At the Intersection of Unsolved Mathematics, Visual Art and Religious Thought: *Unfolding Humanity*

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> *"As I stood twelve feet in the air, in the 100 degree heat, holding one edge of a 250 lb steel pentagon, I saw a wall of dust approaching in the distance. The surface of an ancient lakebed that was now the 'Playa' to the Burning Man community had leaped into the horizon. I had been warned that the weather could turn in an instant, but the Black Rock Desert had chosen the most precarious moment of our build to show her true power. A few seconds, and a gentle breeze transformed into fiendish swirling twenty mph winds. Soon I was engulfed, unable to see, and a voice on the ground fought the roar of the wind, 'Just hang on—it will stop!...eventually!'"*
> -- Diane Hoffoss

This sounds like something out of a "Mad Max" movie, depicting the struggle of human limitations and technological aspirations against the awesome might of the natural world. Rather, the struggle described above took place in the middle of the Nevada desert, not too long ago: the culmination of a project called *Unfolding Humanity,* a two-ton metal, wood, and acrylic interactive sculpture. Undertaken by a team of faculty, students, and alumni of the University of San Diego, along with volunteers from the southern California art community, the sculpture consumed over 6500 person-hours and $50,000 in its making.[1] Rising 12 feet tall with an 18-foot wingspan, the unfolding dodecahedron was externally skinned with black panels containing 2240 acrylic windows, illuminated by over 16,000 LEDs which were programmed and driven by 20 controllers. The interior, large enough to hold 15 people, was fully lined with a massive mirror over each of the twelve pentagonal faces. The resulting artwork was displayed in 2018 at Burning Man, an arts event that attracts over 70,000 people every year. Its home is Black Rock City, a temporary metropolis which exists only during the week leading up to Labor Day. Today, this event has become synonymous with innovative large-scale sculpture exhibitions, with much of Silicon Valley in attendance to contemplate the advancements in technical and engineering feats.[2]

Unfolding Humanity calls attention to two unsolved problems in mathematics. On one hand, it echoes the German Renaissance master Albrecht Dürer's explorations nearly 500 years ago on polyhedral nets: can a polyhedron be cut along some of its edges so that it unfolds into one flat piece, without overlap? *Unfolding Humanity*'s polyhedron is the dodecahedron, one of the five Platonic Solids. This sculpture allows participants to unfold eight of the pentagonal panels of the dodecahedron (though

[1] Satyan L. Devadoss and Diane Hoffoss. "Unfolding Humanity: Mathematics at Burning Man," *Notices of the American Mathematical Society* Vol. 66 (2019), 572-575.

[2] Laura Holson, "How Burning Man has evolved over three decades," *The New York Times*, August 30, 2018.

not fully flat) to illustrate one such possible configuration. But the project is more ambitious: *Unfolding Humanity* asks the observer to contemplate the shape of our universe, as well as the human presence within it: the inside of the dodecahedron is covered with seven-foot-tall mirrors, becoming an illuminated mirrored room designed to allude to the infinite in a finite space, the microcosm within the macrocosm. Plato believed that the dodecahedron, composed of twelve regular pentagons and twenty vertices meeting at three-corner joints, referred to the "quintessence" of the universe, the shape of the cosmos itself, as it encompasses the four elements represented in the four other Platonic solids.

This project was a deeply collaborative effort, with eighty volunteers and a faculty leadership team. The germ of the project was imagined by Devadoss and Hoffoss in summer 2017, and the initial dodecahedral sculpture was formulated by students Jordan Abushahla, Nick Bail, and Eugene Wackerbarth in Devadoss's Fall 2017 Geometry course. Hoffoss was the artist lead for the project, with Dr. Gordon Hoople (School of Engineering) and Nate Parde (Dept. of Theater) providing engineering, design, and logistical support and Max Elliott of Sony Corporation directing electronic installation. As the project was co-fabricated in the Engineering Design Laboratory on University of San Diego's campus and at the community maker space San Diego CoLab, it attracted and inspired collaboration from both university and local maker community volunteers. The collaborative construction[3] entailed not only applied knowledge and development of skill, but the sort of aesthetic cognitivism that converts conceptual possibilities into experiences, and vice-versa: constructing the image creates the reality it represents.

I. Reality and Abstraction

In *De Anima* iii 5, Aristotle describes the divine mind as *nous poietikos*, the active mind, the "mind that makes."[4] Without craft, Aristotle says, nothing thinks (*aneu toutou outhen noei*). The potential of human beings to know what is real pertains to unlocking the latent possibilities within reality by acting upon it. As such, the act of turning potentiality into actuality is deathless and everlasting. We share in what Aristotle called the "divine mind," demonstrated throughout history, as the meaning of being human in reference to making things. We experiment, we build, and we measure, in order to learn about reality; "cosmos" is first *physis*, the "whole of things" pertaining to motion, shape, development and change. The very definition of technology refers to the application of science or knowledge for practical purposes, for a structure or constructed experience that is capable of enabling or explaining the relationship between human beings and the world. Aristotle in the *Poetics* names poetic creation (*mimesis-mythos*) as a mirroring of life. Explains Richard Kearney, "Creators making creatures that remake their creators, in each other's image, in shapes and songs, paintings and poems, dreams and crafts."[5] Indeed, the origin of modern humanity can be traced to the Upper Paleolithic Period, in which we see the adventure of the artistic endeavor coincide with technological innovation and the love of making something beautiful.

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[3] We extend our profound gratitude for the contributions of our volunteers: Michael Sween, Quinn Pratt, Sean Pennington, Sydney Platt, Ava Bellizzi, Viktoriya Alekseyeva, Colin Bowring, Katie Frehaufer, Paul McClure, Ross Watanabe, Steven Brown, Shawn Tuttle, Jack Nguyen, Sladjana Lucic, Erica Esserman, Alex Spilde, Lee Hemingway, Melissa Cairns, Glenn Moss, Elizabeth Sampson, Christiana Salvosa, Steve Saxer, Sam Burt, Eduardo Ortega, Kate Rumann, Kiana Gustaferro, Gabriela Goerke, James Enders, Nat Yee, D.D. Latimore, Sarina Haghiat, Kendal Karch, Riley Evans, Nick Cardoza, Gracyn Otten, Jordan Abushkala, Nick Bail, Eugene Wackerbarth, Kelli Kufta, Sean Hough, Cindy Liu, Brian Tran, Lisa Walden, Jason Good, Jessica Bolton, Nam, Paul Williamson, Dan Reeves, Bob Mule, Breanna Cuevas, Lia Turiano, Rachel Gallagher, Mike McCormack, Amber King, Scott Widmann, Ben Ciotti, Karen Tang, Laura McEntyre, Ken Simmons, Erin Simmons, Jake Holler, Jeff Makey, Laura Makey, Malcolm Napier, Nichole Ma, Sam Mathews, Pierce Dunham-Zemberi, Denise Lozano, Thomas Marshall, Kohji Kawa, Gina Escobar, Ezekiel Bhasker, Ricky Ray Prickett, Sean Nash, Amanda Qassar, Laurel Small, Brian Faires, Joseph Maher, and Ensari Cokur.

[4] Richard Kearney, "Making God: A Theopoetic Task," *Imagination Now: A Richard Kearney Reader*, ed. M. E. Littlejohn (London: Rowman and Littlefield, 2020), 200.

[5] Ibid., 199.

Approximately 20,000 years ago, the earliest of modern *homo sapiens* ventured into a system of caves in what is today Lascaux, France, in a quest to visually explore the contradictions in their world, populated by both dangerous bison and gentle deer. Paintings as high as fourteen feet off the ground necessitated the building of a scaffold; paintings found nearly a mile underground necessitated the invention of oil lamps. This means that applied science was vital to accomplish the more abstract endeavor of painting an image onto a cave wall. Archeologists tell us that the caves were not dwellings, and there is no evolutionary requirement or obligation to survive that explains why early human beings went to such lengths to make art. Rather than from biological necessity, the interest to create, to make, in these circumstances pertains to the desire to innovate methods and mechanisms that advance human inquiry. In terms of the desire to marry technological achievement—such as scaffold building, mixing durable pigments, and fashioning lamps—with the creative expression of visual imagery, human beings today have similar intentions. Artistic exploration through applied technology shapes our environment and enables the physical exploration of abstract objects such as those in mathematics; such is fundamental to what it means to be human, referring not only to the power of expression, but to the power of experience, whether one makes or beholds.

Unfolding Humanity follows this trajectory: a structure that provides an experience of the question, what is the relationship between our humanity and the shape of the universe? How does the material or physical experience of abstract geometrical objects lead to cosmology? "Topology" originally meant the "study of place"—can technology in art change our perception of our place in the universe? Can the construction of a model of the universe enhance our understanding of it, and of ourselves? Topology today refers to the branch of mathematics that studies the fundamental properties of objects; topological properties of an object are consistent when an object is bent or stretched. Can we build or make an environment or object that can enable an experience of place or purpose? What is the relationship between place and meaning of being human? Art, religious thought, and mathematics meet not in collections of information but in ways to enhance the mode or process of knowing, and *Unfolding Humanity* demonstrates that making and the embodiment of abstract ideas are a way to knowledge.[6] In other words, these diverse fields study the same things and can ask the same questions but approach these through different methodologies.

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[6] Semir Zeki, et. al., write, "Unlike visual or musical beauty, *only those versed in mathematics* can experience the beauty of mathematical formulations. And yet the experience of mathematical beauty correlates with activity in the same part of the emotional brain as the experience of beauty derived from sensory sources, such as the visual or the musical," "The Biological Basis of Mathematical Beauty," *Frontiers in Human Neuroscience* 30 November 2018. *Unfolding Humanity* shows that bringing abstract objects into material reality as art pieces leads to new experiences of the mathematics involved.

Plato believed that abstract mathematical objects are pre-existent to, and therefore elements of, all objects in the material realm; thus rather than invent these objects, we *discover* them. However, making art means that we invent how we relate to an object; such is more a feature of Immanuel Kant's assertion that we actively produce the way reality appears to us through the imagination. For Plato, human reason reflects what is real or True and art merely imitates this; for Kant, human reason, in deference to the imagination, is capable of creating new vistas of reality through aesthetic judgment. Aesthetic judgments are different from determinate claims about objective features of the world, as they rely on agreement with others.[7] Reason through the "free play" of the imagination contributes to the experience of what is real, thereby contributing to the reality itself. Plato might have seen the construction of an unfolding dodecahedron as an imitation of the dodecahedral shape of the universe; Kant might have seen the interest to investigate the intersection between mathematics and meaning as the imagination's creation of something new. Numbers and the patterns they symbolize are key to unlocking these questions; so too is our experience of them, and our experience of the process of making them mean something, which is assisted by the aesthetic judgment.

Werner Heisenberg connected the experience of beauty or aesthetic judgment to the intuition of what is real or True. He recognized layers or modes of reality, as "reality" pertains to the pattern and totality of connections that pervade our lives. He argues that the most basic or fundamental level of reality is independent of the process of observation (described for example in classical mechanics, electromagnetism, and relativity theory), and so are objectivized. The next level pertains to reality inseparable from the process of observation: quantum mechanics, biology, and the sciences that study consciousness. The "uppermost" level pertains to the states of things created in relation to the process of observation and gaining knowledge: philosophy, aesthetics and religious studies, "in which the view opens up those parts of the world which can be spoken of only in parable."[8] "Religion alone can speak of the meaning of life," writes Heisenberg, "For 'meaning' signifies that it is we who are addressed here—this is the point to which science cannot advance."[9] Humans are meaning-makers; this much names us *homo sapiens* evolved from Neanderthal in the Lascaux caves, when we were first able to detach acts necessary to the survival instinct (shared by all animals) from those in service of the artistic instinct. For Heisenberg, to be "religious" is to seek meaning; also necessary to the exploration of

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[7] See Angela Breitenbach, "Aesthetics in Science: A Kantian Proposal," *Proceedings of the Aristotelian Society* Vol. 113 (2013), 90.

[8] Werner Heisenberg, *Reality and Its Order,* trans. Martin B. Rumscheidt, Nancy Lukens, and Irene Heisenberg, ed. Konrad Kleinknecht (Cham, Switzerland: Springer, 2019), 116.

[9] Ibid., 34.

reality is the scaffolding, the technological advancement that sets the parameters and structure of the question or method of inquiry. *Unfolding Humanity* as a collaborative project demonstrates that the exploration of reality cannot be absolute and isolated at any of Heisenberg's levels, and the multi-dimensional nature of reality requires reciprocity between the academic disciplines.

The value of mathematics for every scientific field is indisputable. Mathematics has even managed to escape the postmodern critiques of scientific positivism; Sundar Sarukkai asserts that the discipline of mathematics has an aura of the esoteric and the "process of seclusion is strengthened by the contention that mathematics is a formal, axiomatic, deductive and logical system, which is concerned only with a platonic world and whose connection with our real world is only incidental and perhaps mysterious."[10] That mysterious and elusive character of the discipline of mathematics reveals possibilities for integration with the disciplines of aesthetics and religious studies. All three travel in ambiguities and abstractions in their epistemological procedures. These three fields—art as the expression of human creative endeavor, religious theory as the expression of humanity for meaning and the transcendent, and mathematics as the "poetry of logical ideas,"[11] as Einstein put it—intersect in ways that make all three more evident of their respective pursuits. This essay advocates for the necessity of the interaction of these disciplines in education and endeavor, as beyond mere cooperation: when integrated and interdependent, each of these three areas improve and expand their own aims.

II. The Aesthetic Dimensions of Mathematics

When asked to summarize his philosophy of physics in a lecture at the University of Moscow, Paul Dirac famously wrote on the blackboard: "physical laws must possess mathematical beauty." Dirac believed that fundamental physics advances by successively more beautiful theories. Beauty is the attractor that leads to enhanced understanding of the laws of nature. Dirac's method in theoretical physics was to begin with constructing the beautiful equation; he believed that the experience or observation of its reality would follow. For Dirac, the beautiful equation would inevitably—perhaps not immediately—lead to the observation of reality in the natural world. Albert Einstein and Henri Poincaré also valued the role of beauty, the notion of being grasped or attracted by something that fires the senses, in terms of the simple, unifying idea. Dirac interpreted Einstein's law of gravitation as simpler than Newton's, which demonstrates the depth of Einstein's observation.[12] Henri Poincaré believed that

[10] Sundar Sarukkai, "Perspectives on Mathematics," *Economic and Political Weekly* Vol. 38, No. 35 (2003), 3648.
[11] Albert Einstein, Letter to the Editor of the *New York Times*, May 4 1935.
[12] See James W. McAllister, *Beauty and Revolution in Science* (New York: Cornell University Press, 1996), 117.

the scientist studies nature because it is beautiful, and beauty does not need to elicit the useful, but simply what is pleasurable: the response one has to beauty in nature guides the desire to know about it.

