is compared to the atypical perspective. In fact, the measure was chosen precisely for its ability to refer to this normalized, proximal experience while serving as a reference point for the distant object. The measure provides a consistency based on typical, local experience to make sense of atypical or inaccessible experiences.

2.9—The presence of the objects measured can lead us to forget that we are also measuring perspectives. But the role of perspective is further obscured by that fact that in measuring we attempt as much as possible to treat the *position* of the perspective as a zero point. In "putting the meter against the house" we attempt to zero out perspective by removing any intervening angle or perspectival alteration between the measure and the object. At a distance, we cannot zero out in this way. Instead, to measure properly, you have to take the distance of the eye into account, treating the eye as the place from which the measuring starts but which itself is not added to the measurement. Oddly, this zeroing out *is* to take into account the perspective.[3]

2.10—With a measuring standard in place and a sense of proportion, we can produce scale from the measure itself. Since the measure already contains a reference to your usual experience, it can function to relate *any degree of perception (even nonvisual) to our usual experience by applying the proportion to the measure itself rather than to the visual difference*.

2.11—Here, it becomes clear that scale is not a percept but a concept: scale uses a measure to provide a conceptual relation between two perceptions. Scale is a marker about perception, providing a reference for accounting for variations within perception. But, as a concept, it can also be extended far beyond this proximal experience that we used to produce the relation. In doing so, the concept has not lost its relation to perception but rather encodes this relation—including a standard of consistency and a tie to empirical shifts in observation.

2.12—The measure can now be used to account for observations beyond our experience by increasing the number of measures or cutting up the measure. This compounding and cutting up is the projection of a relation to normal experience that permits us to retain the essential scalar ratio. Doing so produces scale as we are familiar with in science: it permits us not only to consider the house but the house on the scale of the nanometer.

2.13—What has changed in this cutting of the measure? With the size of the nanometer, we have changed the size range of our perspective while retaining a reference to normal perspective. The reference "nanometer" becomes a signifier of the scale of observation.

2.14—These *Homo sapiens* bodies will never really perceive the nanometer scale in the same way they perceive the house. Yet the reference "meter" preserves the relationship between that scale of observation and the scale of experience, at which a meter is clearly discernible. From this perspective, the great innovation of the metric system is that it retains this reference to normal experience clearly in view by simply compounding a measure selected from the scale of normal experience. Such measures embed the appropriate degree of consistency (2.6, 1.11) into the scalar shift.

2.15—In this extension or dissection of the measure, this second perspective—the "over there"—has now become embedded so that, insofar as we try to take it on as an actual perspective, it becomes mediated and represented. When we find ourselves with representations of objects on a scale exceeding the human lifeworld, the whole process becomes further disconnected from perspective. *Now, looking at the map or the picture, we are tempted to state scale as a relation between two objects (the image and the thing being represented)—and this is incorrect.* Rather, when we are looking at the object that contains a scalar image, we are not experiencing that image as an object but rather as a perspective.

These perspectives have been navigated by the scalar relation and embedded within the representation.

2.16—In representation, scale retains the measure as the statement of a relationship to normal experience. The ratio on the map or image says not just "this object is *x* times smaller than the landscape" but "the view you are having of this object bears *x* relationship to your usual experience of the landscape." It is the latter observation that permits us to use a map to maneuver through a landscape. However, this is again why we must distinguish cartographic scaling (1.32) from scale here: representations inevitably have other alterations, filters, or distortions that are a product of the representation rather than the shift in observational scale.

2.17—We can now understand how scale uses a measure to orient us to technologically produced representations. Scale says: "This picture you are viewing of Jupiter would be the equivalent of 139,822,000 of these meters you are familiar with" (Figure 1). I cannot perceive that number of meters stacked next to each other except via this scalar compression. Projecting out the measure taken from our usual perceptual field makes the incomprehensible comprehensible, but in a limited way by using our reference to compare this phenomenon (Jupiter) in relation to our usual phenomena around us. In sum, the scalar notation is a sign that allows the perceiver to perceive her own perception (here, the picture of Jupiter) as it is projected out beyond its usual perceptual constraints but, through the scalar consistency of the measure, rendered in ratio to the phenomenon around them. Without a scalar reference, someone who had never seen Jupiter would have no reason to think it was an object much larger than our whole planet (this could, in fact, be a beautiful little marble or a sphere suspended in a liquid).

2.18—If scale is the relation between one "over there" and another "over here" (2.8)—or the equivalent in the more projected forms of observation—then where is the perspective that is scale? Properly speaking, a scalar perspective is in both places at once: *it is a situated dislocation*.[4] The microscope or telescope does not avoid this problem, but rather more properly takes that "over there" and transforms it, that is, scales it, so that we do not even need to come down from the mountain to see the house as we would standing in front of it. In viewing the house with a telescope or, in a further abstraction, just viewing the image of a

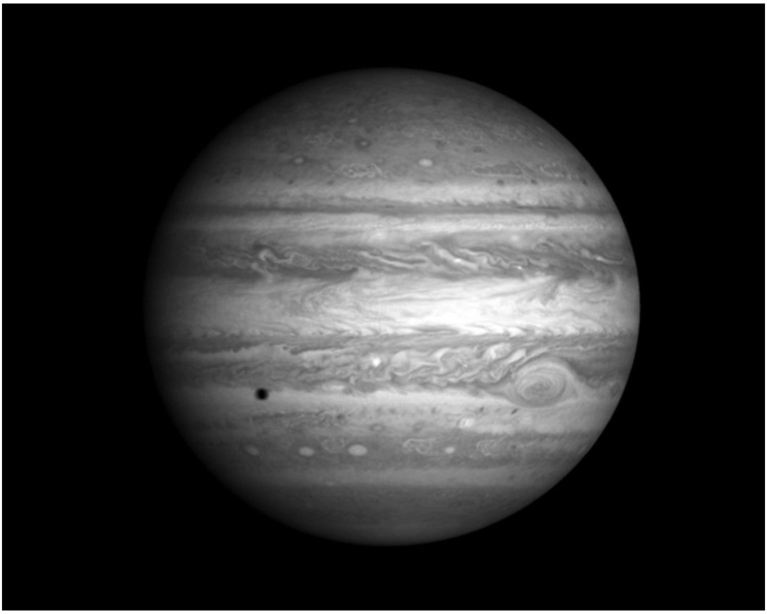

FIGURE 1: This is how to see 139,822,000 meters. Such images not only present an object but represent two perspectives, as long as the scalar relation is in place. Image by NASA, JPL, and University of Arizona.

cell or a planet, we may seem to have made these two perspectives into one. But the making-one of the perspectives is only rendered scalar if within it is buried the reference to two.

2.19—Consider, in contrast, an example of Gulliver's scaling (1.31): the distortions in scale that can occur in film. Prior to computer-generated special effects, filmmakers used the relationship between vision and distance in order to distort the scale of objects.[5] For example, to produce the sense of enlargement, two shots taken at different distances can be overlaid onto each other to produce the sense that something is far larger than it is. Likewise, one might use a proportionally smaller model, as in King Kong. In the former case, two different perspectives are presented as one, which voids scale by overlaying these perspectives without an intervening scalar measure. In the second case, the scale model is presented *as if* it is a normal-scale perception such that the distortion is not taken into account. In both cases, measurement and ratio are impossible. In fact, the "effect" occurs by obscuring them. If we treat the image in the microscope or telescope as functioning in the same way, we miss the fundamental difference in perspective that creates the phenomenon of scale (we will return to this problem in chapter 11).

2.20—*Scale holds oneself to a measure*. This is not to say that the measure is being imposed onto oneself in some arbitrary way. Rather, the consistency of that measure gives one a consistent reference point for tracking the transformation of objects as a function of a transformation in perspective. This "transformation of perspective" is not a transformation of something external to the whole operation out of which the phenomenal world appears. Therefore, the measure is one necessary means of holding oneself consistent for changes in any observation.

2.21—Scaling in the microscope or telescope can be seen as systematic, consistent, and measurable distortions of the apparatus. Likewise, alternative modes of "seeing"—for example, in the atomic-force microscope, protein crystallography, neutrino detection, and so forth—are coherent perspectives as long as they are put in relation to some measure derived from normal experience.

2.22—But in transforming this perspective, the question remains: what has been transformed? What is this entity who is perceiving such that it is capable of such a radical transformation? Our first inclination is to say "the apparatus." But, crucially, even the microscope or telescope *does not change*. Rather, the device is added to perspective so that the eye sees differently. Perhaps we could say that the compound apparatus eye-microscope has changed, but even so, the consistency that renders it all measurable—and therefore accountable as a scaled perception rather than a distortion—requires that all of these factors be taken into account (e.g., accounting for the magnification power being used) in a way that also includes the object, the properties of light, the effects of gravitation, and so on. In less visual or direct modes of observation (e.g., protein crystallography, colliders, neutrino detectors) the problem is only more marked. What and where is that "thing" that sees (or detects or pieces together differences) if all of these are part of the seeing?

2.23—The final step is thus to turn the same apparatus on oneself, not just in the measuring of perception but in the taking into account the one who can maintain and compare these perceptions across these shifts such that one can have, at once, two very different perspectives. The real difficulty will always be, in the situated dislocation (2.18), where is the one who has this "perspective"? Who is scaling? In scaling is there any object, for example, the eye, that can be said to possess the perspective? But, as we have seen, the eye that scales is always already in at least two places at once (2.8), must be taken into account (measured) (2.7), and must be treated as the zero point from which the measuring begins (2.9). But, since scale produces an experience, this question of pinpointing the perspective makes more sense by referring not to each of these individual points of perspective but by reference to the experience of that dual location (1.14, 2.5), and the transformation between them. This dual location is the first way that scale dislocates the subject—subject taken here in the formal sense of the one for whom an object appears.

2.24—This dual location introduces a tension between the production of perspective and identification of the "subject" who has that experience. If we now start from a scalar perspective and ask "who scales?" we can see a further dislocation of the notion of subject, subject now in the sense of identification with an "I" who experiences. Our usual sense of identification might be rewritten as a scalar error: within the normal scale of experience, an object has been selected to be the subject—that to which experience is ascribed. But if we switch scales, acknowledge the tentativeness of objects (1.21), and acknowledge that scale places that perspective in two places at once (2.8), then we cannot likewise ascribe experience to a particular, clearly distinguished object definable in and of itself on one of these particular scales. In other words, we need to extend the partial-whole problem (1.28) to the sense of identification. We can call this the *ego-structure problem* and treat it as a subform of the partial-whole problem.

2.25—Just as we suggested in 1.27 that scale required a momentary zeroing out of differentiation, we must likewise suspend absolute identification with the scale of experience in order to properly grasp a scalar perspective. In other words, "I" cannot identify with one or the other of the perceptions bridged by a scalar reference if the experience is going to be truly scalar.

2.26—The transformation here is thus also a transformation of what one holds to, the experience held to be normal, and the assumption that one will be inevitably emplaced within any apparatus taken as an object on a given scale. Most importantly, scale transforms our sense of our "selves" as the *Homo sapiens* body only definable at the scale of experience. In this sense, the ego-structure problem preempts or perhaps holds in place the partial-whole problem, since the egoic identification provides the grounds for scalism (1.30). It is one thing to attempt to zero out the divisions of the world and another to zero out one's whole complex identification and structure of values built around this-scale experience.

2.27—If one no longer looks for any particular object on any given scale to identify as the subject, then the apparatus or "one who scales" is thus, in a literal sense, the Cosmos itself. That is, if one cannot delimit within the Whole any object to *have* the experience, then the experience is, properly speaking, open to these possibilities and comparisons only because there is not a coherent, separate, divided subject experiencing these things from the outside. Instead, the Whole itself is that out of which, in which, and for which such divisions are made, preserved, compared, and extended.

2.28—The particularity of any experience could then be defined as a specific configuration of the Cosmos delimited within itself in a particular way. If so, properly speaking, within any view on any scale is already contained the whole of what is, filtered according to the particular parameters of that experience. However, for reasons that will become apparent later (5.11), a majority of the universe is too minuscule or too extensive to be registered directly within an experience in a way that produces the thresholds being registered with scale.

2.29—We have, then, projected our "selves" beyond the confines of the "I" and rediscovered a sense in which, properly speaking, this "I" is the Whole experiencing itself in the sense articulated in the Hermetic microcosm/macrocosm or Vedanta's Atman/Brahman. The primary function of these articulations is to transform perspective held to be "mine" for the sake of scrubbing ourselves of the scalism developed out of the habits of this-scale experience and values.

2.30—One might, via another apparatus within the Whole, trace out the significant structures, delimitations, and filters that produce any given scalar experience, using the thresholds provided by scale (1.16, 5.11) to identify a series of relations that produce one observational configuration. Thus, the perception of a protein molecule can be traced, as the anthropologist of science Natasha Myers has done, in a cross-scalar configuration of proteins, crystallographic techniques, polymerase chain reactions, microscopes, modeling, animated gestures, laboratory setups, funding streams, artistic renderings, personal motivations, dance competitions, and so on.[6] It is in this sense that scholars in science studies have emphasized the networks and apparatuses of science. However, this is a secondary tracing that already presumes another apparatus tracing the process of knowledge-making. We will take this point up in chapters 7, 8, and 10, since even these notions of networks or apparatuses do not fully account either for the scalar nature of this tracing or for the way that they dislocate identification even as they situate an experience.

3

Scope and Accumulation

The Third Experiential Origin of Scale

3.1—A final experiential origin of scale can be found in quite a different approach: in terms of the accumulation of knowledge. While we could begin with science, the social lives of humans present us with a starting point that begins from the simple inquiry into one's surroundings.

3.2—Looking around her and attempting to get better at this thing called "surviving," the *Homo sapiens* begins to inquire into the organization of her surroundings. She discovers or is told about some relations: this plant helps with this, these animals are good for that, these people are related to you in that way, and these all bear such and such relationship to ensuring that you get fed, don't get killed, and are able to reproduce. Inquiring into and remembering this map of relations is useful, even necessary for navigating the landscape of this *Homo sapiens*'s experience. Within this relatively immediate field of relations, most things are within reach and limited to what can be handled without much assistance.

3.3—In reality, the scope of consideration for *Homo sapiens* quickly extends into a larger organization of interaction and knowledge, which we can call the tribe, the estate, the city, or the like. Why? Beyond a single *Homo sapiens*'s range of experience, there is a frequency of interaction and an accumulation of data about relations that necessitates a move beyond any *Homo sapiens*'s limited experiential field and cognitive capacity. This creates a point of reference for a larger scope of consideration, relations, and organization beyond our immediate surroundings.

3.4—This higher point encodes a field of relations as a range of inclusion. The category—for example, the city—in itself is not an entity of consideration. Rather, the people, interactions, buildings, transactions, conditions, and so forth that are considered together as "city" are the topic of study. The term "city" indicates the interactions within a particular range, as the scope of the interactions to be considered together. To speak of the city is to speak of all of these interactions, and yet the city itself is not any one of those interactions. In this grouping, we find ourselves speaking of the city—its well-being, its structure, its status, its growth, and so forth.

3.5—At this point, the boundaries of the city need not be clearly defined. But the physical location of a city, as well as the limited scope that can be sensibly and usefully grouped within it, means that at some point the city itself becomes more clearly delimited. We can imagine this occurring in relation with another city. In this encounter, the definition and delimitation of the range of relations belonging to that city has to be clarified for the sake of a new set of relations that is now made possible: the relationship between one city and another city.

3.6—We have not quite arrived at scale, but now we encounter a form of logical typing. The theory of logical types was initially proposed by Bertrand Russell as a solution to a problem in set theory of the sort we are dealing with here. Set theory attempts to define the basis of mathematics using sets of (abstract or mathematical) objects. Logical typing becomes necessary when, as is inevitable, you begin to deal with sets of sets. A logical problem arises, known as Russell's Paradox. By way of example: a barber is a man in a city who shaves all those, and only those, men in the city who do not shave themselves. Who shaves the barber? If the barber shaves himself, then he doesn't shave himself. If he doesn't shave himself, then he does. The problem here is that we have two different levels of categorization or sets: the city, a collection of individuals; and the barber, one of those individuals. Because the city contains the individuals, the rule produces a contradiction, since it considers the barber together in one portion (as a city) and the barber apart (as an individual) in another. In response, Russell proposes the theory of logical types, in which you distinguish types according to the level at which you are considering. One arrives at a new level when you make a set of sets, for example, the city is a set of individuals. To fail to acknowledge these distinctions in logical types creates conceptual and interpretive problems, since you fail to acknowledge that what you are referring to is the same entity grouped in two different ways.

3.7—In encountering another city, a logical typing occurs: we become aware of the city as a distinct domain of relations to be discussed and put in contact with other entities that also exist on this higher logical type. But, even as we do so, we risk obscuring the fact that, at this higher logical type, the "city" is already formed and produced out of an aggregation of relations. Indeed, it is usually not so much the "city" that is making this recognition—at least not when considering the *Homo sapiens* within it—but a part of the city taking reference to this larger domain of relations.

3.8—The nuances of this logical typing are further confounded when, as more and more cities find themselves tightly woven in relations, we find ourselves defining nations as an additional logical type above cities. In turn, nations find themselves in relation with each other, and we start to speak of global relations. Each logical typing provides another name to describe a scope of relations. Each expansion of range does not erase the previous set of relations, but instead groups them according to levels at which we consider these relations together. But we must nonetheless attend to the level at which these relations are categorized and designated. To study the interactions within a city involves a different set of interactions that does not necessarily apply in the same way to the interactions between cities, and likewise in nations.

3.9—In this scheme, we have not found scale so much as layers of how humans might group together their relations. A logical typing does not immediately imply scale, particularly since one could create such sets even within the same scale domain according to any delimiting criterion. We find ourselves with the example of the city because of its tie to the basic *Homo sapiens* experience and social life, which provides a basis for the delimitation of logical types. When we apply this same structure not to social organization but to knowledge and inquiry more generally, then we arrive at a more interesting and thorough scheme that brings us to an account of scale.

3.10—Above, we noted that the limits of knowledge are one element prompting us to move to speaking of the city. Just as physical limitations prevent one *Homo sapiens* from building an entire city on her own, inquiry into the nature of reality, broadly conceived, will always fail to be exhaustive. One *Homo sapiens* alone cannot study every interaction and knowledge available even in her vicinity. A limit is inevitably encountered within thought, language, and perception: as one adds more and more to any inquiry, one inevitably reaches a limiting threshold at which there are simply too many objects to consider.

3.11—So what do we usually do? We get someone else to help or rely on the work of others. In doing so, however, the individual comprehension must encode the inquiry and accumulation provided by this cooperation. In scientific work, for example, you cannot repeat every experiment that your further experimentation requires. Others have done this, and others have checked those scholars, and as long as you spend enough time in that conversation to be comfortable with proceeding, you can proceed with them.

3.12—Here we see in knowledge something similar to what we saw in our first thought experiment about perception. Science must always find itself grouping things together, speaking of species, types, systems, and so on which exist on a different logical type than the individual encounters that make up these groups. Doing so makes possible some knowledge of—or at least a way of functionally describing—larger patterns of interaction. Doing so does not necessarily sacrifice the dynamics that produce this aggregate discernment. Instead, this maneuver creates two domains of inquiry: the inquiry into any specific encounter with an object of study, and the aggregation of those entities being studied together.

3.13—Science produces this aggregation effect systematically so that it uses an aggregation of empirical data to go beyond any given empirical moment. This maneuver permits science to expand the scope of empirical inquiry beyond what is immediately experienced. While the technologies of the microscope and the telescope are necessary for expanding the scope of what is *in* present experience, it is the printing press and the circulation of observations that permit the cataloging and accumulation of observation that could extend to large groups of organisms and places.

3.14—In this accumulation, the conception of a larger population or species starts to take on new meaning, as categories (e.g., species, populations, geological formations) that function, much like the city, as reference points for an aggregate of relations. With these larger entities, a shift in thought can occur: you can start to consider their relationship on a new logical type that extends beyond any delimitation according to types of objects in question. Rather than speak of a giraffe interacting with a tree, you speak of these species of giraffe interacting with the larger flora of the savanna or, in turn, the ecosystem as a whole scope of relations.

3.15—There is a difference between studying a bat, bats, and an ecosystem in which bats exist. In the first, you are dealing with a particular creature, here in front of you. In the second, you are dealing with all possible specimens grouped together in a category (species). In the move to the ecosystem, however, a more significant leap has been made: the delimiting criterion by which you only study one group of organisms (the category, bat) has been removed, and instead a whole structure of relations becomes the defining factor. An ecosystem becomes anything that can be designated as relevant within a broader field of relations.

3.16—We have now run into something similar to our designation "city": the ecosystem becomes a domain of relations that includes all relations within a particular spatial scope. However, this domain differs from the city, since the city retains two kinds of forced exclusivity which kept this formulation from being truly scalar: the city is set apart and defined by the humans who would mark out (in their maps and territorial battles) its boundaries, and, more importantly, the city always *uses the human as the defining factor* for cities. In other words, even if it is delimited spatially, the city is a grouping of human relations, while the ecosystem does not necessarily retain a distinction with regard to the relevant kinds of relations.

3.17—Bats do not provide the same logical typing of their relations as do humans. The ecologist may attempt to delimit the ecosystem using spatial criteria as we do with cities: everything within X boundary becomes relevant for study. However, this presents a difficulty, since spatial delimitations on this planet are tenuous and not contained. Scientific studies then must make additional choices about how to delimit their ranges of study. They might attempt to use some kind of boundary phenomena, some of which are less tenuous and porous (e.g., a lake or an organism's body) and some of which are more so (e.g., a river or an organ). This attempt to delimit produces two difficulties. First, any spatial designation within the Earth is already going to have many relations that move across that boundary. This will be the case unless you expand the scope enough that even the ecosystem starts to take on a new set of relations at the scope of the entire planet. The planet then becomes the point of relation for interplanetary interaction (e.g., the sun's energy, the moon's gravitational fields, an occasional extraterrestrial object large enough to affect this planet). Only at the level of planet is a meaningful boundary present for delimiting possibilities of an ecosystem as planetary relations (climate, atmosphere, orbit, gravity). Such planetary interactions are then more clearly relations with something we can call ecosystem, which is now a description of conditions for smaller-scale relations, for example, what is available for bats (see 6.30–33).

