Point: **Space**

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In the seventeenth century, Galileo famously stated that our Universe is a “grand book” written in the language of mathematics. More recently, the physics Nobel laureate Eugene Wigner argued in the 1960s that “the unreasonable effectiveness of mathematics in the natural sciences” demanded an explanation.

- Max Tegmark Our Mathematical Universe 2014

In a world increasingly immersed in analytics and abstractions it has become difficult to grasp some of the new discoveries in mathematics and science. Humans have an innate desire to learn and categorize phenomena, and every year cutting edge science is discovering hidden gems in the multiverse, quantum, and theoretical realms. Although these discoveries are monumental, they are increasingly abstract and distant to those outside of academic circles or those who do not actively seek the information. One of the byproducts of these discoveries is a beautiful visual language lost in the dense notes of academic papers. Through already established principles, university, corporate and research group scientists, map dense arrays of data and logic into visual information. One famous example includes Edward Lorenz’s cloud structure observations and use of Chaos Theory to predict and visualize weather patterns using a system of just twelve equations. Even more incredible still, research groups are starting to observe some of these abstract phenomena directly using machines like the Large Hadron Collider (LHC), which slams elementary particles into each other, or the quantum microscope which peers into previously unseen realms. These ideas fascinate me. I want to understand these concepts in a more tangible way, not just through mystifying graphs, but through concrete visual discoveries. For example how does the shape of an excited electron orbital look scaled up to fit in one’s hand? Do the manifold
sets of two spaces that generate a cobordism create a compelling three dimensional object? Ultimately what is the resulting form that I can make through the visual language of metalsmithing? I have been looking through the notes of various books and papers that relate to set theory, cosmology, topology, differential dynamics, and quantum mechanics, and have asked, can these images from a purely abstract or unattainable realm become objects with which viewers can interact? Once they become objects will they become ironic devices for learning, useful functional tools, or abstract sculptural forms? Can the viewer (and I) get a better understanding of these dense scientific concepts through a compelling three dimensional object? To start answering these questions, I began to rigorously look at some mathematical definitions to understand at the base level of each image.

The first subset of mathematics I began to research is known as topology. A topological space can be rigorously defined as:

A set $X$ together with a collection $S$ of subsets of $X$, called open sets, such that:

1) The union of any collection of sets in $S$ is in $S$.

2) The intersection of any finite collection of sets in $S$ is in $S$.

3) Both the empty set and $X$ are in $S$.

The collection $S$ of open sets is called a topology on $X$ (Hatcher 4). A definition like this is essentially jargon, so Allen Hatcher gives a much more reasonable explanation at the beginning of his essential text saying, “One way to describe the subject of topology is to say that it is qualitative geometry. The idea is that if one geometric object can be continuously transformed into another, then the
two objects are to be viewed as being topologically the same” (Hatcher 1). This field of mathematics essentially studies how different sets of shapes can be created, transformed and moved to create other sets of shapes. See figure two for a visual example. Theoretically this idea can be implemented to map out almost anything, from tori to coffee cups. Through the study of set theory Hatcher explains the idea of the neighborhood which is defined as, “a neighborhood of a point \( x \) in a topological space \( X \) is any set \( A \) [within set] \( X \) that contains an open set \( O \) containing \( x \)” (Hatcher 9). Essentially this means that a point within a set can have a small group around it that is also a set and is within the larger set. This idea is important to the idea of manifolds and metric spaces. For anyone who has used CAD software to model different shapes virtually in three dimensions, the word ‘manifold’ probably came up in some context. The manifold as defined by James Munkres in his book *Topology* is, “a Hausdorff space \( X \) with a countable basis such that each point \( x \) of \( X \) has a neighborhood that is homeomorphic with an open subset of \( \mathbb{R} \)” (Munkres 225). Manifolds link Euclidean geometry to topological spaces, a manifold is a topological equivalence that locally (like the idea of a neighborhood) acts like Euclidean geometry. With this idea mathematicians can describe simpler shapes using manifolds. For example a 1-manifold describes a curve, and a 2-manifold describes a surface. Building from these basic concepts, I can create a unique language of shapes that then can be “surgically” altered.

