In-*Form*-ation

The Molding of Scientific Knowledge

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Acknowledgements

The completion of this thesis would not have been possible without the expertise of my supervisors: my daily supervisor, Prof. Marcel Boumans, who mentored the formulation of my ideas from the very beginning, and my second supervisor, Prof. Paul Ziche, who focused and enriched my perspective. Thank you both for the guidance, inspiration and creative space.

A special thank you to my family who provided endless support throughout these turbulent times and the writing of this thesis.

Content

Preface

| An Exercise in Form

Four years ago, as an independent designer and patternmaker (garment constructor) searching for new inspiration in nature, I became occupied with the connection between art, science, and nature in the creation of new designs. How did nature make such wonderful patterns? Subsequently, this interest has led me deeper into research. Fascinated by the Renaissance and the early modern period, historical periods during which the boundary between a scientist, artist, or engineer was at its blurriest, I set out to find the underlying relics of science and art's shared origin.

When sharing this with my supervisor, Marcel Boumas, early in the research process of my thesis, he introduced me to René Thom's *Structural Stability and Morphogenesis*. Thom's work was inspired, among other things, by a return to the early modern period and the work and thought process of the natural philosopher. Studying his writings, I was surprised to discover that many of the questions and challenges scientists, more specifically mathematicians, face when applying their mathematics to nature, could be paralleled with those of the patternmaker. I discovered that leaving the fabric continuous in a design can be paralleled to topology and the modeling of continuous phenomena or discontinuous phenomena. I learned that smooth streamlined lines often don't represent natural forms; Harsh averages of diverging data points do not depict a law of nature, just as smoothing out wavy lines too harshly when copying a fabric pattern to paper results in an ill-fitting garment. I also learned that scientists can construct theories and models through the simulation of natural forms, much like patternmakers construct patterns and garments by simulating forms in a sketch.

All of these realizations were due to a significant exercise I was given during an internship in 2015. It all began on an early September morning in 2015, when I climbed up the double staircase facade of a 17th century Herengracht building in Amsterdam. The golden doorbell I rang was ornamented with the company's famous wax seal logo, the V&R monogram embossed in its center. It was my first day as an atelier apprentice for the innovative couture brand Viktor&Rolf. My role in the following months would be to research, develop and construct conceptual garment patterns.

The atelier, the working studio, was at the top landing of the 4-story building. White robes were mandatory for all staff and the sterile environment did not permit food or beverages in the rooms. White papers covered the high tables and an assortment of measuring apparatuses, from shaped rulers to measuring tapes, surrounded each working space. An observing layman may identify the space as a laboratory rather than a design studio. But a clean, streamlined environment was necessary for the meticulous work.

To begin the research, we were brought into a room in which one wall was covered by images of cubist and minimalist sculptures from the early 20th century. The head designers wanted to create a collection inspired by cubism, and our task was to research how these abstract forms can be made of fabrics. As my first research exercise, I was given a printed image of a Modigliani head made from limestone. "Make this out of fabric," said the head pattern maker. "Try any method and any fabric but use the least amount of seam lines and leave the fabric continuous. Don't cut the fabric if you don't absolutely have to." This was the only restriction I was given, one that I found justified and at the same time extremely challenging. The cleanliness and elegance of a garment is determined by its meticulously placed and simple seamlines, and a collection inspired by cubism and minimalism would certainly require sharp patterns.

Eventually, this simple exercise transformed the way I create patterns, but, more importantly, it influenced how I view the role of forms in my daily life. In many ways, this thesis is inspired by that first simple exercise I was presented with at the V&R atelier. My aim here is to display the resemblance between scientist's and the artist's craft, and show how their technique, much like those of artists or designers, can and should be investigated as a creative practice of representing nature.

Introduction

We perceive a world composed of many forms. Forms play an integral part in the arrangement of our reality, whatever the true nature of that reality may be. These forms, whether sensory or conceptual in nature, make up the multiplicity and diversity of objects we interact with and experience in the world around us. In the introduction to *The Philosophy of Symbolic Forms*, philosopher Ernst Cassirer writes that "it would seem as though we could apprehend reality only in the particularity of these forms, whence it follows that in these forms reality is cloaked as well as revealed."[1] His introduction presents forms as something more than a sensory experience, and rather as an epistemological link between our inner consciousness and external reality.

Any creative or intellectual human pursuit, be it science, art, language, or religion, carries in its essence an examination and expression of form. We intuitively experienced the rolling of a ball and the building properties of a block as young children before we could physically name these objects. Geometry itself is fundamentally infused into our developmental stages as individuals and in the historical development of our human communication as a species.[2] This perspective calls for an examination of the role of forms in the creation of knowledge and, particularly, in the creation of scientific knowledge as a creative pursuit. An initial general question for such a quest would be: What is the epistemological role of form in the creation of scientific knowledge? In other words, how do forms help us know?

Since the mid 20th century, philosophers and historians of science such as Thomas Kuhn and Norwood Hanson have shown us how scientific laws and concepts are not a

[1]Cassirer, Ernst, Ralph Manheim, and Charles William Hendel. *The Philosophy of Symbolic Forms*. Vol. 3, the Phenomenology of Knowledge. New Haven: Yale University Press, 1985, p. 1
[2]Wildgen, Wolfgang. *Evolution of Human Language : Scenarios, principles, and cultural dynamics.* Philadelphia: John Benjamins Publishing Company, 2004, pp. 65-66

given.[3] On the contrary, it is the reframing of concepts and questions within science that deepens our understanding of nature and induces paradigm shifts. This idea displays how our knowledge of the world around us is created rather than unveiled (I will expand on this idea and its current importance below). Therefore, just like an artist studies his or her craft and perspective by drawing shapes and colors onto a canvas, or by giving form to clay, I intend to examine the craft of scientific conceptualizing and framing. If we can explore further into creative interaction and observation of form, perhaps we can further learn about qualitative changes of perception. In this thesis, I aim to examine scientific theorizing as a creative craft, in which the material at the scientist's disposal is the collected observational data, and the technique is the shaping or the framing of that data. We must ask: how can the process of conceptualizing and framing data be studied as a process in and of itself? Or, even more so, as a creative human activity of giving form to matter? What is needed to begin such a pursuit?

By placing form as the central concept through which knowledge creation is examined, we can move a step closer to reframing scientific activities in a conceptual framework that is more relatable to the work of the artist. Artists and designers apply different techniques of giving form to diverse materials, and their practices can subsequently shed light on the creative aspect of scientific theorizing. Therefore, constructing a conceptual framework for scientific theorizing which relates to knowledge creation in terms of form and not in terms of measurement is important for the task at hand. To accomplish this, theories which make explicit use of forms in their construction should be examined and their methods of conceptualizing extracted. I will return to elaborate on these points further below. But beforehand, placing form as the central concept through which I examine knowledge creation presents a number of problems and initiates further questions. First, which perspective am I looking through at forms as a prerequisite for knowledge? Forms can be approached in different ways, such as quantitatively or qualitatively. On the one hand, forms can be measured and can produce quantities and numerical values. On the other hand, forms and shapes are qualities; they can be representative concepts that are difficult to measure, but are meaningful

[3]See T. Kuhn, and Ian Hacking. *The Structure of Scientific Revolutions*. 4Th ed. /ed. Chicago, IL: University of Chicago Press, 2012. Hanson, Norwood Russell. *Patterns of Discovery : An Inquiry into the Conceptual Foundations of Science*. Repred. Cambridge: U.P, 1975.

nonetheless. Thus, when examining the production of scientific knowledge as a creative activity, the viewpoint through which I examine forms must be established. Second, the broadness of form as a concept, as well as its usage, requires special elaboration before its epistemological role can be inspected. What, then, does the term ‘form’ mean in this investigation?

| Exploring Forms of Knowledge

In order to begin the investigation into the role of forms in scientific knowledge, the term ‘form’ itself needs to be accounted for. The concept of form implies an object or a configuration in space. Yet, aiming to define ‘form’ as a general concept, independent from specific disciplinary considerations, is challenging. An art or architecture dictionary defines ‘form’ significantly differently from a mathematical or philosophical dictionary.[4] An interesting distinction between definitions of form (based in German), however, is made by *The Oxford Companion to Architecture.* Here, ‘form’ appears either in its Gestalt meaning, which is “the shape of objects as perceived by the senses”, or in its abstract meaning where it is “implying an abstract realm divorced from concrete particulars.”[5] Form as a concept here displays a spectrum of meaning which extends from a concrete physical particularity to an abstract generality of meaning.

In both the architectural and philosophical entries, there is a tension between the physical and the abstract meaning of ‘form’. Scientific activity, which relies both on conceptual theorizing and empirical observations, requires a definition of form which encompasses both meanings. In the history of philosophy, a theory of forms was most prominently characteristic in the doctrine of Plato, in which ‘form’ was related to ‘idea’ and geometry. Forms as ideas, such as the idea of perfect roundness, are idealizations that do

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[4]According to "form" In *The Concise Oxford Dictionary of Mathematics*. : Oxford University Press, 2021, a form is a “homogeneous polynomial in two or more variables.” On the other hand, P. Goode, in *The Oxford Companion to Architecture*. : Oxford University Press, 2009, defines ‘form’ as having two meanings “based on the distinction in German between ‘*form*’ being the shape of objects as perceived by the senses (*Gestalt*) and *Form*, implying an abstract realm divorced from concrete particulars.” In, *A Dictionary of Philosophy*. : Oxford University Press, 2016, S. Blackborn, refers to Plato’s theory of forms where “the forms of things are intelligible but abstract shared features” and to the concept of form according to Pythagoras as the key to physical nature.
[5]P. Goode, "form." In *The Oxford Companion to Architecture*. : Oxford University Press, 2009

not exist 'as is' in the world but their conception contributes to intelligibility of things they are approximate to. The earlier Pythagorean concept of the term saw forms as the key to physical nature, and closely coincides with Cassirer's quote above.[6] Indeed, Cassirer referred to symbolic forms, described as a complex logical relation between image and thing, as "instruments of knowledge."[7] These perspectives display form as indispensable to knowing.

Another philosophical perspective of the term 'form' was presented by Aristotle as one of his four causes–the second 'formal' cause. Here, form is to be understood as a cause in itself; it is the pattern or blueprint of material, the arrangement of matter in a specific structure or shape.[8] It is a pattern of relationships. In this sense, forms are determinate and have an explanatory power. More than a key to knowing, they provide a means for understanding.

One last reference must be made to the Kantian use of the term 'form'. Kant's philosophy in reference to the role of forms and their cognitive, epistemological and aesthetic implications, among others, is complex and has been analyzed extensively in philosophical literature.[9] For the discussion at hand, it is only necessary to mention the distinction Kant makes between 'form' and 'matter'. In broad brush strokes, 'matter' is the content of cognition given by our sensations a posteriori, while 'forms' are *a priori* pure structures of the mind.[10] In this sense, forms are the mental arrangement that allows us to grasp and make sense of sensible experiences. This distinction which categorizes form as a mental faculty would be important throughout this work. However, forms should not be understood here only as symbols. Cassirer, who trained in the Neo-Kantian school of Marburg, focused his analysis on the creation of *symbolic* forms as a human cultural

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[6]S. Blackburn, "forms." In *A Dictionary of Philosophy*. : Oxford University Press, 2016
[7]Cassirer, Ernst, and Ralph Manheim. *The Philosophy of Symbolic Forms : V. Vol. 1: Language*. New Haven: Yale U.P, 1954.
[8]C. Shields, "Aristotle", *The Stanford Encyclopedia of Philosophy* (Spring 2022 Edition), Edward N. Zalta (ed.), forthcoming URL = <https://plato.stanford.edu/archives/spr2022/entries/aristotle/>. And S. Blackburn, "forms." In *A Dictionary of Philosophy*. : Oxford University Press, 2016
[9]For examples see: Donald Phillip Verene. *The Origins of the Philosophy of Symbolic Forms : Kant, Hegel, and Cassirer*. Topics In Historical Philosophy. Evanston, Ill: Northwestern University Press, 2011. Sgarbi, Marco. *Kant and Aristotle : Epistemology, Logic, and Method*. Ithaca: State University of New York Press, 2016. Hughes, Fiona. *Kant's Aesthetic Epistemology : Form and World*. Edinburgh: Edinburgh University Press, 2007. Deleuze, Gilles, Hugh Tomlinson, and Barbara Habberjam. *Kant's Critical Philosophy : The Doctrine of the Faculties*. Londres: Athlone Press, 1995.
[10]Sgarbi, Marco. *Kant and Aristotle : Epistemology, Logic, and Method*. Ithaca: State University of New York Press, 2016, p. 79-80

activity. Here, forms go beyond their symbolic function, and lean toward their non-physical Kantian definition. This is not to say that the term form would not reference at times the shape of a physical object here such as a work of art of a physical phenomena. However, the nature of these forms being flexible and changeable, as opposed to strictly *a priori*, is not determined here yet and remains to be examined.

As seen thus far, the meaning of the term 'form' broadens with every example and displays a clear connection to the terms 'shape' and 'structure'. Drawing definite distinctions between these terms is as tricky as defining 'form' and is not necessary for the task at hand. As seen above, and will be demonstrated further in this thesis, these terms are often used interchangeably while still having distinct meanings in cases that will present themselves throughout this thesis. It is worth pointing out, however, that the scope of the term changes with each of these terms, so that the meaning of 'shape' leans towards the particular and 'structure' towards the general. The term 'structure' can be used to describe a general arrangement of parts without referring to a specific object. 'Shape', on the other hand, is often used simply to describe a specific configuration of lines or an outline. A more fitting term for 'shape' in terms of outline, I believe, is found in the literal translation of the word 'outline' from Hebrew, 'kav mit'ar' (קו מתאר), meaning 'description line' or 'defining line'. For this reason, shapes suggest the particular, as their presence often is used to describe or define a form. 'Form' can be thought of, then, as residing in between two ends of the spectrum; a dimensional configuration of relating points and defining lines. Nevertheless, the full meaning of 'form', as an epistemological concept, should not be confined to the description provided thus far. It is my intention that a full understanding of the term will be reached through the reading of this thesis, as further examples and nuances would be illuminated.

The next step towards investigating the role of forms in the creation of scientific knowledge is determining the perspective from which these forms should be examined. Forms can be studied both quantitatively and qualitatively. An interplay of these two general epistemic perspectives or traditions, can be traced in the history of science. One perspective maintains that the world is ruled by, or rather *is itself*, form. This worldview prevailed during the Renaissance and could be found among the Neoplatonists who, to explain it roughly, believed that mind preceded matter and that the world was matter in form which emanated from divine consciousness. Forms are the true entities of consciousness that are translated into and shape matter.[11] In this sense, form precedes number, as forms are the link between our consciousness and what we experience to be the external world of matter. Natural philosophers such as Galileo and Kepler, who applied mathematics to their investigations, did so with the understanding that it was natural forms they were investigating through geometry and qualitative, as well as quantitative, observation.[12]

The second perspective maintains that nature's language is numerical and mathematical and is therefore best unveiled through quantification and measurement. The book *The Scientific Revolution: The Essential Readings* lists the application of measurement and mathematization to nature in the 17th century, as one of four basic influences that sparked the historical shift known as the Scientific Revolution (alongside the rise of empiricism, experimental analysis and the emancipation of science from external authorities).[13] Using number and measurement as a tool to gain knowledge of the natural world became a tool used by artists such as Leonardo da Vinci and natural philosophers such as Johannes Kepler and Galileo Galilei alike.

The growing implementation of measurement and quantification to science since the early modern period gradually moved from being a tool in the arsenal of the natural philosopher to a norm for scientific knowledge in the 19th century. The idea that measurement and depiction in number became the epitome of scientific knowledge can be traced in the writings of prominent figures such as the polymath Francis Galton, scientist and mathematician James Clerk Maxwell and mathematician, physicist and engineer William Thomson. Galton wrote on measurement that "Until the phenomena of any branch of knowledge have been subjected to measurement and number, it cannot assume the status and dignity of a science."[14] In a similar tone, Thomson wrote "I often say that when

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[11]C. Wildberg, "Neoplatonism", *The Stanford Encyclopedia of Philosophy* (Winter 2021 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/win2021/entries/neoplatonism/>

[12]Galileo's discovery of the mountain of the moon, for example, was a result of a qualitative observation and understanding of the interaction of light and form. His training in the arts and knowledge of chiaroscuro (light and dark contrasts) allowed him to recognize the edged line between the light and shadowed sides of the moon as evidence of mountains on the surface of the moon.

[13]Hellyer, Marcus. *The Scientific Revolution : The Essential Readings*. Blackwell Essential Readings in History. Malden, MA: Blackwell Pub, 2003, p. 22

[14]Galton, Francis. "Psychometric Experiments." *Brain : A Journal of Neurology,* 149-162, 1880. p.149

you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."[15] Maxwell specifically spoke of the importance of quantities, remarking usefulness of arithmetic over other forms of mathematics when he wrote: "Thus numbers may be said to rule the whole world of quantity, and the four rules of arithmetic may be regarded as the complete equipment of the mathematician."[16] If one wishes to maintain true knowledge of nature, according to these assertions, one must do so through the world of numbers, measurement and quantification.

In *Making Natural Knowledge: Constructivism and the History of Science*, Jan Golinski noted the increasingly crucial place precision measurement occupied in both scientific training and research throughout the 19th century. Precise numbers and measurements achieved with instrumentation replaced what was considered the "vague impressions of sense".[17] Numbers, measurements and quantities were perceived to be more reliable and valuable than qualitative impressions. Precision measurement was argued to be of the same moral value as mathematical theory (argued by Maxwell in reference to electromagnetism for example).[18] Goliski also referred to Latour who emphasized how quantities and measurement standards allow for compatibility and replication of experiments between different sites.[19] Gradually, numerical depiction became the hallmark of highly regarded sciences such as physics and chemistry, which use numbers and abstract symbols to detail mathematical phenomena and entities out of our physical reach.[20]

However, some proponents of the new science in the early modern period, such as Francis Bacon, argued that while mathematics is an important scientific tool which studies natural phenomena, it does not generate new knowledge. For Bacon, measurement and mathematics was a tool of precision that could determine and describe natural phenomena

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[15]Kelvin, William Thomson. *Electrical Units of Measurement*. The Practical Applications of Electricity. London: Institution of Civil Engineers, 1883.
[16]Quoted by Bell, Eric Temple in *Men of Mathematics*. Repred. A Fireside Book. New York: Simon and Schuster, 1965.
[17]Golinski, Jan. *Making Natural Knowledge : Constructivism and the History of Science*. Cambridge History of Science. Cambridge: Cambridge University Press, 1998, p. 137
[18]J. Golinski, p. 138
[19]J. Golinski, p. 173
[20]In the 21st century, this trend is seen in theories such as the 'Mathematical Universe Hypothesis' developed by cosmologists such as Max Tegmark who proposed a general theory if everything in which all physical reality is composed of entities that are mathematical in essence.

more precisely, but that does not give rise to new knowledge of the world.[21] In this sense, numerical depiction is used for the articulation of knowledge but is not its origin. Quantification and measurement were only one side of the coin.

The idea that numbers and measurement articulate knowledge and are not its basis, alongside the view that one can unveil reality through the understanding of form was generally abandoned by the 20th century. The beginning of the shift is often historiographically marked by the Scientific Revolution and Newton's physics, in which he applied numbers and measurement to natural phenomena. By the 20th century, practices of measurement, quantification, prediction and numerical description permeated scientific methods (as displayed by Golinski) and replaced older more descriptive approaches aimed at understanding natural phenomena. This long and complex process, that introduced measurement and prediction to the study of nature and gradually replaced qualitative natural philosophy, has been extensively studied in the history of science and will not be discussed here.[22] Instead, this thesis will focus on comprehending qualitative modes of thought in reference to form (as opposed to quantitative).

Comprehending qualitative modes of thought is important to understand our construction of scientific knowledge. The widespread application of measurement to the study of microscopic or astronomic natural phenomena, alongside endless amounts of numerical data that have been continuously gathered, have distanced quantitative theoretical concepts of modern science from the observable world. However, the data and measurements in question are not a given, but a product of a specific paradigmatic perspective. Philosopher and historian of science Thomas Kuhn commented on the nature of this gap in his *Structure of Scientific Revolutions*.[23] He wrote:

> "Far more clearly than the immediate experience from which they in part derive, operations and measurements are paradigm-determined. Science does not deal in all possible laboratory manipulations. Instead, it selects those relevant to the juxtaposition of a paradigm with the immediate experience that that paradigm has

[21]M. Hellyer, p. 22
[22]See examples in bibliography under J. Golinski and M. Heelyer
[23]Kuhn, Thomas, and Ian Hacking. *The Structure of Scientific Revolutions*. 4Th ed. /ed. Chicago, IL: University of Chicago Press, 2012.

> partially determined. As a result, scientists with different paradigms engage in different concrete laboratory manipulations."[24]

Measurements and numerical data are, therefore, only determined in a specific paradigmatic perspective. Collection of numerical data, as well as new formulations of mathematics, such as the discovery of non-Euclidean space at the turn of the 20th century, have opened up a realm far removed from our immediate three dimensional formed reality. They have become ever more contingent on the manner in which we construct the world around us and scientists. Maxwell commented on this notion when he wrote: "Mathematicians may flatter themselves that they possess new ideas which mere human language is as yet unable to express."[25] In other words, the specialized concepts that emerged from a need for determinism and a focus on precision and measurement, left behind the link between knowledge and form in the general language of modern science. This is not to say that there are no qualitative considerations and reasonings in modern science and mathematics. On the contrary, the presence and importance of qualitative theorizing are obscured by disciplinary language and placement of higher epistemological value on quantities.

The reasons for shifting our attention back to forms and qualitative decision making may be questioned. Why is it important to better understand the role of forms in the creation of scientific knowledge? Looking to the history and towards the future of scientific activity, the necessity to return to forms as an epistemological object of investigation in its own right arises in different ways. Kuhn demonstrated how, in times of scientific crisis, two or more theories of explanation were placed in competition.[26] In many cases, he argues, the theory which eventually prevailed had an additional qualitative value; its formulation was simpler or its structure appealed to a more aesthetic form.

A good example for such aesthetic considerations is seen in *The Copernican Revolution*, an earlier book which inspired Kuhn's influential work.[27] There, Kuhn

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[24]T. Kuhn, 2012, p. 126
[25]Maxwell, James Clerk, and P. M Harman. *The Scientific Letters and Papers of James Clerk Maxwell*. Vol. 2, 1862-1873, Cambridge: Cambridge University Press, 1995, p. 328
[26]T. Kuhn, 2012, p. 154
[27]T. Kuhn, *The Copernican Revolution : Planetary Astronomy in the Development of Western Thought*. Cambridge: Harvard U.P, 1957.

recognized that the new astronomical structure introduced by Copernicus was not necessarily more comprehensible to grasp than the preceding Ptolemaic astronomical scheme. Nor did it present greater accuracy. The content of Comernicus' influential *De Revolutionibus* was mathematically dense and complex, providing a challenge to many readers. Its appeal, according to Kuhn, was found in the structural harmony it presented. Interestingly, Kuhn remarked that "only astronomers who valued qualitative neatness far more than quantitative accuracy (and there were a few - Galileo among them) could consider this a convincing argument in the face of the complex system of epicycles and eccentrics elaborated in the *De Revolutionibus*."[28] When presented with a choice, certain scientists would choose the one with greater qualitative appeal. Kuhn's reference to 'qualitative neatness' displays how theories have prevailed and paradigms have shifted based on qualitative considerations rather than quantitative accuracy. But it is a certain type of attention, a Neoplatonist one, that allowed the Copernican system to prevail. The presence of Neoplatonic thought at the time Copernicus published his work has allowed astronomers to be more sensitive, and therefore responsive, to such qualitative arguments.

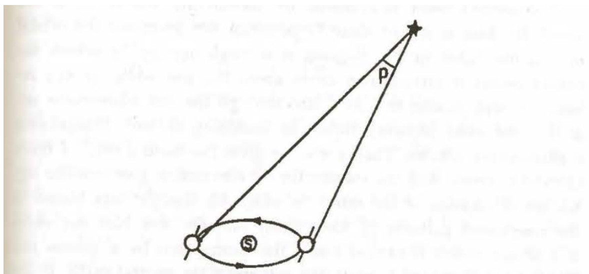

Figure 30. The annual parallax of a star. Because the line between a terrestrial observer and a fixed star does not stay quite parallel to itself as the earth moves in its orbit, the star's apparent position on the stellar sphere should shift by an angle *p* during an interval of six months.

Figure 1

Copernicus' novelty should not be understood in terms of *structure* alone, but as a change in form. The imaginary lines upon which the planets moved has changed. When examining the visual and linguistic descriptions in Kuhn's book, it becomes clear that Copernicus' scheme offered a new set of relations; it allowed for new description lines to be drawn between the data points and new simpler forms to eventually emerge. Figure 1, taken from *The Copernican Revolution* displays how the structural change has led to

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[28]T. Kuhn, 1957, p. 172

relational changes, i.e. changes in the lines drawn between points (one of which can be the observer).[29] The text accompanying the image displays the change in the imaginary lines drawn. In this sense, we see that forms are determined by sets of relations. A scientific revolution, in essence, is a change in relations and perspective, that is, a change in form.

Seeing how forms have played a significant role in the developmental trajectory of science from the early modern period, we can now turn to justify their relevance for the future of scientific activity. An important example for this can be seen with the rise of Big Data, which exposed us to such extreme amounts of information, rendering it completely unintelligible in themselves. Here, an accumulation of numerical data, no matter how rich or accurate, does not constitute knowledge in itself. The gap between the measured data and our comprehension of it reveals compelling clues to the nature of understanding. It allows us to ask the question: what is the gap between collecting numbers and measurements and making them intelligible?

A possible clue to answering this question is seen when examining the rising role of the data scientist and data visualizations. In order to make numbers comprehensible, patterns are traced by data scientists and visualized in graphic representations, shapes and forms. Numbers must be visualized qualitatively, such as by means of graphs or lines, to convert them from being abstract data to comprehensible information and knowledge. The successful marriage of mathematics and scientific inquiry is therefore not merely due to the cold logical neutrality of the coupling. Collected and measured, numerical data still requires qualitative interpretation and placement in graphs in order to be made coherent. What is missing in this picture is the inevitable qualitative considerations in the analysis of data and scientific decision making. Big data displays how the graphic arts are a scientific necessity. Forms arise as inseparable from, and essential to, quantified numerical comprehension. As seen with Copernicus in the historical example, a revolutionary change is also a change in form, i.e. a qualitative change in perception.

The intellectual process that shifted knowledge creation from its natural philosophical character to a modern scientific one resulted in frameworks and concepts that are either highly complex and specialized or quantitative in nature. These conceptual

[29] T. Kuhn, 1957, p. 163

frameworks are therefore insufficient for fully grasping the qualitative significance of theories that explicitly emerged from an inquiry into form and a qualitative philosophy. It is therefore important to examine theories that emerged from a qualitative perspective and were explicitly aimed at understanding form as a configuration of defining lines (in the third dimension and above), rather than aimed at quantifying and predicting. Extracting the qualitative philosophies of such theories, will provide insight into the role of form in the creation of scientific knowledge, as well as set the stage for relevant concepts to emerge. This requires the inspection of theories which are based on geometry and topology and maintain explicit links (as in conceptual links that go beyond pure mathematical elaboration) to form throughout their philosophical elaboration. Moreover, these theories should possess qualitative concepts and epistemic activities, associated more often with the arts than with the sciences. Nevertheless, by tracing the usage of parallel concepts in the literature of science philosophy, I aim to demonstrate their importance to science in general.

| Theories of Form

The prevailing presence of form in nature, art, visual representations and regulations such as signposts, requires examples of theories that explicitly place form as a central component in their inquiry into natural phenomena. We must examine theories which have centered their investigation around form as a key principle through which natural phenomena can be known, understood, and explained. In this sense, the theories in question should echo Aristotle's sentiment, where forms are seen as explanatory and causal patterns of relationships. Or, as described by Cassirer, the theories in question should analyze forms as tools for investigation into natural phenomena. For this reason, I chose my investigation to focus on Kepler's theory of universal harmony as depicted in his

Harmonices mundi and Thom's theory of morphogenesis presented in his *Structural Stability and Morphogenesis: An Outline of a General Theory of Models*.[30]

Several significant reasons make these two theories suitable for exploring the role of form in science. First, Kepler and Thom placed form as a fundamental principle through which natural phenomena can be unveiled and understood. Moreover, both scholars were devout readers of Aristotle. Characteristic of a Renaissance natural philosopher, Kepler established a link with ancient Greek philosophers throughout his theory, often quoting Aristotle extensively in his *Harmonices*.[31] Thom is also a unique example of a 20th century mathematician who read Aristotle, as well as other ancient Greek philosophers, in original Greek for the purpose of detecting topological ideas and correcting existing translations.[32] Both Kepler and Thom developed their mathematical ideas in close proximity to a qualitative view of nature, as seen in Aristotle's philosophy.

As I will display throughout this thesis, for Kepler and Thom, nature is form, and could be explained by it. Kepler searched for the presence of harmonic ratios and relations in everything from music, the distribution of petals on a flower, to planetary motion and the human soul. According to Kepler, while harmonic ratios have a quantitative aspect, their essence was first and foremost determined by their presence in the platonic solids. In this sense, numerical ratios are an extension of the regular polyhedra and therefore an extension of form. Nearly three hundred and fifty years later, Thom was intent on finding, among other things, the underlying topology of natural morphogenesis by observing it in embryos, the evolution of species, the formation of cracks in the wall and human language. The aim of each theory can generally be seen as an attempt to construct a general model of a phenomena each scholar believed to be universal: a universal model of harmony in Kepler's book and universal models for morphogenesis in Thom's. Their theories aimed to go beyond the mathematical comprehension of a distinct phenomenon; each aspired for a more general understanding of nature's underlying structure as a whole. Their focus was to construct geometrical or topological models, through a formal simulation of a phenomenon, rather than through measurement and quantification of these forms in

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[30] Kepler, Johannes, *Harmonices Mundi*, translated to English by E.J. Aiton, A.M. Duncan, and J.V. Field, The American Philosophical Society, 1997. Thom, René, *Structural Stability and Morphogenesis : An Outline of a General Theory of Models* [4Th print.] ed., Reading: Massachusetts, 1978

[31]See Book IV of the *Harmonices mundi* for examples, pp. 284+297-298

[32]Papadopoulos, Athanase, "Topology and Biology: From Aristotle to Thom", ffhal-01929108f, 2018, p. 2

nature. This suggests that both theories can provide insight into the nature of qualitative reasoning, methodologies and concepts within scientific activities.

The disciplinary approach of these two theories was another reason for featuring them in this study. Both scholars were gifted mathematicians, yet who applied their mathematical investigations to understanding natural phenomena by modeling forms. But in many ways, categorizing these two thinkers as mere mathematicians constrains the great scope of their intellectual pursuits. Operating earlier than the paradigm of modern science, Kepler would better be described as a natural philosopher. His work, detailed in the *Harmonices* and elsewhere, is not just investigated by historians of mathematics, physics and astronomy, but has also been studied from the perspectives of musicology, biology, psychology, philology and philosophy.[33] His thinking extended far beyond the realm of mathematics, and he dedicated his time to other creative disciplines, such as music and art. Similarly, Thom's identity as a scientist, as well as his theory, resisted categorization. While he won the Fields Medal in 1958 and built his reputation as a topologist, he considered himself a mathematician only 'sociologically' speaking. In practice his work and interests extended to biology, physics, the social sciences, linguistics and philosophy.[34] In fact, Thom himself argued for a return to natural philosophy and stressed that science in its current state (meaning the second half of the 20th century) has lost touch with its original aim, which was to understand and explain. For him, one of the main problems of science was that of the succession of form.[35] It was the ability to understand and simulate the morphogenesis of natural phenomena (with topological models) that amounted to explanations, as opposed to reductionist types of explanations.[36] Evidently, the natural philosophical approach maintained by these individuals promoted philosophies that were

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[33]Examples of research from the different disciplines mentioned: Philosophy and psychology: J.M. Escobar, "Kepler's theory of the soul: a study on epistemology", T. J. Reiss, *The Discourse of Modernism*, pp. 140-167. Physics: Stephenson, Bruce. *Kepler's Physical Astronomy*. Studies in the History of Mathematics and Physical Sciences, 13. New York: Springer-Verlag, 1987. Biology: Boner, Patrick. *Kepler's Cosmological Synthesis : Astrology, Mechanism and the Soul*. History of Science and Medicine Library, Medieval and Early Modern Science, V. 39 ; Volume 20. Leiden: Brill, 2013. Theology: Wenig, Otto. "7.6. Kepler and the Contemporary Situation of Church and Theology." *Vistas in Astronomy* 18 (1975): 389–90. For history and literature: Grafton, Anthony, "Kepler as a Reader", *Journal of the History of Ideas* 53, no. 4, 1992, pp. 561-572

[34]Aubin, David, "Forms of explanations in the catastrophe theory of René Thom: Topology, morphogenesis, and structuralism", in M. N. Wise (Ed.), *Growing explanations: Historical perspective on the sciences of complexity* (pp. 95-130), Durham: Duke University Press, 2004, pp. 98-99

[35]R. Thom, p. 1

[36]D. Aubin, p. 95-96

directed towards a qualitative understanding of nature rather than that of quantification, measurement and precision.