Finding meaning through aesthetic pursuit has ancient roots, once we consider the way harmony and, consequently, morality, relate to the fundamental patterns discerned in the universe. Justice, the Good, was conceived by Greek philosophy as conceived in geometrical proportion. Aristotle, for example, believed that justice is a cube: in the *Nicomachean Ethics*, Book 5, ch. 3, he writes that equality has two terms but justice has four.[13] The Pythagoreans believed that numbers referred to the building blocks of all things; equations reveal relationships between these factors that lead to the discovery of something new as well as of something beyond the sums themselves, an extension of numbers into the geometry of objects. Hence, there is a transcendent dimension to the process of mathematics. Plato's Academy, which adopted much of Pythagoras' philosophy, required ten years in the study of mathematics before assuming the study of philosophy. Plato understood the goal of this mathematical training more substantively than merely the mental calisthenics of training the mind, however. Plato believed that mathematics leads to knowledge of the Good,[14] which imposes the eternal Forms onto chaotic matter.

The ancient philosophers perceived inherent relationships between what is Good, True and Beautiful, as the form, or eternal and unchanging essence of reality, reveals through these modalities to the human mind. Pythagoras taught this, and nurtured a religious following. Dirac assumed as much: "[a] theory with mathematical beauty is more likely to be correct than an ugly one that fits some experimental data."[15] There are, of course, many definitions and treatises on Beauty and its relationship to what is real, or True, and what is ethical, or Good. For our purposes, beauty is what heightens the senses, and so what moves us to care for, or to pay attention to, something outside utilitarian self-interest. When early humans painted in the inscrutable dark of the Lascaux caves, they were acting in accord with a life that transcends mere survival. Beauty in a religious sense is that embodied, sensory experience of significance or meaning pervading the universe, a sense that all that exists is profoundly interconnected and interdependent. The experience of Beauty is not fleeting, or trivial, or superficial, but pertains to the depth of being human, the depth of what makes life worth living. Beauty directs the

[13] See Elaine Scarry, *On Beauty and Being Just* (Princeton, NJ: Princeton University Press, 1999), 129. The *Nicomachean Ethics* outlines how human action may be capable of the Good. The function (*ergon*) of being human is acting toward establishment of the Good. Mathematics, concerned with proportion and pattern, is in this sense concerned with justice, "right order."

[14] See Myles F. Burnyeat, "Plato on Why Mathematics is Good for the Soul," *Mathematics and Necessity: Essays in the History of Philosophy*, ed. Timothy Smiley, *Proceedings of the British Academy* (New York: Oxford University Press, 2000), 5. Burnyeat is referring to Plato's *Republic*, 526de, 530e, 531c, 532c.

[15] Paul Dirac, "Can Equations of Motion Be Used in High-Energy Physics?" *Physics Today* 23 (1970), 29.

desire for more knowledge; as such, beauty and the heightened awareness of reality that it engenders leads to action, the making of something, the memory of something, the ethical care of something. The desire engendered by the experience of Beauty stimulates creative action.

There may be common characteristics between things and experiences we attribute to Beauty, such as simplicity, harmony, symmetry, and dynamism. Emotion, however, is also an inherent element of the experience. Pertinent to the consideration of what makes a mathematical equation or object beautiful is what Alfred North Whitehead observes about the aesthetic: "an emotional appreciation of the contrasts and unification…[in which] perception is heightened by its assumption of pain and pleasure, beauty and distaste...blue becomes more intense by reason of its contrasts, and shape acquires dominance by reason of its loveliness...This is the phase of perceptivity, including emotional reactions to perceptivity" in which consciousness attains to things beyond its limits.[16] The aesthetic is characterized by the intensity of emotion that occurs in the presence of Beauty; scientists, however, usually prefer to avoid anything as imprecise as emotional reaction. But Whitehead, Dirac, and Einstein welcomed the mysterious heightening of the senses that occurs when the truth of scientific observation intersects with the elegant, simple and harmonious. In this experience, Einstein located his own religious sensibility:

> The most beautiful and deepest experience a human being can have is the sense of the mysterious. It is the underlying principle of religion as well as all serious endeavors in art and science. He who never had this experience seems to me, if not dead, then at least blind. To sense that behind anything that can be experienced there is something that our minds cannot grasp, whose beauty and sublimity reaches us only indirectly: this it is to be religious. In this sense, I am religious. To me, it suffices to wonder at these secrets and to attempt humbly to grasp with my mind a mere image of the lofty structure of all there is.[17]

Einstein shows that the scientist thrives when accepting the mysterious unknown that motivates our curiosity and wonder. Why are scientists often anxious when discussing the more emotive or sensible, mysterious or ineffable elements in the experience of beauty?[18] The intersection between art, mathematics and religious sensibility in *Unfolding Humanity* is the locus of creative endeavor, which

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[16] See Alfred North Whitehead, *Process and Reality: An Essay in Cosmology*, Corrected Edition, ed. David Ray Griffin and Donald W. Sherburne (London and New York: The Free Press, 1978), 213.

[17] Albert Einstein, "Credo" (Mein Glaubensbekenntnis), Speech to the German League of Human Rights, 1932.

[18] See for example, Sabine Hossenfelder, *Lost in Math: How Beauty Leads Physics Astray* (New York: Basic Books, 2018); Angela Breitenbach, "Aesthetics in Science: A Kantian Proposal," *Proceedings of the Aristotelian Society* Vol. 113 (2013). Both authors tend to confuse "beauty" with prettiness or superficial attractiveness. That there may be a mysterious or ineffable dimension to the aesthetic experience may skew too religious or metaphysical to scientists who aim for certainty.

embraces the contradiction between the physical and the abstract. Such tension between the unity and multiplicity of things is essential to mathematics; within the experience of beauty is the magnetic excitation of paradox, in which something can be both simple and complex at the same time. There is also a heady appreciation of the uncertainty behind such a magnetic interaction, as in Heisenberg's Uncertainty Principle or Gödel's Incompleteness Theorem, the tension between what we can know and what we cannot know.