These concepts create an even deeper theoretical framework for ideas like cobordism, another idea that has expanded the visual archive of mathematics. A
cobordism, as presented by Tom Weston in his paper *An Introduction to Cobordism Theory*, is, “two manifolds $M$ and $N$ are said to be cobordant if their disjoint union is the boundary of some other manifold.” Visually this looks like two spaces being merged into a different space, see figure three. This concept then can be applied to help shape spheres and other basic forms. Joshua Plotkin uses the tubular neighborhood theorem to, “add a handle to a manifold with boundary” in his paper *Cobordism and Exotic Sphere* (Plotkin 4). All of this information I am presenting is similar to learning a language. Though most of us have a good grasp on our first language, we need to have a basic understanding of vocabulary to describe even the simplest concepts like walking to a location, giving directions to someone, or describing the perfect flavor of ice cream. By learning the basics of this scientific and mathematical language, I can start to translate some of the complex visual structures into a more manageable reality.

This dense mathematics does not just exist in the abstract. Cobordism and topological equivalences have been used to help map out the world around us. Physicists have been using cobordism theory and advanced topology to map out space and spacetime. John Baez notes, “assuming that spacetime is $n$-dimensional, we are in principle free to choose any $(n-1)$-dimensional manifold to represent space at a given time” (Baez 1). By using cobordisms and topology changes, Baez states, “we can use any cobordism to represent a spacetime going from one space to another” (Baez 1). In terms of real world applications, this can be used to map out wormholes, help navigate vessels through the universe, and understand exactly how objects interact with one another. Now with advanced technology like the LHC, scientists are starting to observe
these abstract phenomena in reality. The super collider in Switzerland recently discovered the Higgs Boson particle that helps suggest the multiverse theory. Through observation of particles like these, understanding how matter travels through space and time can help us understand how humanity can explore the universe. In 2013 scientists at the FOM Institute observed the wave function (orbital) of a hydrogen atom using a quantum microscope (Stodolna 1). Though Erwin Schrödinger, father of quantum mechanics, mapped out the probability density of the hydrogen atom decades earlier, direct observation has never occurred before. As Max Tegmark alluded at the beginning of this paper, mathematics is incredibly good at predicting the behavior and shape of the natural world around us. With the theory established by this scientific population, new visual systems are born through the technical apparatus combined with the scientific method. These exciting ways of measuring and rethinking the world are also providing me with forms and images to rethink and reshape current trends in craft and art.

I admit that all of this language is very dense. How exactly does one parse through and understand advanced mathematics, general relativity, and quantum mechanics without dedicating a lifetime of study? My project explores this question and attempts to realize and celebrate the abstract concepts in physical form as a means to better understand the theory behind them. How exactly can I understand and appreciate these theoretical concepts? As a visual artist and more specifically a metalsmith, I use metal as a medium and apply craft processes to interpret and create some of these shapes. By thinking through craft I hope to be able to bring these lofty abstract realities to the human realm. Some of the physicists studying cosmic phenomena rely on crafted and machined parts to test their theories. One scientist in Switzerland describes the
LHC like a 17 mile long Swiss watch, with every piece soldered together perfectly (Particle Fever). Glenn Adamson in The Invention of Craft asserts craft, “has always been with us, it seems, since the first pots were made from clay dug out of riverbeds and the first simple baskets were plaited by hand. Seen from this perspective, craft is intrinsic to what it is to be human” (Adamson xiii). This is lazy on Adamson’s part, as we are not the only species on this planet that crafts objects and tools to shape their environment, but humans do craft objects more than other species. Nevertheless, by creating an object that looks crafted by human hands’ I hope to make these ideas more relatable while producing objects of intrigue that, by their quirky presence, little known aesthetic and physical nature, can provoke consideration of the concepts I investigate.