The contrast between Kepler and Thom's philosophies, on the one hand, and the more dominant reductionist scientific approach of the 20th century on the other, is seen in their reception by the scientific community and literature. The general understanding of their theories within the scientific community appears to have suffered a similar fate; both scholars were celebrated mathematicians, yet there is an acute imbalance between the positive reception of their mathematics as opposed to the insolent reception of their general philosophies. This can be seen, for example, in the current historiographical state of the *Harmonices*. Kepler clearly accounts for the hierarchical structuring of his hefty book in several places (clearly visible in the introduction to the 4th book of the *Harmonices*) and the importance of each part to the construction of his philosophy. Nevertheless, within the historiography of the work, the entire work has been dissected, each disciplinary element within it studied in disciplinary separation from the other.[37] Moreover, there is still disagreement among historians of science regarding Kepler's worldview (some argue for Neoplatonism while others consider him a proponent of the mechanical worldview).

Thom's theory descended into scientific controversy less than a decade after its publication. Thom's mathematical approach to topics not typically treated by mathematical considerations proved difficult to comprehend by both math savvy individuals and nonmathematicians alike. Oddly, part of the scholarly disagreement centered around the *type* of theory Thom presented. Some argued that his theory was not mathematical and only employed mathematics as a tool, while others considered it to be purely mathematical.[38] These and other aspects of their theories, for example, Kepler's attempt to reform astrology or Thom's explicit appeal to notions such as mathematical intuition and gestalt psychology, resulted in aspects of their theories being characterized as spiritual or obscure in the eyes of the scientific community.

[37]For example, the fifth book of the Harmonices is the most studied and cited one of the five, as it depicts the third law of planetary motion most relevant to modern scientists. The fifth book also appears alone, removed from the other four, in Britannica's Greatest Books collection. The sources I provide in footnote 33 each focus on the book (out of the five) that best fits their disciplines. A comprehensive analysis of the *Harmonices* as a whole has not yet been attempted.
[38]D. Aubin, pp. 96+106

Kepler's place in the Scientific Revolution is known and extensively researched and Thom's models, developed in the branch of catastrophe theory, are used till this day.[39] Yet, in both cases, the stormy controversy which followed their publications resulted in the survival of their mathematical considerations and neglect of their general natural philosophy. This point is particularly compelling, as it refers to the notion of hierarchy and validity when it comes to certain epistemic perspectives and methodologies within the scientific community. Equations and syntactic numerical models remain, yet the philosophical construct that yielded these same equations was abandoned. It is, therefore, essential to review how Kepler's and Thom's categorical appeal to qualitative analysis, holism as opposed to reductionism, and form has hindered the scientific community's ability to understand and receive these theories.

The third reason for choosing these theories is, therefore, their holistic and qualitative character, demonstrated by their reception by the scientific community. It is necessary to question what it was about these theories that made them useful to modern science on the one hand, and remarkably misunderstood or misinterpreted, on the other. By extracting concepts and modes of thought of previously misunderstood qualitative theories, I aim to show the necessity of developing a more adequate qualitative conceptual framework within modern science.

The fourth and final reason I shall focus on Kepler and Thom's theories is the timeframe in which they were written. As noted above, Thom believed that science was in a state of crisis during the second half of the 20th century. Inspired by Kuhn's thesis, he consciously and purposefully posed a "philosophical challenge."[40] His main ambition was to push the boundaries of scientific thought, which he believed had reached a stalemate, or a 'paradigm crisis' in Kuhn's terminology. Thom wanted to provide the upcoming generation of scientists with a new intellectual framework within which they can operate and apply other existing scientific methods.[41] For this reason, he presented his new scientific approach in a manifesto style book. Kepler, being an early modern natural philosopher

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[39]For example, in *The Astronomical Revolution*, Alexandre Koyré wrote that "If there was no Kepler, there would be no Newton". Koyre, Alexandre, *The Astronomical Revolution*, translated to English by Maddison, R.E.W., London: Methuen, 1980, p. 120
[40]E. C. Zeeman, "On the Ideas of John Bernoulli and René Thom", Nieuwe Archief voor Wizkunde, Veirde serie, Deel 11 (1993), pp. 257-282. Text from a John Bernoulli lecture given in Groningen 1993. P. 270
[41]Ibid.

before Newton's time, preceded the scientific paradigm of what would eventually become physics and astro-physics. Working in a pre-paradigm period, Kepler was free to examine and apply methodologies without the restrictions of the 'normal scientific' paradigm.[42] It can be said that Thom operated during a time of scientific crisis while Kepler operated in a pre-paradigm period.

The significance of studying two theories that were written during periods of a paradigm shift is first and foremost the fact that they were entirely depicted in books. In *The Structure of Scientific Revolutions*, Kuhn remarked on how the role of books tends to change between pre-paradigm and 'normal science'. Books that were written for research communication and depict a theory (as opposed to the journal article), were published in pre-paradigm periods or within disciplines where "the lines of professionalization (are) still loosely drawn."[43] Kepler's *Harmonices* easily fits within Kuhn's characterization of a pre-paradigm book. Thom's *Morphogenesis* displays a new type of science (according to Thom himself) by using the still developing discipline of topology at the time. He considered topology a newly developing discipline which still required much elaboration and explanation.[44] The two theories in question, then, were written not only as scientific theories, but as comprehensive qualitative philosophies that were meant to explain the new science they presented. Moreover, Kuhn tells us that it is during times of paradigm shift that stabilized concepts loosen and change into new entities, requiring extensive explanation and elaboration.[45] In this sense, theories and books that were written during paradigm shifts provide valuable sources for studying distinct qualitative approaches within science, as their content is brimming with descriptions.

Another compelling point concerning Kepler and Thom's timeframes is that they wrote their theories during either pre-Newtonian (classical mechanics) or after the discovery of quantum physics (quantum mechanics). Both operated outside the paradigm of classical mechanics, beginning with Newton in the second half of the 17th century and ending with the emergence of quantum mechanics in the early 20th century. Within this paradigm, there was a determinate approach to natural phenomena, which were observed

[42]T. Kuhn, 2012, p. 48
[43]T. Kuhn, 2012, p. 20
[44]D. Aubin, pp. 120-121
[45]T. Kuhn, 2012, pp. 148-149

and studied in a 'linear manner', consisting of cause and effect, local causality, calculation for prediction and isolation of phenomena. Written outside the paradigm of classical dynamics, the two central sources in this thesis must include an account of processes that are undetermined and, therefore, not measurable or quantifiable. For this reason, Kepler and Thom's theories may reveal qualitative approaches to indeterminism.

The continuous branching out and articulation of scientific disciplines in the 20th century has ushered in a transformative wind to the philosophy of science, as philosophers such as Karl Popper aimed to define the boundaries of what is considered a science. In the Popperian sense, true science poses hypotheses, theorems and laws, and makes theoretical predictions that can then be falsified through experimentation. "Real science" is demarcated by determinate and quantitative reasoning. This is what differentiates true scientific theories from other pseudo or pre-sciences according to Popper.[46] Formulation of laws and prediction of data has turned gradually into a standard according to which true science was measured. But placing such strict boundaries around science has placed theories such as Kepler's and Thom's in an odd place within the scientific community, as these theories cannot be fully understood by Popperian standards. While Kepler's Harmonices presents laws and theorems (the third law of planetary motion), Thom's theory does not make predictions and does not pose any theorem; it is better seen as an exploration of natural phenomena through the lens of forms; a simulation of natural phenomena with topological and algebraic-geometric entities. Both thinkers believed that their theories of form can eventually go deeper than detecting a pattern of natural phenomena. They both believed that such a discovery of form also provides an explanation for the operation of natural phenomena.[47]

Due to their natural philosophical character, Kepler's and Thom's theories balance on the boundary of what is now recognized as early modern or modern science. They apply measurement and mathematics to natural phenomena and use empirical reasoning, but

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[46]Thornton, Stephen, "Karl Popper", *The Stanford Encyclopedia of Philosophy* (Fall 2021 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/fall2021/entries/popper/>.

[47]It is noteworthy to mention here that this discussion does not aim to enter the debate of the definition of a scientific explanation. Kepler and Thom lived and worked in two very different timeframes which had distinct concepts of how one should investigate natural phenomena. Entering Kepler's work into such a debate would appear odd. Nevertheless, Thom does make a distinction between prediction and explanation in his introduction which is a hint towards his position on the matter: "(...) and that the purpose of science is to foresee this change of form and, if possible, explain it." R. Thom, p.1

their structure and claims regarding indeterminism are different due to their qualitative approach. This point is compelling since such theories have the potential to observe and understand phenomena qualitatively while not being considered subjective. By analyzing the philosophies behind these theories, I aim to extract and illustrate a qualitative conceptual framework which encompasses a type of scientific reasoning that is based in forms and shapes, as opposed to linear logic, precision, and measurement. Moreover, this conceptual framework will display the presence of a qualitative perspective in science that yields qualitative considerations and choices.

Extracting concepts and methods from Kepler's and Thom's theories can aid with mapping and constructing an adequate conceptual framework of qualitative observations and knowledge creation in science. Studying the presence of this idea in theories written by benchmark characters in the development of modern science is crucial to a more holistic understanding of knowledge creation and decision making in science. Moreover, these considerations may demonstrate the lack of framework for understanding knowledge creation based on form and quality. Their investigations have a visual aspect which is not syntactic (whether it be in words or numbers) and extend to various disciplinary considerations. Examining how these scholars observed the world, their inspirations, and their placement of form (with geometry and topology) as central to understanding natural phenomena is, therefore, invaluable for understanding qualitative reasoning. A study of a qualitative scientific viewpoint requires the development of a conceptual framework formulated for qualitative comprehension that will be a significant element of this thesis.

| Shaping Concepts and Conceiving Forms

A significant part of this thesis will focus on developing a qualitative conceptual framework for scientific theorizing that requires choosing, examining and illustrating particular concepts. As mentioned in the beginning of this introduction, this framework is aimed at relating the theorizing process behind scientific knowledge creation, to creative practices of forming and molding in design and the arts. Naturally, this search should expand from the central concept in this thesis–form. To fully see a form, we must be willing to observe it from various viewpoints. By its very nature, form nullifies the possibility of deeply understanding anything through one perspective, or a detached perspective, as form hints towards active observation: one must meditate on form, turn the form around, or turn around the form, in order to perceive it in its entirety. These properties of forms are important when examining their role in scientific knowledge and when constructing a qualitative conceptual framework.

Before gaining an understanding of the role form plays in scientific knowledge creation and theorizing, the term form itself must be clarified according to Kepler and Thom's theories. Both authors present a short discussion of form in their introductions. Kepler approaches this question from the perspective of the human mind by investigating features that make geometrical objects distinguishable to us. The feature that allows the mind to contemplate geometrical objects is their form–their binding, their "limit or boundary."[48] Without form, objects in general will not be able to exist. In the same introduction, Kepler makes an analogy between having an aim and having a form when: "with the aim of the work removed, as if the form were removed from a building, there was left a formless heap of propositions in Euclid."[49] In this sense, form is not merely a three dimensional object, but rather a framing or ordering that establishes knowledge or direction, a framing that is first and foremost mental rather than physical in essence. It is probable that for this reason he occasionally uses the terms shape and form interchangeably.

Thom opens his introduction with displaying the main problem his theory treats: the succession of form. His referencing of form converges with the mental, like Kepler, on the one hand and leans towards the technical, on the other. He mentions that our ability to recognize changing forms as the same object (for example the morphogenesis of embryos) is equivalent to the philosophical problem of concept.[50] Like Kepler's analysis, forms and concepts arise here as comparable. On the other hand, Thom interchanges the word form with 'shape', 'structure' and 'topological type'.[51] For him, form is a general concept that

[48]J. Kepler, p. 9
[49]J. Kepler, p. 11. Kepler wrote this in reference to (what he believed to be) people's misconception of Euclid's Elements, in particular the 10th book which he believed to be underappreciated and greatly misunderstood.
[50]R. Thom, p. 1
[51]See examples in R. Thom pp. 1, 4, 6.

refers to recognizable objects, whether they be conceptual, physical or mathematical, that are endowed with a degree of stability, but also change naturally.

No matter the angle, shapes and forms pertain to many human sensible experiences, the most obvious being the senses of vision and touch. In Jay Kappraff's *Connections: The Geometric Bridge between Art and Science*, geometrical forms are linked to the very foundation of our visual perspective and the three dimensional experience of the physical world.[52] Forms are also found in the development of our auditory senses and abilities, not just in relation to music, but in the development of human languages and, therefore, in the very concepts we communicate with. For example, in his *Evolution of Human Language*, Wolfgang Wildgen embarks on an interdisciplinary study of science history and art history in order to understand the development of the human language.[53] In his findings, he relates the prehistoric abstraction of visual shapes and three dimensional form to the grammaticalization of our language.[54] It arises that even the foundation of our human language cannot be studied through the partial lens of science history; art history emerges as vital to the understanding of human language and the foundation of physical form.

The basis of human knowledge and its creation is inevitably multidisciplinary and embedded in abstract geometry and forms. Examined in this light, Kepler and Thom's invocation of geometry as the fundamental principle through which phenomena can be explained is justified and must be examined and analyzed. Their general theories, which produced paradigm shifting mathematical models that do not fit comfortably in a specific discipline, are all the more reason to understand their philosophies.

The references to form made thus far display the close relationship between forms and concepts, whether its by Kepler and Thom or by philosophers such as Kant and Cassirer. What arises as essential to thinking in terms of form (dimensionality, analogy with concepts and mental essences, and their framing or defining abilities) will be necessary to include in the qualitative conceptual framework. Questioning the role of form in scientific knowledge creation, therefore, requires us to consider a dimensional framework that refers

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[52]Kappraff, Jay, *Connections : The Geometric Bridge between Art and Science*. K & E Series on Knots and Everything; V. 25. 2nd ed. Singapore: World Scientific, 2001

[53]See Wildgen, Wolfgang, *Evolution of Human Language : Scenarios, principles, and cultural dynamics.* Philadelphia: John Benjamins Publishing Company, 2004. Curiously enough, Wildgen himself is also interested in René Thom's work, and wrote a book titled *Catastrophe Theoretic Semantics: An elaboration and application of René Thom's theory*.

[54]W. Wildgen, pp. 65-66

to observation and perspective, theorizing as framing, and other epistemic activities that parallel the creation of concepts with the creation of forms by the craftsman. In addition, it requires an elaboration on what the term 'qualitative' means here. Therefore, a clear shift will be made, from quantitative information to qualitative information, from quantitative epistemic activities to qualitative epistemic activities and from quantitative observation to qualitative observation.

The formation of a coherent conceptual framework is essential to this study as it approaches ideas in modern science from a quantitative perspective which, I believe, is currently lacking and one-dimensional. 20th century philosophers and thinkers, such as Thom himself, also highlight the one-dimensionality or the binary nature of our current conceptual language and approach.[55] Thom writes: "The dilemma posed (by) all scientific explanation is this: magic or geometry."[56] He referred to restricted options presented by scientific intellectualization that are limited to understanding processes only with three dimensional Euclidean geometry. In addition, he argued that natural philosophy and qualitative investigations were poorly understood in modern science, and invested time and space in his writings to remedy this.[57] I suggest approaching this matter through examining mathematical activity and terminology, as mathematics has already developed multidimensional concepts (which also go beyond the third dimension), and developing scientific concepts by borrowing terms and ideas used in the arts.

Examining artistic concepts and their relationship to mathematics is central to this thesis. In order to parallel mathematical concepts and epistemological activities, which are present and not named explicitly, the concepts borrowed are from the practical aspect of artistic creation. First, I intend to examine and elaborate on concepts such as: molding, stencil, fabrics, materials, and sculpting. Second, the thesis will inspect how other forms of conceptual articulation and communication of natural phenomena, such as mathematics, geometry and sculptures (all able to articulate geometrical and topological notions) are

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[55]Another science philosopher who argued against conceptual dimensional limitations is Evelyn fox Keller in her paper "The gender/science system, or: is sex to gender as nature is to science." pp. 48-49. Keller, Evelyn Fox. "The Gender/Science System: Or, Is Sex to Gender As Nature Is to Science?" *Hypatia* 2, no. 3, 1987, pp. 37-49
[56]R. Thom, p. 5
[57]Thom, who read ancient Greek, believed that his ideas were comparable with Aristotle's ideas and were mistranslated due to this misunderstanding (see: A. Papadopoulos in bibliography). Kepler argues for a conceptual misunderstanding of Euclid's tenth book of the elements (see: J. Kepler, p. 11).

utilized for the purpose of forming a multidimensional perspective and its relationship to concepts such as 'archetype'. Third, this study will examine the articulation of qualitative concepts of perspective that have a dimensional range, such as 'everywhere' as opposed to 'nowhere' (in reference to observation) for example.

The concepts borrowed from art and extracted from Kepler and Thom's theories will be elaborated on in two ways. First, I will examine their presence in the existing philosophy of science literature. The pairing of form and quality in philosophical analysis more often than not leads to discussions on aesthetics and is not found in the core of scientific reasoning. This generalization has prevailed since the Neoplatonist natural philosophers of the early modern period were replaced by the Newtonian method. Some exceptional accounts to this generalization are found in the analysis of art in phenomenology, as seen in the works of philosophers such as Theodor Adorno and Martin Heidegger.[58] Relevant for this analysis, however, are texts in which philosophers of science use qualitative and creative terminology or explanations that detail epistemic activities and observations, such as Norwood Russell Hanson's *Patterns of Discovery* and Henri Bergson's *Creative Mind*.[59] Other texts by philosophers of science and mathematics, such as Emile Meyerson, Hasok Chang, Imere Lakatos, Ernst Cassirer and William Whehell will also be examined.

The second method I will use to elaborate on new qualitative concepts will be to adopt creative techniques of observation and visualization from the arts and humanities as visual metaphors. Techniques such as patternmaking, perspective painting, and abstracting form in sculpting will be used as metaphors and visualizations to illustrate scientific epistemic activities and concepts. These illustrations aim to give the reader a more concrete understanding of the introduced concepts and display the creative components of scientific knowledge creation. Supporting sources will include Leonardo da Vinci's Renaissance visual studies on scientific perspective, Nicholas of Cusa's *The Vision of God*, Constantine Brancusi's early 20th century three dimensional sculptural studies, and Linda Dalrymple Henderson's *The Fourth Dimension and Non-Euclidean Geometry in Modern*

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[58]For their works on art see: Adorno, Theodor W., Aesthetic Theory, London: Bloomsbury Publishing, 2013. Heidegger, Martin, 'The Origin of a Work of Art' (1950), Translation; Nonet, Philippe and Berkowitz, Roger

[59]Bergson, Henri, and Mabelle L Andison. *The Creative Mind : An Introduction to Metaphysics*. Mineola, N.Y.: Dover Publications, 2007.

Art.[60] This approach intends to shed further light on the question regarding the locus of intelligible knowledge; is knowledge found in quantification and numbers or in quality and forms?

Finally, the space of experience must be specified. The beginning of this section mentioned the dimensionality of form and the active observation it entails. Therefore, the two spaces, or domains, of experience should be articulated for this discussion: the inner and the outer. The inner is the domain of individual experience, intuitions and thoughts, and the outer is that of shared information and experiences. Sensible data, for example, appears to move from the outer to the inner. Thoughts and imaginations, on the other hand, are experienced as residing in the inner domain of experience. To describe and refer to these two spaces of experience I employ the terms 'inner sphere' and 'outer sphere'. The term sphere encapsulates both the definition of a domain of activity and also refers to a basic geometrical form which appears to be especially fitting. I will, therefore, refer to the two spheres of experience from this point onwards as the 'inner sphere' and the 'outer sphere'.

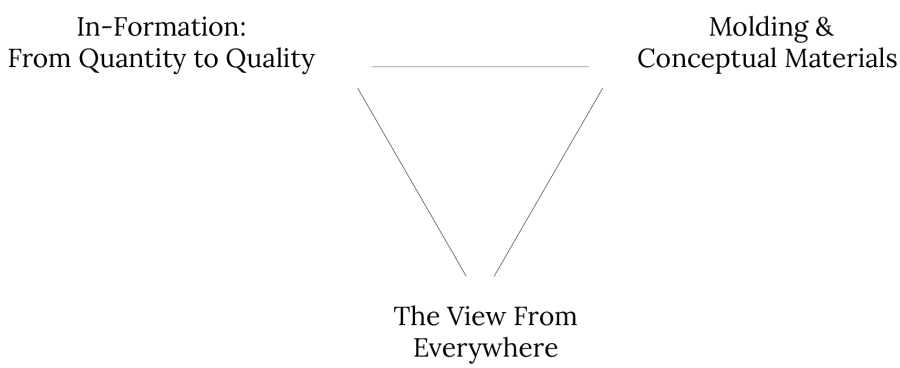
Focusing on form as a central conception in this thesis mandates the allocation of special attention to the structuring of this thesis. A qualitative focus on form suggests that the relationship between the different components of this thesis, detailed thus far, is as important as the components themselves. The main challenge in determining the suitable presentation and starting point was the gap between the syntactic nature of writing and the unsyntactic nature of form. Where does a form begin or where does it end? Despite having clear boundaries, does a square, circle, triangle, or painting have a beginning or ending? Viewing an image or form does not mandate us to begin anywhere specific; the adequate initial point of reference can be debated, or it may be entirely arbitrary. Nevertheless, describing a shape verbally or mathematically does require one to begin *somewhere*.

It is a similar case for this thesis. Due to the linear nature of writing, the traditional 'table of content' displays a consecutive order upon which books or theses are structured.

[60]Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art*. 2nd ed. Leonardo. Cambridge, Mass: MIT Press, 2013.

The very nature of syntax and language requires one to place, to dissect and order ideas or experience, for the purpose of placing one section or chapter before the other. Seeing or perceiving, however, does not require us to internalize information in the same manner; the world is not ordered in and of itself, but rather ordered by us. This simple fact already puts this table of content in question: is a predefined order necessary for comprehension?

After careful consideration of order and structure, I realized that opting to place one section before the other in a predetermined manner is inevitably imperfect. Any determined consecutive order would always require the omission of certain concepts or details until a later stage of the thesis and result in a partial understanding of the other sections not yet read. Each section equally relates to the other two, and only when viewed together can they form the entire image. Just like three corners uniformly form the image of a triangle, these sections do not build upon each other, but rather, build something together. For this reason, I prefer to place the three main chapters in the form of a triangle rather than a list.



As this thesis deals with order, perspective and form, I believe it is important that these ideas be reflected in the structure of this work as well. Presenting the chapters in a form also presents a challenge to the order of reading. As such, this thesis can be read vertically or horizontally. It is divided into the three chapters as they appear in the triangle above: In-Formation: From Quantity to Quality, Molding and Conceptual Materials, and The View From Everywhere. Each chapter further branches out into three sub-chapters, making a total of nine sub-chapters. A vertical reading will follow a traditional reading of each chapter consecutively, beginning in In-Formation and ending with The View From Everywhere. The ordering of this option is based on perspective: The first perspective in the first chapter examines forms and their role in the outer sphere as they arise in the creation of scientific theory. This symbolizes the first shift mentioned above, from quantitative to qualitative information. The second perspective in the second chapter explores the mental 'forming' of concepts in our inner sphere and the effect of this inner experience on shaping the world around us. Here, we shift from understanding quantitative epistemic activities to qualitative ones. And the third perspective in the third chapter discusses the relationship between the inner and outer spheres, and questions notions of perspective in observation and theorizing. Thus, in the final chapter we shifted from quantitative observation to qualitative observation.

A horizontal reading of this thesis divides the sections according to themes as opposed to perspectives. The three themes are: shifting from quantity to quality, focusing on epistemic agency and activity, and the tension between order and disorder. The horizontal would consist of reading the first subchapter of each main chapter, continuing to the second sub-chapter of each chapter and ending with the third. This option may be more challenging, but it allows the reader to continue with a specific theme throughout all three perspectives, before moving on to the following theme. While there is a traditional introduction and conclusion, readers can choose their own preferred order and move between chapters freely according to their own intuitions. For this reason, the chapters are not numbered but only titled. The division can be seen in this table:

	In-Formation: From Quantity to Quality	**Molding & Conceptual materials**	**The View From Everywhere**
Shifting from Quantity to Quality	*Quality, Forms and Information*	*Inner Molds and Outer Patterns*	*Observing Numbers Vs. Observing Forms*
Examining Epistemic Agents and Activities	*Forms as Epistemic Agents*	*Chaos or Pattern? Structuring the Fabrics of Experience*	*Discovering Everywhere?*
Tension of Order and Disorder	*Unsyntactic: Forms of Order*	*Archetypes and Inner Molds*	*Stretching Perspectives*

By allowing readers to choose their own structure, I hope to bring awareness to one's own ordering of experience and framing of knowledge, themes that are important throughout this thesis. Choosing between different ordering options aims to place readers as active observers of this work. Moreover, it is meant to help them embody some of the subjects discussed in the thesis by questioning their own manner of thinking, their own ordering of experience, thus bringing to light how these may be pre-structured or habituated by custom and language.

In-Formation:
From Quantity to Quality

“We do not describe the world we see,
we see the world we can describe.”
-Rene Descartes

In the introduction to *Structural Stability and Morphogenesis: An Outline of a General Theory of Models* (from now on referred to as *Morphogenesis*), René Thom asks the question regarding the nature of scientific inquiries: Qualitative or Quantitative? He remarks that the use of the term ‘qualitative’ in science has a “pejorative” ring to it, and recalls being reminded of Rutherford’s dictum by a physicist who quoted “qualitative is nothing but poor quantitative.”[61] For Thom, this was a misconception that plagued the perceptions of modern scientists in the 20th century. He urged that postulating the existence of a model in science, i.e. making qualitative assumptions without calculating specifics, yields results that are of a local and qualitative nature. Qualitative and quantitative are not in competition; they are both integral aspects of scientific theorizing. Hypothesizing models in science was a qualitative, creative activity of depicting and simulating nature.

We must, therefore, examine the gap that has been excavated between qualitative and quantitative aspects of scientific theorizing. In this chapter, I shall examine forms as epistemic agents residing in the very core of scientific knowledge, and extending far beyond mere aesthetics or subjective qualitative appreciation. In other words, I will examine how form plays a role in our understanding of natural phenomena. This will be done by two parallel discussions: one is providing definitions of key terms, such as ‘quality’ and its relationship to knowledge and understanding, and the second is explaining and

[61]R. Thom, p. 4

supplying examples from Kepler and Thom's theories in which form arises as a central epistemic concept.

Important terms in the discussion at hand are 'knowledge' and 'understanding'. To comprehend how form is imperative to knowledge, the nature of knowing must be shortly elaborated on. There are different types of knowledge.[62] One can acquire knowledge in various ways throughout one's life; it can be attributed to basic human intuition, it may develop from diligent work and mastery of a trade, or it may be acquired through careful education and intellectual study. Knowledge of the most basic intuitive kind can be exemplified in how we naturally know that spherical objects roll, that cubes can easily be stacked upon each other, and that triangles have sharp piercing edges. Knowledge of the second kind can be seen as contained in the body itself and not just in the mind. This idea was elaborated on by the social constructivists who had referred to this type of knowledge as 'tacit knowledge'; a type of knowledge that is acquired through the process of observing and engaging in physical activity, such as weaving fabric or conducting biochemical experiments in a lab.[63] Both of these types of knowledge are essentially part of scientific knowledge, but are difficult to put into words for the simple reason that they are not acquired by means of words alone.

When one speaks of intellectual or scientific knowledge, nevertheless, a more precise type of disciplinary knowledge is generally referenced, one which pertains to logic, i.e. a linear syntactic structure such as reading, speaking, or calculating, and systematic empirical observations.[64] In this sense, knowledge is something that is maintained in one's mind and can be found or expressed with the aid of a linear linguistic or numerical structure. The expression of this type of knowledge is often represented and communicated in linear syntax due to necessity, and does not appear to have, or be a product of, a shape or form beyond syntax. However, when the term 'knowledge' is coupled

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[62]Examples for how types of knowledge have been researched and categorized: Golinski, Jan, *Making Natural Knowledge: Constructivism and the History of Science,* University of Cambridge Press, 1998, p. 137
V. Hösle, ed. *Forms of Truth and the Unity of Knowledge*. Notre Dame: University of Notre Dame Press, 2014. N. Lemos, *An Introduction to the Theory of Knowledge*. Cambridge: Cambridge University Press, 2007. H. J. Watt, *The Sensory Basis and Structure of Knowledge*. London: Taylor & Francis Group, 2015.
[63]Polanyi, Michael, *The Tacit Dimension*. The Terry Lectures at Yale University, 1962. Garden City, N.Y, 1967
[64]Bird, Alexander and James Ladyman, eds. *Arguing about Science*. London: Taylor & Francis Group, 2012, pp. 209-210

with the term 'understanding', a deeper view into the interaction of form and knowledge can be achieved.

'Understanding' is a more profound form of knowledge, one that is, arguably, interlinked with theories of scientific explanation, a prominent subject in the philosophy of science.[65] Science philosopher Michael Friedman, writes about the difficulty in defining scientific understanding, and asserts that its definition is contingent on a theory of scientific explanation and particular examples of natural phenomena. He aims to find a general theory of explanation that accounts for different types of natural phenomena and reaches the conclusion that "science increases our understanding of the world by reducing the total number of independent phenomena that we have to accept as ultimate or given."[66] Science provides understanding through simplification and reduction of the number of laws we have to accept.

Simplification and generalization are indeed attributes of triumphant scientific theories, as also presented by Kuhn in his *Structure of Scientific Revolutions*.[67] However, understanding or comprehension also suggests the ability to transform knowledge and further deepen or develop it in other domains. For example, many people can know that the structure of the DNA molecule is a double helix, they learn it in school and see visual representations of it in their biology textbooks. But knowing that fact does not mean they have an understanding of the meaning or the implications of a double helix structure, as opposed to a single helix one. Let's take another example; many people can know and learn Pythagoras's theorem. They can memorize it and even apply it in solving simple right angle triangle problems. However, knowing the theorem does not mean that one possesses enough understanding of it to elaborate on it or use it in contexts other than what has been learned. Understanding suggests a deeper form and application of knowledge.

As we experience forms or shapes in our outer sphere, it is possible that we are scarcely aware of the role they play in our understanding of data or how they influence

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[65]Examples for theories of scientific explanation: M. Friedman, "Explanation and Scientific Understanding." *The Journal of Philosophy* 71, no. 1 (1974): 5–19. Hempel's Deductive-Nomological model of explanation as seen in C. G. Hempel, *Aspects of Scientific Explanation, and Other Essays in the Philosophy of Science*, New York etc.: The Free Press etc, 1973. Fraassen, Bas C. van. "The Scientific Image." Essay. In *The Pragmatics of Explanation¹*. Oxford University Press, 1980. Theory of causal explanation in J. F. Woodward, *Making Things Happen : A Theory of Causal Explanation*. Oxford Studies in the Philosophy of Science, New York: Oxford University Press, 2004.