Great works of art similarly embody these contradictions: the nearly ten-foot span of Jackson Pollock's *Lavender Mist*, which contains no lavender paint, revels in the space between random and deliberate. The long drips of common house paint were an extension of the sticks he used, which were extensions of his fingers, without having to stop activity to reload paint the way one must stop to replenish a brush. He spread the canvas on a cold barn floor, and succumbed to a feast of automatism, building layers of color in a raw dance. In an interview with the *New Yorker* in 1950, Pollock responded to a critic's comment that his paintings did not have a beginning or an end: "He didn't mean it as a compliment, but it was. It was a fine complement. Only he didn't know it."[19] Standing before *Lavender Mist*, the viewer is engulfed as if in a forest, transported to an intricate chaos that is also ordered and metrical. One is grasped as Pollock was grasped, by an experience both physical and ambiguous, intoxicated by beauty's energy. Whitehead might have explained the experience of a two-dimensional painting on the wall of a gallery as "the interplay between the thing which is static and the things which are fluent," contrasts which are made possible by their patterned relevance to each other.[20]

Perhaps one of the reasons that Pollock's work is so dynamic and unusual--some physicists assert that Pollock's intuitions of fractal relationships make these paintings difficult to forge--Pollock's technique captures the way human perceptivity appreciates the fractal relationships in the natural world. According to neurobiologists, the experience of mathematical beauty comes from the same location in the brain as the emotions derived from experiencing the natural world.[21] A walk through a forest raises the senses in immediate, modest ways, while layered with shifting rhythms and colors and levels of life. We are attracted to the light filtering through the trees, to the shadows of the branches on each other, because there is an inherent pattern and symmetry that we may not be able to see with the naked eye. If we look closer, we see that the branches of trees replicate patterns from the larger to the smaller, such that if we cut a branch off from the trunk, we would see that it resembles the tree itself,

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[19] Jackson Pollock, interview with Berton Roueche, "Unframed Space," *New Yorker* (August 5, 1950), 16.
[20] Whitehead, *Process and Reality*, 346.
[21] See Semir Zeki, John Paul Romaya, Dionigi Benincasa, and Michael Atiyah, "The Experience of Mathematical Beauty and its Neural Correlates," *Frontiers in Human Neuroscience* 13 February 2014.

replicating the pattern further down to twigs. This is an example of fractal geometry, simple repeated processes that are embedded in the natural world, having internal rules of organization but also sensitive to random events which produce different forms of complexity. Pollock's drip paintings repeat these patterns but are also sensitive to randomness, which is how Pollock worked. Sometimes he was satisfied to let the paint drip in a random way; then he would repeat the drip elsewhere on the surface, building up tangled masses of drips that, like the branches of overlapping trees in a forest canopy, do not appear to have harmonious order until cut down into smaller sections. Scientists have studied the aesthetic response in the brain regarding fractals in nature: fractal patterns engage the parahippocampus, which is responsible for regulating emotions and is active while listening to music. The complexity of fractal relationships in forests and Pollock paintings soothe our visual needs in similar ways.[22]

For Whitehead, the aesthetic is the primary value that undergirds all values, because beauty is marvelous in itself and therefore valuable for its own sake; Whitehead took this from Immanuel Kant, who described aesthetic judgments as "disinterested" from an object's utility. Aesthetic judgments rather demonstrate the value of beauty to the exercise of reason. For Kant, there are three active faculties of the intellect: imagination, understanding, and reason. "Understanding" is not synthetic and so cannot produce "principles," the *a priori* concepts, such as axioms in mathematics, which we can apprehend and behold in their objective splendor, as being what they are apart from human epistemology. Reason is the domain of principles, then, operating independently of experience. The imagination, Kant believed, is a governing faculty that directs what the experience of beauty inspires, a "free play" between reason, understanding and sense perception. The imagination is presupposed or *a priori*, and so is productive, forming images rather than relying on representations of perceptions derived from experience.[23]

For Kant, the imagination is the precondition of all knowledge, "the basis for the possibility of all cognition, especially of experience."[24] Kant here affirms the idea that human beings actively and creatively make the world rather than merely passively receive it. The imagination becomes the immediate source of reality rather than an intermediary faculty between sensible and intelligible

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[22] Richard Taylor has done extensive research on the aesthetic response to Pollock's drip paintings as similar to fractal patterns in nature; see Richard Taylor, "Fractal Analysis of Pollock's Drip Paintings," *Nature* 3 June 1999, and Florence Williams, *The Nature Fix: Why Nature Makes Us Happier, Healthier, and More Creative* (New York: W.W. Norton and Co., 2018), 111-118.

[23] See Richard Kearney, *Poetics of Imagining, Modern to Postmodern* (New York: Fordham University Press, 1998), 47.

[24] Immanuel Kant, *Critique of Pure Reason*, A 118, trans. Werner S. Pluhar (Indianapolis, IN: Hackett, 1966), 166.

experience. The imagination makes meaning rather than receives it from an eternal essence, as Plato thought.

III. The Platonic Solids and the Mathematical Mode of Being

In the West, the desire to systematize and categorize reality has marked the human pursuit of truth since the pre-Socratic philosophers, but Plato gave systems coherence by using mathematics as evidence of the existence of an abstract realm of unchanging, eternal Forms. In the ancient world, philosophy was preoccupied with naming the objective origin of reality: what is “True” must be necessary to reality apart from the whims and variety of human perception. Hence, Plato argued that mathematical objects have *a priori* existence, or existence independent of human thought and experience. Such a reality was for Plato the realm of eternal or unchanging Forms, abstract objects that exist outside time and space and so are outside of sense perception. However, Plato also believed that there is a rational structure to the universe: the realm of eternal Forms must therefore be intelligible, but only by cognition, intuition or memory. This is why Plato believed that numbers are imprinted on the soul: because we can reason in mathematical objects, we have evidence both that these abstract entities exist, as well as evidence that the soul has access to them. Hence, access to the Forms is possible even while the soul is “imprisoned” in the body and so in the material world, as long as the changeable properties of matter do not obstruct what the mind apprehends.

Plato’s understanding of the human person is obviously dualistic, but so too is the scope of his ontology: the only things that are “real” are the Forms, the eternal objects that do not change or evolve, reflected in material counterparts that inevitably change and evolve. For Plato, mathematical objects are no different: numbers are identified with eternal forms, the fundamental building blocks of what we encounter in the material world. That mathematical objects lack concrete extension in space and time, but are considered fundamental to extensions in space and time, means that they belong to a different level of reality. Martin Heidegger points out that this is similarly true for Descartes: “Mathematical knowledge is regarded by Descartes as the one manner of apprehending entities which can always give assurance that their Being has been securely grasped. If anything measures up in its own kind of Being to the Being that is accessible in mathematical knowledge, then it is in the authentic sense. Such entities are those which *always are what they are*.”[25]

The Greek word, *tà mathémata,* does not refer specifically to numbers or calculation, but rather to the way human beings can in their reason learn the realm of being or reality that is original—that is the origin—of the material manifestations we experience. “In its formation the word mathematical stems from the Greek expression *tà mathémata*, which means what can be learned and thus, at the same time, what can be taught; *manthanein* means to learn, *mathésis* the teaching, and this is a twofold

[25] Martin Heidegger, *Being and Time*, 21.H.95

sense. First, it means studying and learning; then it means the doctrine taught."[26] *Mathémata* is a designation intended of things insofar as they are learnable, and learning is a kind of grasping and appropriating.[27] That we grasp and appropriate things pertains to the *a priori* structures of the human mind that allow this, "an extremely peculiar taking where one who takes only takes what one basically already has."[28]

So characteristic of human nature is apprehension of the rational structure of the universe, that in the *Meno*, Plato indicates that the intuition of mathematical truths is even possible in the mind of an enslaved youth. Even if we might attribute some of the boy's mathematical understanding to experience, Plato believed that this merely prompts his innate knowledge. The Greek philosophical definition of the mathematical is "the fundamental presupposition of the knowledge of things,"[29] according to Heidegger. This is why Plato chose the declaration "Let no one who has not grasped the mathematical enter here" for the entrance to his Academy; not that one must only be schooled in Geometry but that one must understand that the proper condition for the possibility of knowing is "knowledge of the fundamental presuppositions of all knowledge and the position we take based on such knowledge."[30]

IV. Polyhedral Geometry and the Problem of Dürer

When approaching the massive presence of *Unfolding Humanity,* the viewer is immediately faced with the rigid geometry of the object. The dodecahedron evokes classical geometry, from face angles of the 12 tiling pentagons, dihedral angles along the 30 edges, and the high amount of symmetry and regularity of the polyhedron. Walking around the structure confirms full uniformity from all directions, bringing a sense of order and comfort of the known. In order for a viewer to enter the sculpture, the pentagonal faces serve as doorways to be unfolded. The language of unfolding plays a starring role in the mathematical subfield of discrete geometry, to which we now turn.

Polyhedra have appeared throughout history and have been studied since antiquity. A higher-dimensional version of a polygon, the polyhedron is a region of space bounded by a finite number of polygonal faces. In the 16th century, the Renaissance master Albrecht Dürer was interested in drawing these three-dimensional polyhedra on two-dimensional paper. The problem he encountered is

[26] Martin Heidegger, "Modern Science, Metaphysics, and Mathematics," in *Basic Writings*, ed. David Farrell Krell (London: HarperPerennial, 2008), 274.
[27] See Ibid., 275.
[28] Ibid.
[29] Ibid., 278.
[30] Ibid.

one of geometry: if one uses perspective design to draw these polyhedra, illuminating their three-dimensional nature, then the actual angles of the polyhedra are deformed when drawn on paper. For example, a cube is composed of six squares, all with right angles. But when drawn on paper, these angles become distorted due to perspective framing.

It was this tension that led to a breakthrough by Dürer: draw an unfolded state of the polyhedron, called its *net.* Viewed differently, a net is an unfolding (or unrolling) of the polyhedron on the plane, stamping out its distinct faces without overlap. The first recorded examples of polyhedral nets were provided by Dürer in his 1525 masterwork on geometry.[31] In order to obtain a net, three properties must be satisfied:

1. The polyhedron must be cut along some of its *edges* to form the net.
2. The net must be *connected.*
3. The net cannot *overlap* itself.

For the case of the Platonic solids, it is not difficult to construct such nets. Due to the high symmetries of the Platonic solids, they become too specialized and too simple to explore in this regard. A larger class of polyhedra, which include the Platonic solids, are those that are convex: the line-of-sight between any two vertices of the polyhedron is always maintained. Motivated by this framing, G. Shephard[32] asks whether *every* convex polyhedron has a net. In other words, given a convex polyhedron, can one cut along some of its edges so that it unfolds into one flat piece on the plane, without overlap? This problem remains enticingly open and is deeply related to issues of computational origami, folding designs, and discrete geometry.[33]

One of the remarkable natures of this conjecture, beyond having its roots in 500 year Renaissance history, is the current state of belief in its truth. Most of the famous mathematical conjectures (like "Fermat's Last Theorem" and the "Riemann Hypothesis") are believed to be true; only the proof of the statement is elusive. There is no such consensus for this problem of Dürer and Shephard. On one hand, the possibility of finding a net for every convex polyhedron seems to be truly plausible. A recent work by M. Ghomi shows there is no combinatorial obstruction to a solution.[34] In particular, every example that mathematicians and computer scientists have constructed has yielded a valid net. Of course, testing examples is far from a general proof of the conjecture, but it provides promise. On the other hand, there have been exceptional counterexamples created in discrete geometry

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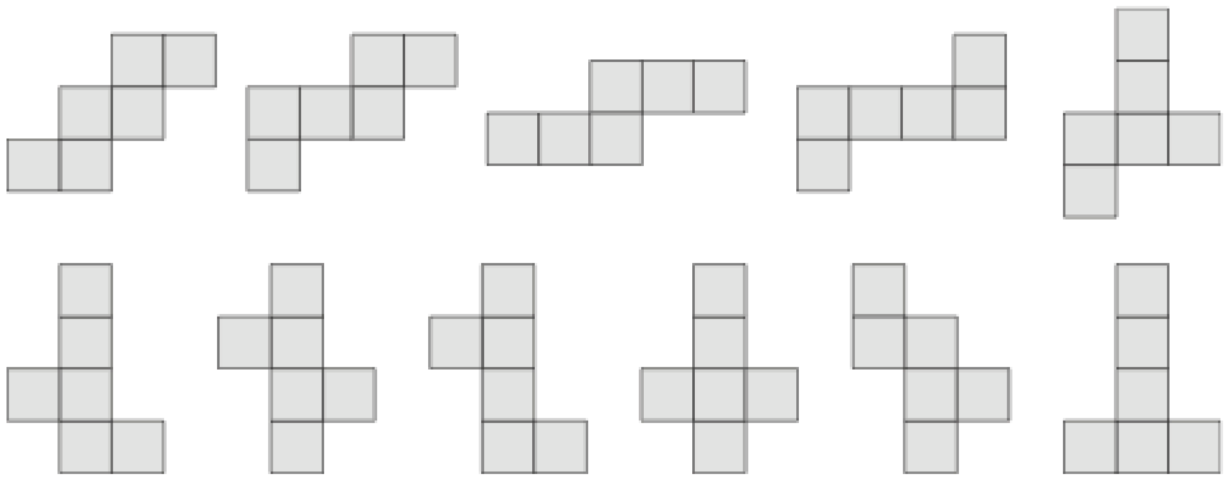
[31] Albrecht Dürer. *Underweysung der Messung, mit dem Zirckel und Richtscheyt, in Linien, Ebenen unnd gantzen corporen*, Nürnberg, 1525.

[32] G. Shephard. Convex polytopes with convex nets, *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 78 (1975), 389-403.

[33] Erik Demaine and Joseph O'Rourke. *Geometric Folding Algorithms*, Cambridge University Press, 2007.

[34] Mohammad Ghomi. Affine unfoldings of convex polyhedra, *Geometry and Topology* Vol. 18 (2014), 3055-3090.

that have mathematicians believing the conjecture to be false. A notable instance is when R. Connelly announced the construction of a flexible polyhedron[35] just two years after H. Gluck proved that "almost all" polyhedra are rigid.[36] Indeed, the unfoldablitiy of polyhedra into nets remains a deep mystery, with true ambiguity in even the nature of the outcome.



Returning to the Platonic solids, it is not a difficult exercise to find a net for each of them. A more interesting question regarding nets was asked by T. Horiyama and W. Shoji: does every unfolding of the Platonic solids yield a net?[37] Under the Dürer problem, they were able to answer this in the affirmative. For instance, Horiyama and Shoji show there are 11 distinct unfoldings of the cube (Figure below) and there are 43,380 distinct unfoldings of the dodecahedron, all of which are nets. One net of the dodecahedron (out of the 43,380) was chosen to serve as a doorway, both literally (as an entryway into the sculpture) and symbolically (pointing to the larger unsolved Dürer problem).[38] In particular, the sculpture allows participants to unfold eight of the pentagonal panels of the dodecahedron to illustrate one such possible configuration.

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[35] Robert Connelly, "A Flexible Sphere," *The Mathematical Intelligencer* 1, (1978): 130-131.
[36] Herman Gluck, "Almost all simply connected closed surfaces are rigid," *Lecture Notes in Mathematics* 438, (1975): 225-239.
[37] Takashi Horiyama and Wataru Shoji. Edge unfoldings of Platonic solids never overlap, *Canadian Conference on Computational Geometry* Vol. 23 (2011).
[38] Initially, the chosen unfolding turned out to present structural issues in the engineering and manufacturing domains. Thus, an alternate net was decided upon, one which preserved the geometry of mathematics and provided strong visual symmetry.

V. From Geometry to Topology

In mathematics, there are two categories in which shape is studied and analyzed. The first is the larger language of geometry, which is classical in education. Geometric notions include ideas such as length, direction, angles, area, and the like. The other, more foundational and abstract in nature, is topology. Topology was created and set in distinction to geometry mostly famously by Leonhard Euler with the "Königsberg bridge" problem.[39] Euler dismissed typical geometrical data such as length and distance and instead examined only notions of adjacency to determine if it was possible to cross each of the seven bridges of Königsberg exactly once. Indeed, geometric data presented an obstacle to the bridge solution by introducing extraneous information, clouding the underlying structure.

In general, *topology* emphasizes the foundational structures such as adjacency, connectedness, orientability, and boundary, while *geometry* builds upon this with the added notion of length (denoted as a *metric* in mathematics), from which all means of measurements arise (such as area, volume, and angles). In his seminal work in the 19th century, Bernhard Riemann[40] showed that a topological space allows for numerous types of metrics, each of which yields a different geometric space. For example, classical shapes such as spheres and cubes are both geometric in nature, with measurements of length allowing calculations of shortest distances between two points. Yet both shapes are identical topologically, and easily allow twisting, contortions, and the like while maintaining their identity as spheres. From a geometric viewpoint, we obtain five distinct Platonic solids, each with their unique structure. Topologically, however, all of them become deformable (and equivalent) to a sphere.

VI. The Dodecahedron and the Shape of the Universe

Burning Man takes place on a vast, desolate expanse of dry lake bed which gives one the sense of being adrift in an infinite, flat universe. This space is sparsely punctuated by sculptures which appear finite and small in comparison. The vision of a faint object in the distance entices one to endure the harshness and emptiness of the environment to approach the next art installation, our human nature drawing us towards anchors rather than floating adrift.

In contrast to its harsh external surroundings, *Unfolding Humanity* is a brightly lit invitation to enter a sheltered, protected realm. Entering the sculpture via an open pentagonal face transitions the viewer from the ordered geometry and vivid lighting of the exterior dodecahedron into a softly

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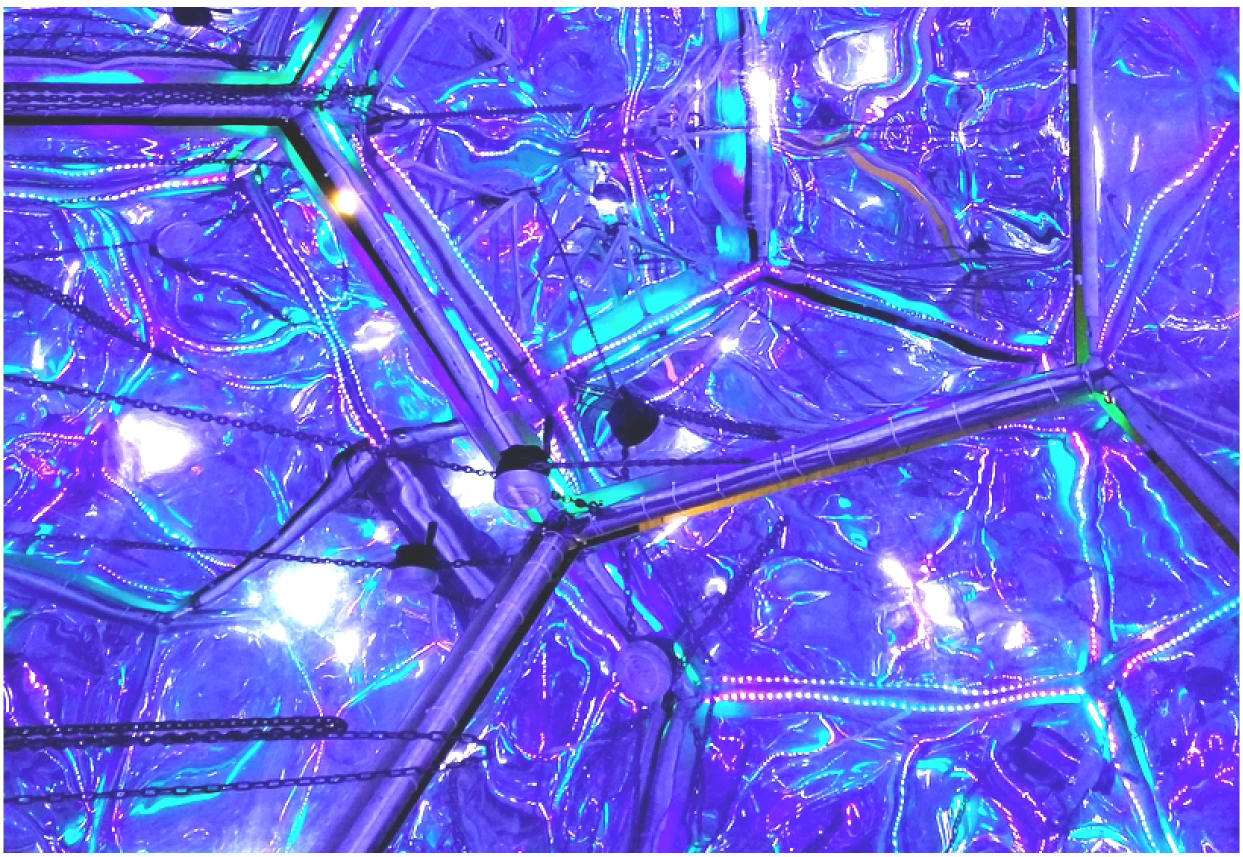
[39] Leonhard Euler. Solutio problematis ad geometriam situs pertinentis, *Commentarii academiae scientiarum Petropolitanae* Vol 8 (1741), 128-140.

[40] See Riemann's *Habilitationsschrift* lecture at Göttingen in 1854 entitled *Ueber die Hypothesen welche der Geometrie zu Grunde liegen.*

illuminated, contained haven for travelers. However, the repeated reflections from the fully mirror-lined interior faces create an inner world with a new sense of infiniteness, promoting synchronous feelings of immersion and expansiveness within this finite space. It is this simultaneous contrast of the finite and infinite of *Unfolding Humanity*, coexisting in tension, that sets the stage for pondering on the nature of our own universe, the physical context for our existence. Despite being an elemental topic of study, scientists are still unable to answer the most fundamental questions about the shape[41] of space: Is our universe infinite or infinite? And if it is finite, does it come to an end, reaching a boundary? These profound questions are all topological in nature, emphasizing the underlying structures, with no need for stronger geometric ideas of metric and distance.



We will first consider evidence from cosmologists, and then interpret this evidence through a topological lens. To investigate the question of whether our universe is finite or infinite, NASA launched the Wilkinson Microwave Anisotropy Probe (WMAP) in 2001 to observe data from the origins of the

[41] Here, the phrase "shape of space" does not refer to the local curving, or distortion, of spacetime caused by the mass of celestial bodies as proposed by Einstein's beautiful theory of General Relativity. Instead, it refers to something larger, and even more exciting, about the structure of the universe as a whole.

universe[42]. Early data that returned from this probe suggested a finite universe[43]. Moreover, the data had some irregularities which were well explained by a particular topological space called the *Poincaré Dodecahedral Space*[44,45] (which we will describe in detail below). WMAP data in 2012 supported this particular shape for our universe less strongly, and would have allowed for either a finite or infinite universe[46]. Recently, a set of data has come in supporting a finite universe, while other data suggests an infinite one: a 2019 analysis of a major data set from the Planck satellite was found to prefer a finite universe at "more than the 99% confidence level,"[47] whereas new measurements in 2020 from the Atacama Cosmology Telescope allow for either a finite or infinite universe.[48]

Regarding a boundary or an end to the universe, the Cosmological Principle (generally assumed to be true by physicists) supports our visual perception that the universe has no boundary. The Cosmological Principle is often stated formally as "Viewed on a sufficiently large scale, the properties of the universe are the same for all observers."[49,50] As we see no boundary in our visible universe, we expect that there is no boundary elsewhere either. Although at first thought it might seem impossible for the universe to be finite yet have no boundary, our own earth gives a good example of exactly this.

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[42] The WMAP satellite took measurements from the Cosmic Microwave Background, which is radiation thought to be left over from the Big Bang. Specifically, the WMAP data helped cosmologists estimate the Hubble constant, which is a measure of how fast the universe is expanding. From this constant one can estimate the average density of the universe, which in turn uniquely determines the geometry of the universe. In particular, if we scale density values so that a value of 1 indicates a flat universe with zero curvature (the so called "critical density"), a density greater than indicates a positively curved universe, and a value less than 1 indicates a negatively curved one.

[43] Specifically, the data lead to an estimation of the density of the universe to be slightly larger than the critical density (1.02 +/- .02 times the critical density), which strongly implied that curvature of the universe was positive. And a universe with positive curvature must be finite.

[44] Jean-Pierre Luminet *et al*. "Dodecahedral space topology as an explanation for weak wide-angle temperature in the cosmic microwave background." *Nature*, 425**,** and 593 - 595, doi:10.1038/nature01944 (2003).

[45] Jeffrey Weeks. The Poincaré Dodecahedral Space and the Mystery of the Missing Fluctuations, *Notices of the American Mathematical Society* Vol 51 (2004).

[46] This data implied that the density of the universe was within 0.4% of the critical density; positively curved, flat, and negatively curved universes are all consistent with this estimate. See G. Hinshaw et. al, "Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Cosmological Parameter Results," *The Astrophysical Journal Supplement Series*, 208:19, October, 2013.

[47] Di Valentino, E., Melchiorri, A. & Silk, J. Planck, "Evidence for a closed Universe and a possible crisis for cosmology." *Nature Astronomy* 4, 196–203 (2020).

[48] Aiola, S. et al, "The Atacama Cosmology Telescope: DR4 Maps and Cosmological Parameters," arXiv:2007.07288, 2020.

[49] Keel, William (2007). *The Road to Galaxy Formation* (2nd ed.). Springer-Praxis. p. 2.

[50] The Cosmological Principle also implies that in addition to the universe having the same properties at different locations, its geometry, or rule of measurement, is also the same in any direction from a fixed location. In other words, the universe is isotropic. Of the eight possible geometries for a 3-dimensional space, only three of these are isotropic: spherical geometry with positive curvature, Euclidean geometry with flat curvature, and hyperbolic geometry with negative curvature. Thus these are the only three geometries considered when studying our universe. The distinction here is interesting and important: if our universe has positive curvature, then it is certainly finite, whereas if it has flat or negative curvature, it could be either finite or infinite.

The surface of the earth is a two-dimensional sphere, with finite area, but with no edge or boundary. The sphere has avoided having an edge because its surface is not flat, but instead curves back upon itself in three dimensions and eventually closes up, or connects to itself. The question of whether, and how, a space is connected to itself is what topologists mean by the phrase "shape of space." Like a sphere, it is possible that our universe curves back on itself so that if one were to travel along a straight path in one direction long enough, one would return to the starting point.

The Poincaré Dodecahedral Space, which was once a favored model for our universe, has exactly this property of being connected to itself in a nontrivial way, as we will now describe. Consider a dodecahedron, a finite shape which has a boundary consisting of its twelve faces. Now imagine the view from inside the dodecahedron, but with an interesting twist. Just as going around the equator of a sphere in one direction will bring one back to the starting point, suppose that heading directly out the top face of the dodecahedron caused one to re-emerge through the bottom face (with a 2/5 rotation so that the top pentagon lines up with the bottom pentagon), leading one right back to their starting location. The top and bottom faces would no longer be boundaries of the interior space, as they'd be connected together seamlessly, and this folding of the space onto itself has erased the boundary. Now do the same thing with every pair of opposite faces. The resulting space, the Poincaré Dodecahedral Space, has both finite volume and no boundary.

Intriguingly, inside a universe shaped like the Poincaré Dodecahedral Space, the small finite world would appear infinite. As a line of sight going straight out the top face would come back in from the bottom and return back to its starting point, looking upward, one would see what appears to be another small room above, containing another (rotated) copy of oneself, and by extension, infinitely many identical small rooms above that. This repeating effect would happen in all directions, providing infinitely many views in one small room.[51]

The interior of *Unfolding Humanity* alludes to a universe aligned with Poincaré Dodecahedral Space. Although the physical object that we built in the desert cannot be an exact replica of the Poincaré Dodecahedral Space--such would require access to higher spatial dimensions--*Unfolding Humanity* offers a hint at the experience of living inside this possible shape of our universe. The mirror-lined interior of the sculpture creates endless repeated reflections, bending both light and line of sight, to give its audience an illusion of the vast infinite inside this small finite space.

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[51] This idea has been used to try to identify the shape of our universe: cosmologists have looked for repeated spots in the sky, which could possibly be two images of the same object, to help determine the universe's shape.

Imagining a self-connected space such as the one illustrated above is more than just an exercise. A theorem of mathematicians Lickorish[52] and Wallace[53] reveals that every possible finite universe without boundary can be obtained by beginning with some polyhedron and connecting faces together[54] in a manner similar to what we have described above. Results such as this, which offer a surprising overarching framework from which to understand a mathematical idea, are seen as beautiful by mathematicians. This is measurably true: neuroscientists report that the area of the brain that shows increased activity when a person encounters beautiful visual art or music is the same area of a mathematician's brain which lights up when shown a beautiful piece of mathematics.[55,56]

[52] Lickorish, W. B. R. (1962), "A representation of orientable combinatorial 3-manifolds," *Annals of Mathematics*, 76 (3), 531–540.

[53] Wallace, A. H. (1960), "Modifications and cobounding manifolds," *Canadian Journal of Mathematics*, 12: 503–528.

[54] Such a connection of faces is not only possible in one's imagination, it is also physically possible, though one may need to go into a higher spatial dimension to do so. To understand this, it is important to distinguish between the dimension of an object and the dimension of the space that it lives in. Consider a meandering curve drawn on a piece of paper. The curve itself is one-dimensional, because only one piece of information is needed to determine a location along that curve. Said another way, a nearsighted ant on the curve would believe it was on a line, which is one-dimensional. However, the piece of paper that the curve is drawn on is two-dimensional, as two pieces of information are needed to determine a precise location on the paper. The curve is a one-dimensional object living in a two-dimensional space.

To understand how connecting faces is possible in a higher dimension, we will first consider an analogy in a lower dimension. A line segment is a one-dimensional object with finite size, and with a boundary consisting of its two endpoints. We could eliminate the boundary of the segment if we simply connected one endpoint to the other. To achieve this physically, we would bend the line segment into a two dimensional world until we are able to connect the endpoints to form a circle. This bending could not take place without moving from the one-dimensional line into the two-dimensional plane, so the physical connection requires a higher dimension. Note that our resulting shape would still be one dimensional, and it would still have finite size, but would now have no boundary. In a similar manner, the connection of the faces described above in the Poincaré Dodecahedral Space would be physically possible by bending the shape in a higher dimension. Michael Freedman proved that the Poincaré Dodecahedral Space can be embedded topologically in 4 dimensions (see "The topology of four-dimensional manifolds", *Journal of Differential Geometry,* 17 (1982), 357–453). Simon Donaldson proved that the Poincaré Dodecahedral Space can not be embedded geometrically in four dimensions (see Donaldson, S. K., "An application of gauge theory to four-dimensional topology," *Journal of Differential Geometry* 18 no. 2(1983), 279-315), but results of Morris Hirsch show that the Poincaré Dodecahedral Space will embed geometrically (smoothly) in five spatial dimensions (see "On imbedding differentiable manifolds in euclidean space," *Annals of Mathematics* (2) 73 (1961), 566–571).

[55] S. Zeki, J.P. Romaya, D.M.T. Benincasa and M. Atiyah, "The experience of mathematical beauty and its neural correlates," *Frontiers in Human Neuroscience*, 13 February 2014.

[56] S. Zeki, O.Chén, and J.P. Romaya, "The Biological Basis of Mathematical Beauty," *Frontiers in Human Neuroscience*, 30 November 2018.

VII. Conclusion

Burning Man attendees remarked on the similarities of *Unfolding Humanity*'s design to the artistic direction in *The Matrix* (1999), a film that presents a technological nightmare, in which machines guided by Artificial Intelligence control human beings to exploit their organic material as a fuel source. The LED lights run over the linguistic symbols etched in acrylic panels on *Unfolding Humanity*, reminding the spectators of the Matrix, the network of a digital environment that lures human beings to accept a false sense of reality. The running lights and mirrors speak to both the constancy of the presence of technology in contemporary life and the repetition reminiscent of the seemingly endless void of space. But the lights could also symbolize what the universe looks like if light wraps around it.

The attendees of Burning Man lauded the structure's provision of a multisensory avenue for experiencing technology and its relationship to topological problems related to the shape of the universe; the audience was caught between the brilliance of mirrored reflections in an artificial construct and the abyss of the night sky in the cold desert. Hoffoss was gratified by the intensity of connection Burners felt to the piece in the context of the severe landscape. She remembers more than one spectator who meditated inside the immersive space for hours. Indeed, the use of mirrors on the interior is reminiscent of the meaning of the mirror for the era just before the Renaissance in Italy: the manufacture of the glass mirror in Venice in the fourteenth century led to the rise of the self-portrait in visual art. Until that point, only polished metal or obsidian offered a reflective surface, which provided a distorted or fuzzy image. The Florentines perfected the mirror with a lead backing during the Renaissance; the focus in Renaissance art toward divinity within the human being is likely connected to the ability of the human to engage the self-image. In 1970, psychologist Gordon Gallup Jr. developed the mirror test, in which a mark is placed on the face of an animal without its knowledge, to measure the self-awareness of various species. If an animal recognizes that the mark is on its own face in a mirror, it passes the test. Most species, even primate species, fail; in 2004, scientists began work on whether a robot could be made to be self-aware by passing the mirror test.[57] In 2012, these scientists were able to teach Nico the robot to recognize its hand in a mirror with a visual token attached; but it has yet to pass the "mirror test." As sophistication in the making of mirrors enabled greater degrees of human introspection in history, perhaps the mirror test will be one more step in creating the artificial intelligence sought after, and perhaps another step toward the artificial intelligence that creates the Matrix, the false construct of "reality" humans in the film prefer to the Truth.

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[57] See Philipp Michel, Kevin Gold and Brian Scassellati, "Motion-based Robotic Self-Recognition," Proceedings of Intelligent Robots and Systems (IROS), 2004 (Vol 3),

Where will technology lead us? *Unfolding Humanity*'s offer of introspection to the attendees of Burning Man was an opportunity to see the universe as both external and internal to the human person and to assess the particularity of the human consciousness of the universe, a way of exploring that belongs only to us, in this time and place. Over 20,000 years ago, we ventured into the caves not for shelter but to experience the dark unknown as a *place*, a shape that influences how we understand the context of our existence. At Burning Man, *Unfolding Humanity* performed its potential as an artwork when people were moved and inspired to contemplate and meditate, when its creators wrestled with the harsh desert conditions and fixed what malfunctioned, and when experts in various academic disciplines were brought together to see something both as ancient as Euclid's final chapter of the *Elements* and as current as the representation of Poincaré Dodecahedral Space. *Unfolding Humanity* participates in the mathematical dimension of aesthetics when it keeps the tensions between these ideas alive and maintains their relationship to the unknown.

W. H. Auden's epic poem "The Age of Anxiety" uses a dichotomy he constructs in an earlier essay on Dickens that there are two fundamental ways of seeing the world. These are symbolized by Arcadia, the mountainous area on the Peloponnesus peninsula of Greece, and Utopia, the "no place" of St. Thomas More, the philosopher and Chancellor of England executed under Henry VIII. Both Arcadians and Utopians see the world in revolutionary terms, profoundly distressed by the status quo. Arcadians mourn a lost past perfection, a Garden of Eden: a time of pastoral simplicity, without the meanness of a city or the relentlessness of technology. Utopians, on the other hand, look to the future, where the dreams of a well-ordered society seem possible if we only took technology and the city to the ethical places. Auden meant usage of references to Arcadia and Utopia in "The Age of Anxiety" as a warning; it is among the first poems in English to refer to the genocide of millions of Jewish people during the Nazi era. Earlier, Auden himself had indicated that he subscribed to the Arcadian, that the innocence of the original state of human beings could be restored. The scientist may be the Utopian, the one who sees only potential when peering into the unknown, but the Arcadian must reign in the sciences and technological advancement when they proceed in the manner of Nazism's Social Darwinism or the heady rush to develop nuclear weapons. But the Arcadian need not fear the developments of technology when the artist, the poet, can remind the Utopian of what must be valued: the seeking of Beauty and the inclination to preserve mystery and the interdependence of all things, resisting the impulse to control and dominate even while on the precipice of discovery.

In other words, both ways of seeing the world, both forms of revolution, are necessary to each other. The sciences need the arts and religious studies, the aesthetic instinct for beauty and the ethical sensibility for the application of lofty ideas, in order to create the Utopia envisioned in discovery; the arts and religious studies need the sciences in order to realize their dreams of sustainable architecture, eliminating poverty, overcoming systemic racism, and coming a step closer to understanding the parameters of the universe. Auden put the anxiety of his age into his work; that anxiety has not dissipated. *Unfolding Humanity* seeks to maintain that anxiety, in the mathematical objects Plato wished to protect by abstracting them from the material world, by making the dodecahedron live on a vast and uncertain desert plane.