3.18—Second, even within that spatial designation on the Earth, there exists more to be included than we might originally discern, a fact made clear by the microscope and other technologies that reveal more to be included within the spatial range already designated. The microbiologist arrives and queries the ecologist: are you also including these microbes in the water as part of the ecosystem?[1]

3.19—In these two problems we encountered a scalar threshold (one in the large, the other in the small). These now prompt us to specify what relations become relevant within a particular range of size. At this point we arrive at scale if we convert something like the magnification power of a microscope into the notion of a range of observation that is not based on any limit or boundary within space (i.e., the borders of a city or lake) but in terms of the size at which one examines that space. Doing so creates this scalar formulation: *to inquire on a particular scale means to include every difference able to make a difference* (1.19) *within a particular size range.* All potential differences able to make a difference become relevant for the study of a particular scale, even if we do not immediately find and register them. This also responds to the objection that one might raise to the first point in 3.17: that plenty of things (even small things relevant for bats, such as sunlight) cross the threshold of the atmosphere and the planet. In turning to size range, we become less concerned about the absoluteness of that boundary and more about the range of relations able to be discerned at any given size. In doing so, the individual logical types formulated by any smaller accumulations come together into a far more significant logical typing that is a true scalar shift: all relations seen at X size become a designation of the scale of inquiry.

3.20—To summarize this progression: in scale we take a range of inquiry and group it together according to common attributes (e.g., all Bats, all Humans). Scale then takes this grouping and turns it into a shift in scope tied to physical location (everything in Q boundary). This physical location or delimitation is then converted into a designation of size (everything at X scale). Now that we have arrived at this scalar configuration, a few essential attributes and implications need to be highlighted.

3.21—Most startlingly, rather than being about a selected grouping, *scale is inherently inclusive*. In fact, it's fundamentally about domains of inclusion, because it is about what can potentially make a difference—that is, form a relation—at a given scale (3.19; 1.19). This has been signaled in 3.20 by the persistent inclusive signifiers "all" and "everything."

3.22—The implication of this inclusiveness is that many "shifts in scale" that we speak about habitually are not properly shifts in scale at all, since they are limited by additional criteria. When we speak of "scaling up" in economics or politics—even in our moving to the city and nation—we have performed only a partial shift in scope. Such a shift might function well enough when dealing with the local realm of actions, where human relations are already clearly embedded in a series of interactions with a local environment. But when we speak of global capital as a new scale of relations, we are already eliding the rest of the significant relations made visible at the scale of the Earth. One cannot speak of global economy or global politics without speaking also of ecology, since the shift in scale occurs in the extended range of relations, not in the mere aggregation of a set of entities already thought to be significant (humans). In short, scale implies that the global scale must include everything contained within the Earth.

3.23—While "all humans" may refer to some aspect of another scale, it is not itself this higher scale. Humans, insofar as they are a definable organism *Homo sapiens*, exist on the scale on which these bodies exist. From a global scale, these humans are a part of a larger domain of relations. The conceptual limitation of our scope of consideration to the human has conflicted directly with the actual change in scale to the planetary that has occurred in practice, perpetuating the neglect that produces the cross-scale disruption of mass extinction, global warming, and widespread pollution. In short, ecology describes the scale of planetary relations, not economics, politics, or culture. Human relations need to be subsumed into ecological relations (as another aspect of ecological relations) alongside the aggregate relations of forests, animal populations, microbial accumulations, fungal networks, and so on.

3.24—In practice, scientists delimit their inquiries to isolate particular factors for study. The filtering of the ecosystem according to bats provides a guiding delimitation in the same way the *Homo sapiens* did above for the city; the "ecosystem" can become anything that is relevant to bats. In doing so, we need to acknowledge that this widening of scope has already admitted into the study the excess already potentially relevant at this scale. This is not, as it might seem initially, that much of a problem, since we can invert the formulation according to this delimiting criterion: if I study a bat population, I cannot study everything on the planet, but I can study anything within the planet as they exist for bats. In addition, science is not usually interested in any single bat but in all bats, and bats as they relate and live in portions of an ecosystem. The conclusion here is just the significant but difficult admission that more is present than can be adequately described. This admission makes apparent the additional criteria as limiting factors and admits that these limits, although functional, will always be exceeded in practice.

3.25—We can now more adequately generalize our notion of threshold and rearticulate in a different way the notion of resolution. The final step of this thought experiment moved us from delimitations of numbers of objects to how we are looking at space more generally. We either expanded our range of inquiry until we found a significant boundary at the planet by which we could delimit the ecosystem (3.17), or we turned to the microbiologist to discover more relations embedded within an object (3.18). When we apply this to the ecosystem, we can say that the selection of the range of the British Isles is not a scalar shift, but a limiting oneself to a particular location. Scalar thresholds do not occur because you chose a particular nanometer segment of the world, but because the relations and objects being considered are those that become noteworthy within the scope of a nanometer.

3.26—To examine a particular scale is, at least in principle, to open the examination up to everything of note at that spatial range. This "everything of note" indicates that to study anything on a particular scale is to enter into a field of relations that immediately extends to all objects of a similar size. A scale presents a particular field of relations that exists within its own scale domain (1.16). This inclusion does not mean that everything is relevant in a given study (e.g., studying bats); indeed, other criteria no doubt enter for determining relevance. But scale has here isolated a range of potential relations that becomes relevant depending on the scale chosen.

3.27—We can now combine these observations with the concepts of thresholds (1.9) and resolution (1.15). These delineations of scale domains or resolutions are significant thresholds at which the field of relations becomes aggregated and new levels or relations are discerned. When scaling larger from our normal world of objects, the noteworthy objects remain relatively within range until we arrive at the level of the planet. If so, then the most sensible delimitation of range is between our normal set of objects and the global, between local weather patterns (it is raining here) and global weather patterns (climate), between local geological features (here is sandstone) and the whole Earth's geological patterns, between a local species (the hummingbird) and the larger ecosystem, which ultimately must mean the entire potential to interact as far as this organism can potentially range, that is, the whole planet.

3.28—At each threshold of relations (i.e., scale) there are new layers of complexity that are tied to the new ranges of differences that are able to make a difference (i.e., be considered relations). On a different scale, one finds a whole new range of possible variation to include within the study. Going to the size of the cell produces not just more to consider but a whole new domain of interactions discernible at that resolution. Indeed, the selection of a scale of inquiry greatly affects what you are going to examine in any inquiry. But again, this is not as great of a problem as it seems initially. Rather, studies can provide useful results by taking advantage of the thresholds at which differences become relevant (see 5.10–12).

3.29—These scalar thresholds are further confirmed by how life has compounded itself according to logical types of size. As J. B. S. Haldane noted as early as 1926, all organisms have a particular size in which they function well.[2] This leads to some significant thresholds at which organisms must not get bigger but must compound themselves by making aggregates of organisms rather than larger organisms. Single-celled organisms work with molecules but can only get to a certain size, at which point the coordination of single-celled organisms becomes necessary for more complex systems. At some point, these become sufficiently intertwined that a new organism is formed that consists of cells. The shift in size thus requires a shift in logical type, which also yields a different scale of perceptual being as this new logical type forms modes of dissecting the relations discernible at that scale (more on these points in chapters 8 and 9). Thus, the perceptual world of the *Homo sapiens* does not exist in the same field of reference that its cells do. The result is that, as long as our cells have what they need, they will do what they do according to a structure that is not necessarily known or fully determined by the larger structure. In turn, the organism next higher to the multicellular world we live in is not groups of humans acting in consort but the biosphere itself, which has always existed as a scale of interaction but which is still in the process, perhaps, of tying itself together as a cybernetically organized entity capable of reflecting on itself.[3]

3.30—What we have found is levels of relations that form size-bound, scalar logical types. Each of these levels creates another level of objects that function in a different way to the multiplicity of entities contained within that domain. Contradictions can emerge when you relate an entity on one scale to one on another scale, since the scope under which they function and appear distinct is different. That is, when you move across scalar logical types (scale domains), contradictions emerge because *you are talking about the same object from two perspectives* (1.20, 6.14). We can mark these as *scalar contradictions* or *scale errors*, to distinguish them from contradictions that emerge from within the same scale.

3.31—To invert 3.26 into a given object on a given scale, we might say that examining an object already admits everything within it on the smaller scales and potential referent to any larger-scale entity it is a part of. These relations, however, would be *scalar relations* outside of the field of relations immediately available for that object at that scale (see 6.29).

3.32—As we've already performed above (3.23), our language and concepts have a way of dealing with scalar relations in the form of speaking according to "all X" that establishes a relationship between two scales. We have to be careful here: "all humans" relates to "all trees" in a different way than I might relate to the tree in my front yard. This logical typing allows us to relate across scales even as it allows us to distinguish them. For instance, "all bacteria" bear a special relation to the planet's regulatory functions that, through their aggregate behaviors, adjust the larger makeup of this planet and provide the feedback mechanism under which the Gaia hypothesis makes sense. But to say that "a bacterium" does so is a scale error (3.30).

3.33—Such incongruity underlies our struggle to understand our own relationship to the planet. I do not exist as "all humans," even though I am included in that set. Yet this "all humans" is significantly altering, in a dangerous way, the terrain and makeup of the Earth's resources and atmosphere. Yet, I am also included in the set "planet." The traveling of this relationship between logical types is necessary for understanding one's relation to ecology. But to assume that one becomes or acts as "all humans"—and thereby can change the world—is not only to misplace oneself on a logical type that does not apply, but may potentially lead one to counterproductive behaviors that neglect the level on which this *Homo sapiens* exists and acts.

3.34—*One can only act on the scale at which one exists*. While we know this intuitively, we do not always articulate social change in this way: we become focused on the results made visible on a higher scale (e.g., we need to save the planet; we need to achieve X political change), such that we risk neglecting the sites from which these larger patterns emerge. In other words, we mistake the larger-scale patterns for personal actions. Even when such patterns can be manufactured or altered in some way, this alteration arises only by connecting into a larger system that mediates this intervention on a new scale.

3.35—We can now attempt to distinguish and name the scale domains according to these thresholds of perception and relations. As per 1.16, a scale domain is distinguished at the point where the objects on the previous scale are no longer discernible, that is, no longer able to be held within the scope of one's examination without creating a scalar designation. From this definition, we have a surprisingly small number of scale domains:

quantum
atomic/molecular (nanometers)
cellular/unicellular (micrometers)
bodily/normal (meters)
planetary/ecological
solar system (range of gravitational field of a sun)
galaxy
observable universe

We will consider these in more detail in 5.8.

3.36—It is interesting that we have some difficulty naming what I have designated here as “bodily/normal” only because this is the ground zero of scale for those *Homo sapiens* defining them. Most terms are inadequate, since they indicate too much content about that scale; for example, the “human scale” implies that it is ours. As a reference point in experience, this normal scale is the perceptual and interactive field on which the bodies of *Homo sapiens* directly act without intermediaries or compounding structures. It therefore also includes very small insects, animals, plants, and nonliving structures of the size we routinely interact with.

3.37—Note that I have left out a number of scale ranges that we might be tempted to include. These might be called *organ structures* with reference specifically to the organs of bodies and organelles of cells (see 5.10). These are the structures that life forms as intermediaries between different scales but which do not themselves consist of a significant enough shift in size to entirely change the set of relations. The reason for this should be clear when we consider that the scales distinguished by geographers and political scientists—local, city, regional/state, nation, global—are reduced in this scheme only to two scales: the normal and the global. This is because, as we stated before (3.16, 3.22), city, state, and nation all preserve their human-centered reference (see chapter 9). All organ structures are not significant shifts in scale for the same reason: they keep their tie to an organism and only become significant within that organism rather than changing the whole field of relations according to the size of their interaction. It may be that organ structures are the primary sites for scalar mediation between smaller-scale components (atoms for cells, cells for organisms) and larger systems across a scalar threshold (see 6.14–15). If so, then cities, forests, nations, lakes, fungal networks, and the like might be more properly considered as organ structures mediating the relationship between meter scale relations and planetary relations.