[66]Friedman, Michael, "Explanation and Scientific Understanding." *The Journal of Philosophy* 71, no. 1, 1974, 5-19, p. 15

[67]T. Kuhn, 2012, pp. 154-155

explanatory preferences and decision making within science. It is worthwhile, then, to examine how the qualitative aspect of forms, as epistemological agents, play a role in achieving this last type of explanation and understanding. Friedman's account pointed towards a qualitative formal aspect of explanation–simplicity. As noted above, one example for preference of structure that is known in the history of science, is scientists' natural preference of simplicity when it comes to competing scientific theories.[68] The quality of simplicity guided a pivotal decision, a choice of theory, which future knowledge will be developed from. Here, simplicity is a qualitative essence of a theory which can be understood in terms of structure. Another example is the word framework. The terminology 'the problem needs to be reframed' suggests a change in form or structure of existing data, i.e. a change in the relationship between the data points, and not a change in the data itself. In this perspective, understanding structure and form is essentially a way of knowing, a framing of knowledge. It follows that quality as shape is a key concept to our understanding of form as a companion to the creation of knowledge.

| Quality, Forms and Information

There are many sayings that illustrate the strength of a visual experience in the transmission of knowledge or ideas. Some popular examples are 'a picture is worth a thousand words'[69] or 'seeing is believing'. These sentences convey how a complexity of ideas can be communicated in one visual occurrence, as opposed to a more descriptive verbal or numerical approach, which takes time and careful selection of concepts. A visual approach can communicate a quality or essence that is difficult to capture in concepts since these are limited. The trouble with visual descriptions is that their complexity makes them susceptible to subjective interpretation. Nevertheless, these phrases exemplify an important truth, that is our knowledge as humans is very much entangled with a qualitative

[68]This idea is most clearly displayed as Occam's Razor: The simplest solution is always the best one.
[69]This phrase is famously referred to in Larkin, J., and H. A. Simon. "Why one picture is worth more than ten thousand words." *Cognitive Science* 13, 1987. An early use of the phrase is attributed to Frederick R. Barnard, a national advertising manager for the Street Railways Advertising Company, who first used it in an advertisement in 1921 in the version "One look is worth 1000 words."

visual experience. This section aims to untangle the obscure relationship between knowledge and the visual, or sensible, experience of form. The relationship between forms and quality will first be examined, followed by an analysis of Kepler's *Harmonices* and Thom's *Morphogenesis* in terms of qualitative knowledge.

Forms can yield numerical quantitative knowledge, as does geometry for example, or they can yield qualitative knowledge. However, difficulties quickly arise as the term quality itself is elusive and not easily defined, rendering the term 'qualitative knowledge' even more perplexing. Stating the obvious, that quality pertains to something other than quantity, is the initial step to untangling this predicament. Quantity is a measurement, a value that can be precisely determined or estimated and expressed with numbers or variables. One can state that there are exactly two apples on the table, and if there are indeed two, a notion that can be easily examined and falsified, the statement that there are two apples on the table is true. In this case, quantity can be understood in terms of numbers.

If quantity can be understood in terms of numbers, and quantity is different from quality, then quality can be understood in terms of form. Shape or form is a qualitative attribute. In fact, in his *Categories*, Aristotle considered 'shape' to be one of the four species of quality, among 'habits and dispositions', 'natural capabilities and incapabilities' and 'affective qualities and affections'.[70] When one speaks of quality, one may refer to a type of essence that resides within the object or idea in question, although, in many cases, this essence is challenging to pin down or put into words. Nevertheless, the shape or structure of something reveals qualitative information, and studying shape or structure is essentially a study in quality.

Shape, or form, as quality, exposes another difference between quantity and quality which can be understood in terms of dimensionality. Like a point void of dimension, a specific number, the number 4 for example, does not require the notion of space in itself, as it will always be the number 4; its depiction in other symbols, such as the Roman figure IV or the Hebrew letter ד (Daled), will not change its meaning or essence. Shapes and forms, on the other hand, have a higher dimensionality of meaning and degrees of freedom in

[70]Studtmann, Paul, "Aristotle's Categories", *The Stanford Encyclopedia of Philosophy* (Spring 2021 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/spr2021/entries/aristotle-categories/>

terms of perspective. A shape implies the notion of space and requires a dimensionality that is two or higher. I can turn a shape around and every perspective I will take in reference to it as an observer will disclose new information. Following this reasoning, shapes reveal a dimensionality in themselves that numbers do not.

Unfolding the difference between shape and number, quality and quantity, can further be achieved when examined under terms of epistemic activity. In *Scientific Understanding: Philosophical Perspectives*, Hasok Chang discusses counting as an epistemic activity in a chapter titled "Ontological Principles and the Intelligibility of Epistemic Activities."[71] Chang describes harmony between our epistemological activities and ontological conceptions as a precondition for intelligibility, and argues that scientific realism is essentially a search for intelligibility rather than truth. He investigates preconditions for intelligibility and remarks that certain epistemic activities, such as counting, render a certain ontological principle necessary. According to him, assuming that nature is discrete is the ontological principle necessary to engage in counting. The ontological principle in question does not need to be empirically true in reality (whatever reality may be) but is only a necessary assumption during the epistemic activity. Chang writes that "if we want to engage in the activity of counting, we have to assume that the things we are trying to count are discrete."[72] Counting, and by extent numbering, requires us to presume something about nature itself: discreteness or distinction of entities. The intelligibility of numbers, therefore, can be seen as a product of epistemic activity which is contingent on a world of separated units.

Building further on Chang's analysis, it arises that discrete nature consisting of individual units assumes the notion of boundaries; in order to count, one must assume that boundaries exist and whatever can be counted must be more or less defined. In order to define a unit, a distinction must be made between where one thing ends and another begins. However, when we turn to nature to count, boundaries are not always stable and are subject to change. I can count trees, but many trees also form a forest. One tree is also formed out of many leaves, roots and branches. So, in order to count trees, one must define the boundaries of a single tree and not leaves on branches or a forest. Take water as

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[71]Chang. Hasok, in: de Regt, Henk W., Leonelli, Sabina, and Eigner, Kai, eds. *Scientific Understanding : Philosophical Perspectives*. Pittsburgh PA: University of Pittsburgh Press, 2009, pp. 64-82
[72]H.W. de Regt, S. Leonelli, and K. Eigner, p. 70

another example; water cannot be counted as it is a fluid, flexible, continuous substance. And yet, once the boundaries of water are placed in a defined form or body, for example in the form of molecules of water, cups of water, puddles, or oceans, counting becomes possible. Under these considerations, it becomes apparent that counting and numbering is contingent on boundaries, i.e. definitions of forms or concepts. Distinctions and boundaries are the properties of shapes and forms, but here we see that definition and placing boundaries is also an act of conceptualizing. A boundary as a property is of the same nature whether it refers to a boundary of shape or a boundary of conceptual definition (see chapter on 'Molding and Conceptual Materials' for an elaboration on the formation of boundaries in the mind).

If numbering relies on the experience of boundaries, it follows that shapes and concepts are a precondition to counting. Quantification of nature is not a given, but rather an extension of our ability to perceive contrasting qualities of forms and shapes in our outer sphere, which results in the experience of discreteness and the separation of objects or concepts. The study of natural phenomena, which separates one phenomenon from the other, is dependent on the formation of boundaries. Boundaries are created when there is a difference in structural or conceptual quality. In this sense, quality and quantity are as much dependent on each other as they are different from each other. Understanding how quantity is an extension of quality and that the connection between the two is found in the placement of boundaries, is crucial for this discussion, as I am investigating how knowledge is found in structure and form. This perspective is geared towards creating a lens which views form and structure as a precondition to understanding and conceptualizing nature.

Establishing this lens, 'form lens' in short, allows the discussion to turn to Kepler's and Thom's works. How did Kepler and Thom use form to understand nature? The idea that forms and concepts are analogous, as they both suggest the definition and placement of boundaries, is visible early on in both texts. Thom considered the problem of succession of form to be akin to the philosophical problem of concept. In the first paragraph of his introduction, he noted that humans' ability to recognize a given object, despite its existence in an infinite multiplicity of manifestations, is a problem in need of understanding. He related this to the classic philosophical problem of concept; the definition of a concept must be clear in order to be coherent. But, when examined closely, a definite stable boundary is difficult to draw. For example, the concept of 'game' can be stretched to many different meanings beyond it being a form of playing or partaking in sport. Similarly, natural forms stretch, change and develop over time, or have different manifestations of appearance, and yet these changes don't appear to affect our recognition of them in their new manifestation. Thom observed that both physical or conceptual 'things' are, in many cases, dynamic in nature (what he also refers to as 'metabolic'), and that this dynamic quality does not affect our recognition of them.

Thom reasoned that the mind, the inner sphere, plays a significant role here. For him, Gestalt psychologists have opened a door through which this problem can be better understood. He noted that they "alone have posed (the problem) in a geometric framework accessible to scientific investigation."[73] Gestalt psychologists displayed how geometry is a key prospect in bridging the problem of the succession of form and the philosophical problem of concept; the former being a physical problem and the second being a conceptual abstract problem. He, therefore, maintained that understanding the process of change in nature could be best achieved through a topological study. A geometric and topological analysis can say something about nature that numbers can't, at least not yet.

A relationship between concept and form in the inner sphere, i.e. the mind or internal realm of experience, is also visible in the outset of Kepler's writing. He examines the recognition of shape or form in the mind, the inner sphere, by contemplating on the limited as opposed to the limitless, the finite as opposed to the infinite and the mind's ability to conceptualize within these two notions. He argued that recognizing a boundary is the condition that allows us to know something or recognize a shape. Defining a shape and defining a concept are essentially the same mental activity because "finite things which are circumscribed and shaped can also be grasped by the mind: infinite and unbounded things, insofar as they are such, can be held by no bond of knowledge, which is obtained from definitions, by no bonds of constructions."[74] The marking of boundaries and creation of definitions arises from his writing as the mental activity which selects and creates the very fabric of experience. He referred to all this as "the intellectual essence of geometrical

[73]R. Thom, p. 1
[74]J. Kepler, p. 9 sidenote

objects,"[75] displaying the idea that knowledge can be found first and foremost in forms and shapes.

There is an unmistakable resemblance between Kepler's and Thom's reasoning regarding the linking of form to concept. While Kepler stated that 'boundaries' allow us to recognize and therefore know something, whether conceptual or physical, Thom questioned the evolution of those boundaries. That is, which remain stable and which undergo morphogenesis, while essentially remaining part of the same 'thing'. Indeed, this resemblance between the act of forming concepts and the act of determining spatial forms appeared also in Cassirer's *Symbolic Forms*. In his discussion on the concept of space and representation, he argued that "the acquisition of characteristically determined spatial forms requires the same fundamental act as is necessary to concept formation."[76] In this sense, forms or concepts point towards discreteness but clearly consist in a different epistemic activity from counting, as both rely on space (dimensionality) and perspective.

Examining counting, or numbering, as an epistemic activity confronts us with the notion that numbers are dependent on our perception and reasonings as humans. They do not exist independently from us. A similar thought is found in Kepler's fourth book of the *Harmonices*. Kepler wrote that numbers are a result of there being a multiplicity of distinct units (units can be seen here as material or immaterial, such as objects or musical notes) and a human mind. Numbering or counting these units assumes a mind, or in Kepler's words, a human soul. Referring to Aristotle, he writes "if the soul which counts is taken away, all number is taken away, but not the individual units."[77] According to him, it is the human mind alone that creates the realm of numbers that exist in themselves, abstracted from the units experienced in the outer sphere.

Similarly, proportions and relations, which are qualitative properties that can also be described quantitatively, are properties that are abstracted from forms and exist only within a mind which contemplates them; they do not exist independently. Nature, therefore, appears to us first and foremost in form and not in number. A form is experienced through our senses and can remain as a sensible experience alone. This reveals a different ontological necessity from discreteness. In this sense, quality precedes

[75]Ibid.
[76]E. Cassirer, 1985, p. 160
[77]J. Kepler, p. 290

quantity. Under the lens of epistemic activity, forms and shapes are revealed as different from numbers, insofar as they appear to exist independently from human activity (this is not to be understood as an argument for realism however). In order to count and measure, for example, we must first be able to perceive separate entities or units.

Forms, thus, prevail as something elementary or basic which precedes numbers. The existence of distinct forms is the condition of discreteness that allows us to think in terms of quantities. This fundamental principle, that places forms prior to numbers, is apparent in Kepler's and Thom's writings. It prompted Kepler to structure his entire book around this reasoning, (placing his geometrical analysis of harmony in the first book and the mathematical analysis in the second).[78] For him, geometry "was coeternal with the divine mind and is God himself… (it) supplied God with patterns for the creation of the world, and passed over to Man along with the image of God."[79] In other words, we can understand geometry, or form, as a creational principle.

As noted above, however, the intent here is to understand the manner in which form creates knowledge that can be understood in terms other than quantities, but rather, as having epistemological agency. To get a better idea how form precedes number in scientific knowledge creation, or how quality trumps quantity, we can turn to Thom's text. Like Kepler, Thom argues that the study of form is a gateway for a better understanding of natural processes. In an argument for the qualitative, Thom himself referred to the 17th century, to the controversy among the followers of Descartes and Newton and their differing approaches to the investigation of physics. He wrote that "Descartes, with his vortices, his hooked atoms, and the like, explained everything and calculated nothing; Newton, with the inverse square law of gravitation, calculated everything and explained nothing."[80] The difference between quality and quantity, according to Thom, can be understood as the difference between an explanation and a calculation.

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[78]As a Renaissance natural philosopher, Kepler structured his book in hierarchical order. The first book of the *Harmonices*, focuses on geometric analysis which Kepler considered to be the harmonic language of God, the second book examines mathematics and was considered by him to be nature's language. The third book, which focuses on musical harmony, is related to the harmonic language of humans. The fourth and fifth books are applied to finding the harmonic manifestation of the planets. See Kepler's introduction to the fourth book of the *Harmonices* for full description, J. Kepler, pp. 283-290.
[79]J. Kepler, p. 304
[80]R. Thom, p. 5

Thom wanted to demonstrate the workings of qualitative reasoning, which is based on form, by appealing to the mind's natural inclination to give shapes on a graph an intrinsic superior value to quantity. In the third section of his first chapter, he presents a compelling example to this idea taken from modern science. He describes a hypothetical case of an experimental study where phenomena θ yields an empirical graph. This graph has both a quantitative aspect (the quantified data which formed it) and a qualitative aspect–its shape. The phenomena in question must now be related to a theory that can explain it. He postulates a case in which the theorist is presented with two possible competing theories of explanation: the first is a better quantitative fit within the interval considered but of a different visual appearance when visualized on a graph, and the second with the same shape and appearance as the phenomena visualized, but of a greater quantitative error (figure 2 taken from Thom's book).

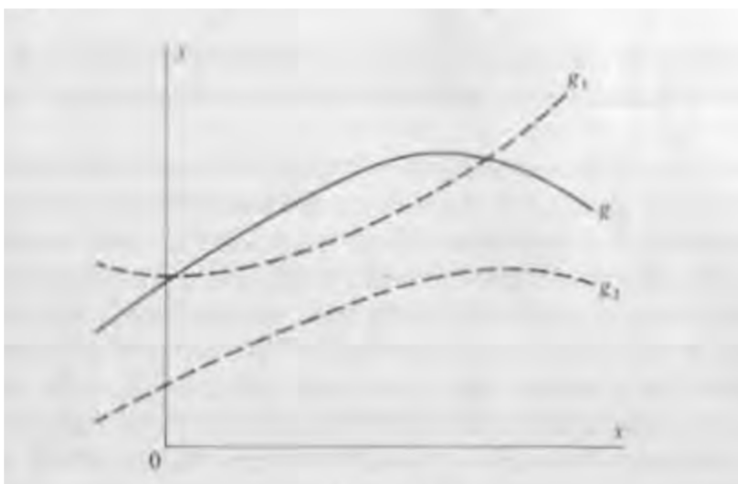

Figure 2

Thom then argues that "in this situation, one would lay odds that the theorist would retain θ_2 (the second option) rather than θ_1 (the first option) even at the expense of a greater qualitative error, feeling that θ_2, which give rise to a graph of the same appearance as the experimental result, must be a better clue to the underlying mechanisms of θ than the quantitatively more exact θ_1."[81] He notes that while this example is not proof, it demonstrates how a researcher would intuitively prefer the option that appeals to quality over quantity.

[81]R. Thom, pp. 4-5

Thom's use of the word 'feeling', in reference to the theorist's preferable option, is an indication of a more qualitative process of recognition of pattern: the second option simply "looks right" despite other quantitative considerations. Here, he explicitly attributes significance to how collected data is translated back into shape. He hypothesized that shapes disclose much deeper information about natural processes that quantities cannot–shapes can be simulated in quality (their form) without precise quantification. The appeal to a relationship between form and its recognition (a pattern) was a cornerstone to Thom's entire theory. He believed forms and shapes are intrinsic in the mind and guide the very decisions scientists make, despite their awareness of them or their preference of quantitative procedures.

As seen from the analysis and examples presented so far, external data, the sensory experience of information, is fundamentally 'in-formation'. Forms resonate in our mind as truth, whether we experience them as such or not. Data can only be turned into knowledge when it is also 'in form'. A clue to this idea is found in the etymology of the word 'to inform'. The term 'inform' is derived from the Latin term *informare* which means 'to shape, give form to, delineate'.[82] The Oxford English Dictionary defines information as 'imparting of knowledge in general' but more specifically 'the shaping of mind or character' when communicating instructive knowledge.[83] Thom himself refers to the present misuse of the word 'information.' He viewed the interchangeability of the word information with measured numerical data (especially by the microbiologists referring to DNA) as "incorrect and unjustifiable." His aim was to free the word from such as "stochastic prison" by encouraging a scientific context in which the word information relates to form.[84] In-formation has a direct link to the reception of knowledge that is not mediated through measurement and numerical depiction.

Forms have an important role in the shaping of the mind which, in turn, creates or shapes experience. Thom's example displayed how shape and form is a type of epistemic tool which patterns and models knowledge. Along the same lines, Kepler explicitly discussed this faculty of forms when he wrote that quantities placed in form have an

[82]Online Etymology Dictionary, search under the term 'inform'.
https://www.etymonline.com/word/inform#etymonline_v_6458
[83]"information, n.".1.a. OED Online. September 2021. Oxford University Press.
https://www-oed-com.proxy.library.uu.nl/view/Entry/95568?redirectedFrom=information (accessed October 13, 2021)
[84]R. Thom, pp. 126-127

"intellectual essence."[85] In other words, quantities placed in form can *inform*, they reveal deeper information, as their quality, their form, can be recognized or identified without specified quantities. Although both scholars did not use the term pattern often, when they did, they used it in reference to a form or a set of relations that is found in repetition. Thom used the term 'pattern' only twice in his *Morphogenesis*. One example is his description of the arrangement of organites on the membrane of endoplasmic reticulum, noting that they "are arranged in periodic geometrical patterns."[86] Kepler used the term 'pattern' slightly more frequently, mainly in reference to a repetition of form or arrangement of relations that can be infinitely continued (as with melody for example). This is seen in his second definition of the congruence of regular figures. He writes: "Congruence is said to be perfect when the angles of the figure which come together do so in the same way at each meeting-point, so that these meeting-points are similar to one another and the pattern meeting-points can be continued indefinitely."[87] It is the repetition of form or relation that allows for recognition and epistemological value to arise. From this perspective, Kepler and Thom's fixation on form arises as an inquiry into underlying natural patterns among a variety of natural phenomena.

An interesting example of a search for explanation in form is seen in Kepler's effort to find harmony in planetary motion. He seeked to translate the abstract idea of harmony, that is a set of relations normally expressed in notes or numbers (i.e. without dimension), into its physical terms in dimensional processes, such as planetary motion and the changing positional relationships of the planets in space. By creating a model of physical, as opposed to melodic, congruence in a three dimensional spherical shape (or what Kepler refers to as 'space'), he hoped to place the data collected by Tycho Brahe in a sensible harmonic pattern. The idea is quite foreign from the perspective of modern science, but I will attempt to roughly explain it. By dividing a perfect circle into harmonic proportions according to platonic solids, Kepler built a harmonic model of planetary motion, tracing the changing distances, and thus spatial relations, between the planets (figures 3 show his research into harmonic divisions of circles). He then examined and compared the collected

[85] J. Kepler, p.10
[86] R. Thom, p. 273
[87] J. Kepler, p. 99

observed positions of the planets with the model he constructed. The model eventually allowed him to see where the observed data diverged from his own model.

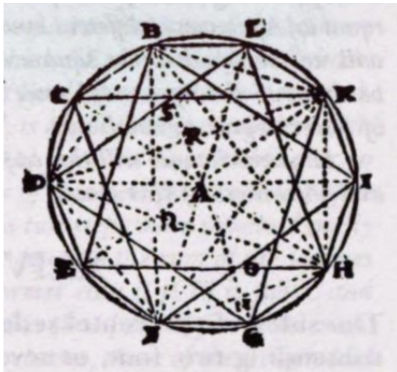

Figure 3.1

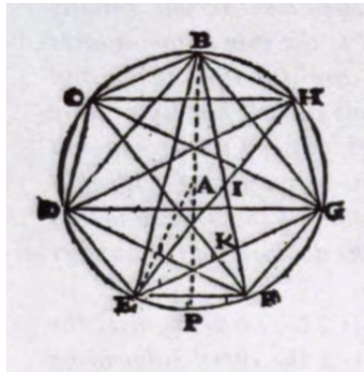

Figure 3.2

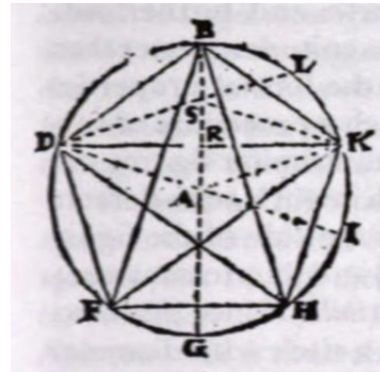

Figure 3.3

Quantities placed in form are fundamentally different from quantities or measurements yielded from a designed experiment and aimed at prediction. Quantities, i.e. numerical data, in form are also different from a series of data or measurements that are averaged into a natural law, such as averaging the boiling point of water at 100 degrees Celsius, following a series of measurements.[88] The idea of data placed in form pertains to a type of intuitive knowledge that sprouts from repetition and recognition and links form to the very act of 'knowing'. Moreover, it restores the necessity of thinking in terms of forms when investigating nature, bringing them back into the center of investigation, a position now occupied by measurement and prediction.

Thinking in terms of in-formation, as an act of knowledge creation, points us to an epistemic activity that is quite different from counting or measuring. 'In-formation' urges us to develop concepts of epistemic activities that are different from 'thinking', 'imagining', or 'counting'. Thinking uses words and syntax which pertain to, in most cases, existing concepts, and imagining does not necessarily require us to follow any type of intelligible pattern. Both scholars' linking of the intelligible mind with geometry reveals a worldview that requires a concept of a mental activity linked to forming and, in a sense, is more like cutting or separating. Creation of knowledge, and scientific knowledge, essentially relies on an epistemic activity that consists in separation or discreteness of experience and its consequential arrangement into form or pattern. An adequate concept should capture the

[88]This idea is demonstrated by Hasok Chang in his work: Chang, Hasok. *Inventing Temperature : Measurement and Scientific Progress*. Oxford Studies in Philosophy of Science. Oxford: Oxford University Press, 2004.

act of separating and of shaping and forming. An inquiry into a conceptual framework aimed to capture this type of epistemic activity, one which is in line with 'in-formation', is the subject matter of the following chapter titled 'Molding and Conceptual Materials. The following section of this chapter continues into an analysis of forms as epistemological agents.

| Forms as Epistemic Agents

As seen in the previous section, forms can be perceived as epistemic agents. In part, their epistemological agency can be seen as a type of guiding agency. This idea, however, must become more concrete. The purpose of this section is to develop the discussion from its current abstract terminology to a language used to describe physical creation in matter and provide examples from Kepler and Thom's theories. A world rich in practical terminology, where forms are used every day to guide creative activity, is the world of art and design. I shall, therefore, continue to develop the role of forms as epistemological agents with the term 'stencil', borrowed from the practice of art and design creation.

As a student of the visual arts, I sat in numerous illustration trainings. In each session, the teacher would instruct us to observe the object we must illustrate as a compilation of underlying shapes and forms. Our observation was to detect these underlying forms and illustrate them in the correct arrangement relationship to each other. The artist, or any type of visual creator, is trained to divide the surrounding visual world into forms when partaking in the initial stages of illustration (this is not to say that is all an artist does, but only to describe the initial stages of an illustration from observation). If one wishes to visually depict a form in three dimensions, one must look beyond the object itself, into the underlying shapes defined by color or texture which form the object. For example,

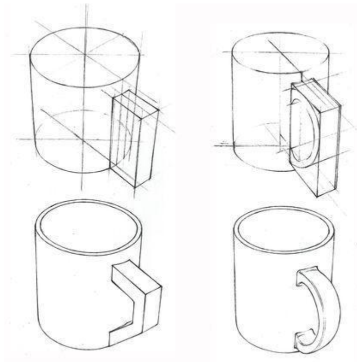

Figure 4

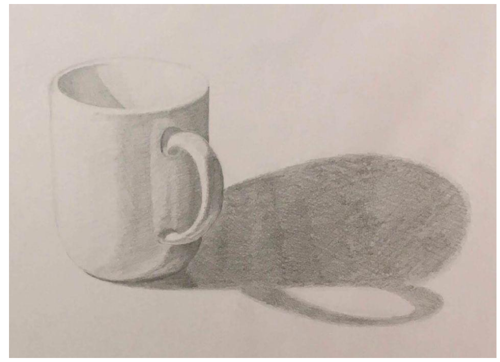

Figure 5

when attempting to sketch a simple cup, an artist can divide it into different shapes. Figure 4 displays how that is done with the use of basic lines to achieve perspective, and figure 5 displays how the object of the cup is divided into different shapes with the use of shadows and light. Both depictions illustrate a specific study into the cup, or a truth of the cup, but in a different manner. The contrasting images illustrate how one could see and divide the same object according to different forms.[89] The diverging types of forms highlighted by each cup are metaphorical of the diverse ways forms that can guide our decisions and arrangement of the world around us. Each cup is essentially the same object, but each illustration technique presents different in-formation, one being the underlying basic forms and the other being the forms of lights and shadows.

The notion of a form as an epistemic guiding agent can be described as a template, or rather, a *stencil* in the creation of knowledge.[90] Numbers and measurements are extracted from what is defined with the form–the stencil. A stencil can be thought of as a window or lens through which nature is studied according to a specific set of considerations. Figure 4 divides the cup with the outlines of the shape that emphasize the underlying form and proportion, to depict the object in perspective. On the other hand, figure 5 divides the cup according to the shapes of its light points and shadows.[91] Each type of division can potentially be extended into types of patterns of observation. Both

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[89]A relatable example is given by Hanson in the Observation chapter of his book: *Patterns of Discovery*, and will be discussed further in the following chapter.
[90]The word stencil is borrowed from the arts. A stencil is a piece of paper, cardboard, metal plate or any other two-dimensional/flat object that has a shape cut out of it. The two-dimensional object with the shape cut-out is a guide to trace or paint designs onto another surface but drawing the outlines or painting through the cut out holes.
[91]This idea is not to be taken literally in terms of examining natural phenomena in science. It is merely an illustration of how forms are used in different ways to construct a cup.

observations are true, in a way, and necessary in order to depict a cup realistically, but each example highlights different elements through which the form of the cup can be studied. Form, then, arises in this approach as a guiding principle for the division and ordering of experience.

The term stencil can be further understood as a type of lens through which one gains a specific viewpoint, like the visual Gestalt switch, and yet, as I shall explain, different. In his chapter on Observation, Norwood Hanson connects the gestalt switch to scientific observation by describing how two scientists, for example Tycho and Kepler, see different phenomena in the same sensible experience; when observing the sunrise, Tycho views a rising sun turning around the earth, while Kepler sees an earth rotating and circulating the sun.[92] Hanson then employs Gestalt images, such as the illustration of either an old or young woman, to account for this change in perception, and therefore description, of phenomena.[93] If a simple set of black lines on white paper can be seen in various ways by different people, then the complexity of natural phenomena can be detailed in a myriad of distinct schemes. In describing the shift in worldview that emerges from a scientific revolution, Kuhn also appeals to the gestalt switch. He noted that "in times of revolution, when the normal-scientific tradition changes, the scientist's perception of his environment must be re-educated–in some familiar situation he must learn to see a new gestalt."[94] But he also remarked that the scientists, unlike the subject of the gestalt experiment, would not be able to shift back and forth between the old and new paradigm freely, as the old paradigm would be considered mistaken. In this sense, appealing to gestalt arguments in reference to scientific theorizing is suggestive.

Unlike Kuhn's reference to the gestalt switch, the term stencil should not be understood as an either/or type of perception that divides up experience. Looking at the two cups (figures 4 and 5) reveals that both types of descriptions are needed, to some extent, in order to depict the cup as realistically as possible. In other words, a view through a specific stencil is not absolute, i.e. it does not cancel out other possible stencils. Rather, it is a viewpoint that can be layered with others. In each illustration of the cup, attention is placed on different qualities (either the underlying forms or the forms created by the light

[92]N. R. Hanson, pp. 6-7
[93]N. R. Hanson, p. 11
[94]T. Kuhn, 2012, p. 112

and shadow contrast), thus creating different forms and boundaries. But placing attention on one quality over the other does not cancel the others. Cassirer discussed this idea of attention placement. He wrote:

> "When our consciousness runs through a series of sense perceptions, we do not (...) consider all their attributes uniformly, but always detach a definite factor, on which we dwell on more than others. In this way the disregarded components are repressed and only those others which stand at the center of attention are retained; and it is thus that the concept came into being, as an aggregate of those factors that came into account."[95]

Following Cassirer's description, a stencil is the centering or focusing of attention on a specific quality. By focusing on a specific quality, we perceive, and thus create, boundaries–forms and concepts–that follow the lines of this mode of attention. Cassirer refers to this observational process as a "formation and creation of centers."[96] The stencil is, therefore, better described as a mode, or center, of attention.

In order to understand and analyze natural phenomena and experience, then, experience must first be divided, or determined, according to something, a principle, that must be shaped and defined before it can be measured and calculated mathematically. This process can also be understood as an act of pre-ordering, of separating one concept or phenomenon from another. The process of shaping experience into discrete phenomena must not be taken for granted. There is not only one way nature can be divided, shaped and ordered. The example of the two cups displays how different realities or 'truths' can be extracted from the same object, and these different truths are a product of different qualitative considerations. According to this idea, observing different qualities of nature would result in different quantitative abstractions.

Our complete conviction in a specific division and order of experience is the result of the mind's ability to generalize and, further, its memory. This idea was brought forward by Emile Meyerson, epistemologist, chemist, and philosopher of science, in the early 20th century, when he demonstrated his philosophy about the forming and ordering of natural

[95] E. Cassirer, 1985, p. 160
[96] E. Cassirer, 1985, p. 158

phenomena in his book *Identity and Reality*.[97] In the first chapter, titled 'Law and Cause', Meyerson referred to generalization and conceptualization of phenomena as a precondition that permits the search into the lawfulness of nature. For his argument, he considered it an "accepted fact" that "the human mind possesses the faculty of forming (generalized concepts)."[98] He gave examples of concepts such as 'man' or 'sulfur', in which case the mind forms generalized concepts from different individuals or units of matter of similar characteristics. These general concepts, 'man' or 'sulfur', are composed of idiosyncratic individuals, but the perceived similar characteristics among the individuals were used to abstract them into concepts, thus classifying and ordering them.

Dividing and forming of concepts is an act of ordering (just as we have seen with the two cups, each divided differently into forms as a result of different considerations). This act of ordering is accomplished through the centering of attention–a stencil. The existence of concepts, and subsequently laws of nature, in our vocabulary leads to a 'conviction' (to use Meyerson's words) of their existence. It is this conviction that allows science's foresight into nature. According to Meyerson, these concepts of order and lawfulness of nature are ingrained into our memories and into our actions, which search them out to such an extent that they seem to exist outside of us. He explains this conviction:

> "So much so that nature itself seems to proclaim its own orderliness; this idea appears to enter our minds from the outside, as it were, without our doing anything but receive it passively; in the end the orderliness appears to us as a purely empirical fact, and the laws formulated by us appear as something belonging to nature, as the "laws of nature," independent of our intelligence. This is to forget that we were convinced in advance of this orderliness, of the existence of these laws. All the acts of our daily life witness to it. This is to also forget how we arrived at these laws. We have observed some peculiar and strictly unique phenomena. We have formed general and abstract concepts of them, and our laws, as a matter of fact, apply only to these latter."[99]

[97]Meyerson, Emile, *Identity and Reality*, London: Taylor & Francis Group, 2004.
[98]E. Meyerson, p.18. It is worthwhile to point out that here Meyerson also used the term 'forming' to describe the act of conceptualizing.
[99]E. Meyerson, p.30

Here, Meyerson reminds us that perceiving nature with a certain order is subject to our own doing and not a passive act. In this sense, if the ordering of nature is an action of the mind, then the manner in which this ordering is conducted cannot be considered a given. Potentially, there are many ways in which natural phenomena may be separated from one another, divided and ordered. In a sense, different ways of dividing and ordering nature can be thought of as seeing nature through different epistemic 'stencils'.[100]

Kepler and Thom's theories provide compelling examples of the manner in which forms are used as different epistemic lenses, i.e. different qualitative stencils, which exist prior to quantification. The assignment of form as the inception of phenomena is essentially an act of placing a specific qualitative stencil through which natural phenomena is examined. In other words, each scholar makes different uses of forms as dividing and ordering principles which look further into natural phenomena. The explicit attention each scholar placed on these underlying structures, and the mathematical approaches they were abstracted from, are what makes these theories available for investigation here. However, further attention must be paid to the time frames each scholar worked in, as each operated within a time of scientific 'crisis' in Kuhn's words.