Studying how other craft artists work to disrupt the everyday and functional object has helped inform my own work. My initial investigation led me to the artist David Clarke who deconstructs and or dismantles traditional silver objects and mashes them up, “into Frankenstein-style agglomerations” to shift the viewer’s perspective and unsettle the viewer (Adamson 47). Clarke plays upon antagonism between the nostalgia of familiar objects and blatantly poor construction methods to create an avant-garde form in the realm of silversmithing. Adamson claims that, “there is a tendency toward tightness and resolution in contemporary silver, which closes down possibilities rather than opening them up. Clarke is determined to try another way” (Adamson 48). Keeping objects in seemingly incomplete states lets Clarke create a diverse range of forms that relate to the table. My own work does not rely on the piecing together of familiar forms and nostalgia to create structure, but instead I hope to have a tangential relationship with the table. I feel compelled to rely on traditional silversmithing skill and aesthetics to create a
sense of preciousness and authority in the idiosyncratic objects I create. I also attempt to choose forms that only have a passing familiarity with tableware objects and through these two decisions, viewers have a more familiar framework to understand the work. Instead of antagonizing, I hope to create a sense of mystery and wonder with my work. Choosing to stay in the same scale as an artist like Clarke allows me to create and place the complicated structures of electron orbits in the same space as a salad bowl. There might be a vague reference to a pouring vessel, as seen in Cobordant but with none of the function.

Hiroshi Sugimoto has a similarly smitten view toward the abstract mathematical notions that struck me. In an essay he says, “The beauty of these pure mathematical forms was a wonder to behold, far outshining abstract sculpture” (Sugimoto 5). This beauty can be seen through his photographed plaster models of different helicoids, hyperspheres, and onduloids. These compelling objects are just models for mathematical students to which he adds authority of black and white gelatin silver prints. I have a similar strategy with my own work. I look to extract images from scholarly texts, but rather than stay in the realm of Euclidean geometry, I have expanded into higher levels of mathematical inquiry. As Klaus Ottoman describes, “Sugimoto practices art as an ecstatic meditation on time. It is in his conceptual forms and mathematical models that art and mathematics converge in their truth content and become a meditation on infinity.” (Ottoman 21). Though these ideas are philosophically admirable, I focus more on the beauty and mystery of these mathematical models and through my inquiry, toward the infinite. In my photography series called, Hilbert Space, I am looking at how the simple algorithm of the Hilbert curve can be manipulated and
photographed to create a compelling space that explores the infinite. I deliberately skew the scale of the installation space I’ve created and manipulated the structures of my laser cuts to create a persuasive visual space for the viewer to enter.

