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Visualizing Scale: Inducing Transformations in Perception through Art and Science

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Abstract: In order for scientists and technologists to describe many of their objects, they must observe at a scale that exceeds typical human experience. Atoms and ecologies, microbes and galaxies all exist at scales that require retroactively reconstructing a picture (whether rendered visually, through an alternative visualization, or simply pieced together as a description) of what human perceptual apparatus usually does not observe. Scale is also central to the production of artwork that uses changes in scale to help us examine the world differently, disorient our normalized ways of experiencing, and direct us to new objects and new relations. This article examines these problems of scale as they are shared between art and science, analyzing contemporary artists whose works highlight core aspects of scale. In examining these artworks together, we demonstrate that scale presents one way of clarifying when and how science runs us into basic questions at the core of many artistic practices.

Keywords: scale; perspective; feminist epistemology; art; science

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1. Sketches of a Transformation in Scale

A cartoonish diagram of a cell, a wiggly circle filled with odd shapes labeled with names like "microtubule" or "golgi apparatus", graces the wall of most high school biology classrooms. It shows the budding biologist a deceptively concrete object, with neat edges and distinctively colored parts. As students memorize the names and reproduce them on exams, they may not question the neatness of these forms. But if they play with a microscope, taking a gander at onion tissue or some other carefully prepared biological speck, they might notice a huge gap between the diagram and what they see of the cell in the microscope. They might wonder about the process of rendering tiny things visible, not just cells but golgi apparatuses, and even smaller scientific objects like DNA, atoms, or quarks. If the scientist needs the microscope to make a cell visible and other, more elaborate equipment to probe and define its parts, then something appreciably artistic can be said to have been given form in that cellular diagram. The image envisages not just an obscure object, but an unfamiliar perspective radically different than ordinary human experience. The authority embedded in the neat lines and labels obscures the significance of this shift in view, a shift that can be understood partly as a change in scale.

Scale is a central point of intersection between art and science, an area which is foundational to both ways of knowing the world. In *Scale Theory: A Nondisciplinary Inquiry* (2021), co-author Joshua DiCaglio describes scale as a way of understanding changes in perception that bring into view new fields of objects, from atoms to cells to galaxies. Scale changes re-describe the world beyond the concrete experiences and interactions of humans, who perceive and operate directly only within the limits of things that can be measured in meters (but not kilometers or nanometers). At the meter scale, humans use devices to bring other scales into view, describing objects only discernible at nanometers or kilometers and pinning them on the wall of high school classrooms as if presenting distinct objects.

In reality, a "cell" is a redescription of the bodies of the young humans memorizing the function of a ribosome.

Thinking together as a scholar of the rhetoric of science (DiCaglio) and an artist inspired by the dance of imagination with knowledge (Tromble), we trace the transformations of scale instigated by scientific practice and consider specific instances where contemporary artists grapple with and inform these radical shifts in perspective. Artists work with scalar experiences in many ways, such as creating destabilizing physical experiences of scale or depicting overwhelming scalar shifts; as new ranges of perception are conceptualized scientifically, artists incorporate these concepts for their own purposes.[1] A concept may come from a scientist using a microscope or telescope; the images produced with those scopes may become photographs or interpretations by a science illustrator. Either way, as the images enter the general cultural sphere, artists extend their range of meanings, as can be seen in the wide variety of uses artists from Wasily Kandinsky to co-author Tromble have made of cellular imagery. Scientists, in describing radically new scales, must create representations for obscure objects. Artists, in examining problems of perspective, measurement, and visuality, find themselves speaking to and engaging directly with the same problems of scale even if they do not view their practices as being related to science. Both scientists and artists grapple with disorienting perspectives on their existence, such as the perspective implied by that simple diagram of a cell. It is at this intersection between domains that we explore.

Our interest here is not with the domain-specific questions of art history: chronology and causality and legibility, in conjunction with style, biography, and context (Preziosi 2009). Nor are we focused on questions central for a historian of the visual culture of science: chronology and technology and representation, in conjunction with the creation and analysis of data, and context.[2] Rather, we address a group of contemporary artworks to illuminate how changes in scale and the accounting practices of scale reorient our perceptions and change our sense of reality. Changes in scale bring our attention to the world differently, disorienting our normalized ways of experiencing, and directing us to new objects and new relations. While science often presents these changes as facts and objective entities, these new ways of experiencing and understanding the world create new reactions and force us to work through emotionally and personally potent reorientations. The artists examined here each deal with these aspects of scale; they range from practitioners who actively engage science to practitioners whose work is infused with scientific tropes unmoored from their origins and circulating in common culture. Whenever possible, we chose works for discussion that were available for us to see in person, as the impact of scale may be lost or masked in reproduction. While there is a longer history of art and visual cultures of science that provides context for these works, focusing on these experiences in contemporary art allows us to work through the way that scale connects the physical with emotionally intense reorientations.[3]

Each section of this essay presents one artist in relation to one aspect of scale. Each artwork brings this aspect of scale to our attention and teaches us to work with these new perspectives that science develops. First, we look at Felice Frankel, an artist making images for scientific use, to highlight how scale opens space for careful, artistic representation in the way that it re-presents the world. We also note here that most attempts to acknowledge the art of making images of other scales touch only marginally on the questions brought by scale. In the following section, Patricia Olynyk experiments with how scalar objects and perspectives reposition the senses; in doing so, Olynyk brings the body into connection with unfamiliar relations and sensations that can become personal and intimate. We then turn to Sara Morawetz, who uses documentation of her performative retracing of the definition of the meter to ground the measures of scale in relation to the possibilities of the human body and human efforts. These sections highlight some basic challenges presented by science, which artists have long taken up by playing with perception, perspective, and measurement. Next, we consider Gego and Sarah Sze together, examining these two artists to determine how they highlight necessary questions about how we piece together perceptions and

conceptions of objects together into parts and wholes. We argue that this inquiry into how we piece together connections between objects is an essential but often missed aspect of scale that is paralleled in these works. Our final example, Bull.Miletic, bridges art and science through artworks directly engaging with scalar imagery and its histories. Their artworks bring together all these aspects of scale to challenge the viewer to examine these shifts in scale and to appropriately situate themselves in relation to these new productions at different scales. In examining these artworks together, we demonstrate that scale presents one way of clarifying when and how science runs us into basic questions at the core of many artistic practices. Specifically, scale highlights how science produces transformations of perspective that bring into awareness objects that are outside usual experience but are nonetheless held in relation to normal experience via the measuring/accounting of scale. In the process, science leaves open the task of attending to these transformations of perspective as reorientations that require an intense and personal reckoning with one's ossified sense of reality.

2. Felice Frankel and High-Quality Scientific Imaging

When the first image of a black hole was released in 2019, Felice Frankel, a long-time practitioner and leading proponent of scientific visualization, wrote, "Were you recently gobsmacked when you saw the very first image of a black hole? I know I was". After smacking us with the image, she continues, "Did I understand what I was seeing? Not exactly. I certainly needed an explanation, or two. But first and foremost, I stopped to look, as I bet many others did, too" (Frankel 2019). Here, Frankel gives us an imperfect connection between a question about perception (what *are* we looking at?) and astonishment (gobsmacked). But rather than say more about the perception, she moves to its impact: got your attention!

This attention grabbing, the "stopping to look," is a recurring trope in Frankel's work. Frankel has spent her career advocating for scientists to spend more time making their images esthetically pleasing and visually striking, and showing them how to do so. Why should scientists take the time to stage and refine their images? Because, notes Frankel, scientists must communicate about their work. As she states in her book *Envisioning Science*, "your images are both valuable for demonstrating your work to your community . . . and making your work accessible to those who would not necessarily be exposed to it" (Frankel 2002, p. 254). In the article about the black hole image, she states: "It's no longer good enough to create photographs or other visuals only for the experts. Learning how to speak to non-experts is essential if scientists are to combat the frightening present atmosphere of scientific mistrust" (Frankel 2019). At stake in producing striking scientific images is to "make science the accessible" (2019) and combat mistrust of science.