Kepler operated and bridged between the Copernican and the Newtonian revolutions. His *Harmonices*, as well as his other writings, reflect this bridging of paradigms, during which the substance of the forces regulating nature shifted from the enchanted and spiritual to the mathematical and physical.[101] Thom wrote his theory within the paradigm of modern science, half way through the 20th century, after the emergence of quantum mechanics had already induced a crisis in physics, placing the determinate forces regulating nature in question once again. Indeed, each theory was written within a completely different paradigm yet with some similarities; both paradigms take place outside the scope of a determined nature. In one, quantification and measurement had just begun the ordering and structuring of nature and, in the other, determinism had dissolved into what appeared as indeterminate chaos, rendering measurement for prediction futile.[102] The paradigmatic crisis transpiring during each period had subsequently alleviated the grip

[100]A deeper discussion into this type of epistemological process transpired in the mind is elaborated on in the chapter 'Molding and conceptual Materials'.
[101]Boner, Patrick. *Kepler's Cosmological Synthesis : Astrology, Mechanism and the Soul*. History of Science and Medicine Library, Medieval and Early Modern Science, V. 39 ; Volume 20. Leiden: Brill, 2013, p. 15
[102]For example with the measurement problem in quantum mechanics.

of perceived ‘natural laws’ and conceptual boundaries (whether they were magical or determinate) of the time. Kepler’s Neoplatonist worldview had led him to search for structural beauty in the ordering of the new heliocentric universe. But the dissolution of determinism during Thom’s period, placing the very structure of natural processes into question, had prompted him to turn back to a natural philosophical worldview in search for a new understanding and structuring of nature (this will be expanded upon below).[103]

Let’s take Kepler’s *Harmonices*. The title of his book immediately reveals the leading scheme of his investigation–harmony. For Kepler, the universe was entirely interconnected, even controlled, by harmonies, and he considered them the primary proportions underlying creation itself. He writes that the harmony found by mathematics “furnishes everything that is important for the contemplation of nature… It restores friendship between things which are in conflict, and relations and mutual affection between those which are widely separated.”[104] The first part of this sentence displays harmony as a guiding epistemological principle, the stencil of harmony through which natural phenomena was to be examined.

Yet in Kepler’s approach, harmony is not merely a mathematical feature in a quantitative sense, but it originates in the geometry of forms and, more specifically, the platonic solids. In the title page of the book itself, he describes the first book as “Geometrical, on the origin and constructions of the regular figures which establish the harmonic proportions.”[105] It becomes apparent that Kepler considered harmonic proportions to reside primarily in forms and shapes, numerical depiction being merely an abstraction of these proportions.[106] Platonic solids were, then, a standard of in-formation, an intuitive form that guides a study into nature.

Kepler elaborated on this logic in the fourth book of the *Harmonices*, the only book of the five that has yet to undergo detailed scholarly scrutiny in the history of science, and

[103]This idea is more clearly seen in his verbatim lecture titled “Towards a Revival of Natural Philosophy” delivered at the University of Tübingen in Germany, when he was awarded an honorary doctorate in physics there in 1978. Here, Thom argues for a return to the natural philosophical approach during a time of scientific crisis. An English transcript of the lecture was published in: G. Güttinger, H. Eikemeier, *Structural Stability in Physics: Proceedings of Two International Symposia on Applications of Catastrophe Theory and Topological Concepts in Physics Tübingen, Fed. Rep. of Germany, May 2–6 and December 11–14, 1978*, Springer Science & Business Media (2012).
[104]J. Kepler, p. 281
[105]J. Kepler, title page
[106]J. Kepler, p. Xxxviii. It is important to note that Kepler’s structuring of his book was strategic and represented the structure he himself believed the world was constructed by.

in which he presented a type of phenomenological metaphysical analysis into the essence of harmonic proportions. In this discussion, Kepler refers to terms such as 'classification' and 'order' in reference to harmony.[107] For him, harmony is an order of a relationship among sensible things of the same nature. The order in question here is not a physical one in space, but one in which things relate to each other to form a unified effect on the observer. He writes: "For the order of which we are speaking here is a relation, and the things which are ordered here are related to each other."[108] These 'things' which Kepler refers to are natural structures and phenomena, such as the pitch of musical sounds, the petals of a flower or the organs of the human body.

Believing that the world is perfectly and divinely structured according to some sort of unifying principle, Kepler sought out natural relations that match his stencil of universal harmonic relations. He also used this guiding stencil to examine similarities of phenomena among things that appear widely distinct and have no visible resemblance, such as music and planetary motion. Kepler supported the use of harmonic relations for his investigation by arguing that the mind's natural inclination to perceive harmony, our ability to recognize it intuitively, reveals something about its fundamental truth. For example, the fact that humans are able to hear harmony through their ears, recognize it intuitively, and express it through the unique and complex structure of the vocal cords, acts as a testament that harmony is a tool through which the divine mind can be better understood.[109]

The *Harmonices* is essentially an investigation and study of harmonic relations in nature. The epistemological agent in Kepler's work, the stencil through which he separates and divides the natural world to conceptualize it for deeper investigation, was harmonic relations that were abstracted first and foremost geometrically from the platonic solids. In other words, Kepler set boundaries and conceptualized natural phenomena according to platonic harmonic ratios. The in-formation of data extracted from his observation of the world is ordered according to harmonic proportions. As with the cups above, one illustration depicting the underlying forms of the cup and the other depicting the shapes of light and shadow, Kepler sketches the lines and boundaries of natural phenomena with

[107]Written in the early 17th century, these terms were not as widespread in the study of natural philosophy as they are today in modern science.
[108]J. Kepler, p. 290
[109]See Kepler's discussion on the structure of the throat: J. Kepler, pp. 314-317

harmonic relations. Kepler used this stencil as a reference point, a centering, for observable measurements and as an epistemic tool for unifying natural phenomena. The observed data he collected was seen in reference to the harmonic stencil he viewed the world through. This approach arises as a search for the existence of an underlying structure or law–the harmonic stencil. Similar to the conviction mentioned by Meyerson, that of a world which allows the formulation of laws, Kelper's conviction in such an underlying structure allowed him to see in-formative deviation from that structure more clearly. His conviction revealed how the natural world was in-formed in reference to his model–the harmonic stencil.

The paradigm Kepler had operated within sanctioned the conviction in a divine design of universal order even during a time of 'crisis'. Envisioning the world as beautifully interconnected and constructed with harmonic proportions conforms with the neoplatonic worldview maintained by Kepler and other neoplatonists of his time. Aesthetics of harmony, therefore, appear as a legitimate point of departure for a natural philosophical study during the 17th century. On the other hand, such an ontological conviction was challenging to preserve during Thom's time, as inevitably, by his time, the world was far more complex. Roughly three hundred years had passed since the worldview of classical mechanics and a determined universe had taken hold, and deep-rooted convictions were shaken to their core by quantum mechanics. The existence of a predetermined stencil through which nature can be studied was once again put into question.

The book title, *Structural Stability and Morphogenesis*, reveals the prevailing problem Thom took upon himself to investigate. He was intrigued by the development and evolution of natural forms that may take unpredictable turns, yet are still recognizable as the same object (within the new structure) once the change of form had occurred. Examples for such developments are mutations in organisms or the erosion of a cliff edge over time. The subject of indeterminate natural phenomena had put the modern scientific enterprise into crisis and Thom set out to explore a new approach to indeterminacy through form. He supported his argument by referring back to 17th century natural philosophy and to Descartes' descriptive explanations in form, such as 'hooked atoms'.[110] Thom assumed an underlying order to the world around us yet remained acutely aware

[110] R. Thom, p. 5

that our experience of the world does not appear as such. It is partially stable and consists of many entities, changes and uncertainties. He writes that the world is composed of "beings or things (that) are forms or structures endowed with a degree of stability; they take up some part of space and last for some period of time."[111] Nature and experience, according to Thom, consists of a tension between stability of form and its change, and change itself is the constant principle.

Thom's views were atypical in contemporary scientific landscape and many of his ideas were more easily found in older periods, such as Neoplatonism during the Renaissance. Relating Thom's views to the ones which prevailed during the Renaissance and the early modern period is justified, especially since Thom himself made explicit appeals to natural philosophy. One example is the verbatim lecture titled "Towards a Revival of Natural Philosophy" he delivered at the University of Tübingen in Germany, when he was awarded an honorary doctorate in physics there in 1978.[112] In another publication, Thom noted that science had reached a point of stagnation as it had fallen into a tendency "of exhaustively describing reality, while forbidding itself to 'understand' it."[113] Science itself was in crisis, since it had deterred from its essential goal, which was to "*simulate nature*" and, thus, to understand it.[114] He understood that such ideas may be foreign and difficult to digest for the 20th century scientifically trained observer as they have not yet been formulated and introduced in modern terms, but his "infinite confidence in the resources of the human brain" had encouraged him to undertake the task of introducing and expatiating these ideas of natural philosophy into modern science and topology.[115]

The problem, Thom argued, is understanding natural change in terms of modern science, since modern science is fixated on quantification and prediction, and therefore aims to study nature through a deterministic approach. Thom points out that change in nature is ill determined and therefore the current tools of inquiry at the disposal of modern science are partial. He writes that:

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[111]R. Thom, p.1
[112]An English transcript of the lecture was published in: G. Güttinger, H Eikemeier, ***Structural Stability in Physics: Proceedings of Two International Symposia on Applications of Catastrophe Theory and Topological Concepts in Physics Tübingen, Fed. Rep. of Germany, May 2–6 and December 11–14, 1978***, Springer Science & Business Media (2012).
[113]Quoted from D. Aubin, p. 95
[114]Ibid.
[115]R. Thom, p. xxiii

"The fact that we have to consider more refined explanations–namely those of science–to predict the change of phenomena shows that the determinism of the change of forms is not rigorous, and that the same local situation can give birth to apparently different outcomes under the influence of unknown or unobservable factors."[116]

Thom criticizes the preference of observing the world through the partial lens, or stencil, of quantification for prediction. He considers the focus on quantification to be merely one way in which the world can be observed and studied, and gives the example of how qualitative and empirical deduction have been used in a sufficient way for prediction in the social sciences and biology.[117]

In this sense, Thom believed that a quantified approach alone would always result in a determinate approach to nature. Following blind calculations without form are of little value in our understanding of nature, which is essentially indeterminate. He pointed out that strictly quantitative and deterministic theories, such as classical mechanics for example, were originally created not to ignore the indeterminism of phenomena in theory construction, but to remove it in instances of moving bodies, in order to construct models for predictions. The problem with this approach is that numerical models of modern science are inevitably localized and partial as they only account for determinate and measurable information.

The consequence is that models used in modern science are not true representations, or simulations, of natural processes. On this Thom noted: "It's ironical to observe here that this science which, in principle, denies indeterminism is actually its ungrateful offspring, whose only purpose is to destroy its parent!"[118] Thus, the observer of an ambiguous biological evolutionary situation, in which the evolution of phenomena is far removed from physicochemical considerations alone and is ill determined, would still try to predict its future development by removing indeterminacy and using a local model. It is at this point that Thom's different approach to indeterminism becomes visible: He argued that

[116] R. Thom, p. 2
[117] Ibid.
[118] Ibid.

by dealing with spatiotemporal objects, such as organisms, an existing model is already assumed in their form. In other words, the scientist's aim should not be to construct predictive models of localized processes within the organism from previously quantified and measured data, but to understand existing natural structures, first and foremost, in terms of their form geometrically and topologically.[119] He dedicated the second chapter of his book to this introductory statement. Thom urges modern scientists to change their approach to the modeling of nature by first understanding the process in terms of its form topologically, rather than by trying to reconstruct it from partial quantitative measurements. He aims to describe dynamics in a topological manner, as opposed to quantitative physicochemical ones. Thus, in his new theory, he aimed to formulate a dynamics of forms with mathematical tools from topology and thermodynamics. Quality and quantity must go hand in hand in the investigation of natural phenomena.[120]

If Kepler used forms to understand the world in terms of harmonic relations, Thom used forms to understand natural processes in terms of general structural relations undergoing change. Kepler used harmonic proportions in forms as his epistemological stencil. The complexity of Thom's undertaking required him to look at the morphogenesis of complex forms as his epistemological stencil. More specifically, Thom looked at the distance between what he called 'metabolic forms', for example a fire flame, and 'static forms', such as a stone. Most forms are somewhere in between the two types, the main difference between the two being the stability of the boundaries of the form itself. The change and stability of these boundaries can be best described as the manner in which these forms deviate from their original state, stretch, curve and fold. He continued to understand natural phenomena according to the way folds, curves and other deviations of forms appear visually and behave in nature in order to map them topologically.[121]

A significant difference between Thom's and Kepler's procedures is found in their point of departure. Kepler began with an existing aesthetic principle, the stencil of

[119]Ibid.
[120]An example for this is given by Aubin: He highlights Thom's preceding work on singularity theory, which catastrophe theory elaborates on, where he successfully classified four types of elementary catastrophic models in simple systems described by four or less internal parameters. Later he would recognize this behavior in embryonic morphogenesis and study it through his application of mathematics and topology. See D. Aubin, pp. 106+120
[121]According to Aubin, an example of this is seen in singularity theory, where Thom successfully "classified the elementary catastrophes that arose in systems described by less than four internal parameters." Thom hypothesized (and was later proven correct by Bernard Malgrange and John N. Mather) that only seven types of elementary catastrophes existed: the fold, cusp, swallowtail, butterfly, and the three umbilics. D. Aubin, p. 106

harmonic relations in a three dimensional Euclidean space, which he set out to uncover and apply to different places and domains in the natural world. While he had to define the terms of this stencil, his ontological perspective mandated its use. Thom, on the other hand, did not have a three dimensional stencil, but searched for one that transcended into other dimensions by observing organic discontinuous phenomena. He was convinced that defining such a stencil had the potential of inducing a paradigm shift in the approach to natural phenomena, since late 19th century mathematics had demonstrated that the world we live in is not only Euclidean space. His study was essentially a search for that multidimensional stencil that existed in a higher dimension than the third. By examining diverse processes of morphogenesis, he aimed to map and categorize different types of natural phenomena. He then set out to understand the stencil's underlying and complex principles by visualizing developments of natural processes in graphs, maps and other qualitative visual aids, and subordinating the non-Euclidean mathematical and numerical depictions to them.

| Unsyntactic: Forms of Order

Just as Kepler elaborated on the mind's ability to intuitively recognize harmony, Thom was drawn to the mind's intuitive recognition of natural lines; these are stretches and foldings, or curves, that occur in natural forms. Not every deviation of form is natural, and, according to Thom, humans are endowed with basic intuition for the recognition of natural forms. Thom's book is filled with visual aids, and the compilation of images of a less technical nature in the center of his book depict images of natural curves, folds, and stretchings of phenomena. Curiously, the first image on the first page depicts a 'non-form' (figure 6), a deviation from shape (here a man's face), the mind would automatically recognize as unnatural. His challenge then was to understand the topological terms in which a form, such as an embryo for example, undergoes the natural process of morphogenesis, a change of form, and maintains its integrity as the same natural object in the eyes of the observer without becoming a 'non-form'.[122]

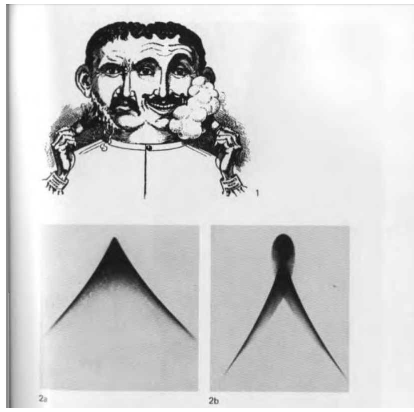

Figure 6: Thom example of non-form

The 'non-form' of the man's face Thom presented, displays how something seemingly continuous may still resonate as unnatural, while on the other hand, discontinuous processes of phenomena, for example the tearing of a rubber band or the emergence of an evolutionary mutation in a species, is recognized as natural. Understanding the stretches, curves and folds that these deviations from original form appear in, is the lens or stencil through which Thom aims to understand discontinuous and indeterminate phenomena. Forms, having an ability to represent dimensionality not easily expressed by numbers, can better portray indeterminacy of phenomena, as they contain processes that are still undetermined and multidimensional. Indetermination, therefore, can be accounted for as part of a whole process put in terms of dimensionality. Thom understood natural processes as being embedded in an infinite dimensional space. He believed that advances in the field of topology, studying the properties of shapes and specifically the properties that are unaffected by continuous distortions,[123] are therefore able to define and categorize natural processes qualitatively in terms of forms. He writes:

> "We therefore endeavor in the program outlined here to free our intuition from three-dimentional experience and to use much more general, richer, dynamical

[122]The term non-form is Thom's own terminology and is given deliberate attention and definition in his book (can be seen in R. Thom p. 14). Further attention to this concept will be given in the following chapter.

[123]Definition for 'topology' taken from "topology." In *The Concise Oxford Dictionary of Mathematics*. : Oxford University Press, 2021 https://www-oxfordreference-com.proxy.library.uu.nl/view/10.1093/acref/9780198845355.001.0001/acref-9780198845355-e-2829

concepts, which will in fact be independent of the configuration spaces (...) In fact, the universal model of the process is embedded in an infinite dimensional space."[124]

In other words, according to Thom, the boundaries of forms extend beyond our experience in the three-dimensional space. He believed this to be especially true in the microscopic scale of biological processes and quantum mechanics. The problem was that entities in these scales were not placed in the correct qualitative conceptual framework, meaning they were not envisioned correctly in terms of forms, thus yielding paradoxes and incompatibilities with micro and macro scales.[125]

Figure 7: Shirt pattern displaying folds with 'hidden' fabric

How, then, does thinking in terms of dimensionality of forms account for indeterminism? We can examine this by thinking of the gap between the second and third dimensions, with an example taken from the world of garment making (also known as patterning). Imagine a curved seam-line (a seam-line is the area where two pieces of fabric are joined together, such as the sleeve that is joined to the body of a shirt around the shoulder) or fold in fabric for example. The two-dimensional material of the fabric is curved into 'tubes' of sorts to allow the garment to encompass the body. Folds and seamlines are necessary for transforming the two-dimensional fabric into a complex three dimensional object such as a shirt, that can cover both our arms and torso, and fit the curves of the

[124]R. Thom, p. 6

[125]R. Thom, p. 125. It is important to note here that Thom did not elaborate much on indeterminism specifically as it appeared in quantum mechanics. Nevertheless, he did mention that he believed that in its scientific current state which considers that quantum indeterminism exists only in the micro, i.e. the subatomic particle realm, and relies on the uncertainty principle, appears to him as "pedantic" and "faulty". Moreover, he mentions that he believes that the obvious paradoxes which arise from the "crude and inadequate model of a particle as a point" are a result of "forcing an object into an inadequate conceptual framework."

body. When this is done, a part of the material becomes unobservable to us. Some of the fabric is either cut away or 'hidden away' from our perspective (see figure 7). This 'hidden' part in the two-dimensional material, creates a three-dimensional object.

Understanding this idea of 'hidden' material as indeterminate phenomena, allows us to better understand Thom's approach to form without resorting to mathematical analysis. As noted above, the epistemic stencil he worked through was curves and folds. A fold in the three dimension appears as a 'cusp' when examined in a two-dimensional image. Therefore, certain appearances of curves, folds or cusps in one dimension, disclose in-formation about aspects of the process that transpire in a dimension the observer is not exposed to. This idea is easily seen in the visual aids used in his book. Figure 8, for example, displays a form defined by two cusps. The dashed lines on both sides of the fold mark the area of the

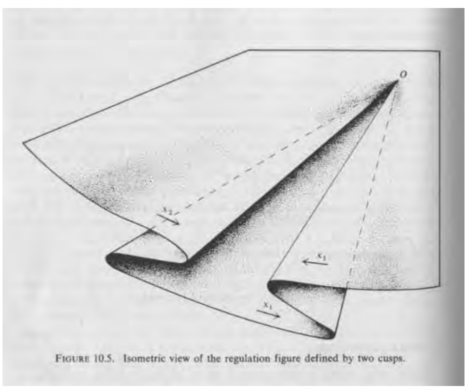

Figure 8

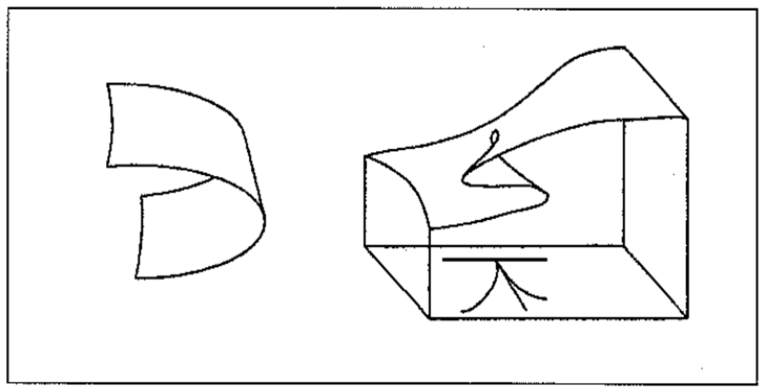

Figure 9: Fold and cusp catastrophes

underlying material that is 'hidden' from the observer. Figure 9 displays how a fold in the three-dimension is visualized underneath in the form of a cusp in two-dimensions. The development of the form, from a curve into a cusp and then a fold, is the process Thom aimed to understand topologically and visually. This can also be seen in other types of visualizations, where he tried to understand the appearance of the three-dimensional complexity in reflecting them on two-dimensional surfaces revealing two-dimensional lines and curves (figures 10 and 11).

The lines along which Thom sketches and divides natural phenomena are the curves and folds of surfaces. The curved and folded lines he investigates illustrate the areas where phenomena appear discontinuous (where the lines suddenly distort or 'jump' as seen in figure 9 or 11), revealing there are underlying 'hidden' materials and processes in play. His aim was to categorize such curves (as seen above visually) and then understand their geometric, topological and algebraic terms. In other words, sets of curves or folds were linked with sets of mathematical formulas. He held that by beginning with a form of a

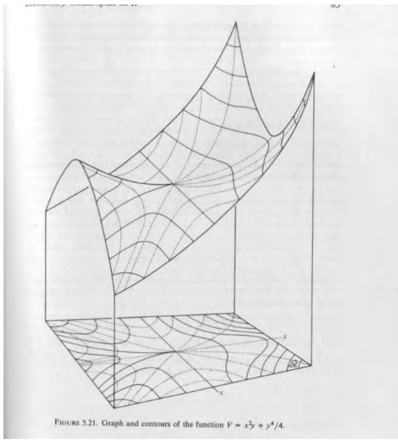

Figure 10

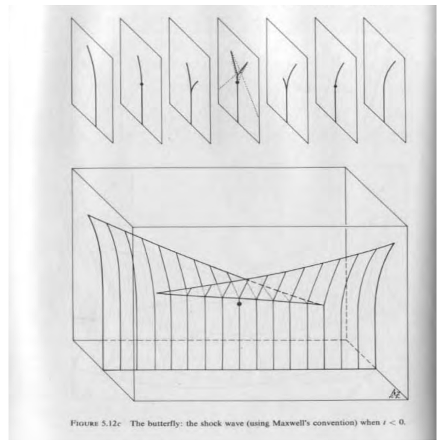

Figure 11

curve or fold, one could recognize similar processes when these appear in different types of phenomena and use the corresponding mathematical formulas to model and understand their terms without entering the realm of calculations and measurements. Processes can be recognized and mapped in qualitative terms alone. More importantly, this thought process would allow a different understanding of indeterminacy of phenomena, since such 'hidden' elements of the process are already accounted for in the mathematical terms of the folds. Curves and folds here disclose in-formation which links process, indeterminacy and dimensionality.

Thinking in terms of folds and curves of natural phenomena raises questions about our experience of a discrete nature. Following Thom's analysis, the 'inner' sections of the fold, the 'hidden' part of the process, which is unobservable, can be understood in terms of dimensionality–processes that potentially transpire across several to infinite dimensions. The gap, seen in the images above between the second and third dimensions, reveals that a discontinuous line in one dimension may appear as continuously 'folded' in a higher dimension. This puts the process and entities we experience as discrete or discontinuous in the third dimension in a new and interesting perspective. This idea can be roughly illustrated by thinking in terms of fabric once again. A technique called 'fabric manipulation' displays how a two-dimensional flat piece of fabric can be manipulated into a complex surface which appears to be created out of discrete units (figures 12 and 13). This visual idea displays a complex topological surface as a product of a 'folding' and 'curving' of a

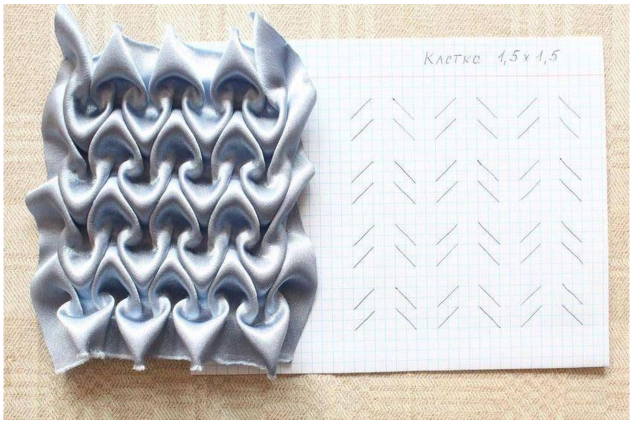

Figure 12: Soft fabric manipulation

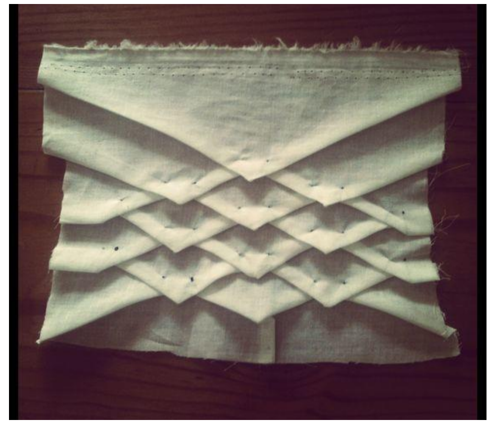

Figure 13: Hard fabric manipulation

potentially smooth and continuous surface. In this sense, our experience of distinct and separated units in the outer sphere may in fact be a result of a curving and folding of that same experience that is continuous in a higher dimension. Thinking in terms of folds and fabrics proves to be useful when aiming to depict natural phenomena in form. Analyzing folds and their patterns to elaborate on mathematical theory is seen in Gilles Deleuze's *The Fold: Leibniz and the Baroque.*[126] In his book, Deleuze provides an interpretation of Leibniz's work through the analysis of the Baroque style and its folds. Folds allow us to imagine an underlying unity and oneness among the array of distinct forms in our environment.[127]

This survey of Thom's philosophy thus far shows that he believed a qualitative structural approach to natural phenomena may fill in the spaces of discontinuous phenomena; that a shift in the way we understand the role of form in nature can act as a bridge when calculations fail and quantitative data collection of unobservables is not possible. While he recognized the efficacy of reductionism and of the classical (Newtonian) approach to calculating natural phenomena, he also condemned the indifference scientists displayed towards indeterminacy and intuitive explanation, noting that "the dilemma posed (by) all scientific explanation is this: magic or geometry."[128] Thom was explicitly unsatisfied

[126]Deleuze, Gilles, and Tom Conley. *The Fold : Leibniz and the Baroque*. London: Athlone Press, 1993.
[127]This idea is elaborated on further in the chapter 'Molding and Conceptual Materials'.
[128]R. Thom, p. 5

with a view of a universe in which all phenomena were governed by completely abstract mathematical processes that did not relate back to forms as they appear to us in our three-dimensional reality. He referred to such a view to be detached as "wonderland".[129] For him, natural phenomena were fundamentally constructed and created by indeterminate as well as determinate forces. Removing such forces from scientific considerations, along with the complete abstraction of mathematics from shape, eventually led to flawed conceptual frameworks seen in quantum mechanics.[130] Here, we can wholly see Thom's objection to the current use of the word information; mathematical abstraction cannot say anything substantial about the world we see/experience without relating it back to form and quality; without it being placed back in-formation.

The significantly different time Kepler operated in, one that preceded the conceptual changes concerning mathematical proofs at the turn of the 20th century, hinders a direct comparison between his approach and Thom's. Nevertheless, a similar sentiment can be seen in Kepler's short reference to mathematical rigor and what he calls 'inexpressible' quantities and degrees of knowledge. He argued that the term 'irrational' was a faulty translation from Greek to Latin, which amounted to "ambiguity and absurdity."[131] Such quantities should be called 'inexpressible' since their usage contributes to reason and thinking. He considered that orders which can only be partially expressible to reside in the "fourth degree in order" and beyond. But they can still be useful to reason since certain aspects of them are expressible under certain transformations.[132] He related them to 'Deaf Numbers' in the sense that "they cannot speak any more than a deaf man can hear."[133] We see here that, like Thom, Kepler considered the importance of inexpressible structures, since they are something quite different from irrationality. The value of such structures and non-forms is further elaborated on in the following chapter (in the subchapter 'Chaos or Pattern: Structuring the Fabrics of Experience').

[129]Ibid.
[130]See footnote 125, where Thom criticizes the model of a particle as a point as being "inadequate".
[131]J. Kepler, p. 21
[132]In J. Kepler, p. 21-26, Kepler describes 'degrees' or 'orders' of knowledge that can be found according to lines in shapes and their divisions. The subject matter is complex and forign so I will refrain from elaborating. What is interesting is the terms Kepler used, terms such as incommensurability of elements on one level which are commensurable and reconciled when placed together with another form.
[133]J. Kepler, p. 21

Kepler and Thom's qualitative investigations offered new stencils of examination for their time, making use of mathematical tools in new ways. While each scholar made use of the mathematics available during his period, these mathematics can be seen more as descriptive tools, similar to the tools used by the artist to depict forms in composition, rather than explanatory laws to be built upon. A more reflective depiction, on the other hand, appears structural here. The idea that shapes reveal complex qualitative attributes of nature is at the very core of both Kepler's and Thom's theories. For them, the study of structure was no different than the study of nature itself, for nature *is* structure and form before it is words or numbers. Measuring or predicting nature is not the same as, and does not amount to, understanding it. Counting or numbering as an epistemic activity, therefore, arises as secondary to a structural approach.

What structural epistemic activity is counting or numbering secondary to? This chapter began with the analysis of Chang's pairing of counting as an *epistemological activity*, with the discreteness of nature as an *ontological necessity*. The argument for quality and form thus far, presented how nature is made discrete by virtue of boundary definition which creates forms and concepts that can be counted. It becomes apparent, however, that the creation of such boundaries is not dependent on discreteness and is quite a different epistemic activity from counting. Moreover, this epistemological activity does not necessarily conform to the ontological necessity of a discrete nature, for the simple reason that the epistemic activity in question results in a discrete nature and does not assume or necessitate it. We must therefore think of ontological necessity in different terms.

An ontological necessity of forms we encountered throughout the discussion is a spatial one, i.e. dimension. This idea encompasses two essential elements: a configuration space and a material of sorts, whether it be conceptual or structural. Nature, in this sense, is not necessarily discrete but layered, or folded, and curved within a configuration space. It is only our perception which separates or 'cuts' nature according to the stencil or the boundaries we place upon it. In his chapter, Chang refers to Henry Bergson who said, "The bodies we perceive are, so to speak, cut out of the stuff of nature by our *perception*, and the scissors follow, in some way, the marking lines along which action might be taken."[134] Chang then deduces that "when nature 'speaks' to us, it is only through the outcomes of our epistemic activities."[135] If nature can also "speak" to us in forms, we must have and understand our epistemic faculties that operate in terms of forms as well. We must, therefore, consider and define an epistemic activity that extends beyond 'counting', 'numbering' or 'thinking', as these suggest conceptual discreteness and syntax. We must do so to allow discourse on qualitative types of epistemic activities in scientific knowledge creation. Describing an epistemic activity that is qualitative in nature will bring us a step closer to understanding the technique, the craft, of the scientific framing and conceptualizing of observations and sensible data.