Another artist from whom I gained insight from would be Michael Rowe and his Euclidean inspired silversmithed forms. Richard Hill describes Rowe’s work as having,”a foot in elementary geometry and a foot in practical life: they are children of the humble bucket family as well as heirs of the pure forms of ancient geometry. In fact it is the individuality or specificity of Rowe’s forms, the sense that they live in our world rather than a cosmic space that makes them compelling.” (Hill 33). Rowe plays with forms seen in calculus to create vessel objects that look like they belong on the table, but clearly have a different function. Rowe’s work has more familiarity with the vessel object than mine, and he also plays with the idea of ornament, but his site specific vessels clearly steal influence from the geometric realm. These objects become convincing when lifted off of the graph paper and graphite and have the authority of silver and copper. In my two vessel pieces, Set Theory 1 and Set Theory 2, my mathematically inspired marriage of metals is a not so subtle nod to Rowe’s work. Like Rowe and Sugimoto, I rely heavily on my source material to generate an object. My art relies on the framework and results of theoretical mathematics to generate form and the visual language of craft to interpret it into physical objects. This intersection of ideas and languages imbues these objects with a physically alluring presence and aesthetically unique outcome that does not pigeonhole them to one category of art or theory. This in-between junction is what compels me to keep making.
With all of this information I should now try to explain how my work has split into two bodies with the overarching concept of mathematics connecting the two. The body of work as a whole I call Point Space, which at its core is a formal investigation of the visual information taken from the mathematical research I’ve conducted. The metal objects I have constructed for this project started with my interest in quantum mechanics. The first piece that started this project is titled, 3D0, in reference to the energy state of a hydrogen atom that creates that shape. My piece consisting of brass and bronze mimics the boundaries of an electron orbiting the nucleus of a hydrogen atom. I decided to create this symmetrical shape through angle raising and soldering the metal into four different forms that I then put together in an almost visibly seamless manner. The bronze and brass have a soft yellow glow and are easily malleable which helped me achieve a curvilinear soft profile to all of the forms. Because of constantly shifting contour of the piece I decided to polish the metal to a mirror finish. This allows the light to bounce off the surface and create unique reflections depending on its surroundings. The surface reflection makes the piece seem almost other worldly and the unique shape which I’ve been told resembles anything from a “weird rolling pin” to some sort of “bodily object” makes this object tactile and seductive. Reflection became incredibly important as then I no longer controlled the light on its surface. Aside from light being related to the physics that I studied, the reflective quality of the surface poetically relates to the actual nature of the electron orbiting the nucleus. It is not a static particle, but a constantly shifting one, any observation or interaction is only a fleeting moment. As with my object, 3D0, unless the viewer can remain perfectly still, the surface constantly shifts.
The piece most closely related to this conceptually is 4F0, again based on the excitement level of a hydrogen particle at that energy state. This object is much like 3D0 in that the shape is almost directly interpreted from the actual boundary of the orbital from Schrodinger’s equation. With this piece I also decided to have a highly polished surface to create that shifting surface quality I achieved in the first piece. The shape of object has a bigger dome form on which I decided to leave some planished hammer marks that gradually fade to a finely polished surface to remind myself and the viewer that these are still crafted objects. I should also address my material choice. In a correspondence I had been having with a theoretical physicist when I had always contemplated these choices during the long hours of hammering these sheets of brass over various stakes. These objects are a complete contradiction to the actual nature of a hydrogen particle since finished metal is relatively permanent. But it was this contradiction I was hoping to exploit. Aside from a shift in scale, by making these objects permanent it ground them in an ironic reality. This piece is not a scientific model, nor is it a functional vessel, but it lies somewhere in the realm of sculptural tactile object that is imbued with information, which encourages viewers to ask more questions about its origins.

While these two objects were successful, I wanted to change my process slightly to break away from just copying the shapes I had researched. This shift in thinking first occurred with the two pieces, Set Theory 1 and Set Theory 2. I started by looking at some forms derived from cobordisms, and began to construct the pieces. Instead of trying to replicate the form exactly, I sectioned parts of the forms off to achieve a more faceted look instead of the very curvilinear fluid feel of 3D0 and 4F0. This thinking was
in line with how mathematicians problem solve difficult equations or proofs. Instead of trying to solve a problem all at once, they will section off part of it, figure out the answer and then build on that. A quick example would be something like Riemann sums, one of the first things taught in basic Calculus. When integrating a function, one must find the area under a curve. To do this one can section off the curve and create many rectangles which approximate the area of that section of curve. It is much easier to find the area of the rectangle than it is to find the area under a curve, so by adding up all the areas of the rectangles one can find an approximation of the integral. With this same thinking I tried to form some more complex topological spaces. Instead of trying to form a complicated undulating cylinder, I instead broke the space down into sections to approximate the topological space. This faceted form then directed the rest of my formal decisions, by faceting both ends of each piece. Then I chose again to finish them to a highly polished surface that every so subtly shows the soldering lines that join each section together. A final touch was put on the tops of each form as a little homage to Michael Rowe with my marriage of metals imagery. These images are interpreted from set theory, as discussed above, the backbone of topological relations.