3.38—Following the argumentative form of our move to the Whole as object (1.23) and subject (2.27), we can ask: if scale functions according to thresholds of relations that are, in some way, within the same object, then what is this object that we might study in inquiring into the world? The term appropriate here is "the All." By "the All" we simply mean "include everything" that could possibly be, not just in terms of the largest size range but all possible resolutions within it. Here the Whole or the One (1.23) is redescribed according to a scope of inclusion rather than a function of unity. Thus, we can describe that-which-is as the One-Whole-All to emphasize these three aspects made clear by the scaling process.

3.39—The All is not a resolution for observation. Rather, it is a threshold of thresholds; it is the inclusion of everything that might be included within any threshold. As the set of all sets, the scale of the All is of a different character than any given scale. Rather than being subject to positive delimitation, the All includes all scales at once but is itself not any one scale. The notion of the All is thus of a different character than anything within it.[4]

3.40—This All-ness creates two reference points for inquiry: the everything and things within the everything. This is one source of the distinction between the one and the many, whether you are speaking of Parmenides's two realms, the Upanishadic Brahman and Maya, or the Hermetic microcosm-macrocosm (see chapter 7).

3.41—Even infinite terms like the All contain within them the possibility of adding more. While infinite terms may seem totalizing, they are inherently built on this openness. An infinite itself is not logically totalizing, as is demonstrated by David Hilbert's Infinite Hotel: if you posited a hotel with a countably infinite number of rooms, all of which are occupied, you can nonetheless always add one more guest to the hotel. When a new guest arrives, you just move each guest from her current room (n) to the next room (n+1) and you've opened up a new spot at the beginning.[5] Scale performs a similar maneuver by fleshing out the All both by adding more scales at which new relations might be discerned as well as leaving open the very limits, spatially and temporally, where relations might be said to exist.

3.42—The scalar descriptions produced by science have greatly expanded what can be considered a part of the All, but they have nonetheless left this openness intact. If anything, science has only reaffirmed that there is more within any given and apparent set of objects and relations as it takes objects that appear to be solid and easily defined (e.g., the body called "mine") and adds to them the relations of cells and atoms, extensive ecological entanglements, and the thermodynamics of suns and whole galaxies.

3.43—Scalar descriptions permit us to hide the openness and not-knowing already inherent in the basis from which these descriptions are drawn. That is, scale permits us to create maps of relations that intelligibly function within and across those fields of relations insofar as we attend to the scale at which we are describing. But within these descriptions and our knowledge of them still lies a deep and essential not-knowing for three reasons: the descriptions of this All remain indefinitely open to what has yet to be included; these descriptions map relations on a scale apart from the entities themselves; and any knowledge of this vast monolith of description will not and cannot be contained wholly by this point of reference called "you" (more on this in chapter 10).

3.44—These broader implications are entailed by the basis of scale itself as an apparatus of inquiry and way of understanding our own observations. Here, at the end of these experiential origins of scale, we can put together a simple definition that distills these considerations: scale is the systematic accounting for significant shifts in a measured range of observation.

4

To the Bottom

The First Thought Experiment in Scale

4.1—In order for any thing to be said to exist whatsoever, a differential must exist out of which a difference can be discerned. Every differential occurs on some scale at which a fluctuation or movement is able to make a difference. If one goes to a smaller scale, any given differential is no longer able to be used to register a difference.

4.2—Thus, if we posit that there might be a smallest scale at which differentials can be perceived and consider a scale smaller than this, then we might properly say, as Parmenides does, that the world is both One and without movement. This lowest scale remains hypothetical, and it might be that we could extend observational capacities to identify differentials at this smaller scale. However, then we merely move to an even smaller scale to find one at which no fluctuations are discernible. Thus, the Planck length[1] might be interpreted as the smallest scale at which differentials might be discerned, but it need not be this length for our experiment to proceed. We'll call this Scale 0.

4.3—If we then return to the scale at which fluctuations (or differentials or quanta) are first able to be discerned, we can track out how such differentials may produce objects at each scale. Let's call this base level Scale A.

4.4—We now need to highlight two essential concepts for the history of physics: a wave is a fluctuation in a continuous substance; and a particle is a discrete object with a discernible difference and boundary, a boundary that marks a concentrated location of affectability.

4.5—I have used the term *fluctuations* to indicate something particular about the particle–wave distinction, as it already causes many conceptual

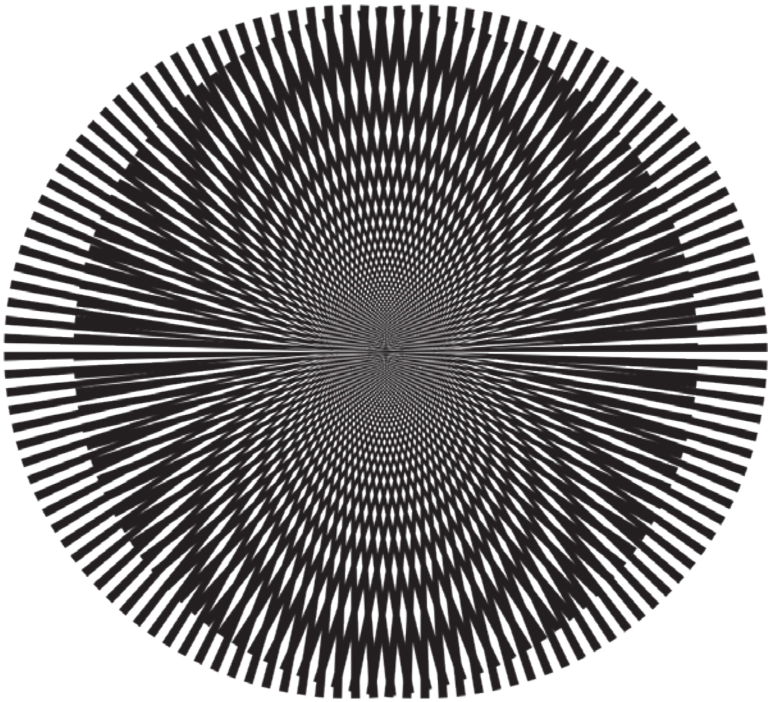

FIGURE 2: An example of moiré phenomena. These two circles made of straight lines produce complex patterns and a sense of depth when overlapping. Moire Lines by SharkD is licensed under CC BY-SA 4.0.

problems in quantum physics (indeed, the difficulty with particle–wave duality may be a result of the following observations).[2] While one might think of waves in terms of common this-scale wave phenomena (e.g., on an ocean), we can conceive wave behavior here as the aggregation of effects—the accumulations of differences that make a difference within what, at Scale 0, is a continuous substance unable to be differentiated.

4.6—The hypothesis is this: particle attributes (or discreteness itself) are an artifact of viewing how fluctuations from a smaller scale aggregate so as to produce a difference that is able to make a difference on a larger scale.

4.7—Wave interaction, diffraction patterns, and related phenomena, such as moiré and beat phenomena (see Figure 2), demonstrate how fluctuations aggregate through interacting patterns in order to create periods of accentuated and negated interaction.[3] When two waves interact, they create patterns where some of the fluctuations cancel each other out and others combine to form bigger patterns. If it is true that such wave interference patterns are generalizable as a principle of aggregation, then we arrive at a fundamental scalar pattern.

4.8—The fluctuations at Scale A, interacting with each other, will create patterns of larger and smaller effects that compound certain fluctuations and negate others. If this compounding is at the edge of a scalar threshold (1.9–10, 1.16, 3.27–28) with Scale B it will create a distinct phenomenon: observing from Scale B, the compounded fluctuations at Scale A will make it appear as if an object has come into existence with the boundaries at the threshold at which those aggregate differences are now discernible at Scale B. In other words, from Scale B, only the aggregate effects that make a difference at that level will be observable (able to make a difference at that scale); everything else will be unobservable at Scale B. In this case, discreteness at Scale B is a result of the aggregating wave patterns at Scale A (Figure 3). Thus, an object—or discreteness and particle attributes—becomes a function of the aggregated effects across thresholds of perceptibility/affectability.

4.9—The movement of this object, now appearing discrete at Scale B, might be conceptualized as itself a wave moving along a string. The "object" might appear to retain essential consistency at Scale B while actually changing place in the fluctuating substance at Scale A.

4.10—We have continued to speak of waves to provide this point about motion of larger-scale objects (at Scale B), tie these effects to wave interference phenomena, and connect these aggregating effects to probability waves. However, this can be misleading, since wave phenomena are usually conceptualized as being on the same scale and do not necessarily result in a sense of apparent discreteness. The point here is that, at Scale B, the aggregating effects of Scale A will appear to be wholly discrete—an object clearly distinct and separable from its surroundings. In reality, the "movement" in 4.9 would be a movement in the aggregation of effects as they compound in size across a scalar threshold.

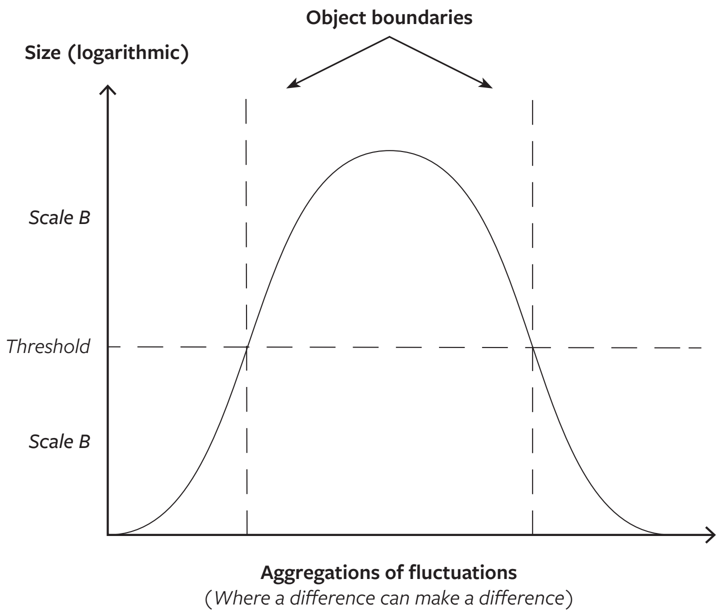

FIGURE 3: Objects as a result of aggregation. The curve is the aggregating of differences that are now able to make a difference at a larger size across a threshold between Scale A and Scale B. From Scale B it will appear that a clearly delimited object exists simply because aspects of the same substance do not aggregate to a sufficiently large degree to make any difference at Scale B, even though they still exist at Scale A. Image created by Graphit Science & Art, LLC.

4.11—If this thought experiment is valid, then the domain of possible objects at any given scale is determined by the pattern of aggregation on the scale below. Or, to put it another way, these objects are a description of principles or possible configurations of the aggregation of fluctuations on a lower scale. Thus, the possible subatomic particles are delimitations of possible aggregations of the scalar threshold below. In turn, the periodic table could be described as the possible aggregating behaviors of subatomic particles.[4]

4.12—After the initial move from Scale A to Scale B, the discrete attributes manifest at Scale B will now be the primary factor for determining what happens on the third scale, Scale C, across another scalar threshold. It seems that with each scale, discreteness plays a more important role, so that, for example, planets become far more significant than cosmic dust with less "stuff" that makes a difference in between. This, perhaps, is the significance that quanta originally played in the development of quantum theory: the quantum scale may be where discreteness emerges as a factor in determining the attributes of larger-scale phenomena. Then, on a larger scale, atoms stabilize this scalar aggregation and generate the possibilities for objects at micrometer scales, where molecular motion and forces are stable enough for patterns of energy to be harnessed in microbial organisms and cells. At the meter scale, volatility is further stabilized into the discernible and relatively stable objects of our lifeworld. Indeed, this provides an explanation for why Newtonian mechanics is able to operate alongside quantum mechanics: many have intuited that the issue is a matter of scale, but this thought experiment provides a potential explanation for why.[5]

4.13—Here discreteness also equals stabilization into relatively determinate patterns in comparison to the scale below. At each level, fluctuations seem to settle into set components with their own attributes and rules of patterning.

4.14—Such stabilization does not necessarily equal less complexity, as is well known in fractal patterns. However, to rediscover the complexity at a particular scale one can widen the scope of consideration, that is, consider a given scale near or at a larger scale. In comparison to the complicated coordination of objects inside a multicellular organism, the organism's body seems like a relatively stable and simple object. But if we consider that organism in relation to complex planetary interaction, complexity reemerges. Thus, we might say that *stability* is a description of viewing a given object in relation to its smaller-scale components, while *complexity* is a description of viewing a given object in relation to its larger-scale relations. A *Homo sapiens* body is a stabilized pattern of trillions of cells but a part of a complex ecology.

4.15—All of these motions are happening and aggregating simultaneously. We could generalize out the point made in 4.9 and conceptualize the movement of a human body, for instance, as also the movement of fluctuations aggregated through the substance described by the unobservable Scale 0.

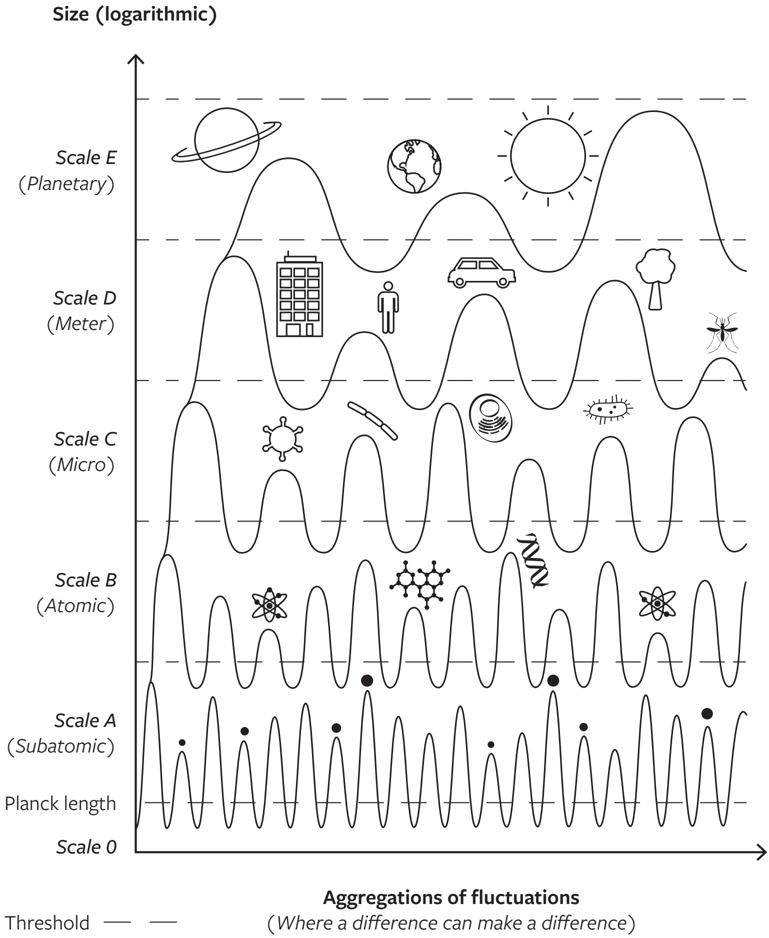

FIGURE 4: The genesis of objects: layering of objects through levels of aggregation and stabilization. If we generalize out the object form of Figure 3, then we can imagine layers in which sets of objects at any given scale are a result of aggregations of the scale below. Each parabola is an apparently discrete object at its given scale, even though it still is part of the same substance seen at lower scales. These then aggregate into objects discernible at a larger scale. Image created by Graphit Science & Art, LLC.

4.16—We could summarize the whole thought experiment as levels of aggregate effects stabilizing into objects at each level, with their own rules provided at each stabilization generated from simple compounding of effects on a lower scale (Figure 4).

4.17—Every part of substance not discernible at a given scale is, properly speaking, still there. It is just simply incapable of being registered at that scale, although it manifests in other ways as part of the patterns of the same substance. The idea that objects are separated by empty space is a product of this-scale lifeworld and vision. In turn, the idea that outer space is largely empty is a product of scales of the solar system or galaxies, where the significant objects, while themselves incredibly large, also imply large gaps between possible effects able to aggregate at those levels.

4.18—It seems that the "spaces" between objects increase in proportion to the size of those objects. This implies that aggregation tends toward proximity.

4.19—Thus, aggregation might be rearticulated as cohesion, particularly when we arrive at or beyond Scale B. Aggregation would be cohesion if considered in terms of how the things at Scale B are able to come together to have effects at Scale C. These points (4.17–19) might be essential for continued attempts to understand what the various "forces" of physics are describing, such as gravity.

4.20—This thought experiment should not be interpreted as reductionist. The experiment here is about the generation of discernible objects such that it produces objects with seemingly empty "space" between them that serve as discrete entities for observation and interaction at any given scale. It is not an argument about causality except to suggest that it is likely that the parameters (degree of freedom of action and existence) on any scale might turn out to be functionally equivalent to the principles of aggregation on the next smallest scale (see 6.21–6.34). The experiment does identify perhaps the most productive element of reductionism: that it has produced the impetus for defining the ground rules for aggregations of effects.

4.21—This thought experiment does highlight the persistent role of probability in science, an aspect central to the development of quantum physics and in the general applicability of systems theory and nonequilibrium thermodynamics.[6] Probability here is not just a function of time but is a function of the aggregation across a scalar threshold (see 6.21).

4.22—We can thus make a more general hypothesis about science's mapping of the regularity of nature: science makes use of the stability able to be defined out of scalar aggregation of effects in order to identify ways that reality is predictable and follows certain functional laws (see 6.39).

5

From the Top

The Second Thought Experiment in Scale

5.1—If scale can be conceived as a systematic alteration in the resolution of perspective (1.15, 3.44), then we can, as a thought experiment, pinpoint a spatial perspective as a function of a coordinate that is a division—or, more precisely, point of specification—of this One, which also encodes the degree of detail or resolution provided by the coordinate.

5.2—Let's designate the largest, most inclusive possible perspective of the universe as 1 (see 1.23, 3.38, 4.2). This may be the observable universe, but it need not be. If we should discover more in the universe, then we can, in the style of Hilbert's Hotel (see 3.41), move the 1 one decimal further up so that what was previously conceived of as "one" simply becomes the first decimal (division) of this new "one." This maneuver should function as long as any new discovery can be said to be "larger" and not of a different sort or alongside what is (although it remains to be seen what such metaphors, as in the notion of parallel universes, might actually mean, particularly since such theories persistently use metaphors from nonscalar experience, as is the case already in "alongside of").

5.3—If the largest conceivable scale is 1, then we can specify a location within this 1 as a fraction of 1.

5.4—In doing so, every additional decimal is not a higher degree of accuracy (as it is usually conceived in mathematics and engineering) but rather a kind of zooming in. Thus, if we conceive of 1 as a sphere, then 0.243 would specify a location within that 1 that would appear as a kind of resolution (1.15) of that 1. If we added four decimal places, 0.2438531, we are increasing the resolution while in some sense staying in the same location. One might view this fraction as a kind of sphere within the 1 whose size is specified as a fraction of that 1. As one adds to the decimal, the sphere shrinks to specify a smaller portion of that 1.

5.5—This notion clarifies the change of perspective entailed by scale. In "resolving" the decimal or, if you'd prefer, in the fractionation of the 1, one is selecting out of the One a portion of it to examine at a particular level of detail. (Note that there is no "outside" the 1 here [see 1.23, 2.27, 6.44] but rather a specification of how whatever is is being viewed within that 1.)

5.6—With this schema, we can conceptualize the way scale provides layers of existence within the same "thing." At 0.285038472 one might observe a galaxy, but then at 0.2850384723413097912323 6719 one might observe a cow.

5.7—This experiment clarifies how to think of scale as resolution. The decimal describes an alteration of perspective, which changes what you are able to observe at any given degree of specification.

5.8—If we apply this to what is currently observed within the scale ranges of the cosmos, we can specify the scale domains as divisions of this 1. First, using the meter as our reference point (see 2.14), we can specify the relative size range of major objects (Figure 5). We can then convert these differences into a chart for the scale domains (defined at 3.35) by simply counting down from the largest size, in this case 1×10^{26} meters, so that we have a decimal correlating with these differences in size. We could then chart the resolution 0.25168312618149054847839687319326608731939640 38 as in Figure 6.[1]

5.9—This conception permits us to specify thresholds with some degree of accuracy by considering when and where a logical typing in objects actually occurs, as is already labeled in the third column in Figure 6. Here we can see how scalar thresholds are made possible by their logarithmic nature. Because we are dealing in orders of magnitude, we could think of thresholds as singularity points for objects of relevance on each scale.

5.10—As noted in 3.37, there are some transitional ranges where one might place a phenomenon in one or the other threshold depending on whether we privilege one scale or another, such as geological features.

Observable Universe (diameter)	**8.8 x 10^{26} m**
Clusters of Galaxies	**1 x 10^{24} m**
Galaxies	
Gigantic	1 x 10^{22} m
Mid-range	1 x 10^{20} m
Dwarf	1 x 10^{19} m
Solar Systems	
Oort cloud	7.5 x 10^{14} m
Heliosphere (of our sun)	2.6 x 10^{13} m
Space Objects	
Large stars	5.5 x 10^{10} m (Rigel)
Small stars	6.9 x 10^{8} m (our sun)
Large planets	7.1 x 10^{7} m (Jupiter)
Small planets	4.8 x 10^{6} m (Mercury)
Continents	1 x 10^{5} m
Objects	
Landscapes	km (1 x 10^{3} m)
Animals/plants/objects	m
Insects/small objects	mm (1 x 10^{-4} m)
Microbes	
Single cell	100 μm (1 x 10^{-5} m)
Organelles	7 μm (1 x 10^{-6} m) (nucleus)
Virus	100 nm (1 x 10^{-7} m)
Molecules	
Macromolecules	10 nm (5 x 10^{-8} m) (average protein size)
Molecules	2 nm (2 x 10^{-9} m) (size of DNA molecule)
Atoms	0.1 nm (1 x 10^{-10} m)
Subatomic	
Atomic nucleus	1 x 10^{-14} m
Protons/neutrons	1 x 10^{-15} m
Electrons	1 x 10^{-18} m
Quarks	1 x 10^{-19} m
Planck length	1 x 10^{-35} m

FIGURE 5: Major objects and their sizes. These are estimates that often fall within a limited range; what is given here should provide a general schematic. For an ongoing compendium of these comparable sizes see https://en.wikipedia.org/wiki/Orders_of_magnitude_(length).

Given this situation, it may be worthwhile to distinguish a kind of medial zone where one observes what might be described as the accumulated objects of a lower scale or aspects of a higher-scale object. These would be: components of a galaxy, patterns or sections in a solar system (e.g., an asteroid belt), parts of a star or planet (e.g., landscape features, continents, ecosystems, geological features, ocean patterns), organs or object components (e.g., rock patterns), organelles or macromolecules, and the ranges of forces or orbitals in or around an atom. However, *the major point of defining thresholds is to attend to logical typing as a function of levels of resolution, not the particular objects of relevance* (3.6, 3.30). Thus, macromolecules may be as complicated and large as a virus and therefore find themselves in the single-celled range. This is no problem: if these macromolecules form big enough chains they can become an even larger object—a rock or a diamond. It is not necessarily the kind of object we're trying to highlight but the thresholds of interactability.

5.11—This mode of specification fits with what is called "scale analysis" in various science and engineering fields. Scale analysis is a method of approximation that simplifies potentially complex equations by eliminating sufficiently small variables. When studying a process or attributes of an object that is primarily definable at one scale, one can successfully eliminate variables beyond a certain point and find that your calculation is perfectly adequate. This thought experiment suggests that a broader conception of scale analysis (perhaps more adequately called *scale-specific analysis* or *principles of specification*) is needed as a general method.

5.12—This experiment translates some problems in mathematics into the context of physical systems. Most importantly, it creates a logical typing of sets along a continuum that is tied to size. This physical logical typing carries with it the same problems already developed by Russell (see 3.6), particularly the warning that one must specify the logical type (i.e., scale) of description and be careful when creating rules or defining relations across these logical types (3.32).

5.13—Undoubtedly, this experiment has some implications for geometry, topology, and questions of measurement. While this pushes far beyond the limits of knowledge of the present author, we can point to some relevant issues by considering how one might create a kind of inverted Cartesian plane by converting the decimal into a distance from the edge of the 1. Doing so adds to the artificiality of the experiment by requiring a number of things that might not be appropriate. First, we have to posit a homogeneous space and, if we are to make it simpler, that the 1 is the same length in all directions. Then, we have to designate an edge from which to start the measurement. We must then define coordinate directions from which to start the variables, starting arbitrarily in one

Example Division of the 1, by Digit	1 x 10^x m	Scale Domain
0.2	26	Observable universe/ groups of galaxies
5	25	
1	24	
6	23	
8	22	Galaxies
3	21	
1	20	
2	19	
6	18	
1	17	
8	16	Solar systems
1	15	
4	14	
9	13	
0	12	
5	11	
4	10	Suns/planets
8	9	
4	8	
7	7	
8	6	
3	5	
9	4	
6	3	Organisms and objects
8	2	
7	1	
3	0	
1	–1	
9	–2	
3	–3	

2	–4	Single cell/microbial
6	–5	
6	–6	
0	–7	
8	–8	
7	–9	
3	–10	Molecules/atoms
1	–11	
9	–12	
3	–13	
9	–14	
6	–15	Subatomic
4	–16	
0	–17	
3	–18	
8	–19	
. . .	. . .	
5	–35	Planck length

FIGURE 6: Scale domains charted according to powers of 10 and correlated with a decimal divided out of a 1 at the largest scale. The first column is the example number, split up by digit vertically. These digits are correlated to a power of 10 and divided into associated scale domains.

direction and providing another at a right angle from that, and third, from a right angle in a third direction from their bisection to produce a (x, y, z) coordinate plane. One could then consider the decimal as a distance by taking the highest unit (the 1)—10^{27} meters or 1,000 yottameters (Y) if we're using the observable universe—and providing three such coordinates. If we are to keep our conception of scale in view, then we need to distinguish between the abstract point of intersection, which produces a theoretically finite point, and what is still able to be observed at that point. We can do this by conceptualizing that intersection as the center point of our sphere of observation within the 1, while the amount we resolve the decimal determines how big the sphere of observation is (see Figure 7).

5.14—This scalar space has some counterintuitive properties, which are useful for helping us continue to think in terms of scale. For one, we could not provide a different number of decimal units in the three coordinates and still adequately speak of it as providing a position, since it would resolve the 1 at different scales. The distance coordinate in each variable is not so much a point on a coordinate plane as an indication of how many of a given unit of measurement we are taking. Thus, if we're using 10^{27} as our base size, then in the coordinate 0.382057914, the first decimal (3) indicates how many 10^{26} meters, the second (8) indicates how many 10^{25} meters, and so on. One could thus convert the decimal into a number with the final decimal determining the unit of measurement: 382,057,914 exameters (10^{18} meters). This is why we have kept it as a fraction: it keeps in view that this is a kind of specification via fractionation of a whole possible length and accounts for how increased specification produces a change in what is resolved. It would be strange, for instance, to designate the distance as 382,057.914 zettameters (10^{21} meters). We can further note that the lack of additional decimals does not imply that they are 0, that is, that the number used here is 0.382057914000000000, but rather that these numbers have not been specified at all because to specify them would change the resolution.

5.15—This thought experiment provides a means of generalizing Benoit Mandelbrot's "coastline paradox," which notes that the contours of a particular object (e.g., the coast of the British Isles) does not have a well-defined length. Rather, the length depends on the scale at which one is measuring, since a smaller scale will include more variations within its

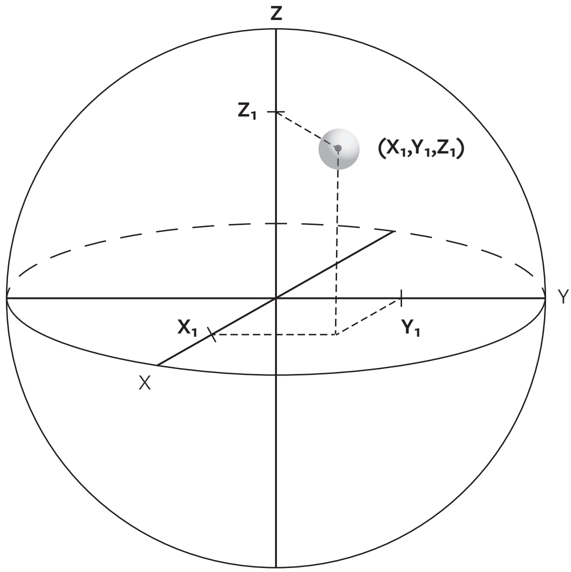

FIGURE 7: A scalar plane. The outer sphere is the theoretically posited highest point, which is set at 1 and artificially rendered equidistant in three dimensions. An (x, y, z) coordinate plane is set up using an arbitrary starting point at the edge of this 1. Unlike a Cartesian plane, the coordinates (x_1, y_1, z_1) are not given from the intersection of (x, y, z), which is an abstract point, but from the edge of the 1. These might be described either as distances from the edge of the 1 or, more to the point, a decimal as a fraction of the potential length of it. In turn, (x_1, y_1, z_1) is not an abstract point at their intersection but a sphere of observation as large as the decimal is resolved. Image created by Graphit Science & Art, LLC.

measure.[2] When put in terms of this scalar coordinate plane, we find a generalized coastline paradox for the measurements of objects and processes. Thus, if I wanted to find the boundary of an object, say a planet, and I resolve the decimal to the meter length, I may define this boundary differently than if I resolve it to the terameter (10^{12} meters). In fact, it is unclear the extent to which we might say that this same "point" we call the "boundary of a planet" is even sensibly described at a terameter. The coastline paradox implies that one might find smaller units to describe the coast, but if one were to select too large of a unit then it would not work as a measure at all. Thus, if you measured the coastline of the British Isles with a megameter (10^6 meters), then the measure would exceed the length of the object. The attempt to divide that unit would actually change the unit of measure, effectively changing scales. Something similar must happen in smaller units of measure: does it make sense to measure a coastline at the scale of the nanometer? Would a clear boundary be possible at that scale?

5.16—The implication is that we need to match the scale of measurement to the scale of the process in order to adequately study its properties. In practice, we might want to take reference to an object on one scale but measure it on another, but this does not change the domain of relevance for a measure or observing apparatus. If algae are growing along a coast, then do we have a coast measured at a micrometer scale but defined at a meter scale? If we specify more carefully what we're talking about, then we would have to say that the micrometer is relevant for each individual alga, but for the aggregate algae the meter is relevant. So we have, again, the problem of relevance as a function of resolution (1.15, 3.28).

5.17—We could attempt to conceive of time in relation to these spatial coordinates. To chart time, one would first have to select a range of perception tied to a particular location, observe an object at that range of perception, and then track its progress toward a second point. In this sketch, we can posit here that timescales correlate to spatial scales partially because timescales are already built on the logical typing of spatial scales. Thus, the scale of the planet corresponds to timescales of relevance for that large of an object. (If we consider this point in relation to our first thought experiment in scale, we might say that fluctuations also equal a kind of time range out of which differences might make a difference.)

5.18—Surprisingly, this thought experiment does posit the *Homo sapiens* as somehow in the "middle" or center of the cosmos in two ways. If we use the "observable universe" as the boundary for our coordinate plane, then this places the observer at the center of possible existence within our scalar coordinate plane (and theoretically someone somewhere else in the universe would have a different starting point for that boundary). However, in a scalar sense we find that the meter is around the center of possible sizes of observation. This is not necessarily a privileged aspect of humans, but of the meter scale more generally: it may be that, just as the micrometer seems to be the appropriate scale for life to begin, the meter scale is the scale at which a certain kind of complex behavior and cognition is made possible.[3]

6

In the Scalar Simulation

The Third Thought Experiment in Scale

6.1—Imagine that reality was capable of being fully represented in a virtual simulation in which one could pause all motion and zoom in and out much like you can with Earth-modeling software, except with as much detail as reality itself seems to produce. (This is obviously impossible. Specifying the ways that this is impossible as we proceed will tell us as much as the experiment itself.)

6.2—In such an interface, you could have a five-dimensional experience. In addition to the three spatial dimensions and time, one could alter the scale of observation. Thus, one would have five controls: up/down, left/right, forward/backward, time forward/backward, and scale larger/smaller. We can think of this experience as being inside the 1 specified in 5.2. We could even track the coordinates of location via the coordinate system developed in 5.13.

6.3—As per 5.17, for the interface to be navigable, our space and time controls must be scaled as well, so that, for example, at the scale of the nanometer, one moves at the unit of nanometers and in a time range relevant to behavior at that scale.

6.4—Moving through this interface on the scale of the meter would be like our normal experience of navigating this world. But the point is that the interface would be scalable such that one might zoom in and out in a way that would alter the scale of this three-dimensional space.

6.5—Here we could experience more acutely the transformation of the entirety of the cosmos simply by altering the scale of observation. If you begin focused on a person, at the meter scale you could examine around them, you could even bisect them and see organs and parts, but you would not see cells. When we change the scale to the micrometer, a refocusing—that is, a change in resolution—has to occur, otherwise one would only see big stretches of, for example, surfaces of the skin. But what has happened when you arrive at cells? Can you see the object "body" anymore? Here we find the full generalization of the point made in 1.15: no, the body is no longer visible. Not even organs would be visible except perhaps as what might be deduced from the patterns of the cells in relation to each other (e.g., the curvature of the cells in a blood vessel), the presence of certain larger nonliving parts, or by similar types of cells.