The term for the epistemic activity in question must enclose the two components of 'space' and 'material'. It becomes evident that such a concept of epistemic activity is yet to be fully realized. The terms 'imagining' or 'conceiving' as an epistemic activity come close, but do not fully suffice here, as these terms do not need to conform to the appearance of natural structures and processes in the outer sphere. The term 'forming' is closer yet, but does not encompass the existence and interaction of the stencil with the outer sphere. The stencil is the inner epistemic structure the outer sphere is ordered by internally. I therefore propose the term 'molding' as adequate for the epistemic activity in question. 'Molding' essentially captures the inner and the outer spheres, the internal structure, the mold itself, and the external materials which are being molded. In the following chapter, I shall further justify and elaborate on 'molding' as an epistemic activity.

[134]Chang in: H.W. de Regt, S. Leonelli, and K. Eigner, eds., p. 75
[135]Ibid.

Molding & Conceptual Materials

"To develop a complete mind: Study the science of art; study the art of science. Learn how to see. Realize that everything connects to everything else."
-Leonardo da Vinci

Throughout the 20th century, the relationship between the observer and the observed became increasingly complicated. The very act of observation has been shown to carry influence over the observed object, resulting in terms such as 'the observer effect' in quantum mechanics, or 'the observer paradox' in the social sciences. Philosophers of science, such as Norwood Russel Hanson, Lorraine Daston, Peter Galison and Thomas Kuhn, have become increasingly aware of the complexities which lie within the concept of observation. Previously held conceptions, such as a separation between theory and observation or the existence of scientific objectivity, were put in doubt.

Examining the creation of knowledge within the terms of in-formation and qualitative reasoning raises many questions in relation to observation. One, for example, being the terms in which we understand observation as an epistemic activity in reference to forms and, another, questions the plausibility of objectivity within the scope of qualitative observation. This chapter aims to answer the first question: What are the terms of a qualitative epistemic activity that relates to forms? The aim here is to understand the relationship between observation and the epistemic activity underlying the term 'molding'. In the following chapter 'The View from Everywhere' we will address the second question: How can we understand objectivity within the scope of qualitative observation?

The term 'epistemic activity' emphasizes the active aspect of observation. The act of observing has passive and active qualities. It can be regarded as the entering of sensible data into consciousness, or it can be regarded as the ordering of the sensible data, i.e. the 'making sense' of it. The first option implies that sensible data exists in a definite order in the outer world and is merely transferred to the inner world. In this case, detached objective observation is possible and there is no essential difference between the act of observation and merely experiencing something through the senses. The concept of 'experience' is the impression left on the self after an event and does require anything more from the individual. Observation, on the other hand, has different implications; it not only implies an ordering of the sensible data being experienced, but it further entails a separation and selection of specific data to bring to the forefront of experience. As seen in the chapter 'In-formation', the epistemic 'stencil' through which the world is viewed is not singular; nature can be divided and ordered in different ways (see the second sub-chapter titled: Forms as Epistemic Agents).

Since observation arises as a process of dividing, selecting and ordering, it is essentially an act of creating. It is a creative act that takes place in the mind or the self–the inner sphere of experience. The term "making sense" itself implies an act of creation, a "making" of meaning from the information perceived. The act of creation is commonly perceived as a physical act in the outer world, an act that transforms something new into a tangible being. It is easy to imagine an artist, scientist or writer, hunched over a table, using his/her hands to jot down ideas, measurements and formulas, mixing paint or chemical substances, or forming poems, sculptures or models out of various materials. Nevertheless, just like with observation, the physical creative process begins in the mind. The main difference between the physical act of creation and observation as creation is the materials the mind works with to create. This is a crucial point of interest.

To understand these intricacies when examining qualitative theories, relevant concepts of observation must be articulated for discussion. The chapter 'in-formation' has shown us that concepts borrowed from the practices of the art and garment making world (specifically focusing on techniques or tools that partake in the practical aspect of creation) can be useful for this discussion. For this reason, I propose the term 'molding' as the concept that captures the epistemic activity in question. Molding, unlike 'forming', 'shaping', or 'sculpting', for example, has two elements: the material being molded and the mold itself. The epistemic activity we are concerned with here assumes two conditions as well: a space/domain of activity and the materials of experience. Molding then is a term that encompasses these two conditions.

The space within which the molding activity takes place is not easily captured as we are seldomly aware of it. Creation is a process that transpires both within the self, the inner sphere, and within the domain experienced outside of the self, the outer sphere.[136] There is an inner process of forming and ordering when experiencing reality which overlaps with our outer reality, whether we are aware of it or not. What we experience as transpiring in our outer sphere is essentially also taking place in our inner sphere. In this sense, our experience of the world transpires in the overlap between inner and outer spheres. We perceive high amounts of stimuli and sense data from the outer sphere into our inner sphere at any given moment. The impressions perceived are inevitably ordered into an experience that we can make sense of. In this chapter, this process, the 'making sense' out of sensible experiences, will be elaborated on by the term 'molding'. The notion of 'molding' will be examined through Thom's and Kepler's work. Using their writings to elaborate on 'molding' may further demonstrate its usefulness in understanding qualitative theories and may shed more light on their structural understanding of natural phenomena. But before the term 'molding' can be applied to an analysis of Kepler and Thom's writings, its meaning in relation to an abstract mental process must be understood and elaborated on.

| Inner Molds and Outer Patterns

The notion of ordering sense data in our visual field was already treated by Hanson in his book *Patterns of Discovery*,[137] in which he discussed the process of ordering the content of visual sensible experiences. In the beginning of his first chapter, Hanson writes that the task of the philosophers is "to show how these data are molded by different theories or interpretations or intellectual constructions."[138] He continues to demonstrate, with the example of Kepler and Tycho both turning East to watch the dawn, that seeing the same

[136] Different philosophies, especially from the far east such as Buddhism or Yogic traditions, would not necessarily refer to the boundaries of the self as being those of the physical body. Here, I place the boundary of one's self as their inner world, the domain of individual experience and processes that others cannot hear or see. On the other hand, what is experienced as outside the selfin the outer world is the domain of shared experience with other individuals.
[137] Hanson, Norwood Russell. *Patterns of Discovery : An Inquiry into the Conceptual Foundations of Science*. Repred. Cambridge: U.P, 1975.
[138] N. R. Hanson, p. 5

physical object and perceiving the same sense data does not necessarily result in the same ordering and "making sense" of the experience. While Hanson continues to examine the concepts of seeing and observation, I would like to focus on the notion of 'molding' and to establish this concept by articulating it as the epistemic activity of creation in the inner sphere. This epistemic activity corresponds with a natural world that consists of forms and dimensions in the outer sphere.

Describing experience as 'molded' by theories or intellectual construction is quite different from saying that our experience of reality is influenced by theories. It is important to clarify and elaborate this point: To say that experience (in this case seeing) is influenced, or even shaped, by a theory or an intellectual construct is to suggest that the measure and manner of the influence is variable. For example, if we imagine the experience of seeing, of perceiving sense data via the retina, as a painting (not the experience of viewing a painting but experience itself being compared to the making of painting or picture) we can imagine our inner sphere as a blank canvas upon which the various sense data creates a picture of experience. In this case, we can imagine how the pre-existing theories or constructs which influence the painting can be seen as directing the colors or composition of the painting. This composition, put together by our sense data, can be changed in different ways or colored in various shades according to the theories or intellectual constructs that one maintains as true or relevant. In this case, the basic or underlying structure of experience remains the same, i.e. what the picture depicts. Our inner sphere appears here as a canvas onto which the sense data we perceive paints the picture. The canvas of the inner sphere is blank and the preexisting theories and intellectual constructs guide the inner paint brush which paints the picture.

On the other hand, molding indicates a different, almost opposite, process–it suggests the preexistence of a mold or form within the individual's inner sphere, into which the entering of material, i.e. the sense data, is poured. In this case, the sense data of the experience itself is formless undefined material which is molded into a form and completely contingent on the inner mold of understanding within us, created by pre-existing theories and concepts. Hanson also addresses this in his chapter and appeals to the theory-ladenness of observation.

But if we have an inner mold, the question is, how is it formed? Is it only formed through one's accumulation of knowledge, or is it combined with one's psychological state, cultural and social influences? Or even etched into the very nature of one's being from birth? Hanson notes that "*why* a visual pattern is seen differently is a question for psychology, but *that* it may be seen differently is important in any examination of the concepts of seeing and observation."[139] He continues to describe that to see an object or a process as a physicist does, for example, one must acquire the knowledge that the physicist possesses. Nevertheless, in the case of Tycho and Kepler, the two individuals worked within the same discipline as colleagues, during the time Kepler served as Tycho's assistant. While we can presume that both Kepler and Tycho were aware of and were exposed to similar knowledge and theories of natural philosophy, their observation of the sun in the East at dawn resulted in different explanations of the phenomena observed. If we imagine both Kepler's and Tycho's inner spheres as the domain where the molding of the sense data takes place, we can easily imagine that the two have distinct inner molds. We must therefore aim to understand this process of mentally 'molding' reality beyond merely psychological considerations.

Before examining how molding takes place in Kepler and Thom's writings, let us first examine the term 'molding' on its own terms. By starting at the beginning, with the original definition of the word, the concept of mental molding can be crystalized. The Oxford English Dictionary defines molding as "to press or cast into a particular form" or matrix.[140] Immediately, the definition of the term confronts us with two components: a mold which is referred to here as a form or matrix, and some additional material which is cast into it. These two components must be understood in their mental abstractions as well. Molding is applied towards the shaping of either physical or abstract/metaphysical materials. One can mold physical objects out of certain physical materials or mold an abstract character or statement out of "certain elements".[141] It follows that these abstract elements are analogous

[139]N. R. Hanson, p. 17
[140]"mould | mold, v.1". OED Online. March 2022. Oxford University Press. https://www-oed-com.proxy.library.uu.nl/view/Entry/122813?rskey=ryA2FQ&result=1&isAdvanced=false (accessed April 09, 2022). Look under entry 2.A.
[141]mould | mold, v.1". OED Online. March 2022. Oxford University Press. https://www-oed-com.proxy.library.uu.nl/view/Entry/122813?rskey=ryA2FQ&result=1&isAdvanced=false (accessed April 09, 2022). Entries 3.A and 3.C.

to physical material. Just as suitable physical materials are chosen for forming a particular physical object, so are abstract metaphysical elements chosen to form particular statements about reality or natural phenomena.

The term mold or matrix is a useful analogy to one's inner sphere, the space within which the act of creation takes place. Furthermore, these terms can be seen as analogous to the creative activity of the artist or mathematician; a matrix is similar to the artist's painting grid or the mathematician's vector space. Since the current discussion deals with mental molding, this argument leaves us with three fundamental notions to follow: the notion of abstract elements, i.e. the formless material to be molded, the notion of the space within which the molding takes place and the notion of the pattern or stencil upon which the material is molded. These three ideas were present also in reference to in-formation and the ontological necessities of thinking in terms of form: the material, the stencil/pattern, and the space.[142] The first two components, the material and the stencil, may appear to be more self-evident than the third, 'space'. It is necessary to note 'space' as a separate component to remember that the process we are concerned with here is a dimensional one. Therefore, the examples used to elaborate on the term molding, and the metaphors and illustrations that will follow, should all contain the notion of space within them (this notion is not as evident under the term 'stencil' for example). These three components of molding are simultaneously distinct and intertwined. One cannot be treated and understood without referring to the other.

The physical mold itself (the cast) and molded material, which can easily be imagined as two separate objects interacting with one another (for example, the pouring of melted wax into a predesigned candle mold) encourages us to remain aware of a number of points when examining the concept of mental molding. First, mental molding cannot be understood in terms of linear time as there is no clear boundary to the timeframe in which the molding takes place. Moreover, some may argue that the process is instantaneous. Hanson himself briefly touches on this subject by noting that the different appreciation of a visual experience is not due to different interpretations, since interpretation is a concept

[142]The terms stencil and pattern are quite similar. The term 'stencil' implies a pattern, but is normally used in reference to a material product that is used for patterning shapes onto another substance. A pattern is a more general term that will be explored further below.

that implies thinking and therefore time.[143] Second, physical molding implies the existence of different states (such as hard, soft, flexible, solid, liquid etc.) and different types of forms (hollow forms and full forms). Considering the idea of materials in different states and forms may be useful when examining the sensible data from the outer sphere in reference to the metaphor of mental molding. Third, the clear separation of physical mold and molded material is not a given when examined in abstract molding terms. How can we refer to an abstract mental mold? Where does it begin or end? What gives it its shape if there are no clear physical boundaries? In this sense, the boundaries of the molded material are not defined either. What are these abstract 'elements', i.e. materials of experience, referred to above?

The first two questions point towards the mold's boundaries and their stability. Molding as a mental process should not be understood as the setting of permanent boundaries. On the contrary, it is an ever developing dynamic activity. In *The Fold*,[144] Gilles Deleuze mentioned the rising status of 'the new object': the object that is not just spatial but temporal; an object that implies a continuous development and variation of form within it. He questioned the dynamicity of the 'object' alongside the terms 'molding' and 'modulation', stating that "modulating is molding in a continuous and perpetually variable fashion."[145] Similar to Deleuze's 'new object', concepts–the objects of our inner sphere–are continuously redefined and reshaped. In this sense, conceptual molding, as it appears in this thesis as a dynamic concept, is analogous to Deleuze's definition of modulation.

To answer the third question, what are the materials of experience, above, we can turn back to Hanson and Cassirer. In the beginning of this section, I referred to Hanson when describing the ordering of sense data in our experience. The abstract elements, or materials of experience, being molded are the data we perceive from our senses. Like Hanson, Cassirer describes the shaping of sensible data into concepts. He argues that sense data is formed into intuitive concepts. These are then formed into linguistic concepts and, finally, into scientific ones. This process is done through representation and described by him as the molding of sensible materials: "Only through representation could the world of

[143] N. R. Hanson, p. 10
[144] Deleuze, Gilles, and Tom Conley. *The Fold : Leibniz and the Baroque*. London: Athlone Press, 1993.
[145] G. Deleuze, p. 19

the senses be molded into a world of intuition and perception."[146] Here, representation is the activity through which concepts are formed and developed perpetually (as seen with Deleuze's definition) into further complex and intricate concepts.

The notion of sensory experiences acting as molded material must be given further attention here. Sensible experiences of natural phenomena, or sense data, continuously and endlessly transpire around us. How does one determine what sense data goes into the mold and what stays out? Where does one natural phenomenon end and another begin? In order to mold the material of observational experience or sense data, experience must first be divided into materials, i.e. segments of experience. One natural phenomenon must be separated from the other. This point is important, since the articulation of distinct natural phenomena, a common practice in modern science which pertains to reductionism, can be done in several different ways. As Thom and Kepler's work show, there is more than one way of comprehending, dividing and defining the world around us, whether physically or conceptually.

Dividing up the world into parts is a human activity and the manner of this division is not granted or obvious. For example, different philosophies, such as Neoplatonism, maintained that all distinct physical manifestations stem from a higher principle of unity and oneness. This type of philosophy, also characterized as strict principle-monism, viewed the world as a whole organism and saw life as one continuous event emerging from a single cause. In this sense, what we perceive to be separate concepts are viewed in unity. Conceiving of darkness, for example, is not possible in separation from light, as darkness is merely the absence of light. In a similar manner, the Neoplatonists view physical matter as a by-product of the One Consciousness which is immaterial.[147] Through this worldview, the demarcation and articulation of objects, experiences and phenomena would be fundamentally different from a reductionist worldview.

The demarcation and articulation of objects in our visual field, phenomena, or experiences, leads to ordering and classification. A worldview that does not emphasize demarcation and articulation, or one that does so differently from what we are accustomed to, would also order and classify the surrounding world in a different manner.

[146] E. Cassirer, 1985, p. 330
[147] C. Wildberg, "Neoplatonism", *The Stanford Encyclopedia of Philosophy* (Winter 2021 Edition), Edward N. Zalta (ed.), <https://plato.stanford.edu/archives/win2021/entries/neoplatonism/>.

Subsequently, it will influence the inner world as well, as the boundary between the two is hard to define. This means that the hierarchy of sequence or importance, whether it is the experiences in one's life, the organs in a body, or natural phenomena, is a construct and not fixed. In this sense, objects, events, or phenomena we consider to be at the forefront of experience are actually a result of a certain form of division of experience (like a stencil) and are not a given. It is the inherited framework we grew used to, whether it is social, cultural, or psychological, or all of the above, which guides our division of experience. Without them, experience is undivided.

This is not merely a matter of interpretation; we actively divide the world into parts, the world itself is not necessarily divided. Kuhn discusses this in his *Revolutions*, noting that in the absence of a paradigm all of the facts that may possibly pertain to a new science "are likely to seem equally relevant."[148] This idea indicates that experience itself is made and can be subject to change. The notion of a sudden change in the way one sees or experiences the world, a change that cannot be understood as interpretation, is presented by Hanson as the gestalt switch in observation. The term paradigm or gestalt switch here can also be understood in terms of the different types of stencils that divide experience and determine how natural phenomena are divided and ordered. As we have seen with Kepler and Thom, who adopted innovative stencils in times of 'crisis', Kuhn also argued that a paradigm shift occurs when normal science enters into crisis. The intellectual construct of the pre-existing paradigm reaches an impasse, a crisis, which can only be reconciled by a change in division of experience–a change of stencil. He writes:

> "These are terminated, not by deliberation and interpretation, but by a relatively sudden and unstructured even like the gestalt switch. Scientists often speak of the 'scales falling from the eyes' or of the 'lightning flash' that 'inundates' a previously obscure puzzle, enabling its components to be seen in a new way that for the first time permits its solution. (... Such intuitions) are not logically or piecemeal linked to particular items of that experience as an interpretation would be. Instead, they gather up large portions of that experience and transform them to the rather

[148] T. Kuhn, 2012, p. 15

different bundle of experience that will thereafter be linked piecemeal to the new paradigm but not the old."[149]

In this particular section, Kuhn essentially describes the moment an inner mold transforms and changes, the moment when a stencil, that cuts up experience according to certain lines and shapes, is removed.

The substantial concepts of this discussion are displayed here. Notions such as 'unstructured' imply a moment where experience is no longer divided and ordered as before. The 'scales lifting from the eyes' can be understood as the moment the previously dividing filters are removed to allow neutral observation. Kuhn refers to experiences as 'portions' or 'bundles' that can be transformed and linked together differently, not unlike 'materials' of experience being put together through a new inner mold. The example of the candle mold and the melted wax given above, is useful here as it contains these implications. However, since reality in terms of form is multidimensional and transpires across several dimensions, we must understand mental molding as a multidimensional process as well. Considering the problems stated so far, we must approach the process of mental molding along its three components (the space of the mold itself, the material being molded and the pattern of the mold) in terms other than physical molding in order to better comprehend it.

A suitable creative act to use as an analogy to mental molding is garment making. When examined alongside the three components mentioned earlier, the abstract materials being molded, the space the mold occupies and the pattern upon which the material is molded, the analogy holds. To begin with, fabric can be seen as analogous to sense data. Sense data is the material of experience for the observer. For the sake of the metaphor, I will call sense data the "fabrics" or materials of experience. Fabric is a useful comparison for the material of experience since it has a wide range of textures and stabilities: fabric can be soft or hard, flexible or stable; it can drape around a body like water, it can be light and catch the wind and flow in the air like a feather, or it can be firm and structured like a sculpture. There are also fabrics that have a contradictory element in them; for example, stable firm fabrics that are also transparent, or thick fabrics that are soft and drape easily.

[149]T. Kuhn, 2012, pp.122-123

Fabric, as a working concept for materials of experience, allows us to think on two different levels: first is the reference to fabric which forms garments. Second, is the composition of the fabric itself. Fabrics can be made of various materials and in diverse techniques. There is a distinction between the material the fabric is made of and the manner in which it is weaved or knitted into fabric. This difference can determine if a thread of silk will result in a soft fluid material, such as silk satin, or a hard and stable material, such as silk taffeta. This difference in construction of the material itself also determines whether the final fabric texture will be shiny or matt, rough or smooth, with visible weaving lines or not. So, there are ingredients, for example silk, cotton, wool, polyester, which are woven into fabric, and there are the various types of fabrics which form and construct the garment. A similar process happens with experience: we have pure sensory data which are the ingredients that need to be woven together into a substance that can be worked with, the way the pure data is collected and understood, and the various fabrics, which together form an experience of natural phenomena. To be able to organize our experience in space and time, our minds weave together sensory stimuli into fabrics (which can be understood as singular concepts) and pattern them into recognizable phenomena.

In *The Fold*, the term fabric appears as a metaphor several times. In one section, under the subtitle 'paradigm', Deleuze noted that the model of the fold, its form, goes hand in hand with the choice of material. Paper would yield a different fold than that a soft fabric would yield.[150] In this sense, the form is contingent on the fabric used to shape it. This idea is related to the first degree of fabric noted above. In another section, he referred to Leibniz's statement that sequences of syllogisms and definitions are a "fabric", but that there are infinitely more complex fabrics available for our use.[151] This second example alludes to the second meaning of the term fabric. It demonstrates how different combinations of raw materials, i.e. sense data, can be brought together in diverse ways to form fabrics. Fabric then can be understood as concepts which have diverging degrees of complexities within them.

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[150] G. Deleuze, p. 37. In addition, see fingers 12 and 13 (in the sub-chapter Unsyntactic: Forms of Order) for examples.
[151] G. Deleuze, p. 49

Cassirer's and Deleuze's references to the term molding displayed the temporal character of the concept and noted how a concept goes through various stages of complexity, from an intuitive concept to a scientific concept. Using the term 'fabric' as a metaphor allows us to retain this temporal quality of the concept, as it contains within it varying degrees and articulations of underlying concepts. The term 'fabric' as a metaphor for a convoluted concept that interweaves an array of ideas within it, ranging from the elemental to the more intricate, has been used in passing by many thinkers. While Thom does not explicitly refer to the term 'fabric', Kepler used the term twice in such a manner in his *Harmonices*. In both cases, Kepler used it in the phrase "the fabric of the world" when discussing his investigation into an underlying united whole. For example, he wrote: "while I ascend by the harmonic stair of celestial motions to higher things, where the true archetype of the fabric of the world is laid up and preserved."[152] The complexity of the phrase 'fabric of the world', is emphasized by the contrasting term archetype (the third section in this chapter 'Archetypes and Inner Molds' treats the term 'archetype' along with its appearance in Kepler and Thom's writings in full). Nevertheless, the term 'fabric' here also is used to describe the wholeness, the singular, that contains the many distinct threads. Cassirer provides us with another crucial example to how the world we perceive is a single fabric woven out of many ideas and concepts. According to him, the division of these constituent concepts, as I argue here, is not a given, but a creation of our inner sphere. He writes:

> "As soon as we find that the classification of the world, the *divisio naturae*, into objects and states, genera and species is by no means "given" from the very beginning, the question arises: to what extent is the rich and varied fabric of our intuitive world itself wrought and governed by definite spiritual energies? We can answer the question only by unraveling the fabric, so to speak, and following its various threads separately."[153]

[152]J. Kepler, p. 441. The second example can be found on page 115, where Kepler wrote: "Twenty-four years ago, I found a very different relation between these five figures and the fabric of the world." Like with the first example, there is a contrast between a search for underlying simplicity, seen here as the five basic figures, within a complex wholeness.
[153]E. Cassirer, 1985, p. 116

Like Kepler, Cassirer shows here how the term 'fabric' contains within it both unity and multiplicity. And simultaneously, it is a material that can bend and stretch to form further forms and concepts.

Which materials or 'fabrics' we use to mold our experience of the outer world and natural phenomena depends first and foremost on the manner in which we "pick out" the relevant fabrics of reality. How we internally believe the world to be constructed may determine where we place our attention and how we separate one sensory stimuli or observational experience from the other. On this matter, Hanson notes that "our attention most naturally rests on objects and events which dominate the visual field."[154] However, what dominates our visual or observational field may differ according to our innate worldview–our inner mold. In this sense, the notion of the inner mold corresponds to Kantian categories, where the mold–the form of our inner construct which is nonmaterial–shapes the external materials–the sense data.

As the fabric metaphor I used in the In-formation chapter showed (page 61), the very notion of fabric suggests a space where the molding of the material takes place. This is the second component. The use of fabric for creating shapes and forms that fit the body consists of a multilayering and molding of experience. In this sense, a garment implies a shift between dimensions. Two dimensional sheets of fabric are patterned into pieces which form a three dimensional design when put together, as the fabric must bend and curve to make a garment. The type of fabric chosen for the garment and the manner in which it will be constructed will depend on the desired final result–the designed aspect of the form. The body itself is another spatial aspect which must always be considered when constructing a garment from two dimensional sheets. It is the folds in the fabric (also known as darts or pleats) which allow the two dimensional fabric to take the form of a three dimensional space or object. The worn garment, like a concept, is temporal; it changes and stretches according to the form of the wearer, deviating from the original shape it was molded into.

The construction of the garment alludes to a third component; the pattern upon which the molding takes place. This is especially fitting since the professional term for a

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[154]N.R. Hanson, p. 17

constructor of garments is 'patternmaker'. A garment must comply with certain behaviors and must allow movement. The basic essential form of a garment entails a patterning based on a dynamic shape, but it is not a copy of anything. It is a distinct creation, yet its basic form and construction is almost entirely contingent on its function and the space it is meant to cover and occupy. There are several factors that determine the manner in which a garment is patterned. First, the underlying form, the body, dictates the elementary necessities of the final design and the garment's pattern. Second, a specific garment's final design and its desired movement, which also dictates the choice of materials. And third, the actual patternmaker who patterns the garment, and this individual's personal style, education or preference for dividing up the sections of the fabric in order to put them together into a form.

This point calls for further clarification: the patternmaker, the individual constructing the garment, has a whole piece of fabric which must be divided into shapes that together form a three dimensional object. There isn't one definite formula to choose from. Some may choose to divide up the fabric into many small pieces and sew them all together to form a well fitted and body forming garment. Others may choose to leave the fabric continuous and have as little seams as possible, opting to use techniques such as folds or other fabric manipulations. This second option usually means that the solution is more technically sophisticated, but that the garment would not be perfectly body forming. Much like in mathematical or scientific theorizing, these choices may be based on traditional, practical, essential, or aesthetic reasonings and differ from person to person. There are many ways one can pattern a garment and attach its different pieces; patterned sheets of fabric can be sewn together to form one object or can be kept in one piece, which is then folded and stitched into a certain pattern (not unlike continuous and discontinuous phenomena). These types of details are important since they give us a range of methods for construction which will be useful when we examine types of phenomena and disciplinary concepts, such as continuous and discontinuous phenomena, stable and unstable phenomena, mathematical rigor and so on.

It follows that, in addition to molding, the concept of 'patterning' is crucial to the discussion at hand. 'Pattern' must not be confused with the term stencil, which will only be used in an explicit manner from now on. Both concepts, patterning and molding, are necessary since each suggests distinct ideas which will be important when examining Kepler and Thom's approach. Nevertheless, their different applications must first be established and shortly elaborated on.

While a pattern and a mold may be interchangeable at times,[155] an important distinction between them is the manner in which they are used. The term pattern, in the field of garment making, refers to a template of a garment's structure, one that can continuously be the basis of many garments. The pattern, i.e. the template of the garment, can be used as is or as a basis for developing further variations of the garment. In this sense, a pattern does not refer to the singular or the individual.[156] A mold, on the other hand, refers to the individual variation or deviation from the pattern. In *The Creative Mind*,[157] Henri Bergson touches upon this in a discussion about metaphysical concepts. According to him, the true essence of metaphysical concepts lies in their ability to depart from rigidity of pre-existing concepts and reshape themselves. These concepts are "flexible, mobile, almost fluid representations, always ready to mould themselves on the fleeting forms of intuition."[158] In this sense, molding refers to the forming of the particular, the specific moment of variation, and not the underlying general form. This aspect of the term is relevant to understanding the ordering and molding of observational experience in one's inner sphere according to Kepler and Thom. Both terms suggest an initial cause of sorts, yet in different ways. A pattern alludes to a universal or general origin or archetype, while mold points towards an individual or particular form of a particular object. As we aim to understand the individual accounts of observation and experience of reality, we must, therefore, remain conscious of and aspire to isolate the universal experience and description from the particular.

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[155]According to the OED, a pattern is also defined as a matrix or mold (OED online 'pattern', 3.a) and a mold is defined as a pattern by which something is shaped (OED online 'mold', ii), emphasizing the similarity of the two terms. "pattern, n. and adj.". OED Online. March 2022. Oxford University Press. https://www-oed-com.proxy.library.uu.nl/view/Entry/138977?rskey=Ik50vx&result=1&isAdvanced=false (accessed April 11, 2022).

[156]A pattern is "something shaped or designed to serve as a model from which a thing is to be made; a design, an outline, an original." OED online 'pattern', 1.a. Interestingly, a pattern is defined also as an "example or model; an archetype" (OED online 'pattern', 2.a). "pattern, n. and adj.". OED Online. March 2022. Oxford University Press. https://www-oed-com.proxy.library.uu.nl/view/Entry/138977?rskey=Ik50vx&result=1&isAdvanced=false (accessed April 11, 2022).

[157]H. Bergson, 2007.

[158]H. Bergson, 2007, 180

This process of variation is seen in the technique of pattern making. Once the pattern maker observes the desired design, he or she takes a 'basic pattern' (a general basic shaped template of a garment) and begins a molding process. In this process, the pattern maker re-examines the necessary lines (seamlines) needed to create this new design and re-molds the lines of the basic pattern; the boundary lines of the garment pattern are stretched or shortened, and pattern pieces change their form or the placement of their seamlines in order to create the new shape. Gradually, the pattern maker molds the general basic pattern into a specific individual design. But, moreover, the patternmaker molds the pattern according to his/her individual patterning preferences. So, two different pattern makers may create a different pattern for the same design. When investigating the natural world scientists, much like patternmakers, mold sense data into different sets of relations and phenomena.

Let us return to the beginning, and to the discussion of Hanson's comments. As we have seen, two individuals 'see' different natural phenomena even though they may be observing and experiencing the same sensory data. They do not order the materials of experience in the same manner and therefore describe different operations of reality. This difference persists even when the two observers are trained within the same discipline and work in close proximity to one another, as seen with Kepler and Tycho above. A similar idea was also referred to by Thomas Kuhn in his *Structure of Scientific Revolutions*, when he described the notion of incommensurability between two scientists approaching the same phenomena from different paradigms.[159] Although Hanson remarks that this difference, the question of *why* this happens, is a question for psychology, the term molding he uses suggests a process that can be described by non-psychological considerations. The term molding can help us approach this problem with little discussion on psychology, by attributing different inner molds to the two individuals.

This can be understood as a discussion concerning two spaces (or spheres): an inner sphere consisting of molds and an outer sphere consisting of patterns. The detection of patterns in the outer world is influenced by the inner mold. What is in the foreground and what is in the background of experience (or as Hanson put it "what dominates the visual

[159] T. Kuhn, 2012, pp. 147-147

field") can therefore change according to one's inner mold and, subsequently, shape the way the sensory data fills in that mold and forms a pattern. The sense data in the outer sphere does not trickle down into our consciousness, but arises at once. Experience can be divided in many ways according to the inner mold or the lines of different stencils (see page 48). This ordering of experience can also be imagined as the stencil that 'cuts out' one continuous experience into distinct elements and phenomena, or as a special lens that gives certain areas and objects within the field of vision greater definition.[160]

Molding signifies a placidity, as seen in the reference above to Deleuze's 'modulation'. Molding is subject to change and reshaping. Its shaping subsequently influences the way external stimuli enters our inner sphere of experience and forms our reality. This thought brings up a number of questions: does our inner mold in the inner sphere shape the ordering of experience in the outer sphere only, or does the sensory data in the outer sphere also shape the inner mold? In other words, how do forms in each sphere interact and influence each other? Are individual inner molds essentially different or are there basic shapes of inner molds that can be found universally? Can we 'objectively' perceive the material of experience and allow it to shape our understanding of natural phenomena? Or do our inner beliefs about the universe shape the way we describe and explain it? These are large questions that call for a detailed analysis. Nevertheless, the following sections and chapter will begin to examine these questions in reference to Kepler and Thom's writings.

| Chaos or Pattern? Structuring the Fabrics of Experience

In the previous section, molding as an epistemic activity was examined in its own terms. We must now examine how this activity emerges in theorizing and aim to elucidate the interaction between forms in the inner and outer spheres during observation. In other words, we must examine the affinity between one's molding and its relationship with one's reason when observing the outer world.