My last two metal objects are a combination of these two approaches. Cobordant and Topology were heavily influenced by the actual images from which they were derived, in some sections I tried to partition the piece off like a mathematician, and also take form language from other sources to change the original. These two pieces are also made from copper (Cobordant also has some silver sections as well). This was made to achieve a different surface quality. For my Topology, I wanted to have my solder lines be more prominent on the surface to indicate that this form was analytical in
nature. I didn’t want this to be the virtually seamless forms that the other objects were. I had the same idea with Cobordant, the appendage part of the form was changed from a flowing shape to a partition shape. The lines of solder became very prominent on this form even without patination. And of course there is some very intentional directional filing, as this decision alludes to the actual nature of a cobordism. The two manifold space (the silver tops) are mapped onto a different manifold space (the small silver bottom). Personally, I find these two pieces to be most successful in their ability to translate as an object with a foot in the realm of craft and a foot in the realm of mathematics.

My decision to place all of these objects together on two pedestals comes directly from the visual cues seen on Set Theory 2. The objects were placed as opposing one another like a function mapping one set to another. By having these objects in pairs, this arrangement becomes a bijective function where each element (object) can relate to its corresponding object. I’m not sure how well this idea is translated with just my white pedestals. After seeing the arrangement set up in a gallery I need to develop some more information to the viewer to indicate the logic behind the display set up. This problem does not occur with my drawings and photographs.

My drawings I believe are much more easily recognized as mathematical or analytic. This body of work which I call my Hilbert Series derives from the Hilbert Curve. The Hilbert Curve is a mathematical algorithm which has a line traveling through the interior space of a square until it hits each point inside the square. As the algorithm iterates toward infinity, it hits more and more points in the square. This idea fascinated me, trying to capture the infinite within a finite space, but there was also just a beautiful
effect to the mat board as I cut through it with the laser. The drawing *Hilbert Progression* shows each step in the process up until the 9th iteration. At that point the width of the laser cut is bigger than the space between each line and the mat board just burns up. Even with technology I am only able to achieve a certain level of intricacy before it gets lost in reality! Each step higher in the algorithm created a more and more intricate pattern that blurred the overall curve but created a beautiful gradation. My 9th *Order Hilbert* exemplifies this, as it is a three foot square with over two hundred thousand lines hitting each point in the square. Up close, the viewer can see the mathematical perfection of the laser, but a step back the whole is blurred into an undulating surface of grays and whites. The *Hilbert Tiles* drawing breaks from the rigidity of the algorithm and I start to invent shapes from the algorithm simply by scoring and folding certain parts (try as I might, even when I’m drawing I cannot get the metalsmith out of my head). I wanted to push the possibilities of the form from a flat two dimensional drawing into a more three dimensional installation.

This installation was documented in my two photographs labeled *Hilbert Space 1* and *Hilbert Space 2*. Originally I had intended to create an installation using these tiles, but the photographs actually became more compelling images. The creation of the installation came through the same process I used to create *Hilbert Tiles*, but in a more repetitive format. I then skewed the viewer’s perspective by photographing the installation to make it seem almost larger than life. These I felt needed to be in a larger frame with a similar folding method that was created in the actual photograph which is why I created a large steel frame with a faceted cut out. I wanted the viewer to feel like he or she was peering into this analytical realm of information and beauty. By doing this,
I could have the viewer feel the same way I have been feeling throughout the process of making Point Space.

This whole investigation did not exactly provide answers to all of the questions I had asked at the beginning. My metal objects still leave a lot of unanswered questions as to where they live in terms of the realm of craft, art, and science. They are seductive and tactile, but also ironic and playful. Not a terrible place to be in, but something I should develop more if I want to push these objects to be tools of information, or function tableware. I almost certainly cannot make these objects be everything at once. I might partition this investigation further to explore more avenues of the crafted object and the mathematical beauty that interests me. The drawings and photographs do better at communicating the visual excitement of mathematics, but there seems to be much less room to expand the idea outside of adding scale, color or other formal qualities without ruining the integrity of the information. Either way, I believe a good project should leave the artist, as well as a scientist, with more questions than he or she started with otherwise what more is there really to explore?
Works Cited:


