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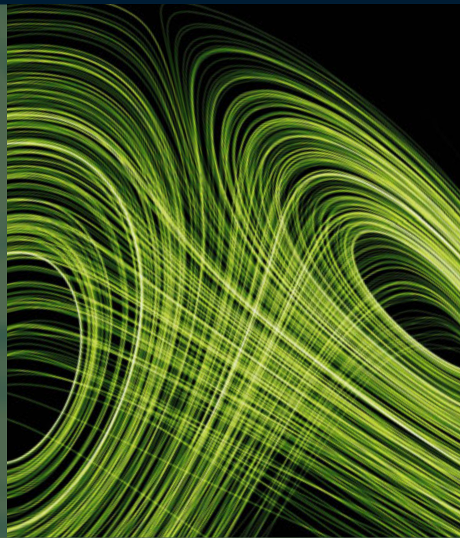

Shyam Wuppuluri
Dali Wu (Eds.)

ON ART AND SCIENCE

Tango of an Eternally Inseparable Duo

With an Afterword by Sir Martin Rees

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Editors

On Art and Science

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"*What do artistic and scientific experience have in common? Where the world ceases to be the scene of personal hopes, wishes, wants, where we face it as free creatures, admiring, questioning, beholding, there we enter the realm of art and science. We do science when we reconstruct in the language of logic what we have seen and experienced; but when we communicate through forms whose connections are not accessible to the conscious mind, yet we intuitively recognize them as something meaningful—then we are doing art. Common to both is the loving devotion, the being above the personal, removed from our will.*"

—The common element in Artistic and Scientific Experience, Albert Einstein, published in *Menschen. Zeitschrift neuer Kunst* 4 (1921):19.

Preface

Every art should become science, and every science should become art.
—Friedrich von Schlegel

After a certain high level of technical skill is achieved, science and art tend to coalesce in esthetics, plasticity, and form. The greatest scientists are always artists as well.
—Albert Einstein

My work always tried to unite the true with the beautiful, but when I had to choose one or the other, I usually chose the beautiful.
—Hermann Weyl

In this volume, some of the world's leading thinkers come together to expound on the interrelations between sciences and arts. While some proponents of modern science segregate art and place it outside the scientific realm, it is all but inextricably linked to our deepest cognitive/emotional/perceptual modalities and abilities, and therefore lies adjacent to the mental exercises of science and philosophy.

Works of art are definitely grounded in empiricism, akin to science. But that is not sufficient to qualify a particular work as art. Refuting F. H. Jacobi's "chain of conditions",[1] F. W. J. Schelling argued how Artwork, though being empirical, can't just be understood purely in terms of its initial conditions like the materials that went into it. It rather goes deeper into the level of "unconscious" and also can't be understood in terms of the intention of the producer. In describing the Artist, he writes, "the I is conscious according to the production, unconscious with regard to the product". Art is a bridge between the unconscious and the conscious. An object of art should please *judgemental* degrees of freedom of the subject and *ipso facto*

[1]He starts with the view that the task of any scientific investigation is to reveal the chain of conditions behind any phenomenon (via the principle of *sufficient reason*). He then goes on to derive various paradoxes given the aforementioned view and invokes the concept of "Supernatural" which was later criticized by many other philosophers. (For more on this, refer to Jacobi, F. H. (1994) Main Philosophical Writings. Cambridge: Cambridge University Press.)

should provide something beyond its own objective nature. Sciences on the other hand chart out a different path in this regard. The scientific process does include the element of the unconscious but the resultant finished product must have an objective (mutually agreed with the intersubjective vocabulary) grounding. Schelling, therefore, places Art on a pedestal, calling it the "*Eternal Organ*" of the absolute. He had a religious belief in the status of the art, which to him revealed truth, as it revealed what is "good" in life to Nietzsche. Though there is a high degree of commonality in the ingredients that go into the methods of art and science—use of metaphors, faculty of intuition, representation, perspective, symmetry, etc.—they do differ in this aspect of expressing the inexpressible.

But what is the relationship between a piece of artwork and the real world, or between a scientific theory and reality? Is art ontological? What about scientific theories? What inspiration can scientists draw from art and how can a scientific spirit foster our understanding and creation of aesthetic works? How are art and science grounded in our cognition? What role does perception play? How do science, art and scientifico-artistic frameworks shape society as a whole and help us address its pressing issues? The epistemological and ontological aspects haunt artists, philosophers and scientists alike. These questions can't be directly addressed in the philosophies of art and science per se but in an amalgamation of both, treated using metaphysics. I definitely can't express my views on these—limited as they are—more beautifully than is done within these pages by the intellectual leaders, whose contributions I warmly recommend. Through this volume, we try to address some of the aforementioned aspects while retaining the pragmatic role they play in daily life. The articles are deliberately not categorized under different sections but are interleaved, allowing the reader to partake in an intellectual balancing act, tipping this way and that but not tumbling towards either extreme, the metaphysical or the pragmatic. The book does not claim to address everything there is to the subject, but we hope it will at least open up avenues for readers to further explore the deeper and subtler interrelationships between art and science.

In shaping this book into reality, an essential role was played by Dr. Angela Lahee, Editor at Springer, who has accompanied it throughout with her pertinent feedback, editorial support and troubleshooting. I thank her from the bottom of my heart. I express my utmost gratitude to Sir Martin Rees, who has been supremely supportive and took time off his busy schedule to provide us with an afterword. I take this opportunity to acknowledge his immense humility and humaneness! I would also like to thank Dr. Judith Wechsler for the time and effort she has invested in the foreword. This book would literally not have been possible without the help and kind support I have received from all the authors, especially from that of Prof. Nader El-Bizri and Otavio Bueno. In the context of typesetting the book, I would like to acknowledge and thank the wonderful editorial support I have received from Rangaraj Sadagopan, Sudhany Karthick and their team. Words can't express my gratitude towards my co-editor, Dali Wu, for being such a source of inspiration. This idea to assemble this volume arose from our conversations. She is chiefly responsible for triggering my interest in this topic. Last but

not least, I would also like to thank Markus Joos from CERN, who spared no effort and accompanied me to numerous art museums during my stay at CERN, Geneva. He watered the seeds of my curiosity and strengthened my belief in accomplishing this project.

CERN, Geneva Shyam Wuppuluri

Introduction

Interactions of Science and Art: Some Issues and Questions

As a young associate professor of art history at MIT, I organized a course, Topics in Art, Science and Technology, designed to encourage students to explore interactions and communalities between the disciplines. I hoped that by understanding the aesthetic dimension in their own fields, they would be more receptive to appreciating the cognitive aspects of the making of art. The students were asked in their own term papers not to look at apparent aesthetic qualities, such as microscopic or telescopic imagery, but rather to examine the role of aesthetics in the doing of science, its concepts, metaphors and analogies and the different and contrasting modes of scientific imagination. Participating were members of the MIT faculty, Philip Morrison who lectured about broken symmetries in physics, Jerome Lettvin, from biology, on visual systems, Cyril Stanley Smith, from metallurgy, on *Structural Hierarchy in Science, Art and History*, Seymour Papert on intuition and pure logic in mathematics. There were a few invited scholars from outside MIT, including Howard Gruber who lectured on classic and romantic imagery in nineteenth-century biology, and Arthur I. Miller on the role of visualization and non-visualization in quantum theory. The course was offered three times to an ever expanding audience and resulted in a book *On Aesthetics in Science* (MIT Press, 1978), which has gone through several editions, printings and translations.

Since leaving MIT, I turned my attention back to my field of nineteenth-century French art and the making of documentary films, primarily on art. Now, after a hiatus of some 40 years, I have been asked to write the preface to this book, a collection of essays about the relationship of art and science, mainly from the point of view of science and the history of science.

Artists and historians of art have different perspectives on the interaction with science. In the 1960s and 1970s, there were arguably more efforts at collaboration between artists, scientist and engineers with various movements, exhibitions and catalogues on the subject, such as kinetic art, Sciart, Arts Catalyst and others.

Jasia Reichardt wrote extensively about cybernetics and art and organized exhibitions on the subject in the UK and Japan.

In 1966, Experiments in Art and Technology (E. A. T.) was founded by engineers Billy Klüver and Fred Waldhauer and artists Robert Rauschenberg and Robert Whitman. By 1969, there were over 2000 **artist** members and 2000 engineer members willing to work with artists. Their goal is "to expand the artists' role in social developments related to new technologies". The next year, the Center for Advanced Visual Study (CAVS) at MIT was founded by Gyogy Kepes, focusing on the interactions of scientists, architects and artists. The Center's initial mission was to facilitate "cooperative projects aimed at the creation of monumental scale environmental forms".

Some art historians were skeptical about the usefulness of art/science comparisons. The relationship between modern physics and modern art was challenged by art historian Meyer Schapiro and others, countering popular interest in the subject, and arguing against the Cubism-Relativity myth.

Leo Steinberg argued, "that art and science differ in purpose and in the response they illicit. To predict and control is seldom the objective of art; and the findings of science are only rarely regarded as a matter of taste" (*Daedalus*. "Art and Science: Do they need to be yoked", Summer, 1986, p. 2). Steinberg doubts the validity of looking for analogies. "Even if the condition of art were unchanging, its relation to changeable science would be inconstant. But in fact we are trying to throw a bridge between two moving bodies". In any case, Steinberg objects to unhistorical art–science analogies (3).

Philosopher Stanley Cavell in "Observations on Art and Science" (*Daedalus*, op.cit., 172) also doubts the validity of comparisons. While they may function in certain ways that have common qualities, it is their differences, he wrote, that matter more.

Other art historians have engaged in studying the role and influence of science on art.

Most notably, artists were interested in ideas of time and motion in the twentieth century, suggesting, to Moholy-Nagy, a more dynamic world view. Linda Dalrymple Henderson in, *The Fourth Dimension and Non-Euclidean Geometry in Modern Art,* 1983, brings to light many manifestations, referring to artists Hannah Hoech, Naum Gabo and El Lissitzky, and architect Erich Mendelsohn, who encouraged stylistic innovation influenced by science and created a new iconography.

How time and space are differently conceived, perceived and experienced was a key subject of comparison for artists and art historians. Carolyn Jones notes, "The spatialization of time had always been one of painting's quintessential problems". With Claude Monet's series paintings "time would also be its subject" ("Rendering Time", Einstein for the twenty-first Century, His Legacy in Science, Art and Modern Culture, edited by Peter L. Galison, Gerald Holton, Silvan S. Schweber. Princeton UP, 2008, p. 139).

From the perspective of scientists sympathetic to a broader perspective, Niels Bohr theorized that complementarities exist in different forms of human cognition in both art and science. English biologist C. H. Waddington explored the relationship in *Behind Appearance; A Study Of The Relations Between Painting And The Natural Sciences In This Century* (MIT press, 1960).

Gerald Holton in "Thematic and Stylistic Interdependence" (*Thematic Origins of Scientific Thought* 1973, 1988) examines underlying relationships of art and science and discusses the role of style, which reflects the thought of a period. He considers the role of individual sensibilities which are usually more associated with art in the doing of science: "The transformation of conceptions from the personal to the public realm, the scientist, perhaps unknowingly, smuggles the style, motivation and commitment of his individual system and that of his society into his supposedly neutral, value-indifferent luggage. And it is at this point that the concept of projection will help us to understand how the style of contemporary personal and social thought introduces itself into scientific work" (p. 101). He concludes, "If at every turn we had to construct science anew out of science alone, without the guidance of style and knowledge in their widest sense, how could we hope to catch this complex and infinitely fascinating world with our minds at all?" (p. 112).

In thinking further about correspondences between art and science, here are some of my thoughts and questions.

Scientists and artists have in common passion for their work, experimentation and originality but the processes are different. Science is more concerned with verifiable results arrived at by objective methods. Art is more concerned with perception, sensation and emotion. Occasionally, they are each concerned with beauty, though that criterion is no longer predominant. Art is now more concerned with processes, and with subject matter that intersects with technology and science, in the use of computers, cybernetics, ecology and new media.

There are many questions:

Why is the relationship between art and science significant?
Do art and science equally benefit from this exploration?

Is science "humanized" made more accessible, by reference to aesthetics?
Are the arts made to seem more vigorous, more structured by allusion to scientific principles or methods?

Are the interactions or analogies fundamental or superficial?
What does science gain by association with art?
Who is served by treating scientific visual images as artworks?
Do the categories of science apply more to art or the traits of art to science?

Are aesthetic preferences due to cultural factors?
Is beauty important in science and how is it defined?
Are the criteria for beauty the same in art and science?
Following Darwin's theory of beauty, one might further explore whether beauty, aesthetic preference, is a driving force in evolution, or at least a factor.

What other subjects beyond time and space are relevant to the interaction of art and science?
Are there case studies in art and science of the methods by which one sets up and solves other problems?

Are there scientists, particularly physicists, who don't prefer simplicity and symmetry in their equations, methods, images?
I have long wondered whether aesthetics in science could include twentieth-century antithesis to beauty, such as Chaos theory in science and various manifestations of art, such as Art Brut or graffiti art. Do the disruptions and destruction we have witnessed in our time enter into consideration of science as well as art? Gerald Holton argues that "It may be that we are beginning to train new sensibilities which will set a new style" (*Thematic Origins of Scientific Thought*, p. 98). Holton presents an important antidote to the usual reference to the role of aesthetics, meaning beauty, simplicity, etc. He notes newer themes, "the antithetical *thema* of disintegration, violence and derangement" (p. 95).

Do more recent developments in art seek dialogue with science?

Does conceptual art engage in its themes and strategies with science and technology?

To what extent does the audience for art overlap with those engaged with science and technology? Does the role of reception enter at any level?

There remains much to be explored.

I wish to thank Professor Gerald Holton and Dr. Ricardo Bloch for their suggestions.

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Art and Science: A Tangled Relation

James W. McAllister

Introduction

Broaching the topic of the relation between art and science 500 years after the Renaissance plunges us into a complex set of tangled congruities and incongruities in flux. Some writers portray the Renaissance as a golden age in which art and science were united or integrated (Crombie 1980). Some go on to lament the fragmentation of areas of human endeavour since the Renaissance, and work to recover hidden unities of purpose and of method between art and science.

One difficulty is that the categories of art and science are neither static nor self-evident. We have witnessed the rise of several different instantiations of art since the Renaissance: in visual art, for example, these have included on most accounts a shift from exhibition of knowledge and skill to expression of personality and brilliance, and more recently a further shift to critical reflection on the art-historical tradition, on notions of originality and creativity, and on the formats and conventions in which art is customarily exhibited. Each of these instantiations of art embodies different epistemological and social presuppositions about representation, affect, and aesthetic and artistic values.

Similarly, we have known several instantiations of science since the Renaissance: even leaving aside the rise of the social sciences in the late nineteenth century, modern mathematical physics, molecular biology, and historical sciences such as palaeontology represent genuinely different ways of investigating the world scientifically, which embody different presuppositions about representation, evidence, and objectivity.

Furthermore, none of these categories is self-evident: whereas I have just listed historically specific forms of art and science as though they spoke for themselves, it is far from settled at the outset of an investigation what art and science are, what features they show, and what essence they have. Only philosophical interpretations of

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the two domains, which construct what we take art and science to be, can settle these issues, and only within a way of theorising that the interpretations themselves proffer. As a result, any discussion of the relations of art and science is simultaneously and primarily a debate between philosophical conceptualisations of art and science.

These dimensions of flux and of theoreticity mean that any project that supposes that there are stable and well-defined categories of art and science, and that it remains for us only to ascertain their interrelations, risks essentialising a single form of both art and science. We will quite easily reach appealing conclusions about the similarity of modes of representation in art and science, for example, if our view of art is based on old master paintings that count as artworks on the strength of morphological properties such as composition, draftsmanship, brushwork, and use of colour, and our view of science is based on classical physical theories that provide a coherent visual and causal representation of reality. These conclusions, however, will come at the cost of neglecting other forms of science and of art and other philosophical conceptualisations of them.

As a consequence, it is best to proceed episodically and partially in tracing consiliences between art and science. In what follows, I limit myself to respects in which we might consider that science exhibits facets that resemble art.

Scientific Images Treated as Artworks

Scientists produce many images in their work. Some of these images strike some viewers as embodying aesthetic values, such as beauty, the sublime, and the ineffable (Cazeaux 2015).

Many of the best-known examples are astronomical images, since astronomy is both a highly visual science and one in which visualisation and imagination of exotic structures excite fascination. NASA scientists using the Hubble Space Telescope produced “Pillars of Creation” in 1995, a photograph of interstellar gas and dust in the Eagle Nebula. Retouched for aesthetic effect, the image evokes fascination and wonder, much like some Romantic landscape paintings. In virtue of these aesthetic aspects, such images can attract nonspecialists to science and can heighten public interest in and support for science (Kessler 2012; Casonato 2016).

A more recent, slightly more abstract example is the iconic image of a black hole in galaxy M87 that scientists using the Event Horizon Telescope produced between 2017 and 2019 (Event Horizon Telescope Collaboration 2019). Whereas many commentators have hailed this image understandably as an aesthetic milestone in human exploration of the cosmos, on a par with photographs from the NASA Apollo lunar missions (Heyne et al. 2018), black holes are a largely nonvisualisable phenomenon and the image is perhaps more properly regarded as a graphical display of heavily processed measurement results rather than anything akin to a photograph.

Many of the best-known astronomical images, including “Pillars of Creation”, are, of course, a spin-off from scientific research rather than a tool that astronomers have used as the basis of further scientific investigation. Images that play a functional role in scientific work, however, also give rise to aesthetic appreciation. Of these, we can distinguish three sorts.

The first category is displays or representations of empirical data. An example is "Photo 51", an X-ray diffraction photograph of B-DNA taken by Rosalind Franklin and Raymond Gosling in 1952 (Gibbons 2012; Cuevas and Heglar 2013). Maurice Wilkins showed this photograph to James D. Watson in a famous chapter in the development of genetics. J. D. Bernal wrote that Franklin's "photographs are among the most beautiful X-ray photographs of any substance ever taken" (Bernal 1958). Simultaneously, of course, empirical data are supposed to be the warrant of objectivity in scientific work.

The second category is visualisations of mechanisms, which are a synoptic rendition of current knowledge about stages, interactions, and pathways of causal processes (Bechtel et al. 2018). An example is the diagram of the citric acid cycle, also known as the Krebs cycle, first produced by Hans Krebs and Albert Szent-Györgyi in 1937. It represents the metabolic pathways of cell respiration. Such a diagram incorporates a greater degree of theory and interpretation than a visual display of empirical data does. Mechanism diagrams are notable also in that many examples, such as the diagram of the citric acid cycle, display an aesthetic of complexity, in which the eye and the mind revel in the sometimes almost baroque intricacy of causal pathways; most scientific representations, by contrast, cultivate a classic aesthetic of simplicity.

The third category is arguments in visual form. These are visual images that are supposed to lead the informed viewer from a set of premises to a conclusion, much as arguments in propositional form do. Admirers of the idea of visual arguments typically claim virtues of immediacy and irresistibility for them: whereas it takes time to absorb the statements of an argument in propositional form, the apprehension of a visual image is completed almost instantaneously, so they say, and the visual nature of the experience imparts a sense of certainty that a succession of verbal claims cannot match.

Arguments in visual form include visual proofs in mathematics, such as a visual proof of Pythagoras's theorem (Alsina and Nelsen 2010). In the purest form, visual proofs consist of nothing more than a diagram, with no verbal explanation or guidance: the viewer with sufficient mathematical knowledge will spontaneously understand the pertinence of the graphical configuration to a problem or result in mathematics. There is much debate about the status of picture proofs and whether they function wholly independently of more formal mathematical proofs (Brown 1997). Many commentators, however, note that visual proofs are able to convey insights in a much less effortful way than proofs in words can, and they relate this advantage to the sensual and aesthetic aspects of visual proofs. It is also possible, of course, to attribute intellectual beauty to a traditional mathematical proof in the form of a logical argument from explicitly stated premises to a conclusion: this phenomenon falls within the next heading.

Most arguments in visual form, including visual proofs in mathematics, are meant to be interpreted literally. Some other forms of visual reasoning, by contrast, make use of visual metaphors, inviting beholders to explore an image with their eyes and draw conclusions on the basis of association of features and by appeal to background factual knowledge (McAllister 2013).

Scientific Output Evaluated on Aesthetic Criteria

Whereas we relate beauty most centrally to visual experience of concrete objects, abstract and intellectual constructs can also provoke aesthetic pleasure and displeasure. The aesthetics of chess games is a good example, but some scientists also regard scientific theories, laws, models, and other accounts of the world as having aesthetic merit or demerit. Theoretical physicists write about the mathematical beauty of fundamental equations in their discipline: they appreciate the simplicity and symmetry properties of Maxwell's equations in electrodynamics, for example.

One respect in which aesthetic evaluations in science differ from those in art is the poverty of aesthetic properties and criteria to which the former refer. Scientists and mathematicians have a comparatively limited aesthetic vocabulary by means of which they assess their output: they rarely reach beyond the terms "beautiful" and "elegant" in discussing their theories, proofs, and the like. Most artists and art critics, by contrast, would find such a vocabulary rudimentary in the extreme: in fact, the category "beauty" plays no significant role in discussions of modern art.

A central question under this heading is the relation between the aesthetic evaluation of theories and laws and empirical evaluations of them, which aim to estimate their epistemic merits such as truthlikeness or empirical adequacy. Are these evaluations distinct or partly overlapping? Is beauty in scientific theories and laws a sign of truth, as the classical thesis of the unity of the virtues might tempt us to believe?

I have proposed an inductive account of the way scientists form and update their preferences among the aesthetic aspects of scientific theories and laws (McAllister 1996). This account assumes that scientists are engaged—albeit for the most part without being explicitly aware of this—in a systematic inductive search for aesthetic properties of theories that constitute a sign of truth. This search exploits the fact that any such property would be correlated with good empirical performance.

In many cases, an aesthetically innovative theory strikes many scientists as aesthetically displeasing when it is first put forward. If such a theory demonstrates substantial empirical success, however, scientists come gradually to regard it as having aesthetic merit. There are many historical examples. At first, many astronomers regarded Johannes Kepler's theory of planetary motions of 1609 as displeasing for portraying the planetary orbits as ellipses rather than as the combinations of circles that had defined the aesthetic of planetary astronomy since Ptolemy. Similarly, Isaac Newton's theory of gravitation first struck many of his contemporaries as unacceptable in aesthetic as well as in other ways for postulating action at a distance. Most recently, many physicists—most notably P. A. M. Dirac—initially regarded quantum electrodynamics as ugly for its reliance on nonstandard mathematical operations in renormalization. The relevant scientific community gradually came to see each of these theories as aesthetically pleasing, however, as it built up an impressive empirical track record.

These historical examples and others suggest that scientists' aesthetic preferences respond inductively to the empirical performance of theories. More precisely, scientists at a given time attach aesthetic value to an aesthetic property such as a simplicity or a symmetry property roughly in proportion to the degree of empirical success scored up to that date by the set of theories that have exhibited that property. If a property is exhibited by a set of empirically very successful theories, scientists attach great aesthetic value to it, and thus see theories that exhibit that property as beautiful. If a property has no association with empirical success, either because theories exhibiting that property have been demonstrated inadequate, or because such theories have as yet no empirical track record, scientists attach no aesthetic value to it, and thus feel no aesthetic attraction for theories that exhibit it.

We see a similar inductively shaped aesthetic response to empirical performance in the applied arts, such as architecture. Every material used in architecture—timber, stone, brick, cast iron and steel, concrete, plate glass—has a distinctive set of technical characteristics that allows it to satisfy particular practical needs. In order to exploit a material's virtues, however, it is necessary to use it in an appropriate design. When a new architectural material is introduced, the designs most suited to exploit its capabilities frequently strike conservative architects and the public as ugly: this aesthetic resistance dissipates only gradually, as the new material demonstrates its utility in buildings. With the passage of time, the designs suited to the new material come to define the architectural aesthetic.

The inductive updating of aesthetic preferences has greatly influenced the development of science. If a given theory scores notable empirical success, its aesthetic properties win increased favour within scientists' aesthetic preferences. Scientists will consequently tend to prefer theories that show these properties to other theories, and will strive to formulate further theories that satisfy this preference. As long as such theories remain successful, their aesthetic properties will acquire greater and greater favour. When such theories cease to demonstrate empirical success, the properties that they exhibit will lose favour relative to any other properties whose correlation with empirical success appears stronger.

Thanks to this inductive mechanism, if an aesthetic property that is a sign of truth exists, then we can expect scientists' aesthetic preferences to converge on it, provided science is practised for long enough and with sufficient inventiveness. Suppose one day scientists formulate a theory that exhibits such a property. Since any such theory must be true, it will score great empirical success. Scientists will attribute aesthetic value to the property in question, and will seek to formulate further theories that exhibit it. Since these further theories must likewise be true, the aesthetic value attributed to the aesthetic property will increase without limit. The question whether there indeed exists an aesthetic property that is a sign of truth, however, will remain open until such a time.

Effort and Effortlessness in Art and Science

An established route to objectivity in science is via the expenditure of increasing effort, for example in the aim to ensure the accuracy of findings and the avoidance of error. Another way to heighten the objectivity of scientific findings, however, is to portray them as arising effortlessly (McAllister 2016). This route to objectivity rests on the traditional view that truths are natural and discovered, whereas departures from the truth are artificial and constructed. From this, it follows roughly that any conclusion established with little effort is likely to be true, whereas conceiving a falsehood requires more effort. Salient examples include cases of discovery by serendipity, in which the finding strikes the investigator out of the blue.

Many thinkers link economy of effort with beauty, especially in mathematics. Henri Poincaré endorsed the view that "the mathematical entities to which we attribute this character of beauty and elegance […] are those whose elements are harmoniously disposed so that the mind without effort can embrace their totality while realizing the details" (Poincaré 1910, p. 331). Drawing on his experience as a mathematician, George D. Birkhoff proposed a general, formal theory of aesthetics in which the "aesthetic measure" of an entity was given by the ratio of two variables that he called "degree of order" and "degree of complexity". Birkhoff added: "The well known aesthetic demand for 'unity in variety' is evidently closely connected with this formula. The definition of the beautiful as that which exhibits the greatest number of ideas in the shortest space of time […] is of an analogous nature." (Birkhoff 1933, p. 4).

A similar dialectic occurs in art. Expenditure of effort is capable of increasing the realism of representations of the world in artworks, but a laboured performance is liable to emphasise the artifices of the work more than the faithfulness of the representation. A seemingly effortless artwork, by contrast, can also strike the viewer as authentic and objective, as if the world were revealing itself through a minimum of human intervention (Byerly 1999). The more recent category of "found art", such as Marcel Duchamp's *Egouttoir* ("bottle rack", 1914), for example. mimics serendipity in science in seeming to involve no manufacturing effort, and superficially even no artistic skill (Buskirk 2003, p. 64; Roberts 2007).

Of course, effortlessness in both science and art can be a matter of semblance more than of reality. Scientists in their formal reports tend to provide rational reconstructions of their research, routinely portraying it as having involved fewer mistakes, false leads, and wasted effort than it actually did. In art, similarly, the impression of effortlessness is achieved often by painstaking preparation and practice. Sometimes this insight is formulated in terms of the difficulty of relearning and recreating a child's uninhibitedness. Picasso said in 1956, seeing some children's drawings: "When I was their age I could draw like Raphael, but it took me a lifetime to learn to draw like them." (Penrose 1981, p. 307). The concept of "latent work" thus plays a big role in both science and art.

Science-Mediated Aesthetic Appreciation of the Natural World

As scientific theories inform us about the features of the world, so they inform us about the world's aesthetic features. Science thus promotes our aesthetic appreciation of the world by enhancing and refining our view of it.

This process takes place on two levels. On one level, science tells us more about natural objects and scenes that are already visible to the naked eye and, in most cases, are already the object of aesthetic appreciation: the additional insight reveals to us aesthetic features of which we would otherwise be ignorant, and leads us to a higher appreciation in consequence. Scientific investigation brings out implicit aesthetic features of the natural world, fostering appreciation of its complexity, harmony, and seeming perfection in much the same way that the rise of landscape painting in Western art in the seventeenth century stimulated aesthetic appreciation of landforms (Parsons 2006). In environmental aesthetics, Allen Carlson's scientific cognitivism, or the view that scientific knowledge is required for aesthetic appreciation of natural objects, has carried influence since the mid-1990s. Carlson wrote, for example, about the experience of perceiving a rorqual whale, a moose or a tidal basin:

> To appropriately appreciate objects or landscapes in question aesthetically—to appreciate their grace, majesty, elegance, charm, cuteness, delicacy, or "disturbing weirdness"—it is necessary to perceive them in their correct categories. This requires knowing what they are and knowing something about them—in the cases in question, something of biology and geology. In general, it requires the knowledge given by the natural sciences. (Carlson 2000, p. 90)

On the second level, science appears to reveal to us objects that are outside our visual scope, thereby broadening the category of objects of aesthetic attention. For example, Maxwell's four equations in electrodynamics are composed of two equations describing the evolution of electric fields and two describing the evolution of magnetic fields. Since there is a pronounced symmetry between the equations pertaining to electric and the equations pertaining to magnetic fields, most commentators have concluded that Maxwell's equations tell us that electric and magnetic waves in electromagnetic radiation show particular symmetries. Since, moreover, symmetry is widely regarded as an aesthetically pleasing property, we may say that Maxwell's equations have shown us previously unsuspected beauty in the physical world.

The idea that scientific theories tell us which aesthetic properties the phenomena have deserves critical scrutiny, though. In most cases, our belief that phenomena show particular aesthetic properties is based entirely on scientific theories. For example, our sole basis for believing that a given phenomenon is to some degree simple is our best theory about that phenomenon. Likewise, our only grounds for believing that electromagnetic waves show particular symmetries are that Maxwell's equations tell us that they do. To some extent, therefore, while a scientific theory may attribute a particular aesthetic property to the world, that property pertains more to the theory than to the world itself. Since there is no general principle that scientific theories must reproduce the aesthetic properties of the phenomena that they describe in order to attain empirical accuracy, the inference from a theory's possession of a certain aesthetic property to the world's possession of a corresponding property seems risky.

Modern Science Relates to the World as Art Does

According to some stereotypical accounts, finally, science and art have little in common: whereas science is an objective, data-governed reflection of reality, art is a creative, emotion-driven expressive practice. With the demise of positivist philosophy of science, by contrast, the suggestion has gained ground that science looks at the world in the way art does—a revitalisation of the Renaissance view in a modern guise.

There are various ways of making this idea more concrete. One is to say that criteria of theory assessment that we take to be logical and empirical are, in fact, aesthetic. It is plausible to say, for example, that the sole available ground for valuing a theory or preferring one theory to another is harmony: the internal harmony of a logically consistent theory, the harmony between two theories that support or explain one another or the harmony between a theory and observations. Harmony is detected and valued by a scientist's aesthetic sense (Thagard 2005). On this view, the scientist's gaze is aesthetic throughout, and some aesthetic evaluations of theories we label logical or empirical according to the nature of the harmony involved.

Another way is to focus on interpretation. Whereas past philosophers might have believed that interpretation was a preserve of art for which there was no call in science, we now think that a level of interpretation is interposed between the world and scientific theories (van Fraassen and Sigman 1993). Scientists are compelled to interpret the world as much as they describe it, and they are furthermore compelled to interpret their theories about the world. Most of the substantial debate about quantum theory revolves around not its empirical attainments but about the correct way of interpreting it. These interpretations add substantially to the theory's meaning and implications: for example, the Copenhagen interpretation of Niels Bohr and Werner Heisenberg denies that physical systems have definite properties prior to undergoing measurement, the many-worlds interpretation of Hugh Everett and Bryce S. DeWitt posits that each measurement act splits the universe into mutually inaccessible alternate histories, and so on. The need for interpretation further undermines positivist notions of objectivism and opens a space for what might be described as an artist's judgement even in mainstream science.

Conclusion

I have picked out in the foregoing some aspects of consilience of science and art. These have deliberately been partial, even fragmentary. Is a more systematic and unified overarching account of the relations of science and art possible? I am sceptical about the chances, for the reasons outlined at the outset. Neither science nor art remain unchanged for any appreciable length of time, and we have no access to either science or art except through philosophical theories that are themselves partial and the subject of controversy. I am eager to be proved wrong, though, and I wish every success to colleagues who wish to propose more encompassing accounts of the relation of science and art.

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Art and Science: Historical Confluences and Modern Dialectics

Nader El-Bizri

Exordium

The relationships between the pictorial *cum* plastic arts and the exact sciences developed via longstanding premodern historical confluences. This is particularly documented in the case of architecture, as expressed for instance in antiquity within the influential ten-volume treatise *De architectura* (ca. 15 BC)[1] of the Roman polymathic architect Marcus Vitruvius Pollio. The fact that architecture stands as an epistemic and practical field, which allows for the confluence of the visual and plastic arts with the exact sciences and technologies, emanates from its own essence as a *praxis* that is concerned with aesthetics as well as engineering technical skills in the application of scientific knowledge to serve the existential modes of dwelling in the world. The relationship of the visual and architectonic arts with technicity and fundamental science, and specifically within the architectural *praxis*, was usually manifested via applied connections between the spheres of the artistic oeuvres and the techno-scientific works, while retaining epistemic distinctions between their respective domains. Such state of affairs was more radically revolutionized in the Italian Renaissance, starting from the *trecento* (1300s *qua* fourteenth century CE) and culminating in the *cinquecento* (1500s *qua* sixteenth century CE). The phases of that epoch witnessed a gradual deconstruction of the Aristotelian *philosophia naturalis* and its *cosmologia* as inherited from the scholastic commentators of the mediaeval era. The pruning out of the concept of classical physics gave way for the engagement of artists and architects with theoretical and practical forms of scientific inquiry, as underpinned by non-Aristotelian methods in investigating nature that relied more on geometry in the Archimedean, Euclidean, and Ptolemaic lineages. This was principally the case in terms of an adaptive assimilation of traditions in

[1] Vitruvius (1899, 1999).

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the Graeco-Arabic sciences that were transmitted into the Latinate European milieu during the scholastic mediaeval period. A significant aspect of this trend focused on the science of optics (*Pesrpectiva*; *De aspectibus*; *al-Manāẓir*) as grounded on the research of the eleventh century CE Arab polymath, Ḥasan Ibn al-Haytham (known in Latin renderings of his name as 'Alhazen'),[2] and in the prolongation of his approach by Franciscan opticians from the thirteenth century CE onwards with figures like Erazmus Witelo (Vitellonis) and Roger Bacon. The appeal to classical optics by the Florentine Renaissance architects and artists, of the standing of the polymath and architect Leon Battista Alberti (in his *De pictura* treatise on painting),[3] or the architectural sculptor Lorenzo Ghiberti (in his *Commentarii*, as remarks on vision),[4] paved the way for transforming the *perspectiva naturalis*, as a scientific optical theory of vision, into a *perspectiva artificialis*, as a pictorial method in the representation of spatial depth (*spatium*; *extensio*) via geometric modelling. *Perspectivism* became then the basis for generating a dominant projective geometric method in depicting natural phenomena, imagining virtual spaces, as well as setting a framework for design in shaping the concrete built or landscaped natural environments. The epistemic function of art receded afterwards from being pivotal within the unfurling of scientific inquiry during the seventeenth century CE onwards; albeit the pictorial arts were modulated in their eventual unfolding beyond *perspectivism* by reconsidering the way we see natural phenomena and in terms of devising novel modes of depicting them.[5]

Modern art eventually caught up *culturally* with the scientific endeavour, rather than epistemically. This was given expression through the *avant-garde* modernist and futurist practices of art in the early twentieth century, and how they aimed at engaging with new aesthetics as impacted by developments in science and technicity. Another facet of the connection and distinction between art and science in the modern era emerged within the phenomenological penchant in thinking, and particularly in the way the fundamental ontology of Martin Heidegger unfolded against the background of rethinking the essence of technology as set upon us in the *en-framing* (*Ge-Stell*) of our *being-in-the-world*, and in how this turns all beings into an orderable standing reserve (*Bestand*). The origin of art appeared in such existential framework as a phenomenon that transcended the actuality of the artwork, or its modes of production and criticism, by granting us another prospect for disclosing *truth* in a mode of unveiling that surpasses the mere reliance on technicity or its *episteme*. This entails that the essence of art in the age of modern technology holds the promise of disclosing the *truth* by way of ποίησις (*poiēsis*) rather than merely via τέχνη (*tekhnē*). Truth is pictured in this sense as an un-veiling that is best expressed via the notion of ἀλήθεια (*alētheia*); namely as *a happening of truth by way of un-concealment*. Such existential event (*Ereignis*) may affectively occur via art beyond what is predetermined in its

[2] Ibn al-Haytham (1983, 1989). Refer also to: El-Bizri (2005, 2007b).

[3] Alberti (2011).

[4] Ghiberti (1998), 'Commentary III'.

[5] A twentieth century philosophical examination of the *perspectiva* tradition in painting is set in: Damisch (1972, 1987).

objectified destiny through techno-science. The connection and distinction between art and science, opens up dialectically for us the spheres for rethinking the meaning, place, and truth of our being.

Pondering over these leitmotifs, this present chapter herein proceeds via a sequential chronology of epistemic historiography in rethinking the relationship between art and science.[6] This will be mediated via axial notions that guide the reflections in the subsequent four sections. When accounting for antiquity and the mediaeval epoch, the focus is on the *artes liberales* in the way the letters and the sciences integrally underpinned the architectural arts. When dealing with the Renaissance period, the emphasis is placed on the *perspectiva* tradition in the manner the science of optics and geometry grounded the scientific inquiries that were mediated via the pictorial and plastic arts. A clearer shift towards establishing projective geometry is a characteristic of the mathematical penchant of the early-modern era, and how this generated an imaging of the representational space via the applications of the '*géométral*' (*geometral*) at the intersection of science with architectural engineering. Finally, the meditations turn to the modern age in addressing the residual aura of the artwork in our contemporary condition, while considering it as a πάρεργον (*parergon*) that supplements science with the generation of existential sense-making and cultural meaning, specifically as the essence of modern technicity unfolds in the form of a planetary will to power that *en-frames* our worldly being.

Artes Liberales

If ἐπιστήμη (*epistēmē*) as science is combined with τέχνη (*tekhnē*) as art/craft, their synthesis produces φρόνησῐς (*phronēsis*; *prudentia*), which designates practical reason; while, when ἐπιστήμη (*epistēmē*) is entangled with νοῦς (*nous*; intellect) this yields σοφῐ́ᾱ (*sophia*) as theoretical wisdom. Reflecting upon the relationship between art and science, the *dictum* '*ars sine scientia nihil est*' ('art without science is nothing')[7] is supplemented with the inverted proposition: '*scientia sine arte nihil est*' ('science without art is nothing'). This demarcates from the onset how in pondering over the connection and distinction between art and science, we become philosophically situated in a *liminal* locale in-between two spheres of our worldliness that are brought together into a dialectical unison. It is in this sense that the co-entanglement of art and science is affirmed, albeit while being held in its togetherness by an inherent tension of innovativeness that tends also to pull them apart.

[6]This present chapter is synthetically complemented by my other publications that tackled related themes on art and science, such as: El-Bizri (2004a, 2007a, 2010a, b, 2014a, b, c, 2015, 2016, 2018a).

[7]This *dictum*, which was attributed to the fourteenth century CE French architect Jean Mignot, has been reported via an anecdote concerning a disputation over the assessment of the structural integrity of the elevation of the *Duomo di Milano* of the Santa Maria Nascente. See: Ackerman (1949), Kemp (1990); El-Bizri, 'Seeing Reality in Perspective', *art. cit.*, p. 26.

The premodern affirmation of a connection between art and science is evident since antiquity. We find an early evidence of it in a documented epistolary form in the *De architectura* script of Vitruvius. This multivolume canonical treatise would have constituted one of the earliest rigorous and systematic studies on how the classical sciences underpinned architectural thinking and the architectonic design-applications in place-making.

The tension that existed between the applied skills of making, the theoretical sciences, the arts and the letters, was addressed through the architectural medium via Vitruvius' distinction between *fabrica* and *ratiocinatione*. He notes in the *De architectura* that: '*fabrica* is the continuous and regular exercise of employment where manual work is done with any necessary material according to the design of a drawing; while *raciocinatione*, on the other hand, is the ability to demonstrate and explain the productions of dexterity on the principles of proportion'. However, *fabrica* is not simply a repeated action of the hand but is *meditatio* too.[8]

Arithmetic, geometry, surveying-mensuration, mechanics, optics, astronomy, and natural philosophy (*qua* Aristotelian physics) were set as prerequisites for the formation of the architectural arts and crafts. Accordingly, the Greek sciences were integral to synthesizing the theoretical and practical domains of practicing architecture as a field of intellection, and as a domain of *praxis* that belonged to the arts and crafts of the Roman material cultures. The sciences became as such entwined with the shaping of the directives of an idealized embodiment of the visual and plastic arts as rooted in the materiality of built structures, and in reflection of the cosmology of an ordered universe (as disclosed through the prisms of commentators on the Aristotelian *De caelo* and *Physica*). This reflected early-on the Graeco-Roman mode by virtue of which architecture was posited as a visual and plastic embodiment in material culture of the scientific picturing of the cosmic order. Dwelling on earth was informed by outlooks on heaven. Such ideals had resonances in the conception of the seven *artes liberales* (the liberal arts of the *trivium* [grammar, rhetoric, logic], and *quadrivium* [arithmetic, geometry, astronomy, music]), which were enshrined in the Roman adaptive reception of Greek philosophy, and particularly of what we find for example in the fifth and sixth century CE traditions of the likes of Anicius Manlius Severinus Boëthius and Flavius Magnus Aurelius Cassiodorus.[9]

In *Book VII* of the *Republic* (Πολιτεία, *Politeia* 522c–534d), Plato's curriculum for the would-be philosopher-king included arithmetic, geometry, astronomy, and music *qua* harmonics.[10] Marcus Terentius Varro (Reatinus; second century BC) also listed the liberal arts in his *Disciplinarum libri IX* (*Nine Books of Disciplines*) as: grammar, logic, rhetoric, geometry, arithmetic, astronomy, music, medicine, and architecture. Such classifications were echoed in Augustine's *De ordine* (2.12.35; 2.20.54), and by Martianus Minneus Felix Capella in his *De nuptiis Philologiae et Mercurii* (*Marriage of Philology and Mercury*); also titled: *De septem disciplinis*

[8]Vitruvius, *De architectura*, *op. cit.*, *Liber* I, *Caput* 1, §1.

[9]Marrou (1969).

[10]Burnet (1903); Plato: *The Republic, Books 6–10* (Loeb Classical Library, No. 276) Greek and English (Cambridge, Mass.: Harvard University Press, 1969).

(*The Seven Disciplines*).[11] Therein, Mercurious is associated with eloquence, profitable pursuits, and divination, while *Philologia* embodied a penchant for the letters. Their wedding gifts were the seven liberal arts, offered as maidens to *Philologia*, while architecture and medicine, as earthly arts, were present silently without being included in the circle of the *liberalia studia.*

The emphasis on the *artes liberales* in the sixth century CE came at a time when tension was rising between the Athenian Neoplatonism, as a manifestation of Greek-inspired pagan philosophy, and the development of a philosophical curriculum in the Alexandrian Christian theology. The School of Alexandria had to adapt itself to the Christian doctrines or face the fate of the School of Athens that was closed under Justinian's anti-pagan imperial edict in the year 529 CE (*Codex Justinianus*; *Corpus Juris Civilis*).[12] The pagan classics had to be programmatically deconstructed within the declarative profession of the adherence to the Christian faith.[13] The tension between the pagan philosophers and the Christian theologians had a previous history. One of the early systematic disputations is contained in an attack levelled at Christianism by the Roman philosopher Celsus (second century CE) in his Λόγος Ἀληθής (*Logos alēthēs*; *True Logos*), which received apologetic counter-arguments in the *Contra Celsum* by Origen of Alexandria.

The focus on the liberal arts curriculum of the *trivium* and *quadrivium* found resonances within the mediaeval circles, including the Arabic traditions in science and philosophy of the premodern Islamicate civilizations. A prominent example in this regard is embodied in the proto-encyclopaedic epistolary compendium of the Brethren of Purity in Iraq (*Rasā'il Ikhwān al-Ṣafā'*; ca. middle of the tenth century CE); especially in the first division of the corpus that dealt with the propaedeutic mathematical sciences at the intersection of the theoretical sciences with the applied arts and crafts.[14] However, the culmination of the tradition that closely entangles the exact and positive sciences with the arts and crafts is best expressed in theoretical and practical terms in the historical and epistemic bearings of the Italian Renaissance scholarship and architectural thinking. The prominence given to the arts and crafts, and to their theoretical inquiries and experimental installations, as well as to the visual and plastic applications in architectonic structures, ensured that the spheres of art would aid scientific investigations at a time when the Aristotelian physics (natural philosophy) was deconstructed.

The optical research of a figure like Alhazen (Ḥasan Ibn al-Haytham; d. ca. 1041 CE in Cairo) would have been inspiring to architectural thinkers, art-theorists and practitioners, especially in Florence with figures such as Alberti and Ghiberti.[15] The unfolding of the *perspectiva* traditions in Renaissance architecture, the pictorial

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[11] Stahl et al. (1971).

[12] The edict resulted in the closure of the Athenian Academy (*Corpus Juris Civilis*, Vol. 2 I.5.18.4). See: *Agathias*, *The Histories*, trans. *J. D. Frendo*, in *Corpus Fontium Historiae Byzantinae* V*ol. 2A*; *Berolinensis* series (Berlin: Walter de Gruyter, 1975); refer also to: Watts (2005).

[13] Pines (1955), Tannery (1925).

[14] I addressed this question in the following volumes: El-Bizri (2008, 2012a, 2018b).

[15] A manuscript of the fourteenth century CE Italian version of Ibn al-Haytham's *Optics*, entitled: *Prospettiva*, is dated on 1341 CE (it is preserved in the Vatican under the following cataloguing

and plastic arts, rested also in part on prolongations of the scientific research of mediaeval European schoolmen, such as the Bishop of Lincoln, Robert Grosseteste, and of Franciscan opticians like Roger Bacon at the Oxford college, and with John Peckham and Erazmus Witelo.

Perspectiva

The crisis of Aristotelian natural philosophy that was subjected to the doubts genre of treatises eventually opened up novel epistemic opportunities for the flourishing of artistic and architectural thought and practice, with inventiveness and experimentation. This came in the context of demarcating the connection and distinction between the *perspectiva naturalis* in visual (physiological) perception, and the *perspectiva artificialis* in the pictorial representation of the perceptual field of vision and its spatial locale. Two pyramids/cones of visibility intersect in the act of seeing by way of perspective. The finite pyramid/cone of vision of the *perspectiva naturalis*, as studied in optics in connection with direct visual perception across finite distances, intersects with the pyramid/cone of the *perspectiva artificialis* of the pictorial order that seemingly tends towards a virtual infinity. The pyramid/cone of vision in the phenomenal *perspectiva naturalis* is finite, and determined by the nearness of its vertex (which is at the centre of the eye of the painter-observer) to its base, while the pyramid/cone in the *perspectiva artificialis* pictorial representational order gives the semblance of tending to infinity via the convergent geometric lines that meet at the centring/vanishing point on the virtual horizon line of the painting.

The *perspectiva artificialis* offered optimal conditions for investigating the relationship between art and science in the pictorial representation of natural phenomena through the agency of painting and drawing *in perspective*. This was undertaken while at the same time grounding these methods of artistic and architectural visualization on science. Optics and geometry aided the construction of legitimate perspective projections, and these facilitated the expansion of scientific inquiry through new visualization techniques that assisted the geometric modelling of physical phenomena. The scientific images could thusly be removed from the familiarities of natural visual perception via complex representational spaces, which render the conditions of their observational perceptibility possible. Such modes of picturing reality found their roots in the entanglement of art with science via the legitimate construction of

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details: Ms. Vat. At. 4595. Folios 1–177). A printed edition of Ibn al-Haytham's Latin version of the Optics was established by Friedrich Risner in 1572 in Basle, under the title: *Opticae Thesaurus*, which was eventually consulted by Kepler, Descartes, Huygens, and possibly even Newton. The recognition of Ibn al-Haytham's *œuvre* is also evident in the high station he was accorded by the seventeenth century German scientist Johannis Hevelius, whereby the frontispiece of the latter's *Selenographia sive Lunae Descriptio* (dated 1647 CE) depicts Ibn al-Haytham standing on the pedestal of *ratione* (reason), with a compass in his hand and a folio of geometry, while Galileo stands on the pedestal of sensu (sensible observation), holding a telescope.

linear central perspective (*costruzione legittima*).[16] Despite the asymmetries between art and science in analysis, imaging, proof, and demonstration, the entanglement of the pictorial arts with the scientific taxonomies of the Renaissance also pointed to an onto-theological entwining of scriptural-textual exegesis with the visual atonement in measuring reality via a '*visio intellectualis*'.

The *perspectiva artificialis* is static and marked by fixity in its optimal viewing point, in contrast with the manner the eyes continually move and vibrate in scanning the visual field in the *perspectiva naturalis*. The representational space,[17] which is depicted via the *perspectiva artificialis* opens up to a seeming sense of infinitude. As a single-point linear and central pictorial construct, it stabilizes the representational order and offers an idealized abstractness in geometric space. This imaging-technique is unlike what is brought into appearance within the horizons of natural visual perception. Artificial perspective reveals a symbolic order that is modulated by the exact rules of geometry, and grants an abstractive viewpoint on what remains hidden from natural sight in the concrete fields of empirical and sensible experience. Artificial perspective lets something 'omnipresent' appear through its geometric order and its seeming openness to infinitude; albeit, there is also the virtual sense by which the painter and observer is looked upon from within the painting when gazing at it. The contemplation of the painting reveals a virtual viewpoint from a seeming infinity that looks back at the painter and observer. This seeming *presence* is situated at the vertex of the pyramid/cone of the *perspectiva artificialis* within the pictorial representational space; namely, at the centring/vanishing point where parallels in the pictorial-depth tend towards a seeming infinitude, while meeting in it as geometric lines traced on a two-dimensional surface of the mural, board, or canvas. As if the painter/observer is also supposedly seen from infinity in a gaze coming from within the painting that remains '*omnivoyant*' (all-seeing; *omnituens*). That idealized virtual

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[16]The '*costruzione legittima*' centred on the consequences of doubling the unique centring/vanishing point of linear perspective, and on debating the risks of distortions, or of compromising the spatial unity of the representational pictorial field. The manipulation of heterodox two-point perspectives, in terms of depicting central foreground figures against architectural backgrounds, in order to neutralize the effects of diplopia, did not always succeed in avoiding visual distortion, or in securing the unity of the painted representational space. See: El-Bizri, 'Seeing Reality in Perspective', *art. cit*., p. 27.

[17]The idea of a 'place' is not readily reducible to the notion of a 'space'. The mathematical conception of spatiality was not accounted for in Euclid's *Elements* and it had therefore to be invented. It is through Ibn al-Haytham's rejection of the definition of τόπος (*topos*; place) in Aristotle's *Physics* that the rudiments of a novel conception of place as *mathematical extension* comes to take shape. Aristotle's place was conceived as being an enveloping two-dimensional surface of the containing body. It was defined as: 'the innermost primary surface-boundary of the containing body that is at rest, and is in contact with the outermost surface of the mobile contained body' (*Physics* IV, 212a 20–21). Ibn al-Haytham posited *al-makān* (place) as a *postulated void* (*khalā' mutakhayyal*) whose existence is secured in the mathematical imagination, and consisted of imagined immaterial distances that are between the opposite points of the surfaces surrounding it. This rested on an isometric 'bijection' function between two sets of distances. The geometrical place is a 'metric' of a region of the so-called 'Euclidean' *qua* 'geometrical *space*'. Ibn al-Haytham's conception of place points to what later was embodied in the 'Cartesian space' as entailed by Descartes' *extensio* and Leibniz's *analysis situs*. I discussed this in detail in: El-Bizri, 'In Defence of the Sovereignty of Philosophy', *art. cit*.

world is sustained via the vision of the Godhead! An onto-theological omnipresent divinity looks upon the virtual realm that is depicted in the pictorial representational space, and set facing the painter/observer. The finite mortal stands in the world of temporal sensible beings, gazed upon from a virtual infinity of an immortal divinity. As if looking via the geometric structure of the perspective from the realm of the Platonic reality of the universal eternal and unchanging intelligible forms unto the domain of the physical realm of sensible copies. The *perspectiva artificialis* discloses as such a phenomenon of geometric structure that underpins the phenomenology of visual perception. Hinting at what cannot itself be visible but suggestively disclosing its signs through geometry. Platonism and Pythagoreanism offered the Renaissance artist the means through which geometry can assist in conducting scientific inquiry when the Aristotelian natural philosophy *qua* physics was withering.

This visual suggestiveness appears due to the fixity of the angle of vision in the geometric representational structure of the single-point linear and central pictorial perspective. As if the idealized representational space of pictorial perspective carries also a deeper sense of reality in unveiling the geometric order that grounds the ordering of the visible universe. In opening up to infinity, the virtual reality of the painting, as an object of sensible experience, in its materiality as paint-pigments brushed on a canvas surface, becomes itself a portion of a much wider world that is enacted in the pictorial art with communicative meanings and symbolism.

Géométral

The pictorial order of artificial perspective, which rested on the science of optics, served as the basis for the development of projective geometry beyond the realm of descriptive geometric constructions. This epistemic turn was embodied in the research of Girard Desargues (d. 1661 CE).[18] This French architect and mathematician developed the optical techniques of the Renaissance *perspectiva*, in addition to furthering the unfolding of geometry in its projective modes as an inquiry concerning the invariant properties of figures and solids when subjected to geometrical transformations (similitude, translation, homothety, affinity). Desargues investigated homography, by having an isomorphic bijection as a point-by-point correspondence that allows projections to take place not only on rectilinear surfaces but on irregular and curved ones as well. He gave a special attention to conics and gnomonic projections, especially in plotting spherical surfaces on a rectilinear plane in geodesic mappings and in designing sundials. He undertook these investigations as a geometer

[18] I addressed this with technical details and analytic diagrams in: El-Bizri, 'Desargues' oeuvres: On perspective, optics and conics', *art. cit*. See also: Desargues (1864). For commentaries on Desargues' contributions in mathematics and the exact sciences refer to: Field and Gray (1987), Hogendijk (1991). Refer also to: Desargues (1951, 1647–1648). Desargues was a member of the seventeenth century famous and influential mathematical circle of Marin Mersenne, which included mathematicians such as René Descartes, Pierre de Fermat, Gilles Personne de Roberval, and Blaise Pascal.

and optician besides his technical knowledge as a practicing architect in the engineering arts of masonry and stonecutting (*coupe des pierres*). His vernacular studies were thusly composed as manuals for craftsmen, builders, artisans, as also promoted by the printmaker and engraver Abraham Bosse.

The angles in Desargues' projective geometry were not the same as those set in the Euclidean geometric constructions. This is the case given that in the *projective space* the angles are not invariant. For example, a square appears in trapezoidal forms in perspective within the projective space, while in the Euclidean domain it cannot but appear *a fortiori* as an invariant square per se. The angles under projective transformation do not remain the same, and lines in depth tend towards a convergence at the horizon line in what is taken to be a vanishing point at infinity, and not simply posited as the vertex of an inverted cone of vision. The projective surface is the picture plane that receives the projections in two-dimensional figures, which represent a depiction of projective spatial depth in a pictorial form of an extended Euclidean plane. Projective geometry allows the imagination to be active in probing the properties of geometric forms, and there is here a radical shift from having a purely mathematical domain to instating a spatial extension that approximates the sensorial realm of the embodied phenomenal experience (that of the human body in the flesh) via visual perception. Such development allows the pictorial imagination to inhabit the projective space via imaging.

The artistic entailments of optics and projective geometry became synthesized in the scientific underpinning of accurate drawings. The natural visual scientific theory was rendered as a pictorial-architectural practice. This was at the core of the episteme of the Renaissance and the transition to the focus on technicity in the early-modern epoch of the seventeenth century. This enacted the directives for generating a representational space that proved useful for art and science onwards in terms of the conception of spatiality as a Cartesian *extensio qua spatium*. Nevertheless, the veridical, and apodictic directives of science, in securing a reliable rational knowledge, which is acquired through procedural precision in logical demonstration and experimenting, transcended the personal choices that affect the sphere of *praxis* in art. However, the practice of art in the *perspectiva* traditions entailed that the pictorial representational space, which is architectural in its ordering, was expected to be projected with greater precision based on geometric rules in optics. The liberal dimensions in art were as such regulated by geometrical and optical parameters. Their representational space proved to be beneficial for scientific imaging techniques, especially since these were executed with higher precisions via geometric modelling. The visual and plastic arts became more reliable in opening up the horizons of scientific inquiry insofar that they were themselves generated on the basis of rules derived from optics and geometry. This facilitated the imaginary modelling of empirical reality through the pictorial ordering of the representational space, and it informed the architectonic designing and construction of new architectural locales. A rigorous rationality ensured the integrity of the representational space in scientific modelling while being open to imagining reality in artistic forms, albeit in being generated as such via geometric system of points, angles, axes, converging lines, triangles.

The representational space of the pictorial arts was enlivened with colour and the anatomies of figurative depictions of human and living beings, which added a narrative to the artistic spectacle and a sense of spatial measure. The choreographies of gestures and postures carried communicative visual metaphors and symbolic signifiers besides the sensorial insinuations of situated lived experiences. Such artistic techniques were vital for developing the imagery that is necessitated in scientific visualization and volumetric renderings in stereography. The designer would as such imagine spatial and architectonic configurations, and measures them via drawing and scaled-models, in order to enact imaginative strategies that approximate the actualization of design within the physical reality in engineering techniques of construction. This entails the coming together of geometry, statics and dynamics in physics, along with material mechanics. These parameters were coupled with the designer's imagining of the spatial shapes, the colour schemes, the texture of materials, the sensorial articulation of formed matter in compositions and actual place-making strategies. The visualizations in art were as such driven by scientific abstraction in opening up vistas on the surfaces of paintings and drawings that looked unto imagined virtual worlds; hence seeing a portion of reality in perspective.

To better situate the implications of Desargues' visioning techniques, we ought to evoke herein his '*géométral*'.[19] This constitutes a method of drawing that involves tracing an orthogonal projection of a given object on a horizontal plane that normally corresponds with the ground, or that is at times set on a vertical plane. The architectural drawing of the *géométral* consists of establishing orthogonal views that facilitate the building activity and ease the reading of measurement in the pictorially depicted object. By way of metonymy, the *géométral* designates the plane unto which the projection is made.[20] It consists of a point-by-point bijective correspondence between the sets of points assumed to be on the actual object of vision, which is geometrically depicted, and the set of points that are supposed to appear on a squared grid that receives the scaled pictorial depiction of that object. Accordingly, for every point in a set F of the received projections, there exists one and only corresponding point in a set E that is being projected:$\forall y \in F, \exists x \in E, f(x) = y$.

The *géométral* was conventionally used by builders, masons, and practitioners of the mechanical arts (*artes mechanicae*),[21] while *perspectiva* was connected with the fine arts as inherited from the Renaissance. Gathering these two approaches with congruence gave a nobler standing to the *métier* of builders, and granted it an architectural status that involves associations with science, the arts, and letters. Handiworks were henceforth construed as being part of the arts. This also meant that gravure and painting became entangled via the new form of engraving as *portraiture*. Engravers become akin to painters, and master-builders more closely affiliated with architects as proto-engineers.

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[19] Desargues (1647–1648).

[20] Ramanan (1997).

[21] Mechanics enters the liberal arts as set in the *Didascalicon* of Hugues de Saint-Victor, in *Libri septem eruditiones didascaliae*, *Artes mechanicae*: ch. 26 (PL 176, col. 760): *A medieval guide to the arts*, trans. Jerome Taylor (New York: Columbia University Press, 1961).

Bosse recognized the significance of Desargues' techniques in elevating the *métier* of printmaking, etching, engraving, stonecutting, carpentry, instrument-making, to a status that is possibly as noble as that of the fine arts and architecture. This offered an opportunity to associate handiworks with the letters and the sciences. However, such proclaimed elevation of the work of artisans was contested by fine artists at the academy of art in seventeenth century France. Strife broke in the face of giving scientific legitimacy or artistic license to what in French workmanship is known as '*compagnonnage*', namely as an apprenticeship lineage that prolongs the method of mentoring and the transmission of techniques by habituation within networks of craftsmanship. One craft that becomes an applied proto-engineering science is stone-cutting and assembly, which is informed by stereotomy that produces sections through solid volumetric shapes. This technical knowledge is required in the construction of complex vaults, domes, arches, pillars, cornices, and articulate plastic forms that impose various intersections of solids differing in geometric shapes, and thusly demands precision in cutting and assembling stones to fit properly in interlocking outlines. This also involves the art of tracing (*art du trait*) that establishes the scaffolding for designing vaults and arches, and acts as an execution drawing that is drafted to scale.[22] For instance, Eugène Viollet-le-Duc (d. 1879) noted in his *Dictionnaire raisonné de l'architecture française du XI^{e} au XVI^{e} siècle* that: '*le trait est une opération de géométrie descriptive, une décomposition des plans multiples qui composent les solides à mettre en œuvre dans la construction*' ('tracing is an operation of descriptive geometry, [namely] a decomposition of the multiple planes that compose solids in order to put them to use in construction').[23]

Classificatory systems carried epistemic and institutional implications in the transition from the high Renaissance to the seventeenth century. The roles that the fine arts and architecture played in assimilating the applied sciences, the mathematical disciplines, and the letters through an effort to study nature in the Renaissance, all were giving way to novel specialized mathematized models in early-modern exact science. This entailed that architecture needed higher precision in its technical applications, which required mathematization. Even though Bosse's promotion of Desargues' techniques compromised his position in the academy of fine arts, the merits of his views found later expressions in engineering. Two of the disciples of Gaspard Monge at the *École Polytechnique* rediscovered Desargues' projective geometry and benefited from its combination with descriptive geometry.[24] Desargues' *oeuvres* were then integrated in the eighteenth century curricula of the *École royale des ponts et chaussées* and the military engineering *École polytechnique*. Desargues' works also figured in academic journals dedicated in the nineteenth century to military engineers

[22] Derand (1643).

[23] Eugène Viollet-le-Duc (d. 1879), *Dictionnaire raisonné de l'architecture française du XI^{e} au XVI^{e} siècle* (Paris: Édition Bance-Morel de 1854–1868), 'Trait (art du)', Tome 9, pp. 197–214.

[24] These were Jean-Victor Poncelet (author of the *Traité des propriétés projectives des figures*. Paris: Bachelier, 1822) and Joseph Diez Gergonne (editor of the *Annales de mathématiques pures et appliquées*. Nimes: La Veuve Belle, 1810–1811), both became aware of Desargues' works through Michel Chasles *Traité des coniques* (Paris: Gauthier-Villars, 1865).

in the French army.[25] This epistemic turn already pointed to what later served the processes of industrialization and the unfolding of the essence of modern technicity, with the unfurling as well of advanced mathematical techniques in imaging and modelling nature to the end of *en-framing* it.

Parergon

The aura of authentic artworks in the epoch of modern technicity calls for thinking about art as being a *supplement* to science. This the case despite the avant-garde modernist efforts in the early twentieth century to critically reflect upon the implications of scientism.[26] The Greek notion of πάρεργον (*parergon*),[27] namely as *what is posited outside the ἔργον* (*ergon* [work; *oeuvre*; *Werk*]), may serve the pondering over what *supplements* the lack of *sense-making* within the intrinsic operations of science. After all, the scientific endeavour is not intrinsically generative of its own epistemic signification, rather signifiers are extrinsically projected unto it culturally, intellectually, or artistically. Hence, the assigning of meaning through art, to what otherwise is a neuter scientific construct, which is concerned with facts and hypothetical-deductive theoretical procedures, becomes itself *a subordinate accessory* to science.

If the essence of modern technology, as analysed by Martin Heidegger, comes forth in our epoch as *that which en-frames all beings*, and turns them into a *standing reserve* (*Bestand*) of locked energies that get mobilized via technical command, then the artwork may still carry the poetizing *aura* of sense-generation that might tangentially evade the *en-framing* by technicity. This calls for thinking about the Heideggerian epigram: 'science does not think' (*Die Wissenschaft denkt nicht*),[28] and in how it ties with the ontological notions that he evokes about *the origin of the artwork* (*Der Ursprung des Kunstwerkes*).[29] The idea of a supplement is accordingly connected with the notion of en-framing, '*le cadre, le cadrage, et l'encadrement*'. Such aspect was pivotal in Heidegger's reflections on the unfolding of the essence of modern technology, wherein its mode of revealing takes place by way of *en-framing* as '*Ge-Stell*'.

In reflections on art, Heidegger evokes the notion of the '*Riss*', which is a rift, cleft, or cleavage (*Die Zerklüftung*), that arises in-between two opposing regions and opens up a *gap* that holds them together while setting them apart at the same

[25] Desargues' *oeuvres* and Bosse's interpretations were edited in Paris in 1864 by Noël-Germinal Poudra who was in the French infantry at the rank of *Officier supérieur d'état-major*, and a graduate of the École Polytechnique.

[26] Thinking of *scientism* herein as a cultural phenomenon that originates from learned modes of commenting on the epistemic merits of science and promoting them over other forms of knowledge.

[27] I discussed this in: El-Bizri, '*Parerga*—Carnet de Croquis', *art. cit*.

[28] Heidegger (1954).

[29] Heidegger (1950). For the English translation see: Heidegger (1971).

time. This brings about a tense intimacy in which seeming opponents belong to one another in having such *gap* as a common ground. The rift that draws them together has an outline and *Gestalt* that can itself be set in the hardness of stone, carved in wood, traced with ink and lead. A shape emerges through the rift in particular mode of placing (*Stellen*) or *en-framing* (*Ge-Stell*),[30] and not simply as a mere tearing open that incises.[31] Reflections on *Ge-Stell* belong in this sense to meditations on the question of being (*Seinsfrage*) in connection with the unfolding of the essence of modern technology and the dominance of its mode of revealing truth that turns beings into a standing-reserve (*Bestand*). *En-framing* veils the 'objectivity' of objects and further conceals their essential 'thingly' (*Dinglich*) character, insofar that they are *things in the midst of which we dwell*, and through which occurs the event (*Ereignis*) of gathering into oneness the fourfold of 'earth, sky, divinities, mortals' (*Erde und Himmel, die Göttlichen und die Sterblichen*).[32] If Heidegger saw a threatening danger in *Ge-Stell*, he nevertheless hinted at a sphere from within which the reflection on the essence of modern technology must happen, and conceived this to the calling of art. Similar sentiments arose at a relatively earlier epoch than Heidegger's, and within a different intellectual mood, over the hopes that were being pinned on the arts, and that were as such called into question by Walter Benjamin in the last three sentences of his '*Das Kunstwerk im Zeitalter seiner technischen Reproduzierbarkeit*' ('The Work of Art in the Age of Mechanical Reproduction'). Benjamin stated therein that 'self-alienation has reached such a degree that it can experience its own destruction as an aesthetic pleasure of the first order' (*Ihre Selbst-entfremdung hat jenen Grad erreicht, der sie ihre eigene Vernichtung als ästhetischen Genuß ersten Ranges erleben läßt*). This was the basis for what he pictured as the aestheticizing of politics by Fascism and the politicizing of aesthetics by Communism. In the case of Fascism, Communism, and henceforth of Capitalist Imperialism, the emphasis on techno-science in militarized agencies aestheticized the manifestation of the planetary political *will to power* (*der Wille zur Macht*) and its dominion over the earth. This is currently taking a much more serious turn in the military research on Artificial Intelligence, Machine Learning, Robotics, Genetics, Cybernetics and Informatics.

If art and science in premodern contexts were co-entangled, albeit dialectically and with epistemic inner tensions in their relationships, the artwork itself resides outside the ἔργον (*ergon*) of science. The artwork stands in this relation as what frames (*encadrer*) the scientific ἔργον in terms of generating meaning and an aesthetic experience. This is the case even if the conceptual take on modernist abstract and conceptual artworks devalued the valuing of sense-making in art, and went further

[30]I discussed this in: El-Bizri (2004b).

[31]The representation of such *rift* figured architecturally in the 'Splitting' a New Jersey house by the artist/architect Gordon Matta-Clark in 1974, and this spatialized incision was recorded by him on film.

[32]Heidegger (1962); Heidegger, *Vorträge und Aufsätze*, *op. cit*., pp. 13–44. See also: 'The Question Concerning Technology', from Martin Heidegger, *Basic Writings,* ed. David Farrell Krell (New York: Harper Collins Publishers, 1993). I also discussed this in detail in: El-Bizri (2011, 2012b).

into an avant-garde framing of ordinary things as still-life, found and ready-made everyday unaltered objects.[33]

Imaging and modelling are integral to modern science without amounting to being artworks per se; unless they are pictured as such via artistic gestures that lift their scientific content from its epistemic, utilitarian, and technical spheres, and then re-inserts it within an artistic *praxis*. Art figures within science by way of displacement in being as such 'neither *in* nor *out*' ('*ni dedans ni dehors*'); hence, when situated in the nearness of science, art in our epoch remains placeless (marked by ἀτοπία; *atopia*). Accordingly, it is 'neither a work (ἔργον; *ergon*) per se, nor something outside it' ('*ni* oeuvre, *ni hors d'œuvre*').[34] This resonates with ponderings over the dialectics of the outside and inside (*la dialéctique du dehors et du dedans*), wherein art is posited in a liminal place, a *rift* and *gap*, akin to the threshold of a portal that is left ajar half-open ('*entr'ouvert*).[35] Such spatial situation contrasts with how the *aura* of authentic art cometh from a region that is poetically suggestive of the workings of μῦθος (*muthos*, myth),[36] which grounds the presence of the artwork in its unique place and temporal horizon as a site of the *origin* (*Ursprung*) from where it came to be in its originality (*qua* what pertains to its *origin*) that cannot be reproduced. This calls for thinking about how the artwork falls outside the spheres of technical reproducibility. How can it be marked by uniqueness, whereby reproduction becomes a non-identical repetition that individuates while copying an exemplary archetype? This evokes the structures of analogy (*mimesis*, *homoiosis*, *adaequatio*), while pointing to originality. One wonders herein about what distinguishes the art-*oeuvre* (ἔργον) from being simply a physical object.

A copy of an artwork is a singular definite entity, since it is individuated even when it is set within a repetitive series. Each drawing within a mimetic chain that reproduces a generic model has its specificity in depiction, representation, and modes of imitation. It defies the serial in repetition ('*hors série dans la série*'),[37] which is not merely that of mechanical reproduction. Walter Benjamin pointed to such repet-

[33]An example of such *avant-gardist* play with signifiers via art-forms was pioneered by Marcel Duchamp in the early twentieth century (for instance, this is the case with the urinal he turned into the '*Fountain*' [Manhattan 1917]; or how his approach was mimetically practiced, albeit at lower modes of expression in the late twentieth century in the British milieu via Tracey Emin's Turner Prize shortlisted '*My bed*' [London 1998]).

[34]Alluding to neologisms in: Derrida (1978).

[35]Bachelard (2008).

[36]This is what Derrida notes with respect to thinking about χώρα (*khôra*; namely what is conventionally rendered in English as 'space', and yet that exceeds the notion of spatiality in terms of its ontological significance and the ineffable character of attempting to account for its attributes). This is derived from Plato's *Timaeus* that points to a 'third genus' (48e4) besides the Platonic forms and their imitations in the realms that are apprehended by the senses. The χώρα is neither intelligible nor sensible. It is an underlying everlasting substratum that serves as a receptacle of becoming for the entities that enter it and withdraw from it (*Timaeus* 49e7–8, 50c4–5, 52a4–6). It is characterless in itself, and yet taking upon itself the character of what enters into it. See: Derrida (1993), Plato (1960), El-Bizri (2001); El-Bizri, '*ON KAI KHORA*: Situating Heidegger between the *Sophist* and the *Timaeus*,' *art. cit*.

[37]Derrida, *La vérité en peinture*, *op. cit*., p. 229.

itiveness when he noted that even the most perfect reproduction of a work of art is lacking in one element, namely its presence in the time and space where it originated, and as what determines the history of its being.[38] The presence of the original is accordingly a prerequisite to the concept of authenticity (*Das Hier und Jetzt des Originals macht den Begriff seiner Echtheit aus*). Such aspired for *authenticity* constitutes the 'aura-character' of the artwork without this carrying parapsychological connotations. This phenomenon is brought forth from the uniqueness that ought to be imbedded in the fabric of the art tradition (*Die Einzigkeit des Kunstwerks ist identisch mit seinem Eingebettetsein in den Zusammen-hang der Tradition*) and of its ritualistic cult-praxis within the specific situational locations of its original use.[39] This ultimately evokes *the origin of the work of art* as emanating from an existential mode of being-in-the-world that is rooted in the historical life of a people. The notion of origin is an ἄρχή (*arkhḗ*) that names not only a beginning but also a commandment (*nomme à la fois le commencement et le commandement*). The origin is a source of growth within nature and of eventful commencements in human history, it is also the site from within which the νόμος (*nomos*; law) is given.[40]

An unchained kinaesthetic energy of human embodiment underpins the production, reproduction, tracing and retracing, moving and shifting, being situated and displaced, of the bodily activities in art-making. Such kinaesthetic ensures the union of fragmented *membra disjecta*, wherein the gaze, *logos*, and gesture are co-entangled ('*du regard, de la parole, du geste*').[41] A manual motion in writing releases the audio-phonetic energies of silent private inner speech, the gaze in sight and the gesture of the hand ('*la motricité manuelle qui délivre le système audio-phonique de la parole, le regard et la main pour l'écriture*').[42] This highlights the flow of handwriting, drawing, and sculpting, as contrasted with the pressing of buttons on typewriters, the sliding of fingertips on the glass screen of highly-sensitive digital equipment of information processing and communication technology. Writing and drawing are brought nearer in the movement of fingers in relationships that emerge between ideograms and pictograms. Algorithms and codes substitute calligraphy, lettering, and freehand drawing, or drafting with the aid of handy instruments that engage bodily motion and postures in relation to the drawing board, such as the stretch of the T-Square, the agility in manipulating compasses, drafting-triangles. A 'trace' is inherent as such in the forming of letters, and is embedded within discourse as well as painting ('*ce trait dans la lettre, le discours, la peinture*').[43]

The notion of '*ductus*' can be evoked herein in the manner it is etymologically derived from '*ducto*' and '*ductio*' (leads, conducts, commands, draws). In technical terms, the *ductus* serves as a chart that displays the geometric ordering and direc-

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[38] Benjamin (1976, 1977).

[39] Benjamin, '*Das Kunstwerk im Zeitalter seiner technischen Reproduzierbarkeit*', *op. cit.*, § II, § IV.

[40] Derrida (1995).

[41] Derrida (1967).

[42] Derrida, *De la grammatologie*, *op. cit.*, p. 127.

[43] Derrida, *La vérité en peinture*, *op. cit.*, p. 13.

tionality of sequences that orient strokes and tracings, which form the calligraphic hand-lettering of a given script-tradition with its embellishment and spacing on parchment, vellum, or paper. The type of *ductus* is connected with the speed in executing individual letterforms or ligatures, which can be slow or cursive, and is measured in terms of modulating the sequence and direction of individual pen-strokes that structure the lettering. A *ductus* apportions and measures the execution by the hand of a calligraphic trace. Its derivative term 'duction' carries a technical ophthalmological significance in terms of referring to the various forms of the eye's rotation. The motion of the hand is thusly closely interconnected with the coordinated movement of the eyes, which renders the hand slightly second to the eye in neurological impulses via which the physical responses to thought become enacted. Moreover, 'duction' refers to a broader idiomatic usage in designating the acts of leading, bringing, or conducting as entailed by '*ductio*', which is furthermore at the root of concepts denoted by the terms: introduction, deduction, induction, production, reproduction, seduction. These describe a system of '*duction*' ('*un système de duction*').[44] This etymological analytic suggests the motion of a draft or draught, as in saying: 'draftsman', or 'draughtsman'; namely, what pulls or infiltrates an enclosure by passing through it as a current. This phenomenon of tracing, as traction or friction, which draws nearer and pulls, reflects the kinaesthetic of embodied lived situational experiences in the flesh of the artist that exceed the en-framing by technicity.

Moreover, the idiomatic is entangled with the pictorial in how the discursive textuality is connected with drawing and sketching ('*l'écriture discursive avec la peinture représentative … le langage et le tableau*').[45] In an analysis of Diego Vélasquez's *Las Meninas* (1656) Michel Foucault hinted that the relation of language to painting borders on being infinite in its horizons ('*le rapport du langage à la peinture est un rapport infini*').[46] Language and painting are seen from this perspective as being irreducible unto each other when we cross from the space of what we say to that of what we see. Albeit, what we see is never fully contained in what we say, and we show what we mean by what we say in terms of images, as well as making what we see clearer by what we utter about it and name in connection with it. This reveals the extent of the intertwining of text with image, the word and the icon, and more essentially, it also points to the development of a new worldview that is detached from the orders of classical representation and realist similarity in their episteme. The image moves deeper into the realm of *what is said* as 'a conceptual modern art', which itself is no longer aiming at showing what it contains as narrative, rather it is silent in its pictorial quality, and necessitates a discourse for letting what it aims at showing become unveiled. This is how abstract installation-artworks are accompanied by texts that explain the underpinnings of their visual and plastic art qualities.

Would art be an artifice that replaces a missing part, fills a gap, points to a lack, a deficiency, and hence is what supplements science with meaning? Is it simply a form of *prosthesis*? However, a supplement does not replace or displace what it supple-

[44]Derrida, *La vérité en peinture*, *op. cit*., p. 14.

[45]Derrida, *La vérité en peinture*, *op. cit*., pp. 182–183.

[46]Foucault (1966).

ments, it is neither a signifier nor a representative, since it does not take the place of a signified or of what is represented ('*le supplément qui n'est simplement ni le signifi-cant ni le représentant, ne prend pas la place d'un signifié ou d'un représenté*').[47] The artwork is in a state of detachment as being dispatched as a messenger or delegate. It is a surplus, a remainder (*ce qui reste*), an additive accessory that whomever deals with it is also obligated to receive it ('*un accessoire qu'on est obligé d'acceuillir*' [*à-côté; à-bord; à l'extrémité*]). It appears as being ancillary to science (*ancilla sci-entiae*); a detachment that is badly detachable or hard to detach ('*Un détachement mal détachable*').[48] It is '*ni propre ni impropre*' (neither proper nor improper), '*entre l'œuvre et l'absence d'œuvre*' (posited between the work and its absence).[49] However, such attributes that were associated with the artwork in its tangible handiness, its concrete objective presence, its physical materiality, are all further accentuated in the manner they get manifested via a digitized instrumentality as exemplified by the graphic luminous colours on the screens of data processing and communicative machines. Such accessories remove the experiencing of drawings, sketches, and the letters in their physicality as they traditionally occurred on material *matrices* (canvas, parchment, vellum, paper, metal, wood, textile, cloth, glass, etc.). They furthermore distance us from their texture as sensed by touch, or even the scent of their materiality, be it that of the receiving physical pad, or the pigment, ink, charcoal, crayon that once came to be traced upon it. Such pronouncements are not meant to be nostalgic, reactionary, or regressive, but rather point to what withdraws from our world and experiential realms in terms of multi-sensorial experiences.

Our electronic digitized accessories are set upon us in such a manner that they are hard to detach ourselves from. Their demands upon us are not neuter. They rather oblige us to respond to their calling, to receive via our own commands what orders us about in the execution of such commanding acts. They refer to what imposes itself upon us as what cannot but be received as it is transmitted unto us harassingly. Human beings fuel such will to power, albeit by being themselves challenged forth, orderable, and made reportable, and by being already and always on-call, held at a distance when responding to this destined *en-framing* (*Ge-Stell*) that has been sent our way.[50] This reflects a movement from unveiling to veiling, which is associated with the switching *on/off* of what retains a latent presence as an active machinery that is mastered via the destined unfolding of the essence of technology (*das Wesen der modernen Technik*). Nonetheless, it remains to be the case that *tele-techno-science* (Artificial Intelligence, Machine Learning, Internet of Things, robotics, cybernetics) has unparalleled promising horizons in terms of enabling wider forms of societal benefit. This is the case despite the over-dominance of how tele-techno-science *en-frames* beings beyond the manner they are turned into *objects of research* under the gaze of science, but by being furthermore posited as *standing-reserves* for the technical will to power. Such state of affairs is not concerned with the existential lived situations

[47] Derrida, *De la grammatologie*, *op. cit.*, p. 429.

[48] Derrida, *La vérité en peinture*, *op. cit.*, pp. 63–67.

[49] Derrida, *La vérité en peinture*, *op. cit.*, pp. 73–74.

[50] Derrida (1996).

of being-in-the-flesh, except if such mode of being translates into a powering energy for actualizing the potentiality of the artificially-intelligent-learning-machine in a planetary technical dominion over the earth. It is from the art-sphere, as rooted in the letters, that science can be called upon to think about how its appropriation as technicity can descend into an unleashing of unprecedented collective oppression. We turn again to the initial reflections from which we commenced by picturing *fabrica* as being a form of *meditatio*.[51] It is in this sense that we muse with Heidegger that: 'The oldest of the old cometh, in our thinking, after us, and yet toward us. That is why thinking orients itself to the arrival of what-has-been, and is remembrance' ('*Das Älteste des Alten kommt in unserem Denken hinter uns her und doch auf uns zu. Darum hält sich das Deneken an die Ankunft des Gewesenen und ist Andenken*').[52] We henceforth ponder again by way of recollecting what is destined our way in the art/science relationship to find a home (*heimisch*) in the provenance (*Herkunft*) of thinking.[53]

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[51] Vitruvius, *De architectura*, *op. cit*., *Liber* I, *Caput* 1, §1.

[52] Heidegger. *Poetry, Language, Thought*, *op. cit*., p. 10; Heidegger (1965).

[53] I dedicate this chapter to my muse Z.M. for having wholeheartedly supported and inspired me not to wither my devotedness to philosophical writing and thought at a time of grave personal trials.

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Art, Science, and the Nature of the Meritorious

Mark Daniel Cohen

The proper context of any idea is the succession of imagination. In any field of inquiry, the appropriate and productive logic of an idea's illumination, its sequencing a germination, its instance an ignition, its methodology is light. The grappling of an authentic thought is an excitation—its potency to instigate its ambiance, for an idea of authenticity when found departs the flow of rumination that led to it, argued it, excused it. The idea becomes an amplitude, incorporates its initial focus into a heightened range of realization. The point made on first reading seems almost beside the point, just one example of a much broader and at times awful range of implication. The idea appears to apply to and disclose far more than could have been intended, like pure ore of insight happened in a field—or else there is genius here. The thought reveals itself to be a truth in principle, depthless in what it imports. In its delving lies the worth.

One such instance arises in the midst of what now seem the dusty and rather labyrinthine library corridors of St. Aquinas's *Summa Theologica*—in *Part II-II (Secunde Secundae)*. In the midst of what feels like a mildly choking ramble through filigreed precisions of theological arcana, considering questions of subtle devotional weightings, to determine what moral actions are more moral than which—such as whether it is better to love an enemy or a friend, whether love as an act of charity is the same as goodwill, whether in loving God we ought to observe any mode—comes this: "Therefore it does not follow that whatever is more difficult is more meritorious."[1]

It is a thought that does not hold its place, that departs from the purpose that brought it forward, that lifts its way out of its original argument, its first point, to make a much wider, a much more penetrating proposition. It tears like an acid through the

[1]St. Aquinas (2007), p. 371.

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soft tissue of much of our accumulated wisdom, for it deracinates the vapid reasoning that often underlies the intellectual conquerings we gesture to respect.

It is not enough to know how hard it is to do a thing. The difficulty does not count. One must know why it should be done, regardless of its challenge. We must know if something is meritorious, if inherently it ought to be done, and why it is. And with that recognition comes the immediate realization of how often we commit this category confusion, how frequently we are waylaid by our enthusiasms and mistake them for admiration. We lose our sense of the distinction between enjoyment and respect. We confuse what we like with what we honor, what entertains us with what matters, what we prefer to indulge with what we cannot, or should not, do without. We lose our sense of what ought to be.

The result is that we think we know what things are for—what our pleasures, and habits, and hobbies, and avocations … and arts are truly about, what purpose they serve—when we don't have a knowing understanding of the reasons why we take them up. We think we know what we don't. Like time, we know what it is until we ask ourselves, and then we don't.

Once we subtract that which dazzles us solely through the mental or otherwise flexing it must have taken to achieve it—the dexterity of the concert pianist, the brushstrokes of Monet, the physical grace and control of a ballet dancer, or a trapeze artist, the piercing lancet of acuity of a chess master—we are left with a question that only increases in urgency as it pursues its scything: What are the things we make and do worth? How do we know how to value every effort? Or are we congenitally incapable of dividing the doer from the deed and always guilty of being respectful, envious, or even merely amused over and at the imagined image of a fellow being endeavoring, without ever concerning ourselves about what that person does and, in doing such, whether someone should?

Incapable of dividing the doer from the deed—and that is the second mistake. Beyond often failing to know the purpose of what we congenitally do, and choose freely to do, beyond failing to consider the relative worth of our devotions, we confuse what we do with ourselves. The thought of an inherent value, of an intrinsic purpose and worth, of a non-relative moral weight eludes us and we come to think of everything as good or bad, as worthwhile or worthless, according to what it does for us, according to how we prefer it or disdain it, according to how we feel about it. The thought of inherent merit, of the value of something being in the nature of it, of the worth of a thing not being up to us, escapes us, and we lose our sense of the difference between what a thing—our goals, our desires, our enterprises, our futilities, our failures, our arts, our pursuits of truth, our ideas—we lose our sense of the difference between what a thing is and what it feels like, between what a thing means and what it means to us.

These considerations are of some value here because the occlusions observed play a role in the pursuit of the relationship between science and art, in the discovery of an innate similarity and the determination of a function each might serve in the practice of the other, of how either might illuminate the other. There is of course a common sense specification to this—if by science we mean hard science and specifically physics, then it is clear that science is largely self-reliant and self-directing. It has a definite purpose and a definite method, and it is an approach to explanation that is thereby self-explanatory. Thus, it is more a question of what role art can play in the progress of science, and more yet—the questioning of the relationship opens the door to an essential question about art: in an age that is increasingly scientific, in which more and more of our understanding of reality and our daily life are both directed by scientific development, what is the role of art at all? Given the direction and the demands of the time, what is the current merit of art? What makes it necessary? What is its advantage?

It seems natural to us to look for a connection between science and art. The question of the connection seems appropriate, answerable. But why, precisely? What is the exact similarity, the true family resemblance? What singles out these two for the same special mention? One might say both art and science are practices of the life of the mind. But so is engineering, so is carpentry, so is accounting. One can say they are both significantly more difficult than virtually all other contenders (maths aside), and we've seen where that goes. We can observe that they are both methods of inquiry, expeditions of discover into realms that are reached only by special training or disposition (talent), not easily sailed to or flown over, not to be had by amateurs, for some price of a ticket. Leaving for now the issue of this being something of a circular argument, for we find science and art both to be enterprises of investigation because we determine them to be so (we are positioning ourselves at both ends of the microscope), there is an issue of imprecision. Even if both projects inquire, do they inquire of the same thing? Are they two approaches that discover they share a common goal of disclosure. Or are they irrelevant to each other?

The goal of science is clear. It is the search for truth, the hunt of the authentic nature of the real. There is little ambiguity about what is meant here, at least for those who adopt an explanation that is frequently attributed to Einstein: the purpose of science is to discover what is going on when we're not looking. It is not a question of determining what we see and why we see it, what our place in the world comes to, what we can do and should do, what the world means to us. It is a question of what is there, and was there before we were. Ultimately, it incorporates the question: what are we when we are not here, but there, when we are on the other side of the lens?

The established goal, the defining characteristic, of art is less clear. Despite a range of objectives towards which art has been aimed over the millennia, one may argue that there have been two principal directions of its thrust: the true and the restorative, revelation and repair, reality and therapy. The two can be said to be encapsulated, broadly, in the approaches of Plato and Aristotle. Plato condemned realistic painting for being a copy of a copy, a falsification of a falsification, an imperfect reproduction of an imperfect embodiment of geometric form, but he admired the art of music, which commits no such misfire. Aristotle viewed the virtue, the merit, of tragic drama as catharsis, the purgation of disturbing and deleterious emotions through observation of the tragic action. Tragedy is thus restorative, it provides an emotional reconditioning. It is therapeutic.

These tendencies in art have continued since. Just a few examples from recent history: In the impulse to pursue the fundamental truth, there is the array of abstract Modernist Art that developed out of the instigation provided by the new maths that arose and gained public notice in the nineteenth century,[2] and displaying the same aspiration although a different spirit, the entire history of religious art, which continued into the Modernist era. The urge to the therapeutic, to social redress, to uplifting of the "spirit," to the improvement of human well-being, and other variants of the same valency can be seen in political art, in polemical literature, as well as in the spate of art therapy programs that seems to grow with every year.

The situation leaves the nature of art rather hazy, and with that, the nature of the possible similarity of and potential for productive interaction between science and art. It is not that the art project is faulty for having more than a single categorical objective. Art, or any other human enterprise, can be whatever its practitioners and recipients choose it to be and can pursue as many aims as they please. It is that, aside from the issue of defining the name of the endeavor so that we use it with some recognizable consistency, there is a risk that, rather than meaning two things, we end up not meaning anything particularly. We lose our sense of comprehending a gist, a core concept, even if it changes from one orientation to another. In short, the two general directions of the ambition remain vaguely realized and recognized, and tend to smear into each other. We stop knowing what we mean. And it is typically the case that, when human beings lose their grip on what they mean, they increasingly think about themselves.

One can see this in the book that sets the baseline for the consideration of the possibility of a connection between science and art, and the worry over the lack of one: *The Two Cultures and the Scientific Revolution*, by C. P. Snow.[3] Snow's book, which is the published text of his Rede Lecture of 1959, established the problematic relationship—in Snow's estimation, nearly non-relationship—between science and art, or science and the humanities (as Snow put it), as a key point of dispute and intellectual concern, and the quality and focus of his concern is made clear in the title. It is for Snow a failure of relationship between two vastly different cultures. It is a sociological problem, a community issue, a difficulty in the connection between people, not ideas.

As he describes the realization he first had when it initially seemed to him there are "two cultures": "For constantly I felt I was moving among two groups—comparable in intelligence, identical in race, not grossly different in social origin, earning about the same incomes, who had almost ceased to communicate at all, who in intellectual, moral and psychological climate had so little in common that instead of going from Burlington House or South Kensington to Chelsea, one might have crossed an ocean."[4] The conclusion he reached was "I believe the intellectual life of the whole of western society is increasingly being split into two polar groups…. They have a curious distorted image of each other. Their attitudes are so different that, even on the level of emotion, they can't find much common ground."[5] Each community, for that is what orients Snow's argument—scientists and "intellectuals" (those who spe-

[2]Henderson (1983).

[3]Snow (1959).

[4]Snow (1959), pp. 2–3.

[5]Snow (1959), pp. 4–5.

cialize in the humanities)—has a consistent "culture" that differs radically from that of the other group. "There are common attitudes, common standards and patterns of behaviour, common approaches and assumptions.... Without thinking about it, they respond alike. That is what a culture means."[6]

Snow's argument leads him to confront the risks imposed by this impasse, risks such as the inability to deal effectively in the future with global problems, among them population growth and world poverty. So, his point of concern is with the building of a coherent culture—a single culture, not two—his focus is essentially with the maintenance of a civilization, a survivable civilization. "All the arrows point the same way. Closing the gap between our cultures is a necessity in the most abstract intellectual sense, as well as in the most practical. When those two senses have grown apart, then no society is going to be able to think with wisdom."[7]

Noble and commendable as this concern is, there is something missing in Snow's analysis. These are utilitarian virtues we require—science gives us technology, the humanities give us the wisdom to use it well, to save ourselves. But what is overlooked is closer to central, and more purely a matter of the "abstract intellectual sense" of the thing. What is missing is the gist of science and the gist of art—what each one does in itself, for its own sake, what makes it worth doing apart from what we can divert it to grant us. And this question—how do these pursuits differ in their essential natures—may be a precondition for Snow's considerations, for there is an unexamined assumption in his argument. In order for a relationship and a mutual understanding of art and science to be forged, it must be possible for them to intersect and interact, it must be possible for them to combine their merits—what they do that makes us feel they are worth doing—and that possibility is merely being taken for granted.

The question that has been occluded, that has not been seen or asked—is it possible that art and science negate each other? That they are not only not alike, but categorically unlike, that they are no more similar than are an aroma and a stone. Is it possible that the incomprehension, the two cultures, that Snow bemoans is there for a reason, that it is a temperature measure, a barometric reading, of a fundamental divide in the world, or in us? Is it the case that both science and art are right, and that they are, in fact, in perfect contradiction?

It is the proposition of this paper that the answer is yes, at least for art as we have understood and practiced it to date. Art and science are categorically different. They exist in the same world, this world, and each conceives of the world in terms that the other cannot render as comprehensible. They are in the same world, and they are not. They are built on different clocks, different topographies, different topologies—they enumerate different dimensions. They are orthogonal to each other. They are as different as are a theory and a tragic poem, as different as are a vector space and a sonata. The difference between them is comparable to the difference between physics and human fate. In fact, it is exactly that.

[6]Snow (1959), pp. 10–11.

[7]Snow (1959), p. 53.

Art, or rather the arts, are rooted in appearances, in the sensory experience, in an intimate awareness of what the senses bring to us. They are about what we can see, and hear, and feel, and touch. Composed and orchestrated for a creature that lives halfway between the gods and the beasts, or if one prefers, between the galaxies and the subatomic particles, they are calibrated to our scale. The arts are human sized, and they observe human things, human concerns. They are about not what we know but what we encounter, not what we theorize but what we live through, what we experience directly, without instruments, on our own and simply as ourselves, and what it feels like. They are about not the theory of the world but the drama of our lives. They are about not the world, but life, which is what we are—or perhaps is what we are.

Modern science—the science of the scientific revolution—has from the start seen a different world. It conceives a world that is not visible, that is populated exclusively by that which in principle cannot be perceived by us, not directly, not by means of any of our unaided senses, that is intrinsically unobservable, in the naive sense of observation. That which science understands is real is categorically unlike all that is observable—in that, even the mind's eye is unavailing. Even a vicarious scenario is by definition inaccurate. This is a world in which we do not live, because we cannot—it contains only that which is not like us—and yet we do, for it is the world. And science carries the same infection here that it does everywhere—it can be proved to be accurate.

The proposition that at least some of what we experience is illusory and at least some of what is real is unobservable took root in the new science of the seventeenth century and was based in two related philosophical ideas dating back to Greek antiquity: the idea of primary and secondary qualities, and atomism. The primary/secondary quality distinction has been summarized and assigned to the start of the scientific revolution by Lawrence Nolan in the opening pages of his excellent collection of essays, *Primary and Secondary Qualities*:

> The seventeenth-century revolution in science ushered in a radically new conception of the nature of physical objects that sought to revise the common-sense picture. Known as 'mechanism', the new science conceived the universe on the model of a machine and tried to explain all physical phenomena in terms of the mechanical properties of the insensibly small parts of matter…. As a consequence, the new science restricted the 'real qualities' of bodies to those that can be understood in mechanical or geometric terms, and treated qualities such as sensuous red as mere appearances. Another way of expressing these points is to say that the 'mechanical philosophers' drew a distinction between primary and secondary qualities and that this distinction was at the heart of the new science…. In addition to being familiar, the doctrine of qualities also seems intuitively simple, perhaps in part because it is often characterized as an appearance-reality distinction: there are certain qualities that objects in the world have intrinsically, independent of our perceptions of them, while there are others that we ascribe to objects only in relation to our perceptual apparatus or sensibility.[8]

And it is precisely this proposition that is offered by Galileo in his volume *The Assayer*, composed in 1632.

[8]Nolan (2011), pp. 1–3.

> When I think of a physical material or substance, I immediately have to conceive of it as bounded, and as having this or that shape, as being large or small in relation to other things, and in some specific place and at any given time, as moving or at rest, as touching or not another physical body, and as being one in number, or few or many. I cannot separate it from these conditions by any stretch of the imagination. But whether it is white or red, bitter or sweet, noisy or silent, and of a pleasing or unpleasant odour, my mind does not feel compelled to bring this in order to apprehend it; in fact, without our senses as a guide reason or imagination unaided would probably never arrive at qualities such as these. So it seems to me that taste, odour, colour, and so on are nothing more than pure names, as far as the objects in which we think they reside are concerned. Rather, they exist only in the mind that perceives them, so that if living creatures were removed, all these qualities would be wiped away and no longer exist. But since we have given them specific names, distinct from those of the other and real primary qualities, we treat them as if they too were real with a distinct existence of their own.[9]

The "insensibly small parts of matter" mentioned by Nolan mark the connection from the start of the scientific revolution between the primary/secondary distinction and atomism, which in a certain sense can be taken as the amplification of the distinction, a plausible accounting of the reason behind the categorical difference. Interactions between minute, innately unobservable particles can be understood to account for the qualities of objects and events that seem obviously inherent to them—shape, dynamics, dimension, relative scale, temperature, pressure—but those interactions seem incapable of accounting for the sensory experiences that appear more intimate, more inside us, more a matter of delectation than of measurement, partly emotional, experiences of qualities we naturally characterize as *qualia*—the very stuff of art.

The distinction between primary and secondary qualities is adequately self-evident and was acquired and sponsored by a large number of modern philosophers, scientists, and mathematicians, among them, Descartes, Boyle, Locke, Leibniz, Hume, Berkeley, and of course, Kant. Atomism as a scientific principle was slower in becoming adopted, for one reason, it clearly had to meet greater explanatory demands. During the scientific revolution, there were differing and generally somewhat vague versions of atomism among such as Descartes, Pierre Gassendi, Boyle, Newton with his corpuscular theory of light, Boscovich, and Dalton. But it was not until Ludwig Boltzmann supplied atomism with statistical mechanics that he had a theory that could explain with mathematical precision how the unobservable molecules could produce such observable effects as the pressure and temperature of gas in a container. And it was then not until Einstein's 1905 paper on Brownian motion that the existence of "atoms" (actually molecules) was accepted as having been proved.

With that paper, the core point of atomism had been established as truth: unobservable particles are what is real, are exclusively what is real. Everything observable is constituted solely of what is not observable. The world we know does not accompany the world of minute particles—it is a world of minute particles. We do not live among atoms. We are atoms.

Throughout the development of modern science, at least until the nuclear age, the proposition of the unobservable, the propounding that the visible is an effect of

[9] Galilei (2012), p. 119.

invisible material, has found a surprisingly, or perhaps not surprisingly, vigorous and dedicated opposition. Only a handful of examples will be given here.[10]

Johann Wolfgang von Goethe, the great German poet and man of letters, took it upon himself to dispute Newton's theory of optics, a position Goethe develops and promotes in his *Theory of Colors*. Goethe devoted many years to scientific studies, and his labors extended into the fields of botany, morphology, and meteorology, as well as optics. His scientific work was tendentious—he had an objection to air and a case he felt he needed to make.

An excellent analysis of Goethe's position on the science of his time was written by Werner Heisenberg, the physicist who created the theory of Quantum Mechanics: "The Teachings of Goethe and Newton on Colour in the Light of Modern Physics."[11] According to Heisenberg, Goethe "sensed an injury in the advance of science."[12] Goethe objected to a science that roots its explanations in the envisioning of theoretical entities—in the intrinsically unobservable—in preference to what is thereby lost: the "living quality" of the thing perceived, the direct experience of direct observation. It was his project to demonstrate that authentic and more appropriate science could be derived, and to its purpose, he proposed that the proper study of optics is not light waves, or Newton's particle of light, but colors—that which our eyes in fact see.

> What is natural to Goethe as a starting point for science is direct observation uninterpreted, transported unalloyed into conceptual frameworks so as to retain the living quality of the thing science attempts to understand. Human perceptions are both preferable to theoretical entities for their authenticity and are comprehensive, providing an immediate and complete vision of the real. From his *Theory of Colours*:
>
> Effects we can perceive, and a complete history of those effects would, in fact, sufficiently define the nature of the thing itself…. The colours are acts of light; its active and passive modifications: … we should think of both as belonging to nature as a whole, for it is nature as a whole which manifests itself by their means in an especial manner to the sense of sight. [Goethe, *Theory of Colours*, trans. C. L. Eastlake (London: John Murray, 1840), pp. xvii–xviii]
>
> Thus for Goethe, the human perceptual apparatus is not an augmentation of nature and is not a particular viewpoint on nature. Rather, it is the ideal mechanism for the investigation of nature.
>
> In one word, our senses themselves do the real experimenting with phenomena, testing them and proving their validity, in so far as phenomena are what they are only for the respective sense in question. Man himself is the greatest, most universal physical apparatus. [Goethe, *Wisdom and Experience*, trans. H. J. Weigand (New York: Pantheon Books, 1949), p. 123]
>
> Goethe's selection of colors as the foundational element for this theory of optics is in preference to Newton's orientation on light, for it is color that is our direct experience, and, as a number of commentators have observed, neither Newton's proposal of the particulate nature

[10] A comprehensive survey of the opposition to atomism and the reasons underlying it seems not to have yet been executed. Either such a study exists and is of remote access, in which case this author is severely delinquent in his education, or is badly in need of being undertaken. For it seems that such an examination would be greatly illustrative of the things we need to believe and why we need to believe in them.

[11] In Heisenberg (1979), pp. 60–76.

[12] Heisenberg (1979), p. 76.

> of light nor the wave mechanics that were incorporated after Newton's time would have received Goethe's assent, for neither is directly observable—neither is within the realm of our perception. Both, as theoretical constructs, are divorced from reality. Reality is entirely rooted in what our senses report.[13]

Heisenberg aptly observes in his essay that the two positions Goethe acknowledges—the position of contemporary science, which Goethe opposes, and the position Goethe adopts in the attempts to practice, or reformulate, science—are precisely those traditional to science and art.

> In estimating the human sensory array as the "greatest, most universal physical apparatus" for investigating the world, Goethe specifically rejects the position of science on sensory input, already well established in his day, as described by Heisenberg during his analysis of Goethe's dispute with Newtonian physics: "In a way, science represents the attempt to describe the world to the extent that it is independent of our thought and action. Our senses rank only as more or less imperfect aids enabling us to acquire knowledge about the objective world." [Heisenberg, pp. 67–68]
>
> On the other hand, Goethe's emphasis on retaining the "living quality" of the thing being perceived and examined through reliance on direct observation rather than hypothetical constructs—along with the inevitable subjective intrusions on those perceptions undisciplined by reference to abstract, and particularly mathematically rigorous, formulations—is the essence of the artistic approach to the world, as Heisenberg points out:
>
> To this objective reality, proceeding according to definite laws and binding even when appearing accidental and without purpose, there stands opposed that other reality, important and full of meaning for us. In that reality events are not counted but weighed, and past events not explained but interpreted. Useful (*sinnvoll*) interrelations here mean a 'belonging together' within the human mind. True this reality is subjective but it is no less powerful for all that. This is the reality of Goethe's theory of colour. Every type of art is concerned with this reality and every important work of art enriches us with a fresh understanding of its scope. [Heisenberg, p. 68][14]

Heisenberg's attempt to be evenhanded, to achieve a reconciliation between what he acknowledges as the differing positions of science and art, is gracious and considerate, but it is even more so ingenious, in that it does what many often attempt to do to console the breaching of a deep divide—play with language. He does so in a manner that is usually effective and SOP, slipping in a metaphor for the literal use of a word, in this case: "reality." It is pleasant to state that both sides in the dispute have their own realities, as if existing equally in their own domains, but the "other reality" of concern to art—other than the "objective reality" studied by science—is not literally a reality. There is only one reality, and the nature of it is the matter at hand. And the issue is being sidestepped—the gist of the matter set aside—in the cause of promoting amity.

The contending positions on reality that divide between Newton and Goethe are easily recognized as Heisenberg saw them, as the standard focuses of concern of science and art. But the opposition to the orientation on the unobservable does not always come from the practitioners and students of art. It has arisen in the debates

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[13] Cohen (2017), pp. 34–35.

[14] Cohen (2017), p. 35.

among scientists, and the one who was perhaps the most aggressively confronted over his belief in atomism was Ludwig Boltzmann, the scientist who did the most to transform atomism into a science.

It was Boltzmann who devised the methodology of statistical mechanics and introduced it into theory building so as to make possible the kinetic theory of heat, which attributes heat to the motions of atoms. The use of statistics, which had never been entered into scientific theory before, provided a mathematically precise instrument for dealing with and predicting the attributes of assemblies of an uncountable (at least for us) number of atoms or molecules. The Maxwell-Boltzmann formula laid out the distribution of the average velocities of atoms in a gas at equilibrium based on energy measurements and predicted temperature and pressure in a closed system, and "remains the cornerstone of the atomic depiction of gases."[15] Boltzmann gave entropy a mechanical explanation and in so doing, created a coherent theory of the relationship between the micro-state (the distribution of unobservable particles) and the macro-state (the world that is directly observable, to us—the directly observable version of the micro-state). And with his introduction of statistical theory into physics, he provided the mathematical tool indispensable to the development of quantum theory.

It is a remarkable life of achievement, but likely due to the issue that was the centerpiece of his thinking, his polestar—the atomism he never failed to believe—he had to deal with opposition to his thinking throughout his career. Many contemporary scientists felt that the introduction of imaginary entities, like atoms, did nothing to elucidate complex experimental situations. Many were uncomfortable with scientific theories that gave only probabilities, not necessary results. And one philosopher in particular opposed Boltzmann's atomism openly and with dedication.

Ernst Mach began as a believer in atomic theory, but early on he changed his position and turned against it, with a rejection that was the core of his thinking. It was his meaning, his gist.

> The goal of science, Mach implied, was to provide logical and rational relationships between facts and phenomena that could be directly observed; the more one invoked the existence of entities whose existence was not immediately apparent, the more one was going astray. Theorizing, in Mach's view, was a necessary evil at best, and frequently an unnecessary one.
>
> In atomism and kinetic theory, Mach found a natural target. It demanded a belief in unseen and quite possibly unseeable objects, yet its results, which merely confirmed what the laws of thermodynamics already said, were supposed to lend credence to the assumptions on which it was based. Apart from the circular nature of this reasoning, it ran counter to what Mach had decided was the essence of scientific explanation: to find laws, as simple as possible, linking observable phenomena.[16]

This is essentially Goethe's position—direct observations constitute the occupancy of the world the scientist studies and the explanations discovered should not be amplified with the invention of invisible, fantasy elements.

Boltzmann had the answer to this.

[15] Lindley (2001), p. 18.

[16] Lindley (2001), p. 86.

> Boltzmann knew, as any scientist must, that strict adherence to Mach's views—which he referred to as phenomenology, meaning that Mach would permit himself to rely on nothing but observable or tangible phenomena—would fatally hamstring scientific exploration: "Phenomenology believed that it could represent nature without in any way going beyond experience, but I think that this is an illusion…. The more boldly one goes beyond experience, the more general the overview one can win, the more surprising the facts one can discover, but the more easily too one can fall into error. Phenomenology therefore ought not to boast that it does not go beyond experience, but merely warn against doing so to excess."
>
> Here was an impasse. Boltzmann argued that to make any progress, scientists were bound to speculate and hypothesize about a "reality" that lay beyond experience. Mach responded that if that's what scientists did, they weren't doing science any more.[17]

With this view, Boltzmann comes close to claiming that, for science at least, theorizing is synonymous with intelligence, leaving Mach's ambition to look like little more than descriptions, or enumerations—cataloguing. The scientific dispute went on to the end of Boltzmann's life in 1906, when he committed suicide, a year after the publication of Einstein's paper on Brownian motion, which proved the existence of unobservable particles. There is no evidence that Boltzmann had the chance to read Einstein's paper, and at the end of his life, Boltzmann felt he was fighting a losing battle, defending a scientific thesis so that one day, when it was rediscovered, it would not have to be reinvented in its every detail.

Boltzmann had a frequently tormented life, suffering it appears from bouts of depression. "During the second half of the 19th century, the peaks and depths of Boltzmann's difficult life mirrored exactly the stumbling ascendency and frequent reversals of kinetic theory itself."[18]

But in the end, his position was the one less like Goethe's, and he was right.

Since the middle of the nineteenth century, the discrepancy between the artistic project and the scientific project has been growing, at an accelerating rate. What was for Goethe and Mach a harmless but pointless fantasy world of theoretical constructs that in their view explained nothing has become a universe of rigorous thought that makes the common sense world in comparison seem dull and mistaken. It is difficult to remember from this remove how much philosophers once valued the insight into the truth of the world offered by art—in the theories of the sublime such as that of Edmund Burke, in the aesthetic conceptions of Kant and Schopenhauer, and in the initial work of a philosopher whose public career largely coincides with the time of the primary developments in kinetic theory and who turned away from aesthetic arguments to approach the insights gained from science.

Friedrich Nietzsche had a nearly 20-year-long publishing career, extending from 1872 to 1889, when he became catatonic. He died in 1900. His first published work, *The Birth of Tragedy*, is an ontological theory rooted in an aesthetic argument. Like his predecessors, he looked to art to discover truth. In two manners of antique Greek tragedy, he found two visions of reality, one true and one therapeutic. The therapeutic vision, the Apollinian, is the compensatory imagination of the "beautiful illusion

[17] Lindley (2001), pp. 171–172.

[18] Lindley (2001), p. 19.

of the dream worlds,"[19] and the truth is the Dionysian vision, "the nonimagistic, Dionysian art of music,"[20] in which all is in incessant flux, all is destroyed as it is created, nothing is redeemed, nothing is saved. This is his vision of the real, the recognition of which we must be spared by the illusion of joyous Apollinian figures that make "life possible and worth living."[21] From which we must be saved by a dream.

Nietzsche turned to other subjects in the years immediately following this book, and in the 1880s, he returned to the issues of ontology, the philosophy of the real—what is going on when we're not looking. But in his later work, he made little use of aesthetic arguments. His thinking was more influenced by scientific ideas. Most of this work was done for a book he never completed. From his extensive unpublished notes and the contents of his personal library, we know he studied Darwin and other theorists of evolution, Roger Boscovich, an eighteenth-century physicist and Jesuit priest, atomism, time atoms, and "the dynamic interpretation of the world"[22] in contrast to "the mechanistic interpretation of the world."[23] More particularly, he seems never to have again formulated an ontological argument on the foundation of aesthetic thinking. Rather, he builds arguments such as that concerning eternal recurrence,[24] an argument about the nature of time that is based on geometric logic and that he celebrates as "the most scientific of all possible hypotheses."[25]

Nietzsche closes his career in a fashion with a remarkable passage from his unpublished notes. It is positioned at the end of the English language edition of *The Will to Power*, which is a selection of his unpublished writings set under what would have been the title of the book of ontology he did not complete. It is not the last note he wrote, but it is a late one, and it summarizes his ontological vision, his Dionysian truth:

> And do you know what "the world" is to me? Shall I show it to you in my mirror? This world: a monster of energy, without beginning, without end; a firm, iron magnitude of force that does not grow bigger or smaller, that does not expend itself but only transforms itself; as a whole, of unalterable size, a household without expenses or losses, but likewise without increase or income; enclosed by "nothingness" as by a boundary; not something blurry or wasted, not something endlessly extended, but set in a definite space as a definite force, and not a space that might be "empty" here or there, but rather as force throughout, as a play of forces and waves of forces, at the same time one and many, increasing here and at the same time decreasing there; a sea of forces flowing and rushing together, eternally changing, eternally flooding back, with tremendous years of recurrence, with an ebb and a flood of its forms; out of the simplest forms striving toward the most complex, out of the stillest, most rigid, coldest forms toward the hottest, most turbulent, most self-contradictory, and then again returning home to the simple out of this abundance, out of the play of contradictions back to the joy of concord, still affirming itself in this uniformity of its courses and its years,

[19] Nietzsche (1968a), p. 33.
[20] Nietzsche (1968a), p. 34.
[21] Nietzsche (1968a), p. 35.
[22] Nietzsche (1968b), Sect. 618.
[23] Nietzsche (1968b), Sect. 618.
[24] Nietzsche (1974: Sect. 341, and other passages, 1977)
[25] Nietzsche (1968b), Sect. 55.

> blessing itself as that which must return eternally, as a becoming that knows no satiety, no disgust, no weariness: this, my *Dionysian* world of the eternally self-creating, the eternally self-destroying, this mystery world of the twofold voluptuous delight, my "beyond good and evil," without goal, unless the joy of the circle is itself a goal; without will, unless a ring feels good will toward itself – do you want a *name* for this world? A *solution* for all its riddles? A *light* for you, too, you best-concealed, strongest, most intrepid, most midnightly men? – *This world is the will to power – and nothing besides!* And you yourselves are also this will to power – and nothing besides![26]

There is nothing of art here—nothing of the sublime, no aesthetic insights. And this is the moment in which Nietzsche sees through to the implication that has been lying in the heart of the modern scientific conception from the beginning, an implication that is in our time becoming inescapable—to field theory, in which the classical categories of common sense, of experiential reality, no longer apply, in which objects do not maintain themselves, form dissolves, time is at best ambiguous, in which the initial suspicion takes hold: if it is possible for some perceived qualities of the experiential to be secondary, conditional, not internal to the object they appear to qualify, is it possible there are no primary qualities, that everything we perceive is merely an appearance, merely circumstantial, that even the root experiences, the conditions of everything, such as the ticking of the clock, and the delay of response that invents distance, are insubstantial and dissolve as mist? That all of reality is a "monster of energy," an "iron magnitude of force," "a sea of forces flowing and rushing together"—and nothing more—without even particles to recall the nature of a fantasy "reality" occupied by self-standing, integral entities?

This is the realization that is overtaking us as our science advances—that at most we and our world of direct experience are necessary illusions, an inevitable set of by-products of quantum events interacting with quantum events, and perhaps it is all not even that. Perhaps it all is unnecessary—an accidental result that after a time will never be repeated—a spark surrendering to the night. For the lesson is dawning that we don't contain quantum events or possess quantum events. There is nothing but quantum events and although we seem real to ourselves, that is an argument proving nothing, for the point is that there is no one to seem real to. One cannot argue that being on one end of the microscope must imply you are also at the other end when in fact you sit at neither end. There is only the microscope.

So, the progress of science and its revelation of the foundation of the unobservable and inconceivable has been relentless and finally beyond dispute, in that, as noted above, science carries the contagion of autonomic reassertion. It proves itself right. That is the flaw in Mach's argument: the proposition of theoretical entities is testable, we can at least figure the odds that the double helix is the correct answer. So science and its inferences are not discretionary. They are determinative. And given that, it is art that must obtain a new dispensation if it is to remain pertinent, if it is to have a role in the world we are entering, a role other than the therapeutic for recipient creatures who require the consoling that they are here, that they are significant, that their native world did not in fact fail to arrive, that they are not indeed figments of no one's imagination.

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[26] Nietzsche (1968b), Sect. 1067.

And as the vectors of explanation of science and art run ever more undeniably in diametric opposition—science points to the imperceptible, art to the observed; science to the logically implied and the mathematically precise, art to the felt and sensuous—the truth function of art is thoroughly dissipated. As Boltzmann understood, we hunt the truth of things by way of theoretical imaginings and not by inspiration and oracular utterance. We have forsaken inexplicable insights for eureka moments, superstitious belief for our powers of inference.

There is no avail in Heisenberg's initiative to split reality between Newton and Goethe, to claim it dual between the subjective and the objective. Aside from the evident ambivalence of convenience and politesse, there are dangers in such gestures of deliberate temperateness, in such false equivalence, in attributing intrinsic merit on the basis of deference. And there are those who have warned us.

James Burke, a British broadcaster and science historian, presented a documentary television series in 1978 titled "Connections," in which he traced several examples of the attenuated, tortuous, centuries-long, and surprising trails of discoveries that led to recent significant inventions. In the tenth and last episode of the series, he approached the question of what such stories could teach us about negotiating the future. In this presentation, he displayed reproductions of famous paintings and a photograph of amino acids under a microscope.

His point of concern is how we learn the key as to why things change.

> That the key to why things change is the key to everything. How easy is it for knowledge to spread? And that, in the past, the people who made change happen were the people who had that knowledge, whether they were craftsmen or kings.
>
> Today, the people who make things change, the people who have that knowledge, are the scientists and the technologists, who are the true driving force of humanity. And before you say, 'What about the Beethovens and the Michelangelos?' let me suggest something with which you may disagree violently: that at best the products of human emotion – art, philosophy, politics, music, literature – are interpretations of the world that tell you more about the guy who's talking than about the world he's talking about. Second-hand views of the world made third-hand by your interpretation of them. Things like that:
>
> [Displays Byzantine icons and Impressionist paintings.]
>
> as opposed to this:
>
> [Displays a photograph taken under a microscope.]
>
> Know what it is? It's a bunch of amino acids, the stuff that goes to build up a worm, or a geranium, or you.
>
> [Displaying the paintings again.]
>
> This stuff's easier to take, isn't it? Understandable. Got people in it.
>
> [Displaying the photograph again of amino acids.]
>
> This, scientific knowledge, is hard to take because it removes the reassuring crutches of opinion, ideology, and leaves only what is demonstrably true about the world.
>
> And the reason why so many people may be thinking about throwing away those crutches is because, thanks to science and technology, they have begun to know that they don't know so much, and if they're to have more say in what happens to their lives, more freedom to develop their abilities to the full, they have to be helped towards that knowledge that they know exists and that they don't possess. And by "helped towards that knowledge," I don't mean give everybody a computer and say, "help yourself!" Where would you even start?

> No, I mean, trying to find ways to translate that knowledge, to teach us to ask the right questions.[27]

For Burke, truth is what it is, and the learning of it is indispensable, for the knowledge provides us with the power to control our fates. And for Burke, art provides no such knowledge. Only scientific knowledge reveals to us what is demonstrably true about the world. What determines human fate does not wear a human face. It is inflected in the image of the molecules. There is no intent there, but there is meaning. There is implication for such as us.

For the philosopher Bertrand Russell, even more is at stake than the control over our futures. Late in his life, Russell gave an interview, a small part of which is available in a video clip on YouTube. During the interview, Russell is asked what he would tell future generations.

> Interviewer: One last question. Suppose, Lord Russell, this film were to be looked at by our descendants, like a dead sea scroll, in a thousand years' time. What would you think it's worth telling that generation about the life you've lived and the lessons you've learned from it?
>
> Russell: I should like to say two things, one intellectual and one moral. The intellectual thing I would want to say to them is this: when you are studying any matter or considering any philosophy, ask yourself only what are the facts and what is the truth that the facts bear out. Never let yourself be diverted either by what you wish to believe or by what you think would have beneficial social effects if it were believed. Look only and solely at what are the facts.[28]

As Russell made clear in many instances over many years of his life, one of his greatest worries was over the departure from accuracy in one's truth claims for any reason other than a well-intended misconstruction of the facts of the matter at hand. Any knowing, willful attempt to falsify a truth claim creates the motivation for manipulation of one's target recipients, for the limitation of free inquiry, for mind control—and potentially all out of a sincere concern for their well-being. Knowledge designed to be therapeutic—Russell's Orwellian nightmare.

For both Russell and Burke, an implication is planted that raises the stakes as high as they could be. For it is the invisible—the inherently unseeable, the sheer facts—that will determine whether we survive or become extinct—not just plagued and beleaguered, but vanished. It is the physically real beyond sensation—what science has been disclosing since Galileo—and not what we believe we see, or what we feel, that will determine whether we live. It is not the stuff of life but the stuff of fact that will judge if we get to have life. The phenomenological realm is now disclosed as completely porous and betrayed as complete fantasy. We are quantum functions lost in a self-induced fairy tale. And we are in peril from what we cannot ever directly know—the chemistry and cosmology of climate change, chain reactions. gamma ray bursts, genetic mutations, viruses … What we cannot conceive pushes through. We are in its sights.

Scientific knowledge is thus imperative. What then remains of the role of art? In what aspect of the thing lies its meritorious nature? What function does it serve

[27] Burke (1978).

[28] PhilosophieKanal (2012).

due to its intrinsic nature, a function indispensable or not? It is no longer a uniquely endowed inherent capability of truth telling, for we no longer take art as incantatory. We could attribute art's virtue to its tradition of playing a home for brilliance, of being a native resort where genius naturally flocks. But is there anything of art in the virtue? Anything of the aesthetic that is thus brought to the table? The same can be said of science, engineering, architecture, economics, any field in which there is a tradition of the newly discovered. Would Shakespeare have done anything less than he did in one of the most profound texts in the canon, *King Lear*, had he done it as an essay? Is it in the dramatic nature, or is it him?

There have been but a few suggestions from thinkers and practitioners possessing a legitimate familiarity with the issues involved and having some investment in the outcome of the game. Snow, in *The Two Cultures*, had his thought:

> It is bizarre how very little of twentieth-century science has been assimilated into twentieth-century art. Now and then one used to find poets conscientiously using scientific expressions, and getting them wrong—there was a time when 'refraction' kept cropping up in verse in a mystifying fashion, and when 'polarised light' was used as though writers were under the illusion that it was a specially admirable kind of light.
>
> Of course, that isn't the way that science could be any good to art. It has got to be assimilated along with, and as part and parcel of, the whole of our mental experience, and used as naturally as the rest.[29]

Naum Gabo was an early twentieth-century sculptor who was a founder of Constructivism and was well-versed in the new geometry of the late nineteenth century and familiar to some degree with physics. His thoughts on the relation between science and art:

> The force of Science lies in its authoritative reason. The force of Art lies in its immediate influence on human psychology and in its active contagiousness. Being a creation of Man it re-creates Man. Art has no need of philosophical arguments, it does not follow the signposts of philosophical systems; Art, like life, dictates systems to philosophy. It is not concerned with the meditation about what is and how it came to be. That is a task for Knowledge. Knowledge is born of the desire to know, Art derives from the necessity to communicate and to announce. The stimulus of Science is the deficiency of our knowledge. The stimulus of Art is the abundance of our emotions and our latent desires…[30]

That art should be assimilated with the whole of our mental experience and that art is stimulated by the abundance of our emotions so as to re-create "Man" is less than fully helpful, one might say, but these observations bear a similarity to more fulsome thoughts by others who addressed the issue—how art should function in relation to science, in the face of science.

In his essay "Dante," T. S. Eliot discussed his sense of the relation between philosophy and poetry—which is clearly a sub-sector of the relation between science and art, for the distinction between the two is a philosophical discrepancy. Although Eliot was not speaking of modern science specifically, or of contemporary philosophical issues, his point is that there cannot be a pure relationship between poetry and philosophy and his reasons cast light on the remarks of Gabo and Snow.

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[29]Snow (1959), pp. 17–18.

[30]Gabo (1996), p. 367.

> The philosophy which Lucretius tackled was not rich enough in variety of feeling, applied itself to life too uniformly, to supply the material for a wholly successful poem. It was incapable of complete expansion into pure vision …
>
> Without doubt, the effort of the philosopher proper, the man who is trying to deal with ideas in themselves, and the effort of the poet, who may be trying to realize ideas, cannot be carried on at the same time. But this is not to deny that poetry can be in some sense philosophic. The poet can deal with philosophic ideas, not as matter for argument, but as matter for inspection. The original form of a philosophy cannot be poetic. But poetry can be penetrated by a philosophic idea, it can deal with this idea when it has reached the point of immediate acceptance, when it has become almost a physical modification. If we divorced poetry and philosophy altogether, we should bring a serious impeachment, not only against Dante, but against most of Dante's contemporaries.[31]

For Eliot, poetry is not capable of expounding a philosophy, of developing it as something new and presenting its ideas for the first time. Poetry cannot defend or teach a philosophy. But poetry can be philosophic when employed as Dante did his Augustinian system—as a completed and incorporated element of the world of the poetry, as something adopted by that world and encountered within it, as a part of the life being depicted and examined. Philosophy as lived is philosophy prepared for poetic investigation. This seems in common with Snow's wish for science (or the philosophy, the vision of the world, it supplies) as assimilated with the whole of our mental experience and Gabo's understanding of art as being stimulated by emotion—philosophy as a coherent part of life, as emotional, as something lived with and among, and within.