[160] This can have different reasons, such as cultural, psychological or other, which can be examined, as seen in Hanson's argument.

Since the process of molding is dynamic, the inner mold is, likewise, flexible. The inner mold shapes how reality is perceived and has influence over which elements are placed in the foreground and background of experience. In this sense, molding affects the nature of reason, i.e., the way one perceives natural relationships, causal links, explanations or justifications, and therefore, the formulation of theory. The molding of experience has an impact on the causal links, relations and boundaries of phenomena one is aware of. This idea is important, since one's arrangement of experience, including the place he/she occupies within that arrangement, may determine the consequent concepts formed to describe and explain the natural world.

The connection examined here is between one's arrangement of the inner self, and therefore inner reasoning (and subsequently theorizing), and the arrangement of outer experience. In other words, how I shape my inner mold determines how my inner mold shapes my outer experience. How I believe the world to be and behave is inevitably linked to how I see myself within that world, and how I will interact with and study that world. In this sense, the term molding is paramount, as it contains within it the two spheres we are concerned with: the 'container' or structure of the mold, the inner sphere of the self, and the materials or fabrics of experience, the substance that is being molded by the containing structure of the self. My inner structure of self impacts outer structures, relations and causal links I become sensitive to. In this sense, molding is linked to the inner self and therefore to one's own identity.

A full analysis of the relationship between the inner mold and identity is beyond the scope of this thesis. It would suffice to turn to the literature and examine the writings of philosophers who had previously used the term 'molding' when elaborating on the relationship between identity and reason. This can also be understood as the self that experiences the world and the subsequent description and explanation of that experience. In his *Identity and Reality*, Meyerson discusses how the outcome of scientific activity–knowledge–is the product of the action that was taken in order to obtain it. He quotes Poincaré, Mach, and Aristotle in his argument that scientific thought seeks to justify itself by focusing attention only on what is most valuable for its own progression and, thus, represses all other "intellectual uneasiness."[161] Reason, he argues, is therefore interlocked with identity. Tying one's own identity with a "scientific" one, and subsequently with "scientific" aims, would influence the perspective from which one gazes onto the world. On this Meyerson writes: "The principle of identity is the true essence of logic, the real mold into which one pours his thought."[162] We see here that reasoning or thoughts (which are formed by the material of experience) are 'poured' into a mold of identity.

Another example for the use of the term 'molding' is seen in Henri Bergson's writings.[163] In a section titled "The Creative Mind", Bergson examines the subject as a thing being molded, which, by extent, molds experience itself. This occurs beyond the sphere of intelligence and is not part of it, as intelligence is not an immediate act of perception. He compares the self and its immediate perceptions to a sculptor molding material; one who must study the creative technique deeply and understand it through repetition, rather than contemplate and analyze the product of the creation itself. He argues that as "artisans of our life, even artists when we so desire, we work continually, with the material furnished us by the past and the present (...) to mould a figure unique, new, original, as unforeseeable, as the form given by the sculptor to the clay."[164] While Bergson describes molding as sculpting, a different process of material manipulation from molding (different from giving shape to material with a mold), the call to study and become aware of our own techniques of forming the world around is what interests us here. He asserts that, as 'sculptors', our task is to study and understand the technique of our sculpting of self and the restrictions of the materials we sculpt with. The materials are our experiences and perceptions. In other words, we must understand our own self and how it influences our perception of the world around us.[165]

The analysis of Meyerson and Bergson's writings displays 'thinking' as an extension of a deeper epistemological process that relates to a creative shaping of experience. Such a process naturally influences how one sees and ultimately theorizes about natural phenomena. Scientific activity, therefore, cannot be seen as a purely intellectual act, but as

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[161]Meyerson quoting Mach in: E. Meyerson, p. 42
[162]E. Meyerson, p. 43
[163]Both Meyerson and Chang refer to Bergson a number of times in their writings. For this reason, it seemed relevant to examine his perspective on this matter.
[164]Bergson, Henri, Keith Ansell-Pearson, and Ó Maoilearca John. *Key Writings*. Athlone Contemporary European Thinkers. New York: Continuum, 2002, p. 225
[165]This idea raises questions concerning scientific objectivity and will be elaborated on in the following chapter.

a creative one as well, furnished by its own ends–knowledge. The pattern maker aiming to create a flowing draped dress must choose adequate fabrics to achieve that goal. Similarly, scientific activity has an end goal that determines the initial ontological angle that will select the correct fabrics of experience in order to achieve it. This means that the desired result dictates the adequate materials of experience that are to be chosen. In other words, the inner mold guides the search for outer materials and patterns that can be shaped by it.

This creative process is not just dictated by inner and outer forms, but also by a desired final product. There is a push and pull of forms, a mutual influence the inner and outer forms have upon each other that is aimed towards the product of knowledge; this is the essence of molding. Bergson, therefore, calls for a study of the creative technique and not the creative product; the technique is the beginning, the initial process that molds and gives shape to the final product of knowledge. In this sense, scientists can be seen as tailors of knowledge, selecting relevant materials out of an assortment of sensible experiences.

We can now turn to examine Kepler and Thom as molders of knowledge in their theories. Understanding the essence of their theories requires us to examine their ontological standpoint and epistemic activities alongside the ends they were trying to achieve. There are several simultaneous ideas at play here that echo the three components of pattern creation: the individual pattern maker that makes the basic shapes of the pattern, the underlying form upon which the garment is patterned, and the final design that also dictates the choice of fabrics. Extracting these elements from Kepler and Thom's work and examining the mutual influence of the inner and outer forms in their philosophical process, is necessary to fully comprehend their worldview.

Based on their own writings, both Kepler and Thom presupposed a fundamental underlying ordering and structure to the universe. The two firmly believed that the universe around us, what we experience as residing in the outer sphere (and therefore external experience), is not chaotic. The statement 'not chaotic' does not only refer to both scholars' conviction of the existence of natural law, but it extends to the questioning (and in the case of Kepler, rejection, especially due to the contemporary Neoplatonic worldview) of the existence of 'chance' in nature. The belief that the world is not chaotic, despite the appearance of chance or random occurrences in nature, mandates a search for order among apparently unorderly phenomena. But since the orderliness of most phenomena is not easily seen, searching for it must be guided by a principle that distinguishes order from chaos.

The guiding principle in question, the imaginary lines along which one orders experience, is a reflection of one's inner mold; the guiding principle is the stencil through which one sees the world. According to this stencil, the fabrics of experience are separated. What is placed in the forefront of experience influences what is left in the background, thus determining what is seen as chaos or noise. We must therefore search for fundamental principles, i.e. stencils, in the texts of these two philosophers. Finding the stencil through which one views the world will point towards the manner of molding (organizing) his external reality. Tracing elemental principles, stencils, in Kepler's work may be a simpler beginning as the contemporary Neoplatonic worldview, aimed at finding a principle of underlying unity.

Kepler's affinity to a profound universal order prevails throughout his work and is the very subject matter of the *Harmonices*. He repeatedly refers to a universal Mind or "eternal craftsman"[166] who constructed all phenomena of the world according to the same underlying law. This, he believed, can be found in geometrical forms, and studied through mathematics. This idea is emphasized by his reference to Proclus's commentary of Euclid's Book I, which opens the first book of the *Harmonices*. Kepler quotes:

> "(Mathematics) contributes things of the greatest importance to the study of nature, both revealing the orderly nature of the reasoning, in accordance with which the WHOLE has been constructed, and so on, and showing that the simple and primary elements, by means of which the whole of the heaven was completed, having taken on the appropriate forms among its parts, are connected together with symmetry and regularity."[167]

From the outset of his work, Kepler makes use of terms such as 'forms', 'symmetry' and 'regularity' in the same description as the idea of the 'whole'. These terms, alongside his search for celestial harmony, reveal to us that he believed the world to be created

[166] J. Kepler, p. 139
[167] J. Kepler, p. 8

according to an aesthetic principle that is harmonic and symmetric. He aimed to penetrate the nature of the reasoning which constructed the 'whole'–the divine mind, by showing that distant phenomena, such as planetary motion, progresses according to the same harmonic principles as music.

As a molder, Kepler divided the world according to harmonic principles, viewing the world through a mold that dictates the recognition of harmonic ratios and intervals. He divided the world, which he viewed as a whole, according to consonance and dissonance, deeming consonances to be the relevant fabrics of experience to be explored, and dissonance to be a realm unintelligible for the mind to understand. In consonance, Kepler believed, cause could be found as it pointed towards beauty–a product of divine creation and reason. Natural law can be traced in harmonies and found in geometry, as these are evidence of the reason with which the universe was constructed.[168] According to Kepler, humans have the ability to trace, i.e. to 'pick out' the evidence of these natural laws, because they are created and endowed with them in their minds through divine creation.[169]

This tracing of harmonies is depicted by Kepler in the fourth book of the *Harmonices*. He once again refers to the 'whole' of the world where the harmonic proportions are not separated from the non-harmonic ones. It all exists together in what he refers to as a "single infinite confusion of things."[170] And from this soup of confusion, the mind uses the sensing organs like a hand uses a pencil to trace coherent lines, in his words "they pick out the more important."[171] Kepler describes here the moment of selection of materials, the harmonic proportions which are most important and are recognized by the mind. In this sense, he believed harmonic resonance to represent natural law, whether it was perceived audibly or through other senses, and this was selected from the infinite whole by the mind, as the mind recognizes its own kind.

Kepler therefore set out to find and map out the terms of harmonic ratios mathematically, in order to trace them in other natural phenomena, where their

[168]J. Kepler, p. 146. Kepler writes: "For geometry (...) is coeternal with God, and by shining forth with the divine mind supplied patterns to God (...), for the furnishing of the world, so that it should become best and most beautiful and above all most like the Creator. (...) Then, since they (human souls) have embraced a certain pattern of the creation in their functions, they also observe the same laws along with the Creator in their operations, having derived them from geometry."
[169]This idea is elaborated on in the following section titles 'Archetypes and Inner Molds'.
[170]J. Kepler, p. 316
[171]Ibid.

recognition is not as obvious as in harmonic melody, thus revealing natural law and order. For him, outer patterns were recognized due to an inner faculty that was endowed with a similar structure. The inner forms and outer patterns must match, and be felt instinctively, as with music or the movement of the planets (as an astrologer, Kepler believed the movement of the planets can influence human emotion), or rationally, as with geometry, if they are to be considered in order. The ordering principle of nature, according to Kepler, the threshold between order and unintelligible noise, is harmonic consonance, what the mind and soul appear to be in agreement with.

Examining the ordering principle in Thom's theory is necessary before the idea of a resonance or mirroring between forms in the inner and outer spheres can be elaborated on in the following section. Thom's *Morphogenesis* was written in the second half of the 20th century, well within the dominant worldview of modern science in the framework of which the ordering and classification of nature had already prevailed. Indeterminism and unpredictable developments were therefore considered a noise to be cleaned out of measurement and modeling considerations (see page 57). However, the indeterminate succession of form was a problem, as it did not hinder one's ability to recognize the developing form despite the morphogenesis it was undergoing. For Thom, this was evidence that indeterminism was not a product of chaos but an underlying and very complex orderly process.

The two opening sentences which appear in the first section of the book's introduction, titled 'The Succession of Form', exemplify Thom's skepticism towards a worldview that endorses chaos and chance in nature. He writes: "One of the central problems studied by mankind is the problem of the succession of form. Whatever the ultimate nature of reality (assuming this expression has meaning), it is indisputable that our universe is not chaos."[172] Later in his book, Thom proceeds to question the modern belief in chance and randomness in nature. In the 12th chapter, titled 'The Basic Problems of Biology', an entire subchapter dedicated to the questioning of chance, opens with the sentence "one of the dogmas of present-day biology is the strictly random (if this means anything) nature of mutations; however, it seems to me that this dogma contradicts the

[172] R. Thom, p. 1

mechanical principle of action and reaction".[173] His choice of language, referring to the attributed random nature of mutations as dogmatic and questioning the essential meaning of such a statement, discloses his skepticism of chance and reluctance to fall in accordance with ideas that seem to contradict an underlying order to nature.

Throughout his book, Thom made a visible effort to find supportive arguments for chaotic order, or in other words, a type of order that has not yet been discovered and therefore appears as chaos. His efforts have a number of manifestations: First, his introduction of ideas and concepts were often accompanied by a division into types based on structure. For example, he divided forms according to 'stable/static models' and 'metabolic models', models into 'formal models' and 'continuous models', types of society into 'military society' and 'fluid society', types of geometric transformation models in cellular differentiation, types of catastrophes according to their shape, chreods according to their structure more on chords below) and so on.[174] He did not regard his division as rigorous, however, but found it necessary for transforming natural phenomena's random appearance into an intelligible structure. Classification into types, whatever they may be, is a tool which molds and aids in understanding.

The types of order, presented by Thom, can be thought of as residing on the spectrum between structural flexibility and inflexibility or stability. The difficulty, therefore, is to distinguish between extreme structural flexibility (indeterminate transformation that can appear to be chance or chaos) and between non structure, or chaos, which would be intelligibly irreconcilable even with the most advanced mathematics and topology. Natural forms, no matter how complex, are of the first type of extreme structural flexibility.

The threshold between order, unrecognized order and what is fundamentally non-order (as seen with Thom's non-form in the beginning of the section titled Unsyntactic: Forms of Order) brings us to a second manifestation of Thom's ordering principle. This principle represents important similarities and distinctions between Thom and Kepler. As mentioned above, our ability to continuously recognize a form despite its indeterminate morphogenesis hints towards the existence of an underlying order. Like

[173]R. Thom, pp. 281-282
[174]Examples appearing in R. Thom, pages 19, 40, 103, 318. A 'chreod' in Thom's theory is a 'type' or 'archetype' of a morphogenic process.

Kepler, Thom regarded intuitive recognition or sensation as an indication for the existence of underlying order, despite the morphogenetic process or object observed as chaotic. A good example of this process is found in his discussion on art, which, he writes, uses familiar concepts in unpredictable ways that can result in disorder:

> "This has the effect of harming the global intelligibility of the model and obscuring or removing the sense. From where, then, does our feeling of beauty come? From the idea that the work of art is not arbitrary, and from the fact that, although unpredictable, it appears to us to have been by some organizing center of large codimension, far from the normal structures of ordinary thought, but still in resonance with the main emotional or genetic structure underlying our conscious thought. In this way the work of art acts as the germ of virtual catastrophe in the mind of the beholder."[175]

His discussion of an organizing center with a large codimension demonstrates that organization should not be understood as an idea transpiring within one dimension that is intelligible to us as humans and within our reach of thought. For Thom, natural order transcends the third dimension we experience, and not seeing it as such is not a testament for chaotic nature, but rather of our limitations as humans.

Both Kepler and Thom, albeit in different ways, make use of the notion of order, disorder and non-order. A significant difference between their work is that Kepler's threshold for order and non-order can be seen as more strict than Thom's. Kepler demarcated divine order to be in accordance with harmonic ratios whether they were within reach of our senses or not. Thom expands the domain of order to far more diverse types and dimensions. He considered the notion of order to transcend three dimensional space, conceding that it is the interdimensional existence of phenomena that obscures its underlying order. Order cannot have one intelligible type of model, such as Kepler's Harmonic ratios, but many underlying models that can be discovered through the study of natural form.

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[175]R. Thom, p. 316

It is evident that both Kepler and Thom implicitly refer to an emotional intuition, i.e., an ability to recognize order that is not yet detectable through our senses (which should not be understood as logical intuition) but is perceived as an order, nonetheless. They both use the term resonance in describing this moment of recognition. Yet, a word must be said here about things that are fundamentally non-order or non-forms. In the previous chapter, an image from Thom's book was presented (page 61) that displayed his definition of a non-form. He defined this idea by dividing it into two types: forms with a complex and chaotic inner structure that is not amenable by analysis, and forms that are composed by a number of identifiable objects that exist in contradiction and form an unusual structure (such as the image of the smiling and frowning shaving man). Thom does not elaborate further on the first type and nor on what such a form may look like to us. On the second type, however, he remarks that the effect of experiencing such a form results in "disgust or disquiet" of the observer, and that this technique is used purposefully by artists, such as the surrealists.[176] A similar idea is found in Kepler's reference to 'dissonance'.

What the ideas of non-forms or dissonances display, is a clear "selection" of sensible fabrics to work with as true forms. Both Kepler and Thom, dedicate space in their theories to demarcating the boundary, that is structural (and therefore qualitative) in essence, between form and non-form, order and non-order. This is done according to the mold one shapes internally and, by extent, forms a pattern externally. In this sense, the molding process, the selection of sensible fabrics and their shaping, is an act of in-forming, an act of shaping the mind (as the etymology of the word discloses), and by extent, the manner in which matter is perceived.

Ending this section with its beginning in mind, we can return to a comment made by Bergson. He remarked that "our normal faculty of knowing is then essentially a power of extracting what stability and regularity there is in the flow of reality."[177] These theories evidently show how the observer or theorist molds nature according to what he/she finds to be 'regular' patterns. What we have seen in Kepler and Thom's theories, is a stabilization of the 'regular' by finding what is in-form and therefore knowable. One can then tread

[176] R. Thom, p. 14-15
[177] H. Bergson, 2002, p. 225

deeper into what is still unknown by examining the behavior of shape in the spaces of the irregular. This further displays how division of phenomena according to structure types encourages intelligibility and creates knowledge of natural phenomena. However, the question of how and what one finds 'regular' still remains. What are the terms of one's inner sphere? Are there 'stable' internal forms, or can they too be of a flexible type?

| Archetypes and Inner Molds

The discussion thus far has demonstrated how the external sphere can be experienced in diverse ways according to one's inner molding and understanding of what constitutes regularity. The idea that external order can be recognized implies the existence in an internal order which recognizes it. For recognition of order to occur, one must maintain an internal idea of the nature and structure of such a regularity. The idea of such a recognition was presented in Kepler's and Thom's theories as a moment of 'resonance'. If one can resonate with an external shape or order, one must then maintain a similar intern shape within.

The term resonance discloses a few points to consider. In mathematics or physics, resonance is said to occur when a body's natural frequency (supposing the body can perform oscillations) and the frequency of the force that is applied onto the body in question is the same.[178] In order for resonance to take place, a matching must occur between two objects or entities, such as a body and a force. Resonance produces a power of amplification (in physical mathematical terms) or the evocation of images, memories, or emotions, when the resonance refers to emotional resonance as a frequency match such as with music. The definition of the term suggests that the meeting of the two entities in resonance results in either amplification of oscillations, or the rise of an emotion or image in the inner sphere of the observer. Therefore, the use of the term resonance can be found

[178]"resonance." In *The Concise Oxford Dictionary of Mathematics*. : Oxford University Press, 2021.

in a broad number of fields, from physics and medicine to musicology and art.[179] The term here refers to resonance in the metaphorical sense, to describe a matching of forms between the inner and outer spheres, which gives rise to a feeling of recognition, or a-ha moment.

For one to resonate with a form, structure, or order in the external sphere, it follows that an entity of similar form, a similar set of relations, must reside within one's own inner sphere. This idea is easy to imagine in terms of music, when a song or melody resonates deeply with one's internal state, stirring up emotions or memories and even physical responses. But this is found within the field of science as well. Such an example was provided by Thom (expanded on in the previous chapter on page 43). He hypothesized that a similarity of shape between the graph of a predictive model and the graph of experiment results would be preferred by a scientist over a graph with lesser quantitative error, but displaying a different curve. The qualitative option would resonate as truth for the scientist.[180] What this example reveals is a moment of resonance–evocation of truth; an effect that is produced by the matching quality of a form in the outer sphere and the inner mold that recognizes the order in form. This implies that we can aim at understanding our inner spheres in terms of form and structure, and not just in purely psychological terms as suggested by Hanson.

Comprehending the terms of the inner sphere with a structural or geometrical framework has already been established by the Gestalt psychologists. Hanson refers to their works in his analysis of observation and how it is influenced by one's own theory-laden perspective. Gestalt psychology is also prominent in Thom's book. He considered their geometrical framework to be the idea that bridges the investigative tools developed in mathematics and topology with the realm of psychology.[181] Linking these disciplines can expand upon the problems Thom was concerned with, such as structural stability and the philosophical problem of concept. According to him, the common denominator between all these different considerations: concepts, psychology, structural morphogenesis, mathematics and measurement, is geometry and topology.

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[179]"resonance, n.". OED Online. Oxford University Press. December 2021. https://www-oed-com.proxy.library.uu.nl/view/Entry/163743?redirectedFrom=resonance (accessed December 30, 2021)
[180]R. Thom, pp. 4-5
[181]R. Thom, p. 1

Even in Kepler's work, there is a linking of shape between the inner sphere and the outer one. As mentioned before, he believed that geometry was a testament to the presence of mind and, more specifically, a divine or universal mind. His introduction opens with a sentence declaring his search for "the causes of harmonic proportions in the divisions of a circle into equal aliquot parts."[182] The following sentence questions how these proportions are perceived:

> "I thus considered that to start with it should be intimated that the features which distinguish geometrical objects in the mind are today, as far as is apparent from published books, totally unknown. (...) and yet unless we engage with our whole minds in the theory of this matter we shall never be able to take in the harmonic ratios."[183]

Geometrical study, for Kepler, is also a study of mind. It is quickly detectable that both Kepler and Thom link the human mind form. In other words, they link the acts of perception and reasoning (which are not to be understood here as interchangeable), i.e. the operations and content of the inner sphere, to the properties and processes of forms in outer existence, the outer sphere. Hanson's allocation of the question of 'why' (why a specific observer perceived a sensible experience in a different way than another observer) to psychology is simplistic. The discussion thus far has shown, along with the comments made by Thom and Bergson, that these structures can and should be examined in terms that do not only apply to the psychological field, albeit parallel and relevant exchanges of information.

When speaking of inner shapes, the term archetype is most useful. In the history of philosophy and psychology, the term itself is charged with many different meanings of original pattern or prototype. It has been referred to by the Neoplatonists as well as famously used by psychologist Carl Jung in his theory on the structure of the collective unconscious.[184] An interesting notion in Neoplatonism is the 'inner' and the 'outer'.

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[182]J. Kepler, p. 9
[183]Ibid.
[184]"archetype, n.". OED Online. December 2021. Oxford University Press. https://www-oed-com.proxy.library.uu.nl/view/Entry/10344?redirectedFrom=archetype (accessed December 30, 2021)

According to the Neoplatonists, every activity in the world is in some sense double, as it occurs both in the inner and the outer spheres. For example, they believed in an inherit forming principle (such as a genetic code) which determines the tree's inner construct as well as the tree's type of outer fruit. As the term archetype was used repeatedly by Kepler and Thom in their works, a focus on their use of the term and its relationship to molding requires attention here.

Due to the many uses of the term archetype, I shall limit this analysis to its meaning arising from Kepler and Thom's writings. However, there is a noteworthy similarity with Jung's use of the term, since he also aimed at finding a collective regularity of the internal sphere.[185] If there are universal regularities in the external sphere, the existence of regularities in the internal sphere are insinuated. The regularities referred to here are not behavioral, but structural, as they refer to how sensible data is perceived and organized. As humans, we appear to respond and be inclined to order. If we mold, order, and normalize our external experience, there is adequate reason for us to infer that a similar process transpires within our internal sphere as well.

The idea of an inner structure that matches the external sensible one is elaborated on in substantial length in Kepler's work. He dedicated the first four chapters of the fourth book of the *Harmonices* to a philosophical analysis of the human mind's perception of harmony. He began this discussion by dividing, or in his words "classifying", the harmonies into two types: 'sensible harmonies', and 'archetypal' harmonies. The two are different in kind as he noted that "for sensible harmony, or things which are analogous to it, is one thing, harmony which is apart from and purified of sensible things is another."[186] Kepler made a distinction between a sensible manifestation of a structural order, harmony, and the pure conception of this order which he describes as archetypal. The archetypal harmony is found in the order "for a sound is one thing: a definite order among different sounds is another."[187] Harmony is not determined by sound in itself, but by the relationship between sounds. This mathematical ratio can be separated from the sensible manifestation of the sound itself and is, therefore, archetypal harmony.

[185]Jung, Carl Gustav. *The Archetypes and the Collective Unconscious*. Transl. [from the German] by R. F. C. Hull. 2nd ed. [4th print.]ed. London: Routledge and Kegan Paul, 1975.
[186]J. Kepler, p. 289
[187]J. Kepler, p. 290

There is a clear distinction here between the physical manifestation, the sensible data of an experience, and the conceptual structure that underlies it. Archetype, in Kepler's work, refers to the latter, a pure conceptual ordered structure. Archetypal harmony, in his words, is not merely the quantitative term but "is a relation of quality or shape"[188] that can be recognized by the mind, the inner sphere, because it is found within it.

The idea of a distinction between a sensible manifestation of data and an archetypal form it is organized in, is found in Thom's *Morphogenesis* as well. In his theory, Thom traced coherent systems of catastrophes, what he called 'chreods' (can be understood as topological models or structures of natural processes, also referred to as 'archetypal morphologies'[189]) and organized these into archetypes. He considered these structures to exist as "abstract algebraic entities independent of any substrate."[190] There is a clear analogy here with Kepler's work, in the sense that the archetype is a structure that is abstracted from any sensible manifestation and yet has a physical influence. Another similarity is seen in Thom's assertion that these archetypal chreods are mental organizational centers.[191] For him, the archetype was of a virtual existence but "exerted a *real* attractive force on existing beings.[192] In other words, the archetype is an abstract essence which organizes sensible data, the materials of experience, according to certain structures which also exist in the inner sphere.

The existence of the archetype in the internal sphere must be justified and elaborated on. The term resonance is a key concept in this justification. As seen in the beginning of this section, resonance implies the existence of two things of similar type. For me to resonate with something that I experience as external to me, it must interact with something that resides within me, whatever that thing may be. In this sense, for a sensible experience to influence my emotion or reason, there must be some sort of 'interplay' between two similar things. If one is found in the outer sphere, the other must be in the inner sphere.

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[188] J. Kepler, p. 296
[189] R. Thom, p. 311, the term 'archetypal morphologies'
[190] R. Thom, p. 316
[191] R. Thom, p. 295. It is interesting to note here that both Kepler and Thom discuss archetypal organization in relation to the organization and functional operation of the body's organs as well. Kepler attributed this to divine design, reasoning that the organs are created to express and perceive sensible harmonies, while Thom used the nervous system as the mediating agent between mental and physical organization of the body.
[192] R. Thom, p. 292

We can find examples for the notion of internal and external ‘interplay’ in both philosophers’ texts. This idea arises in Kepler’s philosophy as the act of comparison. In his work, the mind *compares* the structure of the external sensible data with the inner archetypal structure that resides within it (this process is to be understood as subconscious and not a logical conscious process of comparing). The idea of comparing internal and external structures, can be examined as an ‘epistemic activity’. In the previous chapter, counting appeared as an epistemic activity that required the ontological necessity of the discreteness of nature (as things in the outer sphere are counted by us). By the same reasoning, resonating with an external structure of harmony, explained as the epistemic act of comparison by Kepler, requires an internal structure or archetype as an ontological necessity. He explicitly wrote that “(the soul) makes this proportion harmonic itself by comparison with its archetype. It could not be called harmonic, and would be allotted no power in moving spirits, if this archetype did not exist.”[193] For recognition and resonance to take place, an internal archetypal structure is ontologically necessary to be compared with the external structure one is experiencing.

The idea of an interplay between the inner and outer spheres arises as slightly different in Thom’s work. Here, the idea of ‘interaction’ between forms is present, as opposed to ‘comparing’ in Kepler's. Interaction between forms, according to Thom, is not only between the inner sphere and outer sphere, but between topological structures in general of any kind. He called this interaction the “attraction of forms,”[194] where competing archetypal structures of high complexities, such as different forms of species in evolution, attract the organization of other forms around them, much like a gravitational pull. The introduction of this idea was in part to reconcile the apparent tension between his renouncement of complete chance in nature on the one hand (for example in reference to evolution and the development of new species through mutations and natural selection) and his disagreement with the idea of complete finalism in nature on the other. In this sense, a structure of one type can also interact and influence a neighboring structure of another type.

[193]J. Kepler, p. 295. The words 'soul’ and 'mind’ are used interchangeably in Kepler writing, so where the word soul appears it can also be understood as mind.
[194]R. Thom, p. 291. On the same page, Thom considered the idea of attraction of forms to be one of the essential factors of evolution.

The term archetype arises as an abstract structure that can be represented mathematically or topologically. The discussion thus far has shown that we can aim to understand internal archetypes by studying them externally. Yet, the term archetype itself also implies a universality, a generalization, as opposed to the individual idea of 'molding' I described above. What is then the gap between an inner archetype and an inner mold?

There are two noteworthy terms that appear in Kepler's writings in reference to archetype that can further elaborate on its relationship with an inner mold as an organizational agent of sensible materials. These terms are 'impression' and 'common sense'. First, the word "impression" was introduced to illustrate the meeting of the sensible data with the mind.[195] The term carries two important interpretations for this discussion: the first relates to a feeling or memory that is evoked by the mind's encounter with the sensible experience, and the second relates to the idea of an imprint–a pattern or design made by pressing, that happens upon experience. Both interpretations are relevant to the concept of molding, since one refers to a moment of resonance that produces an emotion or feeling and the second refers to form and shape.

We can think of the inner sphere as consisting of a conceptual shape or pattern that interacts or matches with the external one. The moment of matching is the moment of resonance that evokes movement, whether it is emotional or physical. On the other hand, the term points towards something more dynamic and active, a design made by pressing, which resembles the idea of molding the materials of experience. In this sense, there is a sudden formation of shape–a rapid pulling together of the material into a specific form. The active aspect of molding can be exemplified by imagining the modeling technique of vacuum forming. In vacuum forming, a sheet of plastic is heated and pressed onto or into a shaped mold with a vacuum, thus shaping the flexible plastic according to the mold itself. When observing the process of vacuum forming, we see a fascinating moment where a flat material is suddenly 'pulled' and formed into a three dimensional shape.

Using the analogy of vacuum forming and the 'pulling' of the flat material into form, helps us understand how the materials of experience, the sensible data, is organized or 'pulled together' by the inner mold. When the inner mold changes, the 'pulling together' of

[195] J. Kepler, p. 294

material happens according to a different underlying form, resulting in a different perception of reality. This idea resembles Kuhn's paradigm shift. However, the idea of a 'pulling together' of data according to underlying or archetypal forms does not insinuate that one is more accurate or correct than the other, but rather more fitting for a specific perspective. In other words, data can be examined through different lenses (or stencils) and be 'pulled together' to form different descriptions of phenomena.

Another philosophical example for the idea of 'pulling together' materials of experience is found in William Whewell's *Novum Organon Renovatum* in what he calls "The Colligation of Facts".[196] The notion of 'colligation' refers to the binding of scientific facts or data by means of conceptions. As seen in the previous chapter, a concept is philosophically comparable to a form. It is a structure, in this case a mental one, that has boundaries and limitations similar to a shape or form, which can be stretched and morphed just like a closed topological subset. The boundaries of concepts, such as refraction or polarization, 'bind together' the sensible data into in-formation by virtue of the inner mold. Whewell's description of colligation carries much resemblance with the notion of an inner mold in the formation of scientific knowledge. He writes:

> "In succeeding stages of science, more especial attention and preparation on the part of the observer, and selection of certain *kinds* of facts, becomes necessary; but there is in early period in the progress of knowledge at which man is a physical philosopher, without seeking to be so, or being aware that he is so. But in all stages of the progress (...) it is necessary, in order that the facts may be fit materials of any knowledge, that they should be decomposed into Elementary Facts."[197]

Here, he describes a careful selection of facts in the formation of scientific knowledge, a process that happens without awareness in earlier stages of knowledge creation. What is described here is a process of purification or generalization of sensible materials. The inner mold can be seen as an in-former or shaper of conceptual materials, which become more refined, pure, and convoluted as knowledge is advanced.

[196]Whewell, William. *"Novum Organon Renovatum, Being the Second Part of the Philosophy of the Inductive Sciences". the 3rd Edition, with Large Additions*. London: J.W. Parker and Son, 1858.
[197]W. Whewell, pp. 60-61

The idea of refinement and generalization of concepts brings us to 'common sense', the second noteworthy term that appeared in Kepler's text. Here sensible data in the form of harmonic ratios "are recognized by the common sense" according to Kepler.[198] The term initially implies a universal idea, something that is regular, i.e. common. The idea of 'common sense' being an integral part of the experience of reality and analogous to the activity of science is elaborated on by Meyerson in an entire chapter titled "Common Sense". I will not undertake an entire investigation into this concept here due to lack of space, but will only clarify with some important ideas presented by Meyerson. He attributed common sense to an accumulation of memory which is abstracted, generalized and, therefore, stabilizes phenomena. This idea is also present in Whewell's colligation of facts, where he used the phrases 'common observation' or 'common perception' and referred to their accumulation in memory.[199] An interesting example given by Meyerson to the accumulating effect of common observation is that of impressionist painters, who demonstrated how distant trees can actually be purple, yet would still be perceived as green based on memory and 'common sense'.[200] He asserts that we tend to generalize what we know (what we assume to be stable) even during observation, and equates this intuitive generalization with the notion of law in science. Meyerson later compares the notion of generalization upon observation with the essence of a conceptual object, something that is fixed, durable and is independent of time.[201]

The point of this analysis was to examine the gap between the archetype and the inner mold. What the discussion revealed is a tension between a stable pure structure on the one hand and a dynamic one on the other, one which is influenced and shaped by its environment and evolves into more precise articulation. The archetype arises as the first, a

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[198] J. Kepler, p. 293
[199] W. Whewell, p. 60
[200] E. Meyerson, p. 355. Full quote: "The very colours ,which are the object of my direct sensation, are very different from those I think I perceive. For many long years the pictures of impressionists have provoked exclamations or laughter from the great majority of the public, enlightened connoisseurs as well as the mob, and even from the generality of painters. It was considered absurd that a forest should be violet in the distance. And yet we have no doubt today that it actually is so; but our memory immediately transforms this image, with the help of the memory of the same forest seen close by, and consequently we swear that we see it green, which means that we really see it as such."
[201] E. Meyerson, p. 360. It is important to note that is significant differences between Kepler's idea of common sense and Meyerson's, the most prominent one I noticed being Meyerson's attribution of common sense to an ontology that "affirms the existence of external object and is very far from supposing that existence depends on our consciousness." (E. Meyerson p. 357). It appears that Kepler would attribute a larger role to consciousness, namely that the very experience of law or order depends on consciousness.

pure form of a generalized conceptual object which strives for pure stabilization. Even Thom's search for archetypes of morphogenesis was an attempt to conceptually stabilize the most dynamic processes in order to gain knowledge of them. In relation to the term impression, an archetype also has a shaping feature, as it shapes the manner in which we perceive sensible data. Kepler elaborated on this: "the Mind which uses the Archetype to shape things to fit it."[202] The mold arises as the second active structure in the mind. It simultaneously allows recognition of form based on previous experiences alongside the perpetual articulation and generalization of previous experiences in order to form new knowledge and understanding. We can understand the inner mold to be the active element which uses the stable form of the archetype in its pursuit of knowledge.

It is paramount to point out that the notion of an inner archetype is not meant to imply immobility or inflexibility of thought. Kepler and Thom's works both display a clear flexibility of thought alongside an investigation into archetypes. The time period and the worldview maintained by Thom allowed a larger range of intellectual flexibility. He considered himself to be operating within a time of scientific crisis and, therefore, purposefully searched for investigative methods that resided outside of the deterministic paradigm of modern science.[203] He admitted that the term archetype has a finalist, and thus inflexible connotation,[204] but his thoughts on the purpose of finding archetypal mathematical models reflect a contrary sentiment. This is clearly seen towards the end of his book, where Thom equates the search for models to human play. He considers the fact that the axioms of arithmetic form is an incomplete system a happy one, since it gives hope that many indeterminate and currently incomprehensible phenomena may one day assume a mathematical model. He notes that:

> "By allowing the construction of mental structures simulating more and more closely the structures and forces of the outside world, as well as the structure of the mind itself, mathematical activity has its place in the warp of evolution. This is significant

[202] J. Kepler, p. 139
[203] D. Aubin, p. 95
[204] R. Thom, p. 291. Thom makes an explicit remark about the problematic connotation of the term archetype, but he chooses to continuously use it after the remark, showing that he found it to be at times more accurate then the term eigenform.

play *par excellence* by which man can deliver himself from the biological bondage that weighs down his thought and language."[205]

Thinking in terms of internal and external archetypes, for Thom, of a window, or stencil, through which we can study and bring to awareness the nature of our own structures of thought and language, and subsequently free ourselves from them when and if they become restrictive.

The liberation from a restrictive thought structure, as discussed by Thom, is visible in Kepler's *Harmonices*. Kepler believed the planets to move in perfect circles and four books out of the five which compose the *Harmonices* were dedicated to the analysis of perfect and pure harmonic ratios. so they could eventually be applied to the heavens in the fifth and final book. However, when Kepler examined his comprehensive harmonic analysis in reference to the observed data of planetary motion, he was faced with an unforeseen divergence; the planets did not move in perfect circles but in the form of an ellipse, and the pattern of their motion could not be explained according to the five platonic solids. When faced with this finding he reasoned that the basic principles considered are insufficient for understanding the apparently more complex divine design. This is evident in his words: "On careful consideration, we shall painfully reach the following conclusion, that for establishing the diameters and the eccentricities of the orbits in conjunction, more basic principles are needed than the five regular solids."[206]

It is important to consider the fortitude with which Kepler believed in the construction of the world according to harmonic ratios, and the movement of the planets in pure circular orbits. The prevailing contemporary Neoplatonic worldview, which maintained that the world was constructed according to one unified underlying principle, was shared by him and he aimed to find the underlying unity and proof of divine beauty, in harmony. His entire book was a testament of precise systemization, methodology and conviction in harmony, one which is often discussed by historians of science as the last true attempt to find music in the planetary spheres.[207] His own words describe the pain of

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[205] R. Thom, p. 317
[206] J. Kepler, p. 407
[207] Examples: B. Stephenson, *The Music of the Heavens: Kepler's Harmonic Astronomy*, Princeton University Press (New Jersey, 1994), pp.3-4. P. Boner, *Kepler's Cosmological Synthesis: Astrology, Mechanism, and the Soul,* Brill (2013), pp. 14-15

accepting the truth of imperfection. But what becomes clear in Kepler's concession, is that his archetypal analysis of structure (both inner and outer) did not result in unyielding intellectual rigor. It made him aware of the areas where his own inner mold and conviction in structure diverged from the external one and was, therefore, to be adjusted and re-molded.

Far from being inflexible, the structural archetype arises as a useful tool for understanding the terms of *recognition* of structural patterns, and subsequently the formulation of general laws. The generalized law or standard that is placed in the forefront of one's experience, knowingly or unknowingly, internally directs the manner in which one approaches the world when attempting to understand it, i.e. directs the selection of conceptual materials. This idea is also noticeable in Kepler's assertion that form is intrinsic to one's inner sphere and is, therefore, the guiding internal rule which allows external recognition of it: "for shapes are in the archetype prior to their being in the product."[208] Archetypal form is emphasized here again as a principle that stems from one's inner sphere; our recognition of it in the outer sphere is contingent on its existence in our inner sphere. If one wishes to understand the world around them, one must be aware of the archetypal form within them that underlies their perception of the world. Only through the analysis of their own inner archetypal form can one gain knowledge of their orderdering of the external world.

One last important idea is revealed in these final examples from Kepler and Thom. The divergence from order, from the pure archetype, need not represent indeterminate chaos that must be 'cleaned' out of models for prediction. On the contrary, divergence from perfect order revealed where other principles were in play, where one must turn their attention to and bring the sensible data to the forefront. The idea that disorder is the realm of great intellectual importance is also seen in Bergson's text, where he writes:

> "In reality, there is more intellectual content in the idea of disorder and nothingness when they represent something than in those of order and existence, because they

[208]J. Kepler, p. 281

> imply several orders, several existences and, in addition, a play of wit which unconsciously juggles with them."[209]

Bergson's text displays the hidden possibilities found in notions such as disorder and empty space. What we consider to be disorder, or what we place in the background of our experience, are windows–stencils–through which we can examine the tendencies of our inner molds.

Divergence from order and what we label as the 'background' reveals the habits and shortcomings of our inner structures, the areas where we can (and should) examine and adjust our inner molds in order to find more intricate and sensitive models. Moreover, thinking in terms of structural archetypes suggests that we can find new possibilities in the things we believe to be noise, trivial or residing in the background of experience. In this sense, structural archetypes expand the domain of systematic investigation into the inner sphere, placing the conceptions we have on scientific objectivity in question and making them available for methodological scrutiny.

[209]H. Bergson, 2002, p. 228

The View from Everywhere

"Absorbed in this world you have made it your burden.
Rise above this world. There is another vision."
-Rumi

One of the most contested issues in the philosophy of science is the subject of scientific observation and its relationship to objectivity. Observation is a significant part of scientific activity, as it is often the epistemic bridge between experience, theory and empirical evidence. The once presumed separation between theory and empirical observation (mainly by the logical empiricists) was challenged by philosophers, such as Norwood Hanson, who had displayed how the very act of seeing itself is theory laden.[210] Other philosophers of science questioned the existence of 'pure' collection of objective data. Loraine Daston and Peter Galison, for example, had shown that the nature of 'scientific objectivity' had changed throughout history,[211] and Helen Longino, who argued that even the most original and pure form of data is "not free from researchers' value and theory-laden selection and organization."[212] Observation, therefore, is not free from concepts of perspective. An observer must therefore ask: where am I looking from?

In 1986, philosopher Thomas Nagel defined objectivity as "The View from Nowhere" in a book carrying the same title.[213] According to Nagel, humans possess unique mental faculties that allow them to transcend personal experience and view the world in a detached way from 'nowhere in particular.' Yet numerous philosophers of science have already demonstrated that the creation of scientific knowledge itself is always a "view from somewhere."[214] Nevertheless, Nagel's notion of a 'view from nowhere' displays an attempt to name the nature of scientific perspective.

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[210]See N. R. Hanson, Daston, Lorraine, and Peter Galison. *Objectivity*. First paperbacked. New York: Zone Books, 2010.
[211]See L. Daston and P. Galison
[212]H. Longino "Data in Transit" in: Leonelli, Sabina, and Tempini Niccolò. *Data Journeys in the Sciences*. Cham: Springer Open, 2020.
[213]Nagel, Thomas. *The View from Nowhere*. New York: Oxford University Press, 1986.
[214]Some examples are: Nickolas A. Rupke, David Livingstone, and L. Daston and P. Galison

One of the main problems with the concept of a "view from nowhere" is the detachment from self it signifies. Observation is intertwined with the character of the self that is observing. Daston and Galison showed how the meaning of objectivity was contingent on the type of self that was considered to be scientific at the time. In addition, notions of objectivity contained the necessity to develop and form a type of scientific self to begin with. They demonstrated how the 'hero scientist', who exhibited his professional intervention into the representation of nature, was celebrated at one point in time and then replaced by 'mechanical' observation, when machines were placed between the subject and object, in an attempt to avoid personal bias in representation.[215] In this sense, scientific objectivity is not a given, but intertwined with identity and individual perspective.

The chapter on molding illustrated how the molding of one's perspective is intertwined with identity (see 'Chaos or Pattern? Structuring the Fabrics of Experience). Therefore, the viewpoint through which one views the world, subsequently molds the way one describes and explains natural phenomena. How, then, can we maintain notions of scientific objectivity? Cassirer argued that "what ultimately guarantees objectivity itself is the way in which it is approached, the specific direction that the spirit gives itself in relation to a proposed objective context."[216] For him, objectivity is found in one's awareness of direction, i.e. the perspective through which one examines the world. In other words, objectivity studies the relationship between the inner sphere and the outer sphere; the domain of inquiry extends from the outer sphere of experience, to encompass the inner as well as the outer sphere, once again rendering detachment from one's perspective impossible. But if complete detachment from one's perspective and a view from 'nowhere' is not possible, can we aspire to grasp the view from Everywhere?

This question may appear unattainable and even religious at first; those who believe in a divine order may believe God alone possesses such a privileged perspective. Embarking on the quest towards a view from everywhere initially confronts us with more questions than answers. The term 'everywhere' implies an abstraction or multiplicity of self which immediately exposes conceptual problems and the singular perspective of the individual as limited. Some may find the distinction between 'nowhere' and 'everywhere' to be debatable.

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[215]See L. Daston, and P. Galison, chapter three "Mechanical Objectivity", beginning at page 115.
[216]E. Cassirer, 1954, p. 80

What does it mean to observe something from everywhere; does everywhere imply something different from nowhere when it comes to perspective and the study of our reality? And, more importantly, can the view from everywhere produce different theories of knowledge than the view from nowhere, and if so, how?

I believe these questions can be answered by shifting our attention from numbers to forms, from quantities to qualities. In the previous two chapters, I offered the presence and role of form and qualitative structure in the creation of scientific knowledge. In the first chapter, forms were examined as epistemic agents in the outer sphere, while in the second chapter, their power to inform one's ontological and ordering tendencies in the inner sphere was inspected. The second chapter introduced the concepts of inner and outer structural archetypes and concluded that thinking in terms of archetype allows us to expand the domain of systematic investigation into the inner sphere–into the self. In this chapter I will argue that the difference between nowhere and everywhere can be understood as the difference between quantity and quality, and will provide examples of practices for studying perspective from art and theology.

| Observing Numbers vs. Observing Forms

Numbers and quantitative measurement are fundamental to the practices of modern science. The application of measurement towards natural phenomena during the Renaissance is often considered by historians of science as one of the decisive developments which brought about the process known today as the Scientific Revolution.[217] The birth of classical physics attributed to the work of Issaac Newton is often seen as the turning point during which the key to unlocking the secrets of nature through calculation and prediction was made possible. From this point onward, the merit of quantitative research and analysis had been established as one of the building blocks of scientific objectivity.

[217]As seen in M. Hellyer, Marcus. *The Scientific Revolution : The Essential Readings*. Blackwell Essential Readings in History. Malden, MA: Blackwell Pub, 2003.

The success of numerical application to investigation of natural phenomena has somehow become entangled with notions of objectivity. Numbers arise as detached, impartial and objective. Due to their translatability between cultures and languages, numbers and measurement emerge as a language that is universal and absolute. What can be measured and quantified is definite. Whewell pointed out this idea when he wrote "Ideas of Time, Number, and Space, which are Ideas processing peculiar definiteness and precision; so that with regard to them, confusion and indistinctness are hardly possible."[218] Numbers thus arise as possessing a definite accuracy. In comparison, the qualitative descriptions and explanations of natural phenomena that preceded the scientific revolution, such as the theory of the four elements and their properties (air, fire, earth and water which had to be hot or cold, dry or wet), arise as speculative and abstract. Indeed, there is no questioning the success and value of the transition from qualitative to quantitative investigations.

Beyond changing the essence of investigation into nature, this transition from the qualitative to the quantitative also changed the way the subject, the observer, relates to the object of observation. Equipped with ever developing measurement apparatuses and models, modern scientists operate under the impression that their observational perspective is detached. In other words, by describing and investigating the world with numbers, as opposed to images and words, scientists assumed a neutral and detached observational position. From being merely a precise and definite representation of natural phenomena, numerical depiction turned into a screen of detachment that converted the scientist into a neutral and objective observer.

A recent example to such a belief can be found in Theodore M. Porter's book, such as *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*.[219] His research describes the historical relationship between numbers, objectivity, and truth in academic, political and social circles. Porter aims to understand the public and institutional trust placed in quantitative research and demonstrates how knowledge is made impersonal through its portrayal in numbers. He gives the example of how heat concepts such as "heat

[218] W. Whewell, p. 61

[219] Porter, Theodore M. *Trust in Numbers : The Pursuit of Objectivity in Science and Public Life*. Princeton: Princeton University Press, 2001 It is important to note here that Porter does not necessarily agree with this perspective, but merely aims at understanding it.

capacity" and "latent heat" rendered the phenomena of heat as neutral "with as much precision as in mechanics" once it was treated by physicists.[220] Numbers signify impersonal interpretation of meaning, detachment and universality. Forms and shapes, on the other hand, the visual appearance of phenomena, appear in contrast as subject to personal interpretation. Another example can be seen among the logical positivists who believed that for a theory to be truly objective, it must be possible to depict it numerically. Their attempts to confirm such a theory in the first half of the 20th century have proved futile.

This quick examination into the nature of quantitative research and numerical depiction describes a detached type of objectivity similar to that of Nagel's. The 'view from nowhere' assumes the same detached perspective allotted to numbers. It would be fair to infer a connection between the two ideas, although I will not aim to prove the connection here. What is interesting for the discussion at hand is the question: why do numbers symbolize neutrality and detachment beyond precision and accuracy? Where does the notion of detachment come from?

To answer this question, we must return to the analysis presented in the first chapter regarding the differences between quantity and quality, numbers and forms. A significant difference between quality and quantity was their dimension of representation: numbers are devoid of dimension in themselves and refer to points or discrete units. While they can describe dimensions when placed in formula (or *form*-ula), they do not contain dimension within themselves. Forms, on the other hand, imply dimensionality in their very existence. In order to think or imagine a form requires a space of a certain dimension. However, if one thinks of numbers, one is not required to imagine a space along with it. Numbers exist by virtue of separation, i.e. detachment, forms exist by virtue of space.

The introduction and prevalence of numbers in modern science has subsequently carried with it notions of detachment by the observer as well. In the second chapter, I mentioned the sensible data, the materials, we place 'forefront' of experience. The manner in which we perceive reality is subject to the sensible data we deem most important, and we mold our inner sphere according to it. By placing numbers and measurement in the

[220]T. M. Porter, p. 18

forefront of scientific practices, a position of detachment could be more easily assumed and reasoned by the observer.

The problem is that measurements and numbers do not stand alone; they must be in-form in order to count as information and say something about natural phenomena. To speak about nature (as opposed to speaking about pure mathematics abstracted from any natural phenomena), quantities need to be in-form (as discussed in the first chapter). Therefore, when we think in terms of in-formative measurements or numbers, we are still thinking in terms of form. In other words, whenever we engage with numbers in observation as a description of phenomena, we are actually observing a distinct perspective, a distinct angular view, of the underlying form of the phenomena. The challenge is to become aware of and understand one's own perspective in reference to the object of study.

The difference between the view from everywhere and the view from nowhere is this: the view from everywhere contains dimension, the view from nowhere neglects dimension. If we relate 'nowhere' and numbers in a particular kind of perspective, described as detached objectivity, it is worthwhile to examine the contrary position in the relationship between everywhere and forms. We must examine what a shift towards a view from everywhere entails.

| Discovering Everywhere

Considering a qualitative view from everywhere incites several points for examination. First, the very notion of 'everywhere' suggests that the appropriate outset for such a quest is paradoxical and difficult to determine; if one can access an infinite number of perspectives, in what sense are these perspectives infinite? Does it refer to infinite visual viewpoints, to infinite modes of comprehension? Or to infinite intensities? The very nature of the term 'infinite viewpoints' and understanding each scholar's relation to it requires individual attention. Second, the term everywhere ties the observer to the object, since the observer can no longer be thought of as detached (what was made possible by the term nowhere). If there is always a view from 'somewhere', then the observer's perspective is subsequently contained within the theory or organization of data. Therefore, understanding the structure of theories can reveal information about the phenomena in question as well as information about the perspective of those maintaining this theory.

It is useful to note at this point that ideas concerning the view from everywhere are not entirely new. In other words, the examination of how one can assume a viewpoint that transcends the limited singular retinal perspective we experience in everyday life has been detailed by theologians, scientists, philosophers and artists throughout history. The 15th century theologian and philosopher Nicholas of Cusa is one example. In his book *The Vision of God*,[221] Cusa instructs the monks of Tegernsee to circumambulate an all-seeing icon of God, by making them contemplate the book's text alongside an image, demonstrating how the act of seeing is interactive and by developing the concept of an all-seeing God. This concept was believed to be represented geometrically in the vanishing point developed by the Renaissance artists. The notion of a vanishing point assisted Cusa in conceptualizing an infinite perspective. He imagined the divine vanishing point as a type of infinite angle resulting from a constant movement between angels. The translator Emma Gurney Salter elaborated how "The author brings the pupils to a certain vision of God, by showing the first from one angle and then from another, the gaze of the eternal bent upon each contemplating soul."[222] From this perspective, everywhere arises here as assuming infinite viewpoints; a constant movement around the subject whether it be from angle or distance. I shall return to this point with further examples and illustrations later.

The treatment of ideas of transcending our limited three dimensional perspective by artists is seen in Linda Dalrymple Henderson's *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.*[223] The book exemplifies an interdisciplinary study into different perspectives of non-Euclidean spaces and their representation, linking the sciences, philosophies and the arts in the late 19th and 20th centuries. Likeo Cusa's example of how theoretical ideas are influenced by developments in the arts, ideas of non-Euclidean space or a space of infinite dimensions was elaborated on and investigated visually by the artists

[221]Nicholas, and Emma Gurney-Salter. *The Vision of God Nicholas of Cusa [I.e. Nicolas Cusanus]*. New York: Ungar, 1960. Online version: Cosimo Classics, New York (2007). Originally published by Cusa in 1453.
[222]N. Cusa, p. xii
[223]Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art*. 2nd ed. Leonardo. Cambridge, Mass: MIT Press, 2013.

of the late 19th and 20th centuries belonging to the Cubist, Dada and Futurist schools, among others.[224]

It is evident from these two examples that the notion of everywhere emerged from geometry and the arts and can be interpreted as transcendence from three dimensions, conceptualizing infinity. However, I do not aim to embark on a full examination of the notion of 'everywhere' as a perspective on its own. What is relevant for this study is examining Kepler's and Thom's ideas in reference to perspective. Studying perspectives and viewpoints is not explicit, nor is it a common practice in the exact sciences. Perspective studies and practices of representation are more common in the arts, beginning with the Renaissance painters and continuing into the 20th century with abstraction and dissolvement of perspective. Therefore, I will focus on extracting how 'everywhere', as a dimensional perspective, i.e. a perspective that is aware of its angle (or angles) of observation, can be understood in Kepler and Thom's writings, and elaborate on it with comparable examples of perspective practices from the arts.

We can begin the quest towards 'everywhere' by examining the first question noted above: in what sense can a perspective be infinite or potentially infinite? Our human minds cannot easily grasp the concept of infinity as it denounces any definite boundary. The first chapter of this thesis showed how our minds are able to perceive data as intelligible when placed within boundaries, whether they be conceptual or structural boundaries of form. In a sense, observing nature with the ends of understanding it is a process of isolation, which may or may not be followed by synthesis and integration of multiple perspectives. As such, we need to examine how concepts of continuity, boundlessness and space were conceptualized by Kepler and Thom, alongside ideas of boundary making and isolation.

The process of isolation is necessary, as I have noted before, for scientific investigation, since only through isolation of natural phenomena can boundaries be defined, and practices of measurement be made possible for precision and accuracy. Nevertheless, the process of isolating is an act of structuring, before it is an act of measuring. By structuring, defining a relation or configuration of sorts, the observer assumes a specific perspective into nature by opening up a stencil (window) into a specific

[224] See index for terms 'Cubist', 'Dada' and 'Futurist' in L. D. Henderson

location so to speak. A structure, then, is a perspective, an 'open window' or new stencil. The interesting question to consider here is: does the observer become enmeshed in the structure and truthfulness of this specific perspective, i.e. continues into more precise acts of isolation (isolation being the ontological necessity for quantities and counting as seen in the first chapter, pg…)? Or does the observer remain mindful of dimension and aim to examine the structure from another stencil? (dimension being the ontological necessity for structural quality and molding as seen in the end of the first chapter page 66).

We can begin with looking at Thom's objectives, as depicted in the beginning of his book. I earlier remarked that Thom believed that phenomena transpire in a space of infinite dimensions (page 60). Like Cusa, he wanted to free the scientist's observational intuition from a three dimensional space in order to develop an intuition that can perceive processes beyond the third dimension (as seen with the folds in the first chapter). He explicitly declared his aims by writing:

> "We therefore endeavor in the program outlined here to free our intuition from three-dimensional experience and to use much more general, richer, dynamical concepts, which will in fact be independent of the configuration space. (…) in fact, the universal model of the process is embedded in an infinite-dimensional space."[225]

While one cannot hope to actively see or perceive infinity, Thom aims to find topological models that are independent of the three-dimensional space we see and perceive. By thinking in these terms, a scientist can see a process and its indeterminacies from a transcendent perspective.

An example of this idea is elaborated on early in the second chapter of Thom's book, where he discussed scientific observation. Reminding the reader that the universe is not chaos, he remarks that, as observers, we notice the recurrence of typical forms and patterns. But since the scientific observer or experimenter cannot observe the entire universe at once, patterns must be isolated in order to be studied further. Thom then describes the process of isolation for measurement by writing:

[225]R. Thom, p. 6

> “For his experiments and observations, (the experimenter) is compelled to isolate a subsystem S which is relatively independent of the rest of the universe. In practice he isolates and observes S in a box B whose geometric characteristics and the nature of whose attached measuring devices he specifics.”[226]

What follows, according to Thom, is the experimenter’s precise and complete description of B. This precise description is done with the intended hope that another experimenter in another location would produce space B’ and subsequently achieve the same results within the margin of error. Thom then questions if B and B’ are indeed the same, pointing out that S can never be completely isolated from its interaction with the outside world. What Thom referred to here, is the inevitable continuity that transpires between the phenomena S and its environment, implying how isolation is a method for intelligibility that should not be taken too literally or rigorously. He purposefully pointed out the experimenter’s enmeshment in the isolation process, i.e. in the stencil that was opened, as opposed to the phenomena it was opened to.[227]

Thom’s intention was to understand phenomena S in configurational terms, as opposed to precise quantities, by defining what he calls isomorphic processes. In this sense, S and B are now both seen as components of the same process or phenomena, since they are examined in relational terms and not isolated terms. In other words, Thom aimed to define the relational conditions of an environment that cause a specific structural phenomenon to emerge and not the exact measured conditions. This idea encourages the implication that the enmeshment in B, as seen with the experimenter, happens as a result of definition through isolated measurement alone and not through relational configuration. By turning our attention to relational configurations, we can think in terms of comparable processes and search for them in different locations, or in other words, open up other stencils. Thom, therefore, aims to find archetypal structures of a process: being able to recognize a process in terms of its environmental structure allows the observer to know what influences and mechanisms are at play. As a result, the observer of a similar structure

[226] R. Thom, p. 15
[227] See R. Thom, pp. 15-19

elsewhere can a) understand what influences and mechanisms might be involved, and b) perceive parts of the process that are indeterminate or unobservable for measurement.

This structural understanding of relations was present in Kepler's theory and defined in terms of harmonic relations. As he only defined one archetypal structure, harmonic relations, we can more plainly see how he used this structure to open up possible stencils into nature. According to him (and like Thom), the universe is a whole that can be divided according to infinite quantities and configurations, albeit not all of them intelligible or ordered. What separates the finite from the infinite, according to him, are the boundaries we place around forms or concepts for the purpose of grasping them. Abstracting those boundaries to their basic relational configurations allows one to search for them in various locations. In the introduction to the fourth book of the *Harmonices*, he pointed out the common mistake of attributing an archetypal structure to only one sensible location: "For since the philosophers commonly look for harmonies nowhere else but in melodies."[228] Kepler pointed out the misconception of seeing a natural phenomenon in a one dimensional way, by unnecessarily attaching the underlying relations with the sensible manifestation. Kepler's consideration of harmonies as a natural law, one that was defined first and foremost by structural relations, allowed him to search for the same relational terms in diverse locations, from planetary motion and music, to the shapes of plants and the human body. Kepler is aware here of what Thom would later call an 'isomorphic process'.

The analysis of the view from everywhere thus far presents a number of important aspects to the idea of observation. First, there is the notion of transcendence. By focusing observation on structure and configurations instead of exact measurement, the observer can transcend the common perspective of seeing processes in the third dimension. Moreover, this perspective transcends a specific discipline and places the study of process in a meta field of its own. Here, observation of processes should not be restricted to one isolated disciplinary perspective, but rather be understood as an investigative tool into an infinite number of processes, from physics and biology to language and economy. In this sense, the quest towards a view from 'everywhere' may be considered to have two facets of

[228] J. Kepler, p. 283

multidimensionality: the first being the superimposition of several disciplinary fields, and the second being an investigation into the mental explorations of a multidimensional reality. Thinking in terms of the view from everywhere and structure, sheds light on the limited perceptions of a disciplinary perspective and stresses the importance of the study of structure and form, both visually and mathematically.

Following the first, the second aspect can be seen in the fundamental unity enforced by the view from everywhere. The view from everywhere links processes from different disciplines, but more so, it emphasizes the connection between subject and the definition of the object in observation. It reveals isolation as a necessary tool for scientific activity, but not as a natural truth. And third, the view from everywhere raises an important concept that was touched upon throughout this thesis, that of mathematical rigor and the value of conceptual disorder. A view from everywhere urges us to reconsider our treatment of what we deem to be disorder. It exposes the merit in Bergson's assertion that there is *more* in the idea of disorder than order, and shows us that there is much to be gained by loosening the grasp of rigor.

| Stretching Perspectives

Comprehending the view from everywhere and the latent qualitative considerations in quantitative investigations, raised the subject of mathematical rigor a few times throughout this thesis. It first came up in the first chapter with the concepts of non-forms in Thom's work, followed by Kepler's preference of the term 'inexpressive' numbers over 'irrational' numbers. Both scholars placed explicit importance on properly referring to and defining this realm of mathematics. During the process of working on this thesis and discussing it with my supervisor Marcel Boumans, he pointed out that these notions are comparable with what are called mathematical 'monsters'. In his inaugural address at Utrecht University titled "Historicism and its Monsters",[229] he discussed how the creation and definition of 'normal' types ultimately interprets what is found in the periphery of such definitions as

[229]Boumans, Marcel, "Historicism and its Monsters", Inaugural address at Utrecht University, December 2021

‘not-normal’ or ‘monsters’. The non-normal, therefore, offers an opportunity to study our manner of formulating and stabilizing ‘normal’ concepts. Perspective can also be studied by examining what is in the periphery. I am therefore compelled to follow suit and examine how artistic practices of perspective studies may relate to scientific observation in reference to the view from everywhere.

Voices criticizing mathematics as pure logic sprouted throughout the late 19th and early 20th centuries. This became apparent in quantum mechanics, as pure calculation appears to defy the logic cultivated within the paradigm of classical mechanics. But while paradoxical developments in quantum mechanics did not permit physicists to abandon the implausible direction the calculations steered them towards, the usefulness of what would be called mathematical ‘monsters’, i.e. paradoxes in mathematical reason, were questioned in the field of pure mathematics.[230]

The late 19th century had seen the discovery of anomalies in the discipline of pure mathematics, when cases of function that resisted classification according to the known order began to emerge. This led to a crisis in the foundation of mathematics; the intuition that numbers and mathematics alone can objectively capture the truth of our reality appeared false, since irregularities were discovered within the internal logic of mathematics. In light of these discoveries, mathematicians doubted their own intuition and understanding of the discipline. The mathematician Henri Poicaré was the first to name such anomalies in their recognizable name ‘monsters’, when in 1913 he wrote that “Logic sometimes makes monsters. Since half a century we have seen arise a crowd of bizarre functions which seem to try to resemble as little as possible the honest functions which serve some purpose.”[231] Similar to the biological use of the term ‘monster’, such a reference was used in cases of mathematical objects which resisted classification or the known mathematical order.[232] Mathematical traditions, the Platonists among them, would reject these mathematical or geometrical objects (such as irregular polyhedra), and categorize them as exceptions or ‘irrational’, as previously pointed out by Kepler himself.[233]

[230]Aberdein, Andrew, “Mathematical Monsters.” *Arxiv* (2019 04 19), 2019, p. 3
[231]Ibid.
[232]Ibid.
[233]J. Kepler, p. 21. I previously referred to this in the first chapter. Kepler urged that we should refer to them as ‘inexpressible’. These cannot be considered ‘irrational’ merely because of our inability to definitely speak of them (meaning they do not fit within our existing definitions).

But instead of denying these 'monsters' or 'irrationals', certain mathematicians supported studying them (as Kepler suggested studying them). Their investigation yields further knowledge and develops our mathematical reasoning. Similarly, in the 20th century philosophers such as Imre Lakatos proposed to study mathematical and geometrical anomalies. In his famous work *Proofs and Refutations*,[234] Lakatos inspected this idea through geometry. He asserted that if one wishes to examine any concept in depth, one must examine it in its extremities. Examining places where prevailing logic fails allows one to learn more about pre-established order and concepts. He wrote that "If you want to know the normal healthy body, study it when it is abnormal, when it is ill. If you want to know functions, study their singularities."[235] In other words, to comprehensively study a concept, according to Lakatos, one must stretch it to its limits and study its boundaries. Stretching the concept to its limits to understand where it breaks down is known as 'concept stretching'.[236] True observation of a theory, concept or structure, requires us to move from its definite center to its indefinite edge. Moving to the conceptual edge, we assume a new perspective when observing a structure or object. The edge allows us to examine the boundary of our stencil.