Why would science need to make its way of knowing accessible? What about science is inaccessible? What does the scientist need to communicate that needs the support of images to be comprehensible? Most of all, what has science done to or with our attention? Noting *that* an image catches people's attention says little about *how* and *why* it catches attention, or about the need for it to do so. Frankel's stated concern is with accessibility—getting people to notice, care, and connect to the science—but she does not address why scientific objects are inaccessible. Nor did her context require addressing such questions in written language. It was already a significant move to argue for the value of esthetics in the images she produced. However, there are additional reasons for examining the artistic aspects of scientific images or learning to produce more esthetically interesting images or to attend to the production of scientific images in relation to artistic refinement.

We augment Frankel's justification of her own work by suggesting additional reasons for examining the artistic aspects of scientific images or learning to produce more esthetically interesting images. The core of the matter is this: science's epistemological (knowledge-making) practices create a very particular way of coming to know the world, a way that differs from ordinary ways of perceiving. While changes in scale are not the only arena where this is true, radical changes in scale make this strikingly apparent. The

fact that no light escapes the black hole might produce a portion of its inaccessibility, but it is also inaccessible because it is both extremely distant and extremely large. In Frankel's oeuvre, the most extensive acts of esthetic tailoring arise when dealing with objects and perspectives at scales beyond human ranges of perception.

In making this observation, we note how little perceptual experience we have of black holes and cells. What a scientist must make accessible are different scales of existence which operate at different perspectives, with different objects and relations. Frankel implicitly acknowledges this transformation when she notes the following: "The fact is, science is all around you. Everything you see has to do with various scientific phenomena. Why not start a conversation about what's going on scientifically by looking at those phenomena in a compelling image?" (Frankel 2019). Clearly, the principles and objects of science are about the world around us; the only reason Frankel would need to make this statement is to note that science has brought into view something different, outside, or in addition to the way we usually experience the world. It is not just the act of looking, but the *kind* of looking required by science that necessitates communication and requires attention to and artistic refinement of the process of bringing scientific objects into view. Without a crafted image of a nanoparticle, DNA strand, microphage, black hole, or galaxy, you would not be able to visualize these objects.

A well-crafted scientific image brings science's obscure objects into view in a potent way, assuming we have a sense of scale. However, scientific images often create questions about scale. Consider this image (Figure 1), by Frankel:

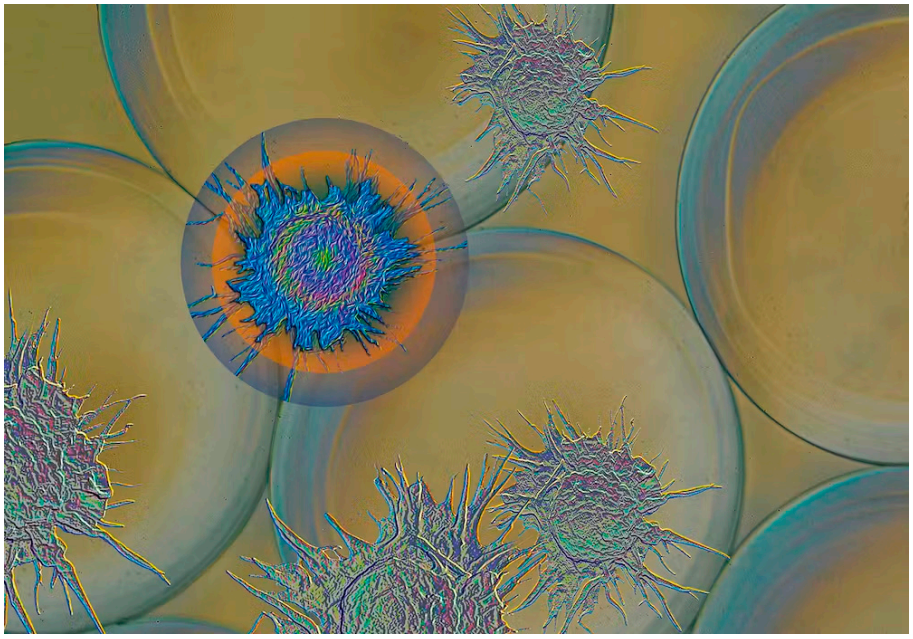

Figure 1. An inaccessible object made accessible. What are we looking at? In a word: macrophages. Felice Frankel, CC BY-ND.

What do we have here? Beautiful splattered spheres. How big are they? What *am* I looking at? We have to read the description given in the article: "Scientists developed a technique that "deactivated" particular cells in our bodies–macrophages–so that they would not fight against an implanted medical device. As a way to illustrate this research, I combined a few pieces of images that I'd previously made to suggest the idea behind it" (Frankel 2019). Only with this caption are we able to learn that these are macrophages. But there is some important information missing here. Where are macrophages? In your body. How big are they? Around 20 µm in diameter. Adding those pieces of information, now we can say that macrophages like this are roaming around in your body, many, many of

them, and they are keeping you safe and alive. Now, look again, and see what the image means to you.

In this re-examination, we are responding to Frankel's invitation to be "less afraid to ask questions when [we] see images." But questions of scale lead us quickly down a rabbit hole that is not just about the scientific facts, but about the scientific "seeing," about the radical change in perspective entailed. This thought reframes one of Frankel's other statements, in which she says, "We have to create standards, not only in the making of the pictures, but in understanding what the pictures are saying—and to really be aware of image manipulation, for example" (Neilson 2016). Although, here, Frankel primarily refers to the need to be aware of scientific sorting and distorting (what were the "few pieces" of images pasted together in the above image? Is this a rendering? What was added in terms of color? Is there any physiological basis for the color?), scale points to a parallel kind of "manipulation" that must be attended to: the way that scalar objects and processes are only possible through a radical, albeit carefully tracked, manipulation of our usual perspectives.

This is essential to DiCaglio's definition of scale: "scale is the systematic accounting for significant shifts in a measured range of observation" (DiCaglio 2021, p. 51). In moving from 20 µm to meters, scale tracks how information must be re-presented and re-imagined. In contemporary life, new tools expand our need for these re-presentations. When scientists delineate and describe new scales and objects at these scales, it creates a need to attend to the production of these perspectives and objects, which are new to our experience; how and why we would visualize/depict them in a certain way, and how we might relate to them. Scientific objects at other scales require a reconstruction and depiction to become meaningful. This is what we mean by "making them visible". In this framework, representation is not a secondary operation or "just" an esthetic process. Even the argument that better communication is needed risks overlooking the creative power of the representations. Instead, with a sense of scale, we can notice how new this view of the world is. Look at what scientists have conjured for us (Figure 2):

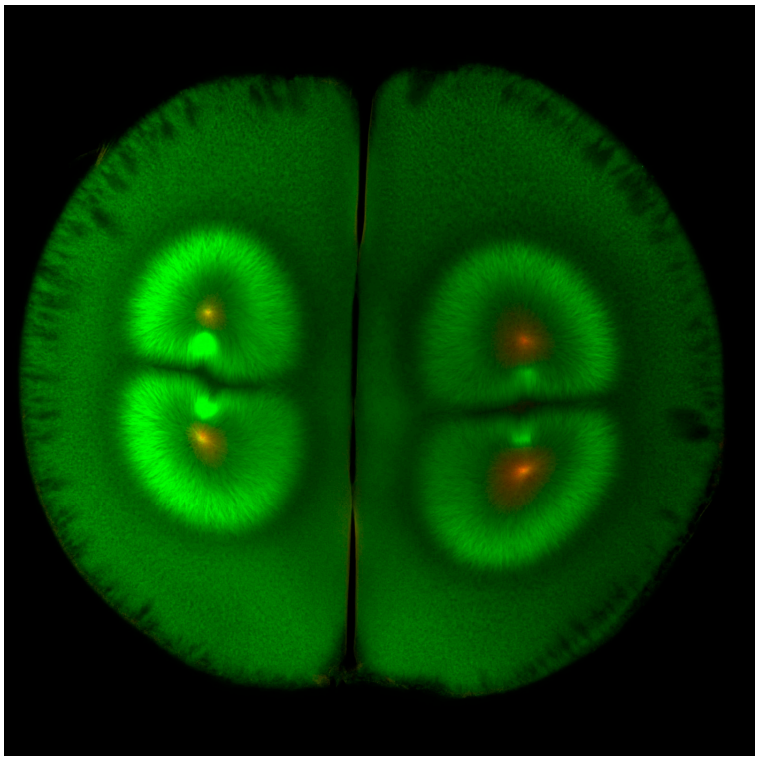

Figure 2. A new conjuring: a cell undergoing mitosis. By Martin Wuehr and Timothy Mitchison, public domain, available at http://www.cellimagelibrary.org/images/36441 (accessed on 16 July 2024). Discussed in Frankel (2018, p. 247).

3. Patricia Olynyk: Triggering Scalar Awareness

Sensing Terrains, by Patricia Olynyk, is a multi-media installation with sound, first shown at the Academy of Sciences in Washington, DC. Intrigued by cenesthesia, the relationship between consciousness and bodily sensation (not to be confused with synesthesia), Olynyk used multi-scalar imagery to call "upon viewers to expand their awareness of the worlds they inhabit, whether those worlds are their own bodies or the spaces that surround them" (Olynyk 2012).

She made scanning electron micrographs (SEMs) from the sense organs of both human and non-human bodies and combined them with her photographs from special Japanese gardens that were created to "tickle the senses" (Figure 3). The resulting images are printed on huge silk panels that, hung high to trigger the physical sensation of looking up at something larger than oneself, impose a reorientation of a viewer's sense of personal scale (Figure 4). This reorientation is supported by a soundscape that subliminally tells the viewer that she is navigating a fluid, expanding space; her bodily relationship to that space is constantly in flux. In doing so, Olynyk follows many artists who examine the transgression of bodily boundaries. For example, Mona Hatoum's *Corps Etranger* (1994) uses medical equipment to image the inside of the body. While *Corps Etranger* deals with an unfamiliar view, this view is still at a familiar scale, the meter scale of the human body. However, in a more extensively scalar conception, this aspect of flux is not about the inside of your body (e.g., organs in your skin) but the much smaller (cells) or larger (the planet) entities related to your body. Olynyk deals with the flux in relation to very small scales only visible through the microscope.

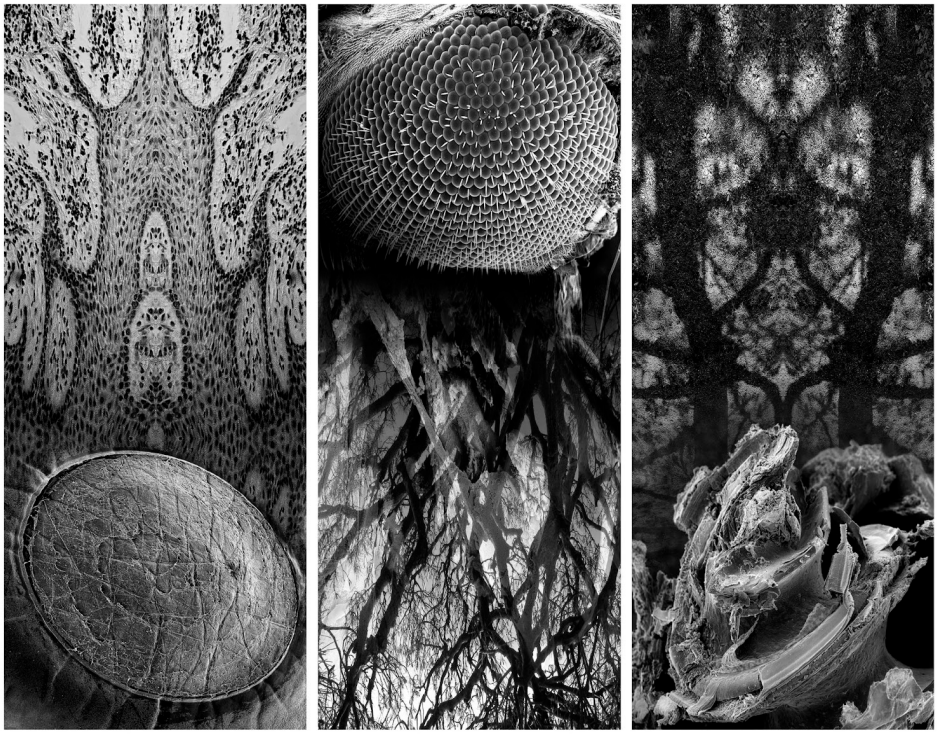

Figure 3. Detail: Patricia Olynyk, *Sensing Terrains*, multimedia installation with sound. From left to right: Human eye cornea and tissue from a transgenic mouse; transgenic drosophila (fly) eye layered with tree limbs and nasal epithelial cells; guinea pig cochlea with shadows of tree branches on gravel of Japanese garden.



Figure 4. Patricia Olynyk, *Sensing Terrains*, multimedia installation with sound; 12 February–16 June 2006, National Academy of Sciences, Washington, DC.

In doing so, Olynyk's installation presents a feminist twist on the epistemology of science, a twist grounded in feminist concepts of situated knowledge. The attention to perspective or "standpoint" developed by feminist scholars of science such as Donna Haraway, Evelyn Fox Keller, Alondra Nelson, Banu Subramaniam, and many others provides a theoretical context for the physical experience that Olynyk's work offers. With these silken cells dangling before us, we are prompted to examine ourselves in relation to strange, unclearly situated perspectives. In doing so, these panels prompt us to experience a shift in perspective as a disorientation. Olynyk refers to this aspect of her work as triggering "cognitive estrangement", a term defined by the poet and critic Darko Suvin as the rational understanding of a subject that seems both recognizable and unfamiliar (Suvin 2014). Olynyk writes, "Cognitive estrangement distances us from our usual assumptions about reality and it is through this rupture that is both perceived and felt on a visceral level that new alternative realities and affective responses can emerge" (Terranova and Tromble 2017, p. 304). In these moments, one's perspective is put in flux, fluid and expanding; in such a moment, one's supposedly static position or singular "truth" cannot keep up; other possibilities come into view. The physical experience brings within reach a commensurate humility about the authority of a "normal" perspective.

Even knowing the experience is a fiction, created by manipulating visual and sonic cues, a sensitive—a sensing—viewer has the physical experience of becoming small in relation to microscale structures. In fact, Olynyk puts these sensory aspects in the center of these artworks: the animal tissues depicted in Olynyk's SEMs include human corneas (representing sight), wild mouse taste buds and olfactory epithelia (representing taste and

smell), guinea pig cochlea (representing sound), and drosophila feet (representing touch); the variety in species communicates that humans are just one kind of being in a world of sensing beings. Extending this theme, the animal imagery is interwoven with plant and mineral imagery from Japanese gardens that were composed to stimulate the senses. The choice of imagery intensifies the cognitive estrangement: guinea pigs are familiar, but how many viewers could identify them by their cochlear tissue? One can easily visualize a fly, or even recollect the tingle of fly feet touching human skin, but the microscopic view of those feet presents an alternative reality. *Sensing Terrains* summons prior experience of the world even as it directs attention to the unknown, specifically the parts of what we experience that we do not know, but which might be brought into view through devices such as microscopes and cameras. If a guinea pig were not already known at the human scale, the microscopic view would not seem strange; the image would not work as effectively as a solvent for prior assumptions about guinea pigs or prior assumptions about the way humans know the world and our place within it, at our scale.

4. Measurement as Maze of Abstraction: Sara Morawetz, *Etalon*, 2018

In her durational performance *Etalon*, Australian performance artist Sarah Morawetz focused on the mystery of the meter, setting out on an expedition "to witness the uncertainty of marking one's self against the Earth" (Morawetz 2019). Retracing the 1792 French scientific expedition that established the meter by measuring the Earth, she carried her own surveying equipment, and, over the course of 112 days, walked from Dunkirk to Barcelona, measuring along the way (Figure 5). She pushed her body to extremes to feel the meter for herself—and, through the story of her quest, gives the rest of us a brush with the fact that the meter is first and foremost here, measured against a human body.[4]



Figure 5. Meter-scale measuring entity poses with reference. Sara Morawetz, *Etalon*, durational performance (detail), 2018.

What generates this quest? Why does Morawetz need to become intimate with the measure in this way? Here, we have an artist following up on the problem of scale. As Morawetz states in her TedX Talk presenting the journey, "I often worry that the language and action of science feel both abstract and inaccessible. . . I use performance as a way to work through ideas physically to communicate their impact" (2019). The struggle to integrate scientific and technical ways of knowing into personal experience shows just how

much our culture has become entangled in ways of understanding reality that we do not directly experience. Obscure chemical alchemy manufactures nitrogen to make the massive crop yields that feed us; tightly knit metal etchings form the computing devices that extend our memory and communication; billions of galaxies, each with billions of stars, frame our cosmic imagination. And yet we walk the Earth. We live here, breathe here, act here, with what the hand can grasp.

Morawetz created a supremely earthy experience to re-center us on the immediacy of measure. Her journey was motivated in part by the recognition that, historically, the meter was created by a gesture across scales. Two astronomers commissioned by Napoleon "traveled the length of the Meridian arc from Dunkerque to Barcelona; surveying both the land beneath and sky above in order to measure the curvature of the Earth. They used this data to define the meter as a 'natural' standard: one-ten-millionth of the distance from the North Pole to the Equator", as Morawetz poetically writes. (Morawetz 2018). She became "fascinated by this story, how this length that relates to the size of my body was calibrated against the scale of our planet" (Morawetz 2019). The meter itself is a scalar connection, a point of reference connecting what we can hold here ("I could hold it in my hand") and the entirety of the planet, which one can only begin to fathom through projected calculations derived from an arduous journey.

This journey exemplifies the great difficulty of significant shifts in scale and the role and nature of scale in bringing us into contact with reality in a new way. On the one hand, scalar descriptions "move us beyond our human-centered ways of dividing and seeing reality" (DiCaglio 2021, p. 5). On the other hand, "one can only act on the scale at which one exists" (DiCaglio 2021, p. 48). When dealing with the vast or the small, considering the galaxy or the atom, "scale holds oneself to a measure" (DiCaglio 2021, p. 34). A marker of scale uses the meter or similar designation which is derived from human-scale experience and relates it to a view much larger or smaller than that experience. But in the process, we can get lost—forget where we are, forget that we have not, in fact, gotten bigger or smaller.

And neither has Morawetz. Rather, walking with and for the meter re-centers her on the scale from which the experience is derived. As she states it, the meter is "a self-reflexive gesture through which we measure space, place, and self against the scale of our own domain. The metre is bound to the Earth, and through our use of it so are we" (Morawetz 2018). In *Etalon*, Morawetz points out that the measure is "natural" only in the sense that it has encoded within itself both the Earth's size *and* the limited human scale. On the one hand, this is a human way of making sense of something that exceeds our ability to sense it. But this measuring is not just a matter of egotistical *homo sapiens* trying to render the world entirely in human terms, as it is often read (although it can be that); it might also be considered "human" primarily in that it is derived from a recognizable object easily standardized at human scale (DiCaglio 2021, p. 29). The French astronomers sought out a reference usable at human scale, but also connected to the planet. Morawetz has retraced the gap between those two scales, bridged by the measure that she recreates by following the same journey (Figure 6).

Today, people cut up and compound this measure of their experience, in order to speak of nanometers and light years, far beyond what is directly accessible here. In this way, we make the inaccessible accessible, but only in a limited kind of way. Human hubris manifests: I will know (traverse) the planet! It is only something like 40,901,000 m. Morawetz laughs and tells us about the struggle of the journey to even begin to draw this measure in relation to this vast Earth. Straining against the difficulty of her quest, Morawetz collides her personal sweaty earthly existence with a threshold of planetary scale—and brings us the deadpan evidence of her vision in the form of a meandering meter. These extensions were not what we thought they were; we have become deluded by our own ability to see and view at these scales while forgetting what we do and where we live.

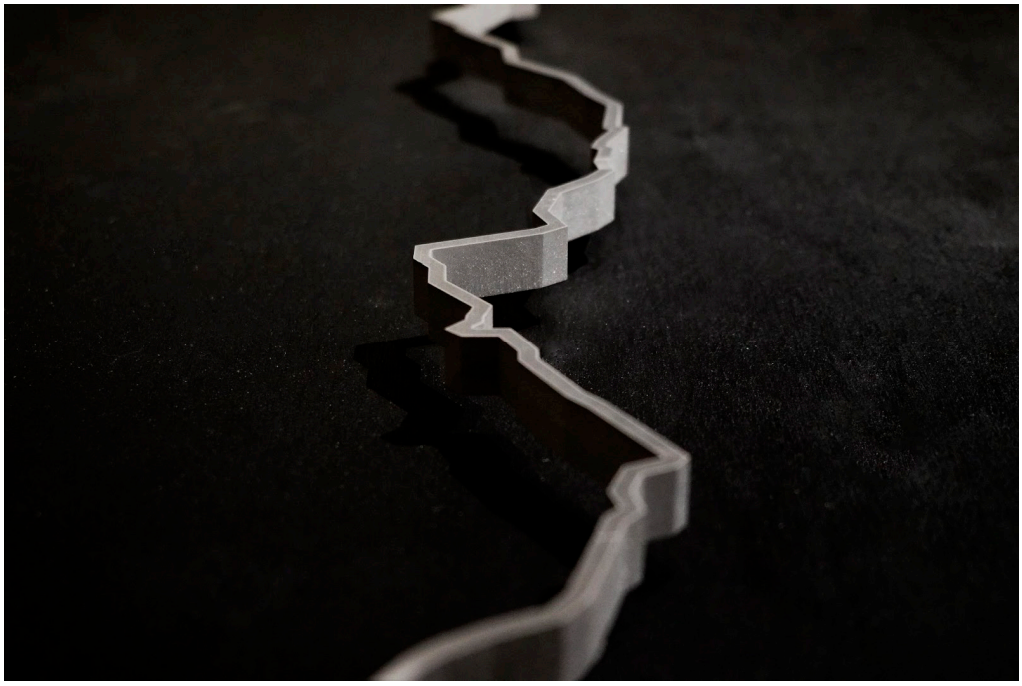

Figure 6. Morawetz re-presented the meandering measuring journey as the prototype for a new meter. Sara Morawetz, *Etalon*, durational performance (detail), 2018.

Morawetz describes this performance as "a study of space" and "a remeasuring of space, place and self". The need for such a study of space and measure arises because our sense of space and scale have become dislodged from our immediate locality. We can thus also speak of *Etalon* as a study in abstraction from space, a version of the classic phrase the "map is not the territory" (a concept that Morawetz addresses in a different body of work). In this case, the map is the scale, measures, and the new perspectives on reality that they track, and the territory is your immediate experience. The problem can thus be articulated as a problem of abstraction. New scales of perception are perspectives pulled away (abstracted) from the perceptual apparatuses evolved to parse the world at meter scale. But all these new objects and relations (atoms, cells, DNA, ecosystem cycles, astronomical phenomena) are about this reality right here, viewed very differently (I am cells. . .). Yet we talk about them in the same way we talk about objects at our scale that we experience directly. Scale thus produces a maze of abstraction, in which we can lose or confuse our sense of what is immediately here in our experience and what has been produced and intervened in via a scalar mediation. We risk treating abstract scalar objects (those that exist outside of our perspective, i.e., at another scale) as if they are concrete (i.e., at our scale). We routinely speak of these objects (viruses) and different perspectives (pandemics) as if they are equally concrete, when to get to them requires a different perspective (of you getting sick). At the same time, we find ourselves treating our meter-scale experiential lifeworld in abstract terms ("I am an agent of climate change"; or "I am a walking talking aggregate of microbes", as per microbiologist, Lynn Margulis). In reductionist science, atoms, strangely, can be considered to be more real than the objects in front of us. That is, unless one attends to scale.

To navigate these changes, we need to account for the relationship between different objects *as* they relate to a change in perspective. Doing so does, in a certain sense, make new scales concrete by tracking the abstraction specifically as a measurable change in perspective. Thus enters the measure. But how quickly it, too, gets away from us, becoming abstract. A galaxy: that is some 1×10^{18} m. A water molecule is about 0.27 of a nanometer. How many meters, did you say?

And yet, the meter itself is just this size here—did we forget to locate it?

Sara Morawetz carries her measure with her. "For me, the meter became a place" (Morawetz 2019). She feels its possible length, the arduous nature of her traversing the land. And, feeling this located limit of the meter, can we access a nanometer? Can we access a million meters? Have we become so large? Have we become so small? All of this is still there, the whole planet; if we are to encounter it from the meter scale, it would have to be traversed slowly, with much effort, despite our scalar conflations.

Humans have measured beyond themselves, but the measure has not lost its bearings. With this measure carried with us, we navigate the scalar view of the cosmos: from here, at the human scale, the meter scale (a significant gloss!), we can now discuss these objects described by science that pushes beyond ourselves. And from there, we notice the incredible shift, following the measure to these sliced-up and compounded perspectives (a millionth, a million!), a measure that seems, suddenly, also about much more than these perceptions that exceed this meter. We gain our bearings only in returning, by way of the meter, back here: to the body gawking at this new way of examining the cosmos.

5. Piecing Together Time and Space: Gego and Sarah Sze

Objects discerned at other scales come to us in fragments, as bits visualized as cells or insertions of the planetary within our awareness. It is disorienting to recall, as DiCaglio does in key moments of *Scale Theory*, that "I am made up of cells," and imagine the isomorphic parallel at the planetary scale, rendering oneself an artifact of a mesh, materializing somewhere between the micrometer and planetary. At such moments, one can feel oneself as a moiré pattern, a participant in patterns of relatively low complexity that overlap, creating a highly complex structure. Especially if, circa July 2023, one visited the Guggenheim Museum in New York and stopped to experience the works of Gego, a mid-20th-century German Venezuelan sculptor, before seeing the installations of contemporary American artist, Sarah Sze. Like contemplating how we are made of cells, Gego's work brings to our attention the ways we generate coherence across seemingly separate objects. Similarly, Sze's installations attune us to the interactions and connections between (often mundane) objects. At the same time, both Gego and Sze also turn our attention to the lapses and gaps in these connections to make us aware that we are piecing things together. They highlight the same attentional processes that allow us to form coherence from the many scales at which science asks us to examine the world.

Gego drew in the air with metal, creating mesh-like objects that appear to shift and change as the viewer moves (Gego 2023). As one walks the exhibit, her increasingly complex experimentation with moiré patterns reveals the way the mind pieces together objects out of perceptual intersections (Figure 7). This is a spatial process, but also one that occurs over time, as eye movements produce the most interesting and complex emergence of patterns. Gego's work points to general processes by which our minds piece together reality from the multiple sensory inputs provided by our bodies; in this way, her work is a precursor to Morawetz's intensive performance piecing the meter together. This cumulative sense-making is what scientific descriptions of scale prompt us to grapple with: cell, cell, cell—BODY. Body, tree, building, plant—PLANET.

By chance or by curatorial insight, after passing through the Gego exhibition, one arrives at the installation entitled *Timelapse* by sculptor Sarah Sze. Using projection with the simplest of materials—photographs (some with the image torn out, leaving only an edge), plastic twigs, mirrors, and household objects—Sze offers viewers multiple perceptions of scale fluctuating across time and space. An image of the sun, first experienced at thumbnail size in a photograph, might expand to fill the next room, racing through it in projection. Iterating her theme through variation after variation, Sze activates an almost gyroscopic form of sensing. The unstable horizon and shifting point of view stimulate an awareness of the immensity of surrounding time and space, a noticing of the larger scales in which the local is embedded.



Figure 7. Moiré patterns, reminding viewers that much emerges in the mesh, depending on how one looks at it. Installation view, "Gego: Measuring Infinity," 31 March–10 September 2023, Solomon R. Guggenheim Museum, New York. Photo: David Heald © Solomon R. Guggenheim Foundation, New York.

The humility of Sze's materials and the humor of her esthetic keep the confrontation with immensity tolerable. Among the repeated images of the sun is a low-resolution projection. It travels across the wall, suggesting the star's daily traverse of Earth's sky, but it also keeps popping up, playfully situated, in less predictable circumstances, in one instance balancing precariously on a tape measure. Piecing together time and space in perceptual collages that are produced partly by her placement of objects and partly by the movement of the viewer, Sze offers her audience the physical sensation of fluxing scales, transforming the intellectual experience of measuring into a felt and physical experience. Her playful approach invites consideration of how perceptions of time and space come together and do not always cooperate with markers of time and space (timelapse!). Sze takes materials with familiar strengths and textures and pushes them several steps beyond the familiar. Plastic sticks, which began as pieces of different things, are arranged into a new, tenuous whole such as a sphere. Projections appear on the individual sticks; then, the projected image, which travels through the translucent sticks, appears a second time on the wall, where it is altered by the shadows of the sticks (Figure 8).

Gego and Sze both tune us into the way that "reality" is pieced together, moment to moment, from sensations. We see this in the movement of moiré patterns of Gego or in the broken yet strangely coherent timelapses of Sze's projections (Sze 2023). This disorienting piecing together occurs at the intersection of our body with the objects we move through, just as the proliferating scalar objects provided by science do, in fact, speak to our scale. Cells are, after all, our bodies, but bodies at that scale appear like Sze's sphere of sticks; through them are projected our understandings of DNA and other molecules. In that way, "reality" is constantly remade and maintained; but what is remade and maintained is still the body. Describe the world as atoms and it is still, at the meter scale, a body.

How do we work with this piecing together, feel it as both fragmentation and bringing together, a profound act of meaning-making that is object-making?

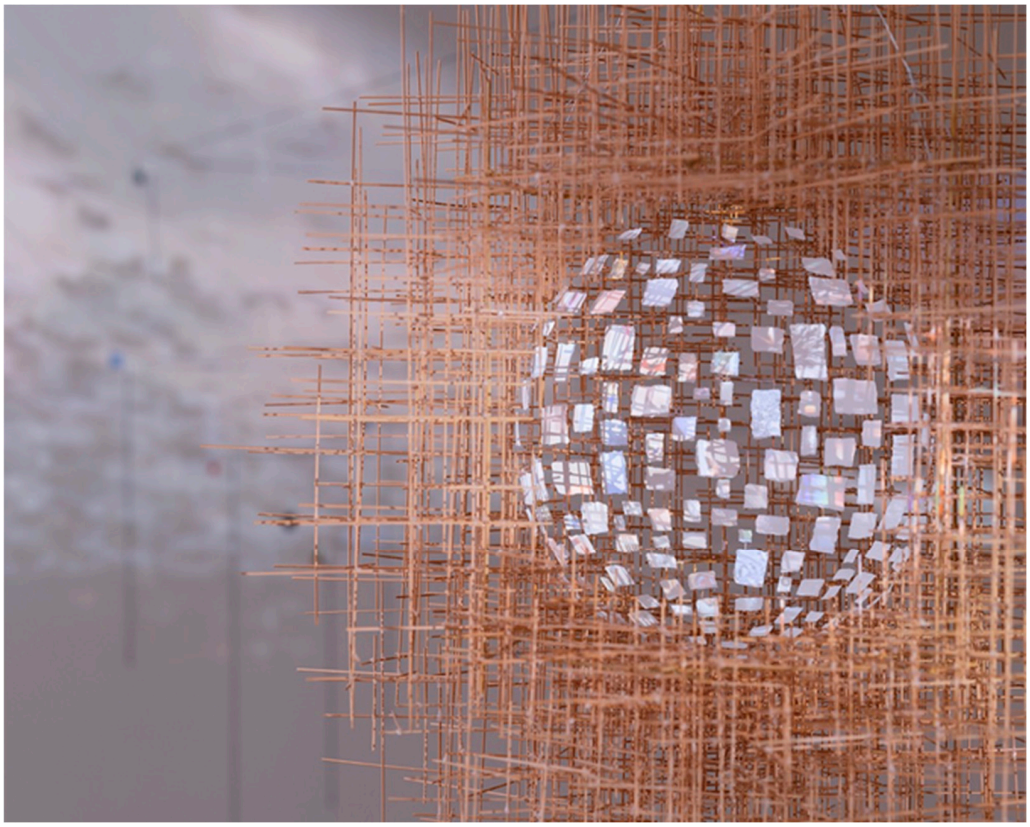

Figure 8. Projected images on paper scrap screens positioned into a fragmented sphere suspended within a scaffolding of fragile sticks, much like us all. Installation view, *Things Caused to Happen* (*Oculus*), in Sarah Sze: "Timelapse," 2023, 31 March—10 September 2023, Solomon R. Guggenheim Museum, New York. Solomon R. Guggenheim Foundation, New York.

On the one hand, the illusion of continuity, one's sense of givens, must be surrendered for realities at other scales to be considered real. Placing a different set of perceptions at the center, one notices gaps in what is seen, allowing other ways of perceiving reality. Scale could be considered a powerful tool to say, "Look—there's all this other reality happening simultaneously!" Sarah Sze physicalizes this idea, putting us in sight of simultaneous scales, shifting and mixing before our eyes. The open, interpenetrating nature of her installations, which have individual presence but also relate to each other and to the architectural space, makes evident that any attempt to piece them together is a pathway through the space of an encompassing structure, and a construction in time within the on-rush of interlocking events.

On the other hand, from this disintegration of stable space and time comes a putting back together, a noticing of the act of making coherence. By destabilizing the customary relationships of familiar things, Sze's work reveals how scale retraces new domains of relationships (Figure 9). As DiCaglio has written, "In a framework of scale, objects are no longer clearly separate, apparent, and self-contained entities 'in themselves', since changes in scale reveal that the same thing also exists differently. All objects must be defined via their scale of interaction and perception" (DiCaglio 2021, p. 6).

It is not just humans piecing together this reality; to the contrary, the surprise of Sze's and Gego's works is that one is subjected to the piecing together and interconnected relations between objects that seem to move on their own. Sometimes, that movement is an "illusion" created by viewers' changing perspectives; other works are literally kinetic. In one passage from Sze's installation, a fan blows a leaf which moves a weight strung over a pool of water, barely touching. Their works suggest the lively movements, the parts and coherences of nature, that are always there, whether we are consciously attending to them

or not. The sun rises, a volcano erupts, water flows, grains of sands move. We breathe (cells' breath, the planet's breath) and it is all pieced together.



Figure 9. A painting tumbles from the wall and falls to pieces; projections of repeated motifs move along the wall. One might resist the urge to piece it back together, but the urge to make sense of the juxtaposition is strong. Installation view, *Times Zero* in "Sarah Sze: Timelapse," 2023, 31 March—10 September 2023, Solomon R. Guggenheim Museum, New York. Photo: David Heald © Solomon R. Guggenheim Foundation, New York.

6. Artist #6: Bull.Miletic: Dislocating the Subject

Crossing scalar thresholds—as when a carbon atom is understood as part of a squirrel's toe, or when that toe takes its place as a tiny part of an ecosystem—we speak of distinct objects, even though the distinction is created when two simultaneous scales are seen at once. In these leaps in scale, we find ourselves considering several scales at once, at least one of which is dislocated from our typical perspective. Where are we in this dislocation?

The artists Synne Bull and Dragan Miletic, who work together as Bull.Miletic, have crafted both art and theory focused on conglomerate scales. Their installations combine historic imagery with contemporary technology to draw attention to cultural constructions of scale. One work, *Zoom Blue Dot* (Figure 10), plays with Charles and Ray Eames' film *Powers of Ten* as well as the Pale Blue Dot image popularized by Carl Sagan.[5] In theorizing their work, Bull.Miletic coined a new word for the concept of scale embedded in their kinetic video installations: "proxistant", a portmanteau combining "proximity and "distance". Bull.Miletic defines "proxistance" as "the ability to visually capture geography from close-ups (proximity) to overviews (distance)" in the same image, zoom, or flight, "most noticeably illustrated by Google Earth's 'digital ride' from a global view to street-level detail" (MCD 2022). They argue that proxistance is a significant paradigm shift in the way that citizens in technological societies conceptualize their location in the world. In scale theoretic terms, they suggest that technologically enabled aerial moving images have provided a global "model" that rearranges the internal concepts, the mapping, of those citizens.

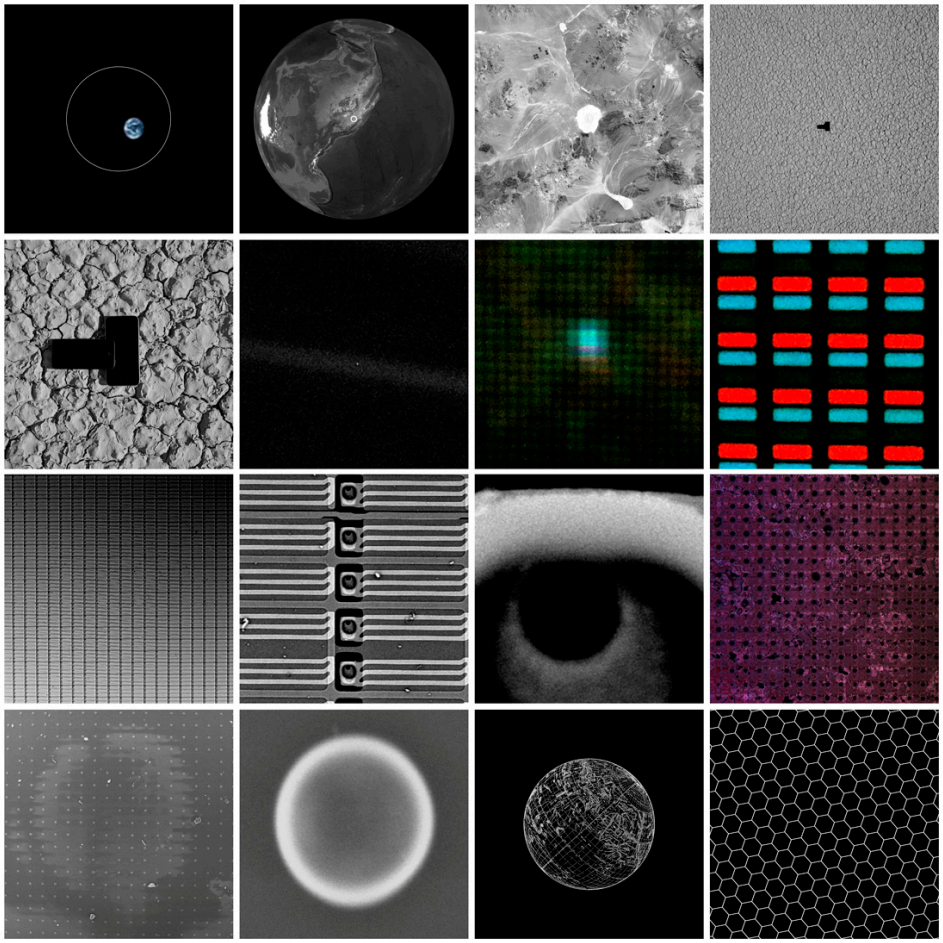

Figure 10. Inserting the proxistant dislocation: an array of perspectives arranged in the same manner as stills from Charles and Ray Eames's film *Powers of Ten* are often arranged. Bull.Miletic, *Zoom Blue Dot*, 2022–2023. Two-channel kinetic video installation. Two-channel video (color, sound), Mylar curtain, Mylar tape, custom robotics.

There is tension in the term "proxistant", which reveals another aspect of the difficulties that arise from science's scalar description of reality. In this context, Bull.Miletic (2023a) returns us to our earlier discussion (Section 3) of feminist epistemology to give us another avenue into the problem of situatedness in relation to scale:

> The goal is to examine the proxistant paradigm as an indicator of how knowledge through vision continues to operate as a major attractor in a topologically organized society of control. However, there are also ways of thinking about proxistance as a form of feminist epistemology. Here, proxistance is the constant move between deep insight and broad overview, narrow focus and wide-reaching attention, knowledge of the detail, and seeing it in context.

The proxistant attempts to bring particularities into control by mapping and ordering from a distance without regard for the particularities (human and nonhuman lives, material structures) being mapped. At the same time, the ability to work between these perspectives is essential for understanding how particularities work in relation to broader understandings and views. The problem highlighted by Bull.Miletic lies in the conflation of these perspectives (the making proxistant), not the changing of perspectives themselves. With a careful accounting of scale, the tension can be diagrammed as a problem of technological mediation that is clarified by noticing the dislocation of perspective. Bull.Miletic's kinetic installations point to these technological mediations and deconstruct the conflation

when the viewer follows through on the following question: where and how am I situated (positioned, placed) in these proxistant visions?