6.6—This is not, properly speaking, a "zoom" in the sense of cinematic zoom, which is a result of magnification. Magnification alone will not produce scale, since scale requires a change of resolution.[1] In our hypothetical interface, this is the difference between moving forward and changing the scale. We can add, in response to critiques of the "smooth zoom," that the change in scale here is smooth only in the sense that the change in scale can be placed on a continuum.[2] However, to produce our "controls" that can change scales, we require not a linear change but a logarithmic one, as per our chart in 5.8 (Figure 6). In addition, even if the change in scale is smooth, the crossing of scalar thresholds is clearly not smooth. Rather, a smooth or continuous change in scale produces a discontinuity in observation.

6.7—In this experiment we will speak as if the interface could be produced in visual terms most familiar to *Homo sapiens* viewing at the meter scale. This is a significant artifice, since it is unclear how much one might render these domains visible. Of course, light is impossible to use beyond a certain scale, and this interface would have to translate other forms of differentiation into visual form to produce these interfaces. In doing so it would highlight isolation, distinction, and separability—aspects most clearly present in vision at the meter scale.

6.8—The idea of bisection mentioned in 6.5 assumes an additional artifice: that we can move through an object that would otherwise be solid. The difference between going "in" in the sense of bisection and "in" in the sense of scaling down highlights a difference in scalar thinking: to go "in" is not to go to a smaller scale.[3]

6.9—Let us now experiment with using our interface to try to understand something about reality. We can consider three different sorts of questions that scientists might ask and see how we might use our scalar interface to answer them. First, what is X? Second, what causes Y? Third, how does Z work, what does Z do, or, more generally, what will happen next? The first is a question of properties, the second of causality, and the third of predictability and process.

6.10—We must first highlight the strangeness of observing the scalar transformation of objects not as a function of time but rather as a function of a change in spatial scale. *How have we changed all of reality without taking any action within it?* This aspect is why I have avoided speaking of scales of time as prior to spatial scales. In approaching these three questions with our interface, let's attempt to avoid time at first to see how scale operates without any action other than the change of the level of observation.

6.11—For the first type of question, we can select a scalar object: What is a cell? To ask this question, we must first switch scales to the micrometer (or slightly smaller), where the phenomena of cells can be resolved. We could then pick out a cell and, without changing scales or time, observe that the cell had certain definable attributes, including cell walls and various organelles. Equipped with a grade school chart of a cell, we could go through the cell and identify its various components.

6.12—Finding a coherent definition for a cell should not be an issue as long as we remain on the same scale. After all, the cell has some clear boundaries at the level of the micrometer, and certain components that make it appear as a separable object. However, if we switch scales, then the object of study will no longer appear like a coherent object. We can experiment with this as a general rule about scale: *studying something as a clearly defined object is only possible when we remain at one scale*. Thus, while we used scale to find the object "cell," we find that we cannot easily add a scalar shift back in and keep in view this object for study.

6.13—There are a number of ways that a seemingly separate object might appear not separate within our simulation. Without time, for instance, things might be indistinguishable if there is no discernible space between them until, adding time, they move apart. Moving our simulation forward and backward in time would produce a sense of objectness by permitting things at a given scale to demonstrate their distinctiveness through their ability to move as a unit at that scale.

6.14—Once one has resolved and defined the cell, it may be possible to study the cell from the perspective of the organism or the molecule. Doing so requires that we switch back and forth between the two scales to see how they relate. The result is quite productive: we might be able to see that the cell is a heart cell by noting its location in that organ. We can then specify attributes of a heart cell as opposed to cells belonging to other organs. But doing so requires that we switch scales so that we can discern the relevance of this organ structure to the larger-scale organism. We might be able to acquire something of a distinction between heart cells and bone cells by traveling in the same scale and noting a difference in kind, but only with a switch in scale would we be able to understand this difference as a function of an organizing principle of relevance on another scale. The term “heart cell” thus already refers to the same object from the perspective of two scales. More precisely, “heart cell” categorizes an object observable at one scale (cell) in terms relevant to another scale (heart).

6.15—Could we distinguish a symbiotic microorganism from a body’s cell when remaining on the same scale? This question exposes our attempts to define a system or class of relevance using a larger scale (the organism). If the microorganism is an essential part of the system, why do we call one a cell and another a microorganism (e.g., why is a microphage a cell but a bacterium in your digestive tract not?). One answer is to use DNA, but DNA requires a switch in scales; plus, it does not account for the well-known fact that mitochondria contain their own unique DNA. The point here is to highlight how certain concepts and distinctions can drift from one scale to another and thereby present problems for scientific description.

6.16—We may also study the cell as it is formed by molecules. Rather than merely a strong reductionism, this maneuver has great explanatory power for understanding properties apparent at the level of the cell. Molecular biology is able to, for instance, study the properties of proteins or DNA in order to say a good deal about what a cell is and how it works. But note how this replicates the same pattern we just defined in 6.14 and 6.15; molecular biology effectively selects new objects primarily discernible on a smaller scale (DNA, protein molecules) and studies those in relation to this larger-scale system.

6.17—These last few points (6.14–16) consider only the immediate scale domains. Some scientists study cells in relation to ecology (e.g., the effect of bacteria on the planetary ecology) or study ecological factors in relation to cells (e.g., the role of the great oxygenation event in producing eukaryotes). In these cases we have significant shifts in scale being deployed to say something about what an object is. Indeed, once an object of study gets defined on any scale, we can relate it to objects and processes on any scale—as long as we remember the scale at which each object is defined.

6.18—For these observations (6.11–17) we chose a living object. If we apply these observations to nonliving objects, other aspects arise. Consider the question "What is water?"—or, to place the question on a particular object in our simulation, "What is this water in this glass?" What scale are we to select to answer this question? At the scale of the meter, water in our simulation would include everything within the glass; we would not have the grounds to distinguish the water from its contents (e.g., one is reminded that H_2O does not actually conduct electricity). At the micrometer scale we could distinguish the water from any microbial and any large macromolecular components. Only at the nanometer scale could we distinguish the water molecule from other molecules within it. We could then study the attributes of H_2o, with the understanding that water's distinctiveness arises at the level of the molecule. We can then observe, for instance, that water at the scale of the planet exists as clouds, oceans, and glaciers and draw some relation among them.

6.19—We can now continue to develop the concept of thresholding (1.9–10, 3.27–29, 4.8, 5.8–9) and speak about phases of materials. Clouds, oceans, and glaciers are three configurations of the same molecular structure (H_2o) relating to each other in a configuration that makes them visible and effective at the meter and kilometer scales. In our interface we can see the significance here of phases, since the difference between ice, water, and water vapor might be described by switching scales and observing the relation between H_2o molecules at the nanometer scale that changes how they appear and what they are able to do at the meter scale. As systems scientist Ricard Solé notes, there seems to be a scalar nature of phase transitions along a critical point: "the term *critical point* . . . describe[s] the presence of a very narrow transition domain separating two well-defined phases, which are characterized by distinct macroscopic properties that are ultimately linked to changes in the nature of microscopic interactions among the basic units."[4]

6.20—Combining 6.18 and 6.15, we can add that the distinction between living and nonliving objects depends greatly on the scale of observation. Because life is invariably a system of smaller-scale objects coordinated into an object on a larger scale, what is considered living depends on the scale used to define the living system. Thus, at the nanometer scale, nothing is living unless we want to consider molecules involved in a cell or microbe as themselves living (then we run into the problems of definition found in 6.15). The point becomes more important at the micrometer scale: in an organism we distinguish between cells and microorganisms as living and material structures (e.g., calcium deposits that make bones) as nonliving. But if we were to change scale to the organism (meter), these "nonliving" components would be an essential part of an organism. Following 6.14, we might say that these nonliving structures seen at the micrometer scale are living in reference to the scale of the meter. This point becomes more relevant in the life/nonlife distinction between the meter-planetary transition, since many things we habitually treat as not part of life—or as mere materials *for* life—ought to be properly treated as part of life on the scale of the planet. This point reiterates the significance of the notion of the biosphere and Lovelock's notion of Gaia as attempts to conceptualize life on the scale of the planet (3.29, 3.32).

6.21—We can now turn to our second form of question, "What causes Y?" While this question seems invariably about the result of action in time, we want to highlight how easily answers to this question can be posed in terms of scale. If we freeze time and stay on the same scale, what can we say about causality?

6.22—The great use of our interface is that we can use it to find a specific answer to a defined problem for the sake of intervention. Medical examples are the most relevant, since they include a presumed problem to locate and fix. Let's say that I have a terrible headache and a pain in my back. Let's freeze time and consider what we can do to examine this situation in our interface. We can check for particular causes without changing scales: there might be someone sitting on my back (observing the relation between two objects on the same scale), or I might be able to peer "into" the body without changing scales and identify whether or not there are any fractures or swelling in the spine (observing attributes in objects on that same scale). If we find no fracture (or someone sitting on my back) but just swelling, we have not found a cause of the malady but a symptom of it. At this point it would not make sense to scale up, since that would leave behind the object (the body) that is manifesting the symptoms. Instead, we scale down and examine the cells in the spine, only to find that there are *Neisseria meningitidis* bacteria present in the spine. Thus, we have found a diagnosis, cause, and potential intervention by going to a different scale.

6.23—Arguably, Pasteur's great discovery was to pinpoint disease's primary cause as activity on the microbial scale.[5] With this notion in place we could always look for a microbial cause for other ailments; we could, for instance, find someone with schizophrenia within our interface and examine if they also have some kind of bacterial cause for this mental illness, as has been periodically suggested. The fringe nature of this theory points to how not all disease is relevant in this way. For instance, another condition might be caused by too much iron (nanometer scale), by other configurations of the system at the micrometer scale (hormones), by DNA sequences, by societal problems, or by patterns in neuronal configurations.

6.24—In these cases we are trying to locate differences (the bacteria) that make a particular kind of difference (the illness), which has been selected in advance. Once we have identified the bacteria as the cause, we can intervene to control that particular object of relevance on other scales: from the epidemic perspective (above the meter scale), we can instantiate quarantines, sanitation practices, and immunizations to effectively target that scalar object. In fact, the effectiveness of this intervention relies on—or even is the evidence for—the proper selection of this difference.

6.25—Significantly, "cause" here is the specification of the difference that makes a difference. If this difference (the meningococcus bacteria) is removed, the disease is likewise removed. To the contrary, if a symptom is removed (taking medicine to control the swelling), then the disease is not removed.

6.26—In actuality, this specification is quite difficult, particularly since we do not have the convenience of our imaginary scalar interface. Even if we did, something like cancer is not nearly as straightforward. How would one find the determinant factor for intervention? Even with a clear specification—cancer is an uncontrolled replication of cells—the larger question remains: what causes certain cells to replicate uncontrollably? Even if damage to DNA produces cancer, what causes the damage? Intervention here might already be of different sorts, which reflects the scale at which one is trying to locate the significant difference: one could fix the damaged DNA, remove the cells via chemotherapy, or avoid the cause of the damage in advance by altering environmental factors (working in a nuclear plant; staying out in the sun too long; smoking tobacco). In any case, the primary scale of interest may be the molecular DNA, but the chain of causality leaves open different scales of intervention.

6.27—The point here is to highlight how scale permits us to identify multiple points of causality by examining the whole scalar configuration. But one can see how there is a general preference for scaling down as a description of causality. Indeed, this could be a definition of reductionism. The caveat for moderating this tendency: *scaling smaller describes the same thing viewed in a different way as the cause of that same thing*.

6.28—In one sense, there isn't a cause at all when we switch scales except insofar as we want to identify a particular intervention or effect. Consider the psychiatrist examining mental health: does the presence or absence of serotonin cause depression? If one is depressed, these neurotransmitters are likely less present. Are they diminished because you are depressed, or are you depressed because they are diminished? This is the same brain described in two ways, via two scales: at the scale of experience and at the scale of neuronal components. However, this does not provide a necessary path for intervention. If we alter the balance of these neurotransmitters, one might effectively alter the feeling of depression while still failing to identify the organismic, experiential, social, or environmental configuration that might instantiate the depression.

Alternatively, one might fruitlessly alter social or experiential factors and find that the feeling of depression does not disappear. The person being treated for depression is always caught in the conundrum of this scalar shift.

6.29—At the same time, these questions about causality cannot avoid the question of how objects at one scale affect those at another scale. We can define two different senses of *scale effects* here. First, there is the effect that occurs when you change the scale of observation. The ecologists Jianguo Wu and Harbin Li, for instance, define scale effects as "the changes in the result of a study due to a change in the scale at which the study is conducted."[6] Second, we have the ways in which actions or objects on one scale affect objects or actions on another scale. To separate these two notions, we can keep the name *scale effects* (i.e., impact of scale) for the effect of scale on our observation, and *scalar relations* (i.e., impact across scales) to describe how action on one scale might influence action on another scale (see 3.31).

6.30—We can divide scalar relations into aggregation and conditioning. Aggregation is the way that the attributes and actions on a smaller scale accumulate into larger-scale actions and attributes (4.8). Thus, the way that molecules of carbon become a diamond or cells become a body are forms of aggregation.

6.31—Conditioning is the way that larger-scale objects or processes set conditions that constrain, enable, shape, or otherwise influence lower-scale activity.

6.32—Both aggregation and conditioning are a form of "setting conditions" for action at other scales. Aggregation sets out a possible range of configurations in a larger structure by providing delimitations in form and attributes. Thus, carbon sets different aggregating conditions than silicon. Both may be mediated by certain principles of aggregation, some of which might be principles of all aggregation across any scale (see 4.11).

6.33—Likewise, conditioning is a setting of conditions under which smaller-scale actions are able to be affected by changing what is available for smaller-scale interaction. For example, self-assembly techniques in nanotechnology set conditions for given materials (e.g., carbon) so that they will assemble themselves into a particular configuration (e.g., carbon nanotubes).

6.34—We have to be careful about how we conceptualize aggregation and conditioning as causal conditions. It may be possible to specify how certain conditions on one scale become effects on another scale, but it is a larger leap to suggest that aggregation or conditioning causes another scale's behavior even if these provide means of intervention or prediction.

6.35—Ideas of control, including notions of hierarchical power, are constantly falling sway to this problem. In what way do "I" control my hand, if I consider my hand as an aggregate of cells? It might be more accurate to say that action at the meter scale sets conditions under which this aggregate of cells is able to do the things that they do. To replicate this structure at the level of the planet: environmental factors, such as oxygen or carbon levels, weather, mineral sources, and geographic features become essential conditioning factors around which living organisms at the meter scale are able to live and organize. Human interventions at this same scale via large-scale infrastructure similarly set conditions for rather than controls for the organisms (human or otherwise) that live within them. From a scalar perspective, what we call "control" is a limited phenomenon that may apply only to same-scale interactions. More importantly, scale starts to highlight how "control" might be a narrative about causality (i.e., a way of mapping a flow of effects, preferentially written to emphasize human intervention) rather than a fact of phenomena. This, of course, has most relevance in trying to conceptualize control at the level of human governance, but it applies equally to our example of self-assembly of carbon nanotubes. Is the engineer controlling the molecules in setting the conditions for their self-assembly?

6.36—However, 6.35 does not preclude the definition of principles of aggregation and conditioning. To avoid the premature and often merely preferential narrative of control, we can note that such principles work separately from the objects aggregating or conditioning. That is, such principles are not caused by any one component but are manifest in the pattern of them.

6.37—We have unwittingly introduced time to make these points about scalar relations. But if we return to our interface and do not factor in time, then we could theoretically see how attributes on one scale relate to other scales. We could examine the structure of the carbon in a diamond to see how it relates to the sharp edges and shiny surface at a larger scale. Similarly, we could see how the heart cells are conditioned by the organ, specifically the role it plays in the larger organism. In turn, we can deduce how the larger organism sets conditions for these cells by making available certain materials and limits for growth and form, limits that one could see even in the structure of the organism itself.[7]

6.38—Although we have already implied a great deal about process and predictability, we can now move fully to this third set of questions. We should note that there are some scalar reasons—having to do with the principles of aggregation and conditioning—why we cannot answer the question "What will happen next?" without going forward in time. To illustrate, we can follow Gregory Bateson's discussion of some related scientific concepts in *Mind and Nature*. His example: if one were to throw a small stone at a pane of glass, one could not adequately predict the resulting fracture pattern. Counterintuitively, the more controlled and precise the conditions—using homogeneous, polished glass with a stone at a controlled speed—the less predictable the fracture pattern becomes. However, if there is a preexisting mark in the glass, you can predict the pattern to some degree. Out of this example, Bateson derives two principles that are principles of scale:

6.39—Bateson states that convergent sequences are predictable but divergent sequences are not. Divergent sequences "concern individuals"—including "the crack in the glass"—while convergent sequences involve aggregate behavior. Bateson's point applies to scale more generally: "The movement of planets in the solar system, the trend of a chemical reaction in an ionic mixture of salts, the impact of billiard balls, which involves millions of molecules—are all predictable because our descriptions of the events has as its subject matter the behavior of immense crowds or classes of individuals." Or, as he says elsewhere, "the generic we can know, but the specific eludes us."[8] In other words, aggregation provides predictability by bringing together the diversity of behavior from a scale below into aspects that are more regular on a scale above due to principles of aggregation (see 4.12, 4.22).

6.40—In terms of scale, we can say that breaking points and fracture patterns describe behavior at a lower scale at the point where they make a difference at a higher scale. Without time, one will be hard pressed to predict the moment of transition or pattern, since one cannot easily find the specific lower-scale item that will serve to instantiate an aggregate effect. We would have a hard time scouring our interface at the scale below, hunting for the molecules in the glass that will serve as the path for the cracks in the glass. The exception is when there is something on the higher scale that conditions this lower-scale behavior, such as the scratch on the glass. But even so, this conditioning does not give us complete information in advance about the precise flow of lower-scale events, even if it does delimit to some extent their aggregated behavior.

6.41—Once we add time, we can examine the patterns of conditioning and aggregation by observing what does happen within any object. We might see, for instance, that a breaking point is reached, know that it has to do with molecular-scale interactions, and retroactively identify the location of that instantiation at the scale of the molecules. But the same problem is always pushed forward in time: we can know something will happen but will be hard pressed to find where the threshold will occur without moving again forward in time. We will always be limited in our ability to trace out the exact flow of a phase transition, aggregation, or result of conditioning except in aggregate, after the fact.

6.42—Here we have perhaps come to the limit of the usefulness of the thought experiment without defining the limits of the whole premise. On a basic level, such an interface would have to simply *be* the universe, since any attempt to encode this complexity would have to be as elaborate as existence itself. This is most relevant for our discussion of time and predictability, since only in the hypothetical interface could one locate the molecule that forms a breaking point. In reality, the breakage itself is this discovery.

6.43—This is also a point about the great variety of existence implied by scale and about the limits of modeling. Scientific modeling will, of course, take advantage of scale to compress the situation via the aspects discussed here (6.38–41), but its limits might be more precisely defined by considering the scalar maneuvers that science uses to produce anything that can be considered predictability, intervention, and explanation. In chapter 10 we will discuss the function and limits of science as a process of specification.

6.44—This experiment's interface follows the common ruse of objectivity, imagining a viewpoint outside the interface to observe reality. But all experience is already within the "interface," not separate from it. In many respects, experience is a result of the operations such an interface would model. But this limit does not mean that this scalar map is an inappropriate way to interpret the knowledge that we do manage to stitch together in the process of science. In fact, *Homo sapiens*, whether the one called "scientists" or otherwise, is capable of prodding at and mapping these scalar layers of reality precisely because they are a part of it and within it.

6.45—However, in eliding the embeddedness of observation, our interface does not account for perspectives had within or by parts of reality. How does a cell differentiate the scale of the micrometer such that it can respond to events at this scale (the basic maneuver of cybernetics)? This point is essential, since we have already assumed in many of our examples that a coherent world of interaction is able to exist at any given scalar level. Because scale is about the mode of observation as well as the possibilities of interaction, one could not avoid considering how these perspectives function (see chapter 8).

6.46—When we spoke of modes of generating visualized perceptions in the interface (6.7), we were trying to make the interface comprehensible by imagining it in visual forms, which is clearly impossible. Such a visual form tied to the *Homo sapiens*'s body would also not account for how the same thing might look differently depending on what signals are received by it. If we add this observation to 6.44–45, we arrive more properly at the notion of *Umwelt*, or lifeworld, as a term describing how any organism selects out parts of reality in a particular way so that it creates a particular environment to respond to.[9]

6.47—To understand "what comes next" one would need to understand both cybernetic responses and the contours of an *Umwelt,* since the responses in the scalar interface require a responsiveness to configurations that are not always present as "objects." One might experiment with stating this in a scalar fashion: if I were to locate the way that a nervous system will respond to a stimulus, I would still have to relate any given neuron to the whole configuration of other neurons in order to get a pattern that we generally call a "learned response" or, in computer terms, a "program." Indeed, in computers we see how a program is to some degree a scalar system: it uses the states of its components to build a pattern capable of determining a response. One would be hard-pressed, even with a great amount of effort, to discover in our interface how such a system would respond next without adding in time—that is, by just running the program.

6.48—The notions of pattern and pattern recognition are clearly far more important in a scalar conception, since scale produces patterns out of which one might create rules for both delineation of objects and predictions about their interaction. In this case, pattern is not simply what comes next but the relationship between the larger and the smaller.

6.49—As a final note: within such an interface (or through the systematic examination of scale via science and careful theoretical delineation) we can add three kinds of scalar principles to scale effects (6.29) and scalar relations (constraints and aggregations [6.30–33]). First, principles of how differences manifest and accrue within any scale domain. These would be *scale-specific principles* that might not be generalizable to other scales and would therefore need to be situated within the scales of relevance. As science writers Joel Primack and Nancy Abrams note, "physical laws that apply at one scale do not cease to be true at other scales: they merely cease to matter."[10]

6.50—Second, *isomorphic principles or characteristics* are patterns or similarities that can repeat between shifts of these scale domains. These provide grounds for making analogous comparisons between scales, such as learning about how to organize a city by looking at a cell.[11]

6.51—Finally, the principles of scale itself: the conditions under which we use this apparatus, thinking as carefully and broadly as possible about what this simple observational accounting does to our conception of the cosmos. Clearly, this is the aim of this work.

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