The 'monsters' Lakatos urged us to study are essentially the disorder and 'non-forms' we have also seen in Thom's analysis. These are the misfits that cannot be classified or the 'noise' around the linear representative line. The main property of such objects is "resistance to categorization."[237] They are reflections of the established order because they resist it. Monsters, noise and non-forms reveal how linear lines and definite categories are a product of our own molding and not of natural circumstances. Lakatos wrote about this: "monsters don't exist, only monstrous interpretations."[238] Examining the objects and concepts that do not fit in the prevailing order is an opportunity to flip the perspective. So instead of standing within the order looking outwards at the world through it, our position is now on the outskirts of the order looking inward. The established order is now the object of investigation.

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[234] Lakatos, I. "Proofs and Refutations (i)." *The British Journal for the Philosophy of Science* 14, no. 53 (1963): 1-25.
[235] I. Lakatos, p. 25
[236] A. Musgrave and C. Pigden, "Imre Lakatos", *The Stanford Encyclopedia of Philosophy* (Summer 2021 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/sum2021/entries/lakatos/>
[237] A. Aberdein, p. 397
[238] Quote of Lakatos given in A. Aberdein, p. 396

Flipping the perspective and placing the order in the center, the way in which we mold and structure our reality and the sensible data we perceive, and studying its exceptions, forces us to evaluate this structure from many different viewpoints. This is clearly reflected in Lakatos's *Proofs and Refutations*. He structures the book as a dialogue taking place in a classroom between a teacher and his students, aiming to prove the Euler conjecture and encountering monster polyhedra, such as the hollow cube. Their dialogue and investigation of the 'monsters' forced them to take on and try out many different arguments and perspectives aimed at preventing or removing the misfits. This circuitous route slowly revealed their own lack of understanding of what a polyhedron was, when they first began their investigation. Moreover, it exposed the reader to the dimensional and non-linear nature of observation and understanding. Monsters, non-forms and noise arise as a crucial aspect of *form-ulizing* concepts, and must be studied alongside the concepts themselves. They expose to us how a concept is form-ulized, and reveal that a well form-ulized concept or structure must be analyzed and examined from all possible perspectives. It must be inspected and viewed from everywhere.

Concept stretching, or perspective stretching, is present also in Kepler and Thom's theories. Prior examples to the view from everywhere presented in the previous section revealed that a dimensional perspective is easily related to and illuminated by art. I will therefore discuss Kepler and Thom's theories by providing two short comparable examples from the art world.

Harmony is the central concept in Kepler's *Harmonices*. By arguing that harmony is not a property of music but an attribute of many natural phenomena, he stretched the concept of harmony into new domains and used it as a stencil through which he inspected the world (although this type of stretching is different from the one presented by Lakatos). He began by establishing, form-ulizing, the basic terms of the harmonies with forms and structures and then depicted these terms in mathematics. But the harmonies could not perfectly account for planetary motion. Kepler then resolved that the principle of harmonic ratios alone, as they arise from the platonic solids, could not account for the structure of planetary motion (see page 104). In another section, Kepler explains that if perfect harmonic order was found in the proportions of the paths of the planets all their other features would be constrained “so that there would be no room for taking thought for harmonies elsewhere.”[239] On one hand, we see him struggle with the ‘noise’ that arose around his perfect structure. On the other hand, he realized that a perfect distribution of harmony on one angle of the system would restrain the rest of it. A measurement that is too rigorous from one perspective would distort and constrain other perspectives. Deviation from the perfect measurement is thus necessary for the system to work as a whole.

The idea that exact measurement taken from a singular perspective causes an artificial distortion can be demonstrated in the tension between linear and scientific perspectives studied by Italian Renaissance artists roughly two-hundred years earlier. As some of the best practicing mathematicians and philosophers of the 15th century, Renaissance artists aimed to create the illusion of depth on a two-dimensional plane by studying the tension between dimensions and imagining they were tracing a landscape reflected through a glass window. ‘Linear perspective’ preceded ‘scientific perspective’ and was first turned into a canonic methodology for the creation of three-dimensional illusion by Leon Battista Alberti in the early 15th century.[240] An exemplary painting of linear perspective is a fresco created by Masaccio titled *The Holy Trinity*. Considering the perspective of the viewer (which was calculated according to the vanishing points marked by the black lines on figure 14 below), the painter measured the painting’s perspective from one specific angle. Figure 14 depicts how linear lines connect at the observer's viewpoint to create the illusion of depth in the two dimensional painting. Figure 15 displays the perfection of the precise calculations: studying proportion on the two-dimensional plane can allow us to extract the measurements needed to recreate the painted structure in three dimensions.

[239] J. Kepler, pp. 423
[240] J. Kappraff, pp. 248-250. And Peterson, Mark A. *Galileo's Muse : Renaissance Mathematics and the Arts*. Cambridge, Mass.: Harvard University Press, 2011, p. 143

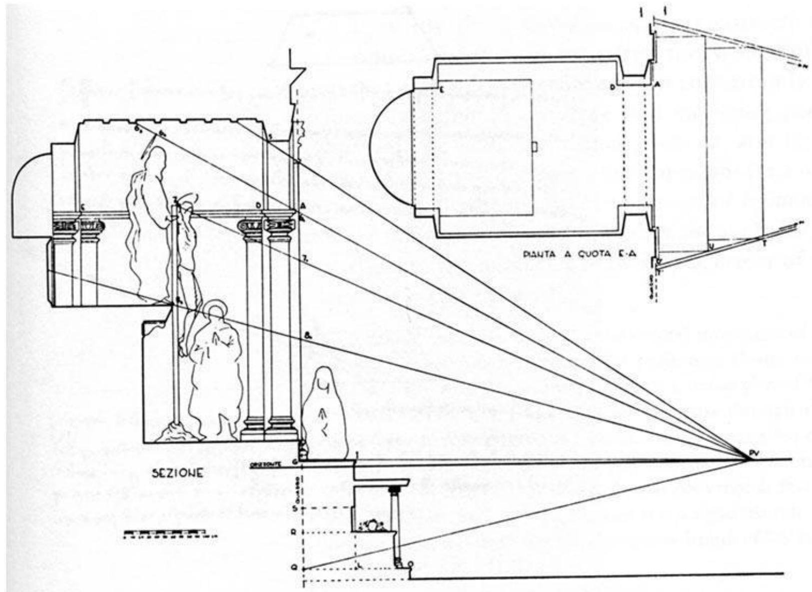

Figure 14: Masaccio, 1427

Figure 15: Three dimensional study of Masaccio's chapel

A close observation of Masaccio's fresco would reveal the slightly artificial or plastic appearance of its content. While the traditional tools of perspective created a convincing illusion, a calculation of perfect ratios from one specific perspective results in a strained appearance from any other perspective.[241] This idea is similar to the reasoning Kepler demonstrated above. There must be a deviation from perfection, a depiction of the 'noise', to arrive at a more natural depiction. In this sense, perfect measurement does not suffice, multiple varying perspectives must be accounted for.

Leonardo da Vinci further studied and developed what we now call 'scientific perspective' ('natural' in da Vinci's words), as opposed to linear. It was aimed at reconciling the different perspectives one may assume upon observation. Instead of a strict measurement he performed once, da Vinci observed his object of study empirically, in a series of observations. His investigation centered around perceptual changes that emerge when the objects, the picture plane, and the observer assume various relations and positions.[242] He realized that there are several different types of perspectives. The boundaries of objects in the visual field are distorted and 'stretched', so to speak, according to the perspective and distance one assumes when observing. The closer the plane of

[241]Ackerman, James S. "Leonardo's Eye." *Journal of the Warburg and Courtauld Institutes* 41 (1978): 108-46, p. 10
[242]Bod, Rens, *A New History of the Humanities : The Search for Principles and Patterns from Antiquity to the Present.* Oxford: Oxford University Press, 2014, p. 215

vision, the further the object stretched and distorted. This perspective is most famously depicted in the skull painted in the bottom of Hans Holbein's The Ambassadors (figure 16).[243]

Figure 16: Hans Holbein, The Ambassadors, 1533

Da Vinci understood that the boundaries of elements in the image changed according to people's different movements and perspectives as they move. Da Vinci then introduced blurry, opaque and less defined, curved lines, 'noise' in other words, into his paintings to make them appear more natural. In figure 17, his study of perspective in pencil displays how the interaction of various relations within one structure causes 'noise' or deviation from the stable perfected structure. He understood that rigorously measuring linear lines was not enough; observation meant movement of one's own perspective and therefore movement of perceived boundaries.

Da Vinci's example can be seen as a visual metaphor to Kepler's resolution. He understood that the relations of an organic system, such as the motion of the planets, do not align perfectly as they do with ideal geometric inspection. In da Vinci's case, the relations of an organic system are represented by the dynamic interaction between the observer, the objects and the picture plane. A natural depiction of these relations was only achieved when exact measurements were veiled by deviating 'noisy' lines.

243 J. S. Ackerman, pp. 112-113

Kepler's and da Vinci's examples are not directly comparable with the type of 'concept stretching' Lakatos advocated, but they illustrate the value and necessity of studying deviation from the rule and molding our internal order and structure according to the 'noise' and exceptions that arise from our observations. Moreover, they display a compelling example to the view from everywhere, and its application to observation, and how the measurement of certain parts of the object of observation changes with a change in perspective. A structure or geometrical object must be inspected from numerous perspectives, quite literally *everywhere*, to fully comprehend its terms and relation to a broader system.

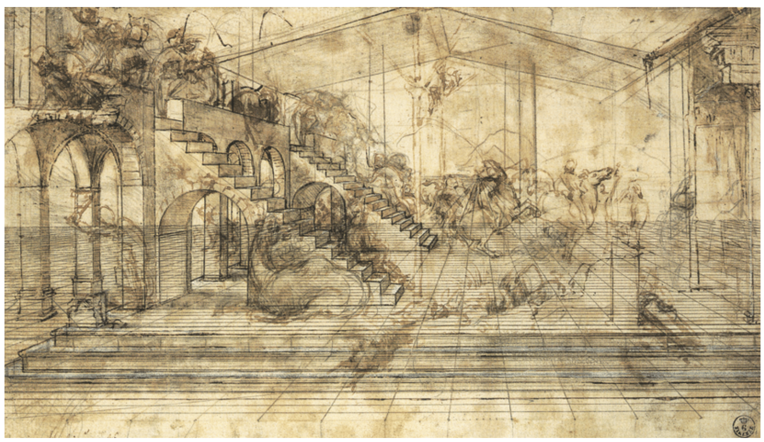

Figure 17: Leonardo da Vinci, study in perspective for the 'Adoration of the Magi' painting

A more analogous type of concept stretching to that of Lakatos can be seen in Thom's notion of non-forms. Thom examines the boundary between a form we do not yet understand and a non-form, the boundary between order that has not yet been discovered (but can potentially be discovered) and fundamental non-order. This idea is also present in his topological investigations. He examined structural morphology, essentially questioning how far a form can be stretched and how many catastrophes it can endure while still remaining recognizable as the same fundamental phenomenon. Thus, Thom examines the structural limits of natural phenomena by stretching them, i.e. examining them in their topological edge, searching for the boundary in which they cease to be themselves. He does so by focusing on the underlying structure of the phenomena and searching for structural archetypes, the generalities of morphogenesis.[244]

[244]Towards the end of his book, Thom makes a short, interesting comment about perspective in a subchapter title 'The Origin of Geometry'. He writes "this is how geometric space is made up, a space of pure unmotivated

Thom's example of concept stretching can be visually represented with the exquisite early 20th century sculptures of Constantine Brancusi . Brancusi is often referred to as the father of modern sculpture. Greatly influenced by Plato's notion of archetype, his aim was to depict timeless ideas in form.[245] For him, forms change with time and, therefore, what is truly timeless is an idea, an essence that underlies many individual forms. His work can be seen as a study of qualitative metamorphosis. In other words, he examines the boundaries within which the original complex form, for example a bird (see example below), retains its essence when undergoing a process of simplification. To find this underlying archetypal idea, Brancusi would begin with a more detailed sculpture representing the concept he had in mind and would gradually begin stripping it of its individual features.[246] Over a series of numerous sculptures, he visually stretched the concept to its conceptual boundaries. With each sculpture he removed more individual 'noise', examining the tension between complete abstract shape and conceptual essence.

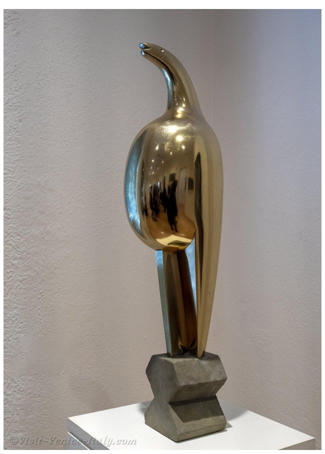

Figure 18.1

Figure 18.2

Figure 18.3

What Brancusi meant to capture in essence, was the reality of life (as opposed to

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movement: the space of all the play-movements of which we feel we are capable." (R.Thom, p. 314). Later in the same page he referred to this as a "appreciation of metrical space." In a short description of this development in early age (responding to psychologist J. Piaget), he remarks that this basic intuition does not extend to one's ability to represent it visually. This task is far more complicated. He gives the example of a child aiming to draw a car, drawing the wheels as they would be seen head on (as when looking at a car from the side) and the rest of the car from its top. He reasons that semantic dominance gives certain objects a "privileged perspective". When there are several sub-object to an object, such as wheels to a car, the privileged perspective overpowers the requirements of the global one. Thom does not elaborate further on this theory, but it is nevertheless an interesting observation in reference to a global view or view from everywhere.

[245] Livia-Ionela, Baciu, "The Archetypal Forms in Brancusi Sculptures. a Syntactic Interpretation." *Acta Universitatis Danubius: Communicatio* 5, no. 2: 22-30. pp. 22-23

[246] Shanes, Eric. "Ideal Forms : Brancusi the Platonist." *Apollo* 171.2010, 574, 108-113 (2010). pp. 110-111

lifelessness) which can be understood as either something that is dead or a lifeless reproduction of the original (this he considered to happen when exact copying of the original image or object took place).[247] This idea was explored through several themes. One example is seen with the theme of the bird. In a series that expanded over three decades, Brancusi explored the essence of a bird and its interaction with time and its surrounding space in a series of sculptures made from diverging materials (casting metals such as bronze and gold and eliminating materials such as marble and wood). What begins as a more detailed and stationary representation of a bird (Figure 18.1, explored from 1910-1915) gradually evolved to a 'bird in space' and finally 'bird in flight', in which Brancusi aims to capture the essence of a bird ready to take flight (Figure 18.3, final phase lasting from 1923-1941).[248]

The concept stretching in Brancusi's work illuminates Thom's philosophy in a number of ways. First, it shows how the search for everywhere arises as a search for archetype, a generalized structure that can represent infinite natural morphologies in Thom's case, or birds, in Brancusi's. Second, it displays how the forms we perceive are entangled with conceptual ideas. Brancusi visualizes how forms and concepts are of the same nature; both can be examined through the stretching of boundaries (in fact, Brancusi would argue that the essence, the idea, is the real element which precedes the form).[249] In order to explore and comprehend the underlying structure, a conceptual essence must be equally explored. Third, like Thom, Brancusi's work plays with the notion of recognition. He asks what the fundamental essence that allows recognition (of a form or a concept) is? His work reminds us that pursuit of the generalized law, faces the risk of losing meaning. The boundary between streamlining the structure and the impairment of meaning with an acute elimination of noise is thin.

One last comparable point in Thom and Brancusi's works (and arguably also in Kepler's and da Vinci's) is found in the basic way we perceive form: The form undergoing change is not merely the stretching of the individual object and its internal movements and morphologies. A form also arises as the structural coupling and interaction of it with

[247]Ibid.
[248]Lazevnick, Ashley. "Impossible Descriptions in Mina Loy and Constantin Brancusi's Golden Bird." *Word & Image* 29, no. 2 (2013): 192-202, p. 196.
[249]E. Shanes, p. 110

additional elements in its environment. For example, Brancusi's later sculptures did not just depict a bird, but represented a bird in space or a bird in flight. In this case, the form must account for the bird as well as the space it is found within; the structure must represent the dynamic idea of 'flight' as well as 'bird'. Consequently, we see a stretching of the bird's form to include the essence of space and potential flight. The contour of the structure now stretches upward (figure 18.3), and our eyes follow the new streamlined boundaries in a vertical pattern. The basic structure of the bird then changes to encompass a dynamic idea that goes beyond the bird itself.

A comparable idea is seen in Thom's theory of the 'capture chreod' (the term chreod was introduced in the section 'Archetypes and Inner Molds'). In this archetypal structure, the form in question extends from the eating/digesting organism to encompass the eating organism along with the capture and ingestion of external food (another organism).[250] The topological structure he examined in these types of chreods, stretched the original form of the organism as an individual to the individual capturing or ingesting food. In this sense, the form is intrinsically dynamic as its definition insinuates metabolism. And in all actuality, can an organism be examined without the inclusion of its capturing functions and food that generates its morphogenesis? This idea further emphasizes the question of boundary in relation to concept and form. By stretching a form to include its dynamic environment, we are faced with the reality of the presupposed boundaries we place on concepts. Once again, thinking in terms of concept stretching confronts us with our inner molds; our own inner order and structuring finds itself in the center of inquiry again.

In the beginning of the first chapter, boundaries came up as a pivotal difference between quantity and quality: quantity refers to what has already been defined and separated by boundaries, while quality explores the nature and placement of boundaries themselves. Shifting from observation that is result driven, as seen with quantitative activities such as measurement and counting, to an observation that aims to first and foremost understand

[250]R. Thom, pp. 187-191. In these pages Thom described the basic topological nature of the 'capture creod'. He began with examining the singularities in unicellular organisms such as the Amoeba as a local model. He wrote: "It is obviously out of the question to describe all the diverse morphology of seizing of prey throughout the animal kingdom, but we may hope that the local singularity of the potential that gives rise to it is fundamentally the same in all species." (p. 190).

the structure of the form observed, places the notion of boundary once again in center stage.

The view from everywhere focuses observation on the establishment of boundaries before they have been stabilized and presumed. It focuses on the choice of perspective before stabilization. 'Everywhere' destabilizes the boundaries of phenomena and therefore introduces indeterminism. By shifting attention to dimensionality in observation, as opposed to countability for example, indeterminism can be more comfortably included. Dimensionality reminds us that our perspective is not determined and that the boundaries we perceive may change according to our perspective. The boundaries we refer to are, therefore, dynamic, and dynamic boundaries imply that phenomena are essentially not determined. Only by stabilizing boundaries can we approach nature as predetermined. And it is this idea that brings our own inner molds, ordering and reasoning into the picture.

The idea that observation and boundaries are originally dynamic is also seen in Bergson, whose philosophy saw reality as being in a state of constant flux. He wrote that "Reality is a global and undivided growth, progressive invention, duration: it resembles a gradually expanding rubber balloon assuming at each moment unexpected forms."[251] The reality and forms we perceive, according to him, are not stable and in a state of constant evolution. In the following sentence, he reminded us that it is our inner mold that aims at stabilization.

> "But our intelligence imagines its origin and evolution as an arrangement and rearrangement of parts which supposedly merely shift from one place to another; in theory therefore, it should be able to foresee any one state of the whole: by positing a definite number of stable elements one has, predetermined, all their possible combinations."[252]

Bergson notes that stabilizing elements is a product of our intelligence, of our inner sphere. A stable determined reality can, therefore, only be a result of our commitment to a specific perspective and thus, its stable boundaries.

[251] H. Bergson, 2002, p. 226
[252] Ibid.

Representing a reality that is in constant flux, either scientifically or artistically, is highly challenging. Such a reality can be intuited rather than properly analyzed. Nevertheless, as seen throughout this chapter, artists commence in areas still out of reach of scientific analysis. Futurist artists, such as Umberto Boccioni and Gino Severini, were influenced by Bergson's philosophy. Their art was aimed at capturing dimensional transcendence. Through their artistic studies of dimensionality and non-Euclidean geometry, they too conceded that perception of higher dimensions necessitated the coupling and identification of object and subject, inner and outer, movement and forms.[253] A dimensional view does not only question pre-established boundaries in the outer sphere, but subsequently obscures the boundary between the inner and outer spheres.

The view from everywhere reminds us that observing boundaries in the outer sphere inevitably circles back to self observation. And this is the challenge the view from everywhere faces us with: it stretches the sphere of inquiry from the outer to the inner and confronts us with our inner molds. It challenges us with infinite possibilities of perception and undermines our basic intuitions and determinism. In Bergson's words "Evolution becomes something quite different than the realization of a program: the gates of the future open wide; freedom is offered an unlimited field."[254]

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[253]L. D. Henderson, pp. 170+228 (Boccioni) +444 (Severini). Boccioni and Severini, who were contemporaries of Brancusi, engaged in comparable investigations. They also aimed at finding the eternal inner core of ideas. Boccioni referred to "a new inner reality" through which this search was conducted (p. 228). Severini noted that capturing the essential and eternal meant "the different perspectives which constitute (the) total form." (p. 444).
[254]H. Bergson, 2002, p. 231

Conclusion

Whatever the true nature of reality may be, forms render that nature intelligible. After completing his *Morphogenesis*, Thom himself noted that "reality presents itself to us as phenomena and shape."[255] His approach to form, along with Kepler's three-hundred year earlier work, highlighted how forms, whether they be external in the outer natural world or within our inner spheres, can be studied as devices of 'sense making'. Forms are revealed to us as the frames which organize the content of our inner and outer landscapes. They package the multiplicity of sense data we are bombarded with daily, and by doing so, they allow us to mold concepts which demarcate one sensible experience or object from the other.

Investigating the gap between quantitative and qualitative in science throughout this thesis, has clarified their interaction in knowledge creation; when a certain discipline or domain of knowledge deepens and develops its knowledge, the need for quantitative concepts aimed at accuracy and precision grows. The quantitative expands our knowledge into a specific stencil once it has been set. However, the quantitative cannot form and shape new concepts–it does not weave new conceptual fabrics, nor can quantities alone open up new stencils. They can only hint towards the necessity of developing innovative stencils, when what we measure refuses to fit the stencil in current use; or as seen during a paradigm shift, when old tools no longer suffice in answering new questions and anomalies.

By focusing on the qualitative aspects of natural phenomena through form, we shift the focus from precision and accuracy to something more primordial. Qualitative investigations question what must be measured and quantified to begin with. Through qualitative investigations and forms, we examine, mold and modulate conceptual boundaries. Within this process of molding, we distort and rearrange our data, finally

[255]Quoted from D. Aubin, p. 119

redefining and re-forming the new concepts that are more suitable for a necessary new stencil. Stepping outside of familiar definitions and stencils allows us to reexamine our concepts in a new light.

It is this aspect of 'newness' that Thom believed displeased the modern scientist when it came to qualitative investigations. He wrote that "what condemns these speculative theories in our eyes is not their qualitative character but the relentlessly naive form of, and the lack of precision in, the ideas that they use."[256] Qualitative investigations reflect an alteration rather than a deepening,a reshuffling, a re-ordering of knowledge. They display the circular nature of knowledge creation. Knowledge cannot be deepened endlessly in a linear fashion through mathematical rigor and accuracy. Reformation and rearrangement is necessary for its growth and further articulation. It is in these phases of knowledge creation that free speculation, or what has been referred to as "mathematical terrorism" in reference to Thom's speculative approach, is needed.[257] As shown throughout this work, in times of scientific crisis, both Kepler and Thom turned to forms (the platonic solids in Kepler's case and natural forms in morphogenesis in Thom's) to speculate and guide a new observational approach, a new stencil and subsequently model. These speculations, such as in Kepler's case and the universal model based on five platonic solids, may prove to be wrong, but they are nevertheless a necessary process of scientific trial and error. In this sense, the uneasiness surrounding qualitative inquiry can be seen as the growing pains of a science or domain of knowledge.

For Kepler and Thom, mathematics was a creative philosophical tool, one that can conceptualize and 'make sense' of natural phenomena, by examining orders and relationships. Their philosophies have shown that by placing form and quality at the center of our investigation into nature, through algebraic geometry or topology, we can develop new models and concepts to add to our investigative toolbox. Similarly, artists such as da Vinci and Brancusi, used the investigation of form through their art to develop philosophical and observational ideas, displaying the creative identity that connects the

[256]R. Thom, p. 6
[257]D. Aubin wrote this about Thom's approach to mathematics in his development of his catastrophe theory. Full quote: "Always a mathematical terrorist, Thom used mathematical notations and language only to express vague correspondences among neurological states, thoughts, and language." D. Aubin, p. 115

mathematician and the artist. Cassirer discussed this relationship between science and art and referred to their creative products by stating:

> "Thus (...) the various products of culture–language, scientific knowledge, myth, art, religion–become parts of a single great problem-complex: they become multiple effort, all directed toward the one goal of transforming the passive world of mere *impressions*, in which the spirit seems at first imprisoned, into a world that pure *expression* of the human spirit."[258]

The compilation of ideas, perspectives and practices of both artists and philosophers of science presented throughout this thesis have demonstrated that forms are not only tools through which we organize the world, but also relational objects in need of investigation in their own right. In other words, forms are not only agents that allow us to detect patterns in the outer world, but are testaments to our own inner structure and perspective towards the outer world.

What many of the sources, from Thom and Kepler to Cassirer and Deleuze, have in common is that they view forms as a relational construction. Forms are 'instruments of knowledge' or a 'complex logical relation' (to use Cassirer's words).[259] Through forms, points of data are colligated together (to reference Whewell) and in-form the observer by displaying an order–a set of relations. In a form, a set of data points assumes a relation, a specific type of dimensional ordering. It is this notion that was reflected in Kepler's idea of harmony: "For the order of which we are speaking here is a relation, and the things which are ordered (musical sounds) are related to each other."[260] Forms determine a complex order that is multidimensional and non-linear.

What makes the order complex is the presence of the observer, who is also a point from which the order is viewed. Therefore, changing one's viewpoint subsequently changes the order that is perceived; changing my perspective may bring me closer to some points and further away from others, or it may flip the entire form upside down and reconfigure a new hierarchy. Becoming aware of the form in which the data is colligated together, i.e. the

[258] E. Cassirer, 1954, p. 80
[259] E. Cassirer, 1954, p. 75-76
[260] J. Kepler, p. 290

imaginary lines upon which we draw connections and relations between points of data and ourselves, provides a window through which we can extend our inquiry into our own perspective. Observation then arises as an act which can be directed inward (beyond a psychological sense) and not only outward towards the observables in the outer sphere.

The manner in which we form-ulate our knowledge of the world can be used to study the perspective of the scientist. Like the artist analyzing and studying the perspective from which to paint objects, as seen with da Vinci, scientists can become aware of their own disciplinary perspective, their own form of objectivity. The medium used and the conceptual objects developed, reflect the individual's or discipline's observational perspective. In this sense, objectivity is also relational to a specific discipline. Cassirer himself warned us that the natural physical object never perfectly corresponds to the disciplinary conceptual object and noted that

> "If the object of knowledge can be defined only through the medium of a particular logical and conceptual structure, we are forced to conclude that a variety of media will correspond to various structures of the object, to various meanings for "objective" relations. (...) because physical, chemical, biological knowledge frame their questions each from its own particular standpoint and, in accordance with this standpoint, subject the phenomena to special interpretation and formation."[261]

Disciplinary concept formation (whether it be scientific or artistic) can thus be used to examine perspective, and through this examination different forms of objectivity can be determined. In this sense, as Cassirer argued, objectivity is not absolute, but relational. The logical and conceptual structures that are not transferable between disciplines, point towards the areas where the perspective of the discipline is particular or partial, and not absolute.

As philosophers of science, these areas of disciplinary gaps, spaces, or incommensurability, should be of a particular interest to us. The still unstable and undefined domains of disorder are spaces rich with potential new forms, orders, concepts and subsequently knowledge. According to Bergson, these areas of disorder, indeterminism

[261] E. Cassirer, 1954, p. 76

or apparent 'nothingness' are not actual but merely "the absence of what we are seeking, we desire, expect. (...) But in reality, there is no vacuum."[262] The space of indeterminism, as argued by Bergson, is the domain of competing options, of new fabrics of experience, the domain of multiple orders and possibilities–the space of true creative freedom. Examining the spaces of indeterminism, as Thom did, and moving beyond the sharp boundary of definition into a more blurred space, as seen with Lakatos, is how we can examine our perspective and shift it.

For this reason, shifting our focus to quality and form in scientific knowledge creation is necessary; it reminds us that knowledge, like forms, is dimensional and relational. And partaking in knowledge creation inevitably places us *somewhere* in relation to our object of investigation, within the 'everywhere' of possibilities. By assimilating this notion of dimensionality back into awareness, an opportunity opens for scientists (and other creators of knowledge), that allows them to move around their object of investigation more freely. Instead of only moving in the direction of depth and further articulation through precision, one can move around towards playful speculation or other disciplines and spaces of knowledge. This is for the sake of examining the validity of their order, their own perspective and form of objective relation. Here, scientists can learn from artists and designers, who diligently study and perfect their creative technique as much, if not more, than they investigate their products. Like the patternmaker, who studies a number of pattern making techniques to arrive at the design prescribed by the designer, scientists can be made aware of their own technique of patterning and molding the fabrics of experience.

Qualitative and relational objectivity points towards further research questions in need of answering. We must ask how we can further examine natural phenomena under the notion of everywhere. What forms of order can we detect? Would framing new forms of order mean causing disorder in our familiar forms and definitions? Or are there different orders, different stencils and molds, that mutually exist within one paradigm? These questions are ripe for further research, especially within the developing field of the history and philosophy of knowledge. But perhaps most importantly for the philosophy of science, we must ask: what would perspective studies within the field of science entail? Can

[262] H. Bergson, 2002, p. 227

scientists learn from artists, such as da Vinci? Can scientists follow Bergson's call to study their technique of molding natural phenomena from the array of observed data? Can they move from merely an external awareness, detaching the inner sphere from the outer sphere during observation, towards assimilating their inner sphere and study perspective? And if so, how can we develop perspective studies for scientific observation?

As we venture deeper into the in-formation age and towards the future of Big Data, gaining a deeper understanding of the role of forms in model creation is ever more important. Focusing on forms as a perspective through which scientific knowledge is researched, can follow two parallel paths: we can examine the re-forming of natural phenomena and structures during paradigm shifts. For example, the new structure of the solar system after the Copernican Revolution or the discovery of the double helix structure of the DNA molecule. In these cases, a scientific breakthrough is a result of a more accurate qualitative simulation of physical natural structures. In the second path, we can examine the success of graphic models which make a clear use of structure and form, such as the doughnut model in economics or the famous bell curve. These types of models are different in the sense that are aimed at finding a pattern, an order, in the accumulation of data rather than simulating a physical phenomenon. It is necessary to examine both pathways to gain a better understanding of form and perspective in scientific activity.

These questions and research trajectories render the gap between the scientist and the artist much narrower. Within the influx of sense experiences, the artist and the scientist use their craft to connect the dots, i.e. the singular sense data, with lines placing them in form–in meaningful relation to one another. Kepler, like da Vinci, used geometry to configure elements within a space. Both subsequently realized that too rigorous of a configuration no longer simulates natural relationships. Thom, like Brancusi, searched for the archetype, the general form, which contained within it an initial idea undergoing process and development. Drawing connections between artists and scientists displays certain in-forming tendencies or fashions, within human culture in general. In this fashion, examining additional representation trends, such as the 'point' in scientific as well as in impressionist or pointillism art, is another potential research path.

Returning to examination of the qualitative aspect of scientific reasoning allows the creative freedom of the scientist to once again be brought to the forefront; practices of design and the visual arts become techniques in the scientist's arsenal. Researching and answering these questions paves a path that circulates back to the perspective of the natural philosopher, or the renaissance polymath such as da Vinci, when the tools at the disposal of the scientist expanded into the territories of the artist. In this sense, Kepler's and Thom's philosophical investigations into natural phenomena display a search for new relational lines and boundaries to trace, in the hopes of finding new orders of explanation. But instead of colors and brushes, chizzles and clay, Kepler and Thom used mathematics to creatively represent the world around them. Thus, as Cassirer's quote above exhibited, science and art become a united effort once again; united, they in-form our knowledge and mold our world of pure sense impressions into an interlinked tapestry of conceptual fabrics.

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