In *Scale Theory*, DiCaglio argues that significant disorientations of scale arise precisely in this proxistant mode, which he calls a "situated dislocation," in which two very different scales of perception are put in relation to each other (32). For DiCaglio, the "distant", or the dislocation, is a different scale domain, and the proximate is the "here" of the meter-scale experience. In this rendering, what Bull.Miletic calls the "proxistant" is a conflation and, to some extent, a forgetting of scale: the proximate and the distant are imagined or imaged as if they are one and the same perspective. Scale, as the relation between two different perspectives (or ways of describing or visualizing the same thing), has been obscured. (This is reminiscent of the way early filmmakers used confusions of scale to create special effects, such as taking two shots of the same object from different distances and overlaying them as if they were shot from the same location. In such cases, the viewer literally has no sense of scale; the effect is created by failing to mark or register the incredible difference in perspective (DiCaglio 2021, pp. 33, 234).) Such conflations make it possible to disregard the particularities and to imagine oneself in control of such views. Reintroducing the question of scale brings the overlaid change in perspective back into the view, situating the dislocation.

Noticing the dislocation *as* a dislocation is a powerful tool. The question "where am I?" directs attention to both the location of one's current perspective and the pull to displace one's attention elsewhere. In scalar perspectives, one is always already in multiple places (in the yard, in a city, on a continent); following the dislocation is to notice the radical re-visioning of one's reality at another scale without becoming lost in the apparent presence of that scale, which seems so close, so proximal.

Bull.Milletic's proxistant series builds on traditions of playing with these problems in film and art.[6] Their work offers viewers proxistant visions, but then disrupts them, bringing the conflation into view and therefore calling on viewers to take the changes in perspective into account. *Zoom Blue Dot* serves as an example. For many people, the Eames's film *Powers of Ten* is the archetypal scalar view. *Powers of Ten* begins with a particular human body in a particular location, a picnicker in a lakeside park in Chicago. As the "camera" jumps skyward, making leaps in scale by orders of magnitude, the picnicker is no longer visible, although presumably still present, even when the "view" is from 10^{24} m away. Then, the direction reverses and the view burrows down into his body, the scale diminishing by powers of ten. As the orders of magnitude go into the negative numbers, the picnicker again becomes "invisible" even though the cells and atoms depicted are presumably his. *Powers of Ten* is often critiqued for the human power relationships encoded in its smooth zoom and seemingly omniscient observer, but it remains an effective visualization of the radical transformation induced by changes in scale.[7]

Zoom Blue Dot complicates the smooth assurance of the *Powers of Ten* zoom, calling attention to the technical apparatus as a demand to relocate oneself. The installation mimics the *Powers of Ten* journey, zooming, however, into a famous image of the Earth on two iPhones. This image is a 1990 shot taken by the Voyager 1 space probe just before Earth receded into invisibility. The Earth was only about 0.12 pixel in size from that distance, roughly 4 billion miles. At the time, astrophysicist Carl Sagan described the image thusly: "the Earth appeared as a glimmering speck of dust, a pale blue dot suspended in a sunbeam" (quoted by Bull.Miletic 2023c). The view in *Zoom Blue Dot* moves from space, to Earth, and then into that famous image, through the 0.12 pixel down into the iPhone's mineral body. Courtesy of imagery from laser and electron microscopes, the viewer encounters brilliantly colored chevrons, circles, and grid forms of this representational device. *Zoom Blue Dot* brings into view the arduous micro- and nanoscale engineering that supports the daily encounter with the fantasy that we can change scale and travel from outer space to atoms with a pinch of the fingers.

In this way, Bull.Miletic reveals "proxistant vison's material support," demonstrating how technological mediation produces different perspectives. Yet even within this support,

one is left grappling with the oddness of the different perspectives, of the images said to be the Earth, of information architectures, of pinch-able views. Feminist epistemology re-emerges from re-situated dislocation, in this instance situating the changing perspectives amongst the empirical objects re-presented from different views of existence. As the images in *Zoom Blue Dot* near the smallest scale, the gridded Earth is interpolated before the final image of a lattice, juxtaposing the largest and smallest scales in the work in a proxistant transition. This insertion is the disrupting addition of an imaginary mapping of control—the grid—at the very moment the work presents the extreme dislocation of scalar views. The viewer is left there to contemplate their place amidst the contradictions of the proxistant and the origins of the pixels and pale blue dots.

Indeed, turning the attention back to the device producing the experience provides a way of disrupting the inevitable scale tricks formed when we re-produce scalar perspectives at this scale. This is made clearer in another work, *Ferriscope* (Bull.Miletic 2023b). This installation proceeds in four stages. First, a simple black and white slide reel shows images from the different perspectives one would have on a Ferris wheel: views of a crowd from high up, then closer up (down to the ground), then of the structure of the Ferris wheel itself, and an image of others having the same experience in the cart across from the viewer. These last two viewpoints make one aware of what is producing the change in view: the apparatus (Ferris wheel) moving around the camera (and therefore the viewer's perspective). The experience comes into view as a technological lattice. In the second stage, the images move quickly, changing perspectives in rapid, barely distinguishable succession. People, buildings, and apparatus flash by, hard to situate in relation to each other. In the final stage, the projector suddenly starts to spin, throwing the projected image around and around the room in a blur. One is made aware that it was not the Ferris wheel that was generating the change, but the projector, which has revealed itself. The viewer is disoriented by the blurred perspective that is nothing but the flash of an image moving too fast for human discernment (Figure 11). In the final movement, signaled by a series of beeps, a newly stabilized aerial view zooms over a cityscape, turning at slight angles, until it runs into the center of a Ferris wheel. Just as it hits the Ferris wheel, the view transforms into a vertical zoom; the whole Earth is glimpsed spinning rapidly for about five seconds before it is replaced with what looks like a stylized Ferris wheel, but is actually a color wheel slowly spinning.

In the progression from the first segment to second segment, *Ferriscope* moves from a deliberate awareness of different perspectives to their proxistant overlaying. The third segment forces a reckoning with the apparatus present in the room (it was not the Ferris wheel after all!), which is blurring all the views together in an incredible disorientation. The beeps signal the re-entry of order, the aerial view emerging from disorientation. But the aerial view does not seem so trustworthy after the forceful bringing of attention to technological mediation, to the spinning projector. Squinting from the light, feeling the disorientation, the viewer is pulled up to see the whole planet. But that is not all: they are left with a color wheel spinning, a reminder that all of this was produced through a visual array of combined colors, spun to create the seamless illusion (wait, was it so seamless?) of the different views.

Scientists, in identifying new scales, have made visible, from here, strange "new" objects, vast and miniscule. But the authority of "scientific models of calculation and prediction", as Bull.Miletic (2023c) describes it, is disrupted when the technological mediation itself is imaged as a disruption of the viewer's perspective. If we pause to notice, as Bull.Miletic forces us to do, that these varieties in perception are manipulations of how we see the world, then we can begin the work of retracing and relocating ourselves in a cosmos that has been redescribed and perceived again in multiple forms. In these moments, we can separate the proximal and distant by noticing how these apparatuses have encoded, in the "here" at the meter scale, new perspectives. In contemplating scale, where are you? In some sense, in both places (the proxistant). But then what is this "you" who is seeing both ways at once, hooked into this apparatus? Here, the hubris of the proxistance gives

way to the realization that these scalar forms pull us outside ourselves. The world is made different by changes in our perspective, and the "me" that notices this is also different. With that feeling, the gap between the proximal and the distant opens up, even as it is retraced by measures of scale, and an "I" can feel just how much reality has been reworked when speaking of cells and planets.

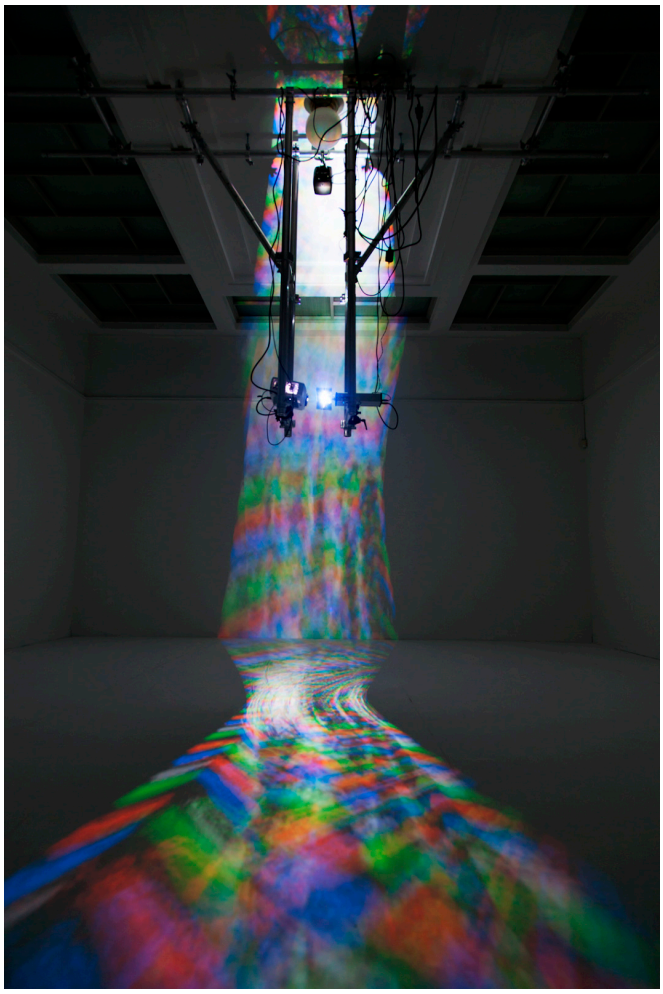

Figure 11. The Ferriscope suddenly whirs towards the viewer who is blinded by their perspective. Installation view, "Ferriscope", Trondheim Art Museum, 2018. Photo by Bull.Miletic.

7. Conclusions: Feeling Scale

The collection of artworks discussed here incorporates varied intentions and emphases, suggesting that scale is such a central experience it can be approached from many directions. Common to each artwork is the challenge presented by the abstract, unfamiliar nature of changes in scale and the scalar objects of science. Each artist brings these aspects into view, teaches us to reckon with the accounting produced by scale, plays with the relationships with these new objects, and puts us into contact with these scalar perspectives in different ways. Frankel suggests visual pleasure as a lure to encounter strange scales. Olynyk triggers multiple sensory modalities—sight, sound, and the kinesthetic sense—to offer her audience a scalar experience. Morawetz taps into empathy, through pictorial story-telling supported by brief texts, to ground the arduous effort to track changes in scale. Gego and Sarah Sze speak the language of three-dimensional forms, "read" through the movement of the viewer, to pull the viewer into an awareness that they are piecing together only a small part of a scalar cosmos. Bull.Miletic both emphasizes and deconstructs the role of technology in creating unfamiliar scalar feelings.

The experience that all the artists discussed here offer their audiences—consciously feeling scale—is rare. These artworks make clear that such changes in scale might be and often are merely understood intellectually, as information provided by science. In such a mode, different scales of existence can be memorized as facts, but remain abstract, like the cell diagram on the wall of the biology classroom. Considered through art, experiences of scale can become emotional, even mystical, relocating a viewer's awareness from within the body to the galactic context of that body or to understanding that body as a universe for others. The challenge is to learn to see and feel, in addition to knowing, the strange facts of scale. Even science mounts evidence that we are part of something larger and that we are something larger to others. To do so, science has the extra challenge of carefully determining ("objectively") what can be said about scalar objects with any confidence that it is reliable and repeatable (empirical). In turn, artists make scalar views empirical in a different way, not objective in the scientific sense but accessible to experience in a deep and transformative sense. Their works ask viewers to grapple with the conditions of this new cosmology, these new parts and connections, large and small. Multiple senses contribute to awareness of different scales, felt anew as (re)descriptions of the viewer's world.

Swaying gently overhead, scaling our sensory systems, Olynyk's silken renderings of cells give us a portal through which we can return to the mundane objects of science, guided and oriented by Morawetz's meter, pieced into strangely coherent shapes like Gego and Sze's installations but aware of the allure of Bull.Miletic's proxistance, we return to the astonishing images of science produced by Frankel. The cell diagram on the wall, carefully labeled and memorized, can now be felt as a radical reorientation present, even if hidden, within the seemingly straightforward facts of modern science.

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Notes

1 Scale is a fundamental aspect of art practice—the *Random House Dictionary of Artists and Art Terms* devotes first place in its essays on art terminology to scale, and scale was the subject of a special issue of *Art History* (Kee and Lugli 2015). A comprehensive list of historic and contemporary artists whose work could be usefully discussed in terms of scale would be of unmanageable scale. Worthy of note, however, are artists whose works engaging microbiomes are loosely grouped together as "bio-art", including Anna Dumitriu, House of Natural Fiber, and White Feather Hunter. The term "bio-art" has also been used for artists working with other small biological structures such as animal or plant cells, genes, or living tissues, including Oron Catts and Ionat Zurr, Kathy High, Adam Zaretsky, and Eduardo Kac, or meter-scale biological structures that are usually hidden from view, such as Mona Hatoum. At the other end of the scalar spectrum are "land artists" including Beverly Buchanan, Agnes Denes, and James Turrell, and "ecosystem artists" such as Mel Chin, Helen and Newton Harrison, and Aviva Rahmani. Another large group of artists, including Harun Farocki, DJ Spooky, and Catherine Wagner, have investigated various aspects of the "scientific" technologically enhanced seeing that makes different scales visible, from addressing history of technology to using specialized scientific equipment to make their work. While we keep these artworks in mind, we have selected recent artists whose work highlights particular aspects of scale and technoscience.

2 Visual cultures of science, particularly in relation to epistemological questions, is a central concern for science and technology studies; see, for example, Pauwels (2005) and Hentschel (2014).

3 The literature on visualization and the history of art, science, and technology is extensive and traces the development of the cultural conditions that made the works we discuss possible; for example, the use of nested spheres to depict the universe discussed in Ferrer-Ventosa (2024) can be seen as a precursor of the nested scales common in contemporary usage. For historical precedents of questions of art and science broadly relevant to all the artists we discuss, see Smith (2006) and Henderson (2019). For a discussion of the 17th-century shift towards a new kind of empiricism that privileged visualization as a way of knowing, framed in terms particularly relevant to the work of Morawetz and Bull.Miletic, see Mukerji (1984); for a discussion of an 18th-century

shift in empirical visual thinking produced by diagrams and awareness of knowledge as process, which suggests interesting connections with Gego and Sze, see Bender and Marrinan (2010).

4 A precedent for this project can be found in Jacqueline Goss and Jenny Perlin's film, *The Measures* (2014). Like Sara Morawetz's performance, *Etalon*, Goss and Perlin retrace the steps of the scientists who first calibrated the meter. However, their work seems to focus on very different experiences, more visual and less concerned with the relationship between the definition of the meter and the tie to the scale of the body. The comparison surfaces the power of esthetics to give meaningful nuance to ideas.

5 Charles and Ray Eames's film, *Powers of Ten* (1977), was inspired by the book *The Cosmic View: The Universe in 40 Jumps*, by Charles Boeke, the *Cosmic Zoom* (1968) directed by Robert Verrall for the National Film Board of Canada (1968), and a "first draft" of *Powers of Ten* by the Eames themselves. The Pale Blue Dot speech was given at a 1990 press conference unveiling an image taken by the Voyager spacecraft at the edge of the solar system showing the Earth as a small dot "suspended in a sunbeam". This speech and image became the basis for a separate book by Sagan under this same title.

6 We are not touching extensively on the problem of scale in film, which has a long conversation in relation to special effects and other scalar imagery, which has been the focus of other scholarship, e.g., Mary Ann Doane (2022), Zach Horton (2021), and Derek Woods (2017). Some artists have pushed at these concerns deliberately within film. One is worth mentioning in relation to the questions about perception and visibility that we discuss here, Hito Steyerl, *How not to be seen: A fucking didactic educational.mov file* (2013), which uses a military resolution target, and playfully dancing "pixels" (performed at human scale) to bmake the deadly serious point that one way to render something "invisible" is to change scale.

7 DiCaglio (2020) overviews these critiques and provides a more extensive version of this argument.

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