One sees a similar conception, but one updated and conceived fully in response to the developments of modern science, in the "Conclusion" to *The Renaissance* by Walter Pater. It is the one thoroughly thought through, fully presented vision of what art now can and should do in the scientific age, and though somewhat lengthy (for a quotation but not for a final book chapter), it is worth citing and reading in full:

> To regard all things and principles of things as inconstant modes or fashions has more and more become the tendency of modern thought. Let us begin with that which is without – our physical life. Fix upon it in one of its more exquisite intervals, the moment, for instance, of delicious recoil from the flood of water in summer heat. What is the whole physical life in that moment but a combination of natural elements to which science gives their names? But those elements, phosphorus and lime and delicate fibres, are present not in the human body alone: we detect them in places most remote from it. Our physical life is a perpetual motion of them – the passage of the blood, the waste and repairing of the lenses of the eye, the modification of the tissues of the brain under every ray of light and sound – processes which science reduces to simpler and more elementary forces. Like the elements of which we are composed, the action of these forces extends beyond us: it rusts iron and ripens corn. Far out on every side of us those elements are broadcast, driven in many currents; and birth and gesture and death and the springing of violets from the grave are but a few out of ten thousand resultant combinations. That clear, perpetual outline of face and limb is but an image of ours, under which we group them – a design in a web, the actual threads of which pass out beyond it. This at least of flamelike our life has, that it is but the concurrence, renewed from moment to moment, of forces parting sooner or later on their ways.
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> Or if we begin with the inward world of thought and feeling, the whirlpool is still more rapid, the flame more eager and devouring. There it is no longer the gradual darkening of

[31] Eliot (2015), p. 147.

the eye, the gradual fading of colour from the wall – movements of the shore-side, where the water flows down indeed, though in apparent rest – but the race of the mid-stream, a drift of momentary acts of sight and passion and thought. At first sight experience seems to bury us under a flood of external objects, pressing upon us with a sharp and importunate reality, calling us out of ourselves in a thousand forms of action. But when reflexion begins to play upon these objects they are dissipated under its influence; the cohesive force seems suspended like some trick of magic; each object is loosed into a group of impressions – colour, odour, texture – in the mind of the observer. And if we continue to dwell in thought on this world, not of objects in the solidity with which language invests them, but of impressions, unstable, flickering, inconsistent, which burn and are extinguished with our consciousness of them, it contracts still further: the whole scope of observation is dwarfed into the narrow chamber of the individual mind. Experience, already reduced to a group of impressions, is ringed round for each one of us by that thick wall of personality through which no real voice has ever pierced on its way to us, or from us to that which we can only conjecture to be without. Every one of those impressions is the impression of the individual in his isolation, each mind keeping as a solitary prisoner its own dream of a world. Analysis goes a step farther still, and assures us that those impressions of the individual mind to which, for each one of us, experience dwindles down, are in perpetual flight; that each of them is limited by time, and that as time is infinitely divisible, each of them is infinitely divisible also; all that is actual in it being a single moment, gone while we try to apprehend it, of which it may ever be more truly said that it has ceased to be than that it is. To such a tremulous wisp constantly re-forming itself on the stream, to a single sharp impression, with a sense in it, a relic more or less fleeting, of such moments gone by, what is real in our life fines itself down. It is with this movement, with the passage and dissolution of impressions, images, sensations, that analysis leaves off – that continual vanishing away, that strange, perpetual weaving and unweaving of ourselves.

Philosophiren, says Novalis, *ist dephlegmatisiren, vivificiren*. The service of philosophy, of speculative culture, towards the human spirit, is to rouse, to startle it to a life of constant and eager observation. Every moment some form grows perfect in hand or face; some tone on the hills or the sea is choicer than the rest; some mood of passion or insight or intellectual excitement is irresistibly real and attractive to us, –for that moment only. Not the fruit of experience, but experience itself, is the end. A counted number of pulses only is given to us of a variegated, dramatic life. How may we see in them all that is to seen in them by the finest senses? How shall we pass most swiftly from point to point, and be present always at the focus where the greatest number of vital forces unite in their purest energy?

To burn always with this hard, gemlike flame, to maintain this ecstasy, is success in life. In a sense it might even be said that our failure is to form habits: for, after all, habit is relative to a stereotyped world, and meantime it is only the roughness of the eye that makes any two persons, things, situations, seem alike. While all melts under our feet, we may well grasp at any exquisite passion, or any contribution to knowledge that seems by a lifted horizon to set the spirit free for a moment, or any stirring of the senses, strange dyes, strange colours, and curious odours, or work of the artist's hands, or the face of one's friend. Not to discriminate every moment some passionate attitude in those about us, and in the very brilliancy of their gifts some tragic dividing of forces on their ways, is, on this short day of frost and sun, to sleep before evening. With this sense of the splendour of our experience and of its awful brevity, gathering all we are into one desperate effort to see and touch, we shall hardly have time to make theories about the things we see and touch. What we have to do is to be for ever curiously testing new opinions and courting new impressions, never acquiescing in a facile orthodoxy of Comte, or of Hegel, or of our own. Philosophical theories or ideas, as points of view, instruments of criticism, may help us to gather up what might otherwise pass unregarded by us. "Philosophy is the microscope of thought." The theory or idea or system which requires of us the sacrifice of any part of this experience, in consideration of some

> interest into which we cannot enter, or some abstract theory we have not identified with ourselves, or of what is only conventional, has no real claim upon us.
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> One of the most beautiful passages of Rousseau is that in the sixth book of the *Confessions*, where he describes the awakening in him of the literary sense. An undefinable taint of death had clung always about him, and now in early manhood he believed himself smitten by mortal disease. He asked himself how he might make as much as possible of the interval that remained; and he was not biassed by anything in his previous life when he decided that it must be by intellectual excitement, which he found just then in the clear, fresh writings of Voltaire. Well! we are all *condamnés*, as Victor Hugo says: we are all under sentence of death but with a sort of indefinite reprieve – *les hommes sont tous condamnés à mort avec des sursis indéfinis*: we have an interval, and then our place knows us no more. Some spend this interval in listlessness, some in high passions, the wisest, at least among "the children of this world," in art and song. For our one chance lies in expanding that interval, in getting as many pulsations as possible into the given time. Great passions may give us this quickened sense of life, ecstasy and sorrow of love, the various forms of enthusiastic activity, disinterested or otherwise, which come naturally to many of us. Only be sure it is passion–that it does yield you this fruit of a quickened, multiplied consciousness. Of such wisdom, the poetic passion, the desire of beauty, the love of art for its own sake, has most. For art comes to you proposing frankly to give nothing but the highest quality to your moments as they pass, and simply for those moments' sake.[32]

Pater dates his conclusion separately from the rest of the book: 1868. This is in the very heart of the scientific upheaval: only a couple of years after Maxwell published his "A Dynamical Theory of the Electromagnetic Field," which contained his equations for field theory, during the time of Boltzmann's most significant work on atomic theory and only a few years prior to Boltzmann's publication of "Further Studies of the Thermal Equilibrium of Gas Molecules," and also just a few years before Nietzsche published *The Birth of Tragedy*. There is much to be observed in this piece of Pater's masterwork, but we will note here only that Pater begins his conclusion with a verbal rendering of his conception of a field, as in field theory—in which one senses that both our "physical life" and our "inward world of feeling" are small portions of an extension that reaches far beyond our confines, that we are in every aspect of ourselves a localization of something that in reality is an undifferentiated continuance, that we are not self-standing, self-defining entities but moments in a constantly shifting reality in which nothing is sustained. It is a vision of the field that is comparable to that in the unpublished note by Nietzsche that has reached us as Sect. 1067 of *The Will to Power*.

There is little said of art here, but there is a proposition of what constitutes "success in life" in such a world: in a reality in which nothing is retained, in which nothing lasts but is unmade as it is made, there remains the intensity of the moment, and "to burn always with this hard, gemlike flame, to maintain this ecstasy, is success in life." This is Epicureanism, and it is well considered, for our oldest extant texts on ancient atomism are from Epicurus.

There is little discussion of art here, but Pater gives us his idea of the function of art in such a world, in the last paragraph of the preceding chapter:

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[32]Pater (1986), pp. 150–158.

> Let us understand by poetry all literary production which attains the power of giving pleasure by its form, as distinct from its matter. Only in this varied literary form can art command that width, variety, delicacy of resources, which will enable it to deal with the conditions of modern life. What modern art has to do in the service of culture is so to rearrange the details of modern life, so to reflect it, that it may satisfy the spirit. And what does the spirit need in the face of modern life? The sense of freedom. That naïve, rough sense of freedom, which supposes man's will to be limited, if at all, only by a will stronger than his, he can never have again. The attempt to represent it in art would have so little verisimilitude that it would be flat and uninteresting. The chief factor in the thoughts of the modern mind concerning itself is the intricacy, the universality of natural law, even in the moral order. For us, necessity is not, as of old, a sort of mythological personage without us, with whom we can do warfare. It is rather a magic web woven through and through us, like that magnetic system of which modern science speaks, penetrating us with a network, subtler than our subtlest nerves, yet bearing in it the central forces of the world. Can art represent men and women in these bewildering toils so as to give the spirit at least an equivalent for the sense of freedom? Certainly, in Goethe's romances, and even more in the romances of Victor Hugo, we have high examples of modern art dealing thus with modern life, regarding that life as the modern mind must regard it, yet reflecting upon it blitheness and repose. Natural laws we shall never modify, embarrass us as they may; but there is still something in the nobler or less noble attitude with which we watch their fatal combinations. In those romances of Goethe and Victor Hugo, in some excellent work done *after* them, this entanglement, this network of law, becomes the tragic situation, in which certain groups of noble men and women work out for themselves a supreme dénouement. Who, if he saw through all, would fret against the chain of circumstance which endows one at the end with those great experiences?[33]

This is a tragic vision, for what remains for us to value and aspire to is freedom, and this is, to some extent, a world of freedom denied, of necessity—not as it was thought to be previously, freedom limited by the force of will of some "mythological personage," but freedom limited by the necessity of natural law, by the central forces of the world, by scientific law that is like a magnetic field running through us and stretching out beyond us to perhaps infinity. The necessity that science is.

Pater's is a remarkable vision, in its clarity, its pertinence to that which it claims to be pertinent to, its incisiveness, and for its offering a thought, an option, where virtually no other thinker or practitioner has had anything distinctive to say. But still—doesn't it leave us just where we were? Isn't this art with a utilitarian value, art that does the job of making us feel better—to help us negotiate the tragedy of necessity, reassure us in the face of that tragedy, let us, if nothing more, at least bathe in the glow of a noble suffering? Is there any merit for art in this vision that we *should* recognize, rather than just judge for the degree to which it soothes us? Have we not again confused the doer and the deed and, so, again engaged in self-pandering? Is this not merely therapeutic?

The core of the problem is that the human being and the subatomic realm of unobservable reality, the macro-state and the micro-state, are irreconcilable. We and every occupancy of the world we perceive ourselves as inhabiting are not just the additive outcome of the micro-state underlying what we see, or think we do. It seems more likely that a phase shift is required to relate events across the radical change of scale. That is potentially why the physics do not entirely match. (Maxwell's Demon

[33] Pater (1986), pp. 148–49.

observes no heat death threatening the universe.) There appears to be a change of nature, a shift in the caliber of what there is, a different category of truth, and it is with that we would be irreconcilable.

And this raises yet another question, another matter of urgency, one that would not be solved by the science because it would be a precondition for creating such science. Are we such creatures as can comprehend what we now confront? Have we imagination of appropriate nature? Are we the apposite context for such understanding? Are we capable of the necessary amplitude? Of the awful range of implication?

The philosopher Alexandre Koyré made the point.

> Therefore what the founders of modern science, among them Galileo, had to do, was not to criticize and to combat certain faulty theories, and to correct or replace them by better ones. They had to do something different. They had to destroy one world and to replace it by another. They had to reshape the framework of our intellect itself, to restate and to reform its concepts, to evolve a new approach to Being, a new concept of knowledge, a new concept of science – and even to replace a pretty natural approach, that of common sense, by another which is not natural at all.[34]

If we are irreconcilable with the truth of us, with the truth per se, and if we are to understand the truth, for we fail to do so at our peril, then we must be remade. In order to do the science that we must, we must be something other than ourselves. We must learn that we are bad delusions, or beautiful illusions, as Nietzsche warned us about everything that we perceive, that we know. We must understand that we are in our every detail compensatory conceptions for the sake of what we truly are—such things as we have never known ourselves to be. We must learn to imagine new possibilities, accede to new successions of imagination: such like: the chance that the appearance of our own existence, and the nature we pantomime, that pantomimes us, are the result of the vagueness that we are doomed to suffer, and are our real tragedy, for the demon is capable of counting all that is and we are not, for reasons that seem natural to us and that we cannot understand or explain. That it is the micro-state that is precise, and we appear as a by-product of the absence of fully defined detail, as a function of the averages we have only recently learned to compute. That the vagueness of the statistical mechanics, the vapor of the probabilities, the ambiguity of the photon between position and velocity, between particle and wave, might be a mirror in which we see the haziness that creates the illusion that we are—that *we* are, rather than our component parts, whose distinctness is lost in our inability to see, to know. We must become capable of conceiving what seems unnatural, inconceivable to us now. It must be ours to imagine the timeless lifting its voice of time, to imagine light as the context immobile away from which we race, to imagine a universe authored in plateaus of scale, a universe that is taller than it is wide, a universe whose physics is capable of scale changes as phase shifts, as close to hand and yet as altered as another spatial dimension.

When there are no other virtues left, there is always one left. It is courage. When there is nothing else worth doing, there is one thing worth doing—that which is needful and which no one wants. It is easy to see why atomism was so opposed, for

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[34] Koyré (1968), pp. 20–21.

the same reason it has been aligned with atheism since Epicurus. How can human beings be made in the image of God or the gods if the human image is an illusion, is not true? No one wants this. That alone is reason enough it is needful.

Theorizing is everyone's business, as Boltzmann subtly suggested. For theorizing is the real form of imagining—not devising vicarious scenarios but seeing what has never before been seen.

Mach had nothing to propound. He would simply not let go.

Let go.

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Aesthetic Agency: Why Art Might Matter to Philosophy

Charles F. Altieri

I hate the fact that I have to call for phenomenological description when I turn to philosophical topics. I am the principle object of my anger since I have insufficient skill at philosophical argument, but some capacity to describe states of mind. Yet there seems to me an intellectual justification for thinking such description may play a useful role in philosophy at a time when the major figures in the philosophy of mind are embarked on reductionist programs. So I hope here to deploy the one undeniable power of description—the power to embarrass by soliciting agreement about complex features of situations that emerge when we indulge in patient acts of attention.

In this case I want to focus the description on what we might call aesthetic agency. What are the powers we must attribute to mind if we are to describe the intricacy of those processes that take place when highly trained observers find themselves deeply satisfied by aesthetic experiences? For this essay I will not rely on my own descriptions but on how aesthetic agency is constructed by Kant and by Hegel, since their descriptions shaped many people's understandings of beauty until the influence of Duchamp began to set in. And I will devote these descriptions to two basic tasks. I cannot focus on my first concern here because the topic is too large. But I want to propose as one test of our descriptions of aesthetic agency whether they capture the kinds of powers that might make plausible Wittgenstein's claim "ethics and aesthetics are one. The claim is also uttered in various fashions by Schopenhauer, Nietzsche, and Pater, so it is high time to characterize what in the agency developed for aesthetic experience might allow us to extend those concerns to other domains.

In making this assertion I am not without self-interest. It should go without saying that defining these aspects of agency in practice would also give literary criticism perhaps richer tasks than the current emphases on a politically inflected historicism or adherence to modes of studying cognition whose assumptions I am challenging.

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This concern for agency will involve shifting our attention from the critic as one seeking distance from the many illusions driving our interpellated lives. Instead, we will have to pursue an ideal of criticism as cultivating capacities to cast self-consciousness as neither an illusion nor a curse but as a capacity for appreciation that has significant consequences for how we see ourselves inhabiting our worlds.[1] My proposed emphasis on agency would realign how critics write in order to better fit what they can strive for in their teaching.

The second task involves even more extensive and intricate fields of inquiry since we will have to indicate how these descriptions of aesthetic agency might persuade materialist thinkers involved in characterizing how minds work to spend more time facing what our minds on art seem to be doing. I think I can handle this because I do not have to make positive arguments. Instead an initial probing would simply characterize a domain where minds seem to pursue powers that do not enter into mainline theorizing. I hasten to add that while these powers were elaborated by thinkers who were mostly idealist, the value of description may be free of such bias: the powers I will speak of are difficult to locate in frames shaped by current materialist

[1]By this reasoning we almost have to begin with a rough catalogue of prevailing justifications for the values possible within specific reading practices. I think there are two basic models. One is primarily descriptive. We could invoke much of the discourse that has gone under the names of poetics and narrative theory, since these discourses try to produce self-consciousness about the instruments one deploys in constructing assertions about particular texts. Description also proves central to establishing the provenance of new perspectives on criticism—what traits warrant invoking queer theory or how can one relate to one another the subcategories that come into play when one talks about globalization. The second kind of theory is primarily speculative: its task is to develop frameworks for talking about conditions of agency visible in and projectable for what writers make and what audiences perform in conjunction with those makings. Here again two major models emerge, closely entwined with all too easily parodied figures of the "realistic" reader bound to critique—in the service of myths of the labors necessary for freedom in an interpellated world—and the celebrator of Romantic genius who raises self-consciousness to the level of theology.

I think it fair to say that despite powerful criticisms of models of suspicious reading, the character traits cultivated by ideals of Critique dominate contemporary theory because it is so insistently resistant to any kind of ideal of the unified self or triumphant moments of dialectical solution. These stances stress the critical forms of thinking that ideally expose illusions about social practices and pursue democratic interests in disestablishing problematic modes of authority by accurately displaying actual costs and benefits of certain ways of treating practices of reading. But if we look at the models of agency such positions idealize, it may be possible to define basic weaknesses in those perspectives that justify alternative paths of speculation. This is one reason why I want to put conditions of agency at the center of our theorizing about theory. A second reason is that I do not know any contemporary work in theory considering classical texts about the arts as providing powerful idealizations of agency worth recuperating in an academic literary culture. We are increasingly interested now in characterizing our responsiveness to the arts in empiricist terms that consider these idealizations fantasies oriented toward maintaining cultural capital. So by focusing entirely on agency conditions made possible by responsiveness to works of art I hope to revive those discourses—not primarily as argument but as projections of imaginative orientations that we can now test by how they might afford phenomenological accounts of who we become as self-conscious participants in providing audiences for these works.

values, but science has an obligation to the nature of things not to what is likely to turn out are methodological biases.[2]

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Let me speak in as undefended a manner as possible by simply asserting what Kant and Hegel make it possible to think and to say about these conditions of agency made possible by aesthetic experience. Kant sets the stage by elaborating four fundamental principles with enormous consequences. Then Hegel refines these notions by affording richer and more dynamic elaborations cleaning up what strikes most critics as problematic in Kant's account.

I think it fair to say that most traditional art theory posed the audience as reflective beings seeking both pleasure in the artists' modes of inventiveness and edification in their capacities to bring depth and understanding to the conditions their art elaborates. Kant at his best makes a quite different case: the work provides the opportunity to dwell imaginatively in how the artist develops particulars and finds ways of shaping their interrelationship. The aesthetic invokes practices of reflective judgment that do not refer particulars to purposes or categories, thus forcing a sharp distinction from the kinds of judgment posed by the empirical understanding. The arts present "purposiveness without purpose" because they produce pleasure in attending to how the work develops a structure of internal relations.

In making these claims Kant brings within practical psychology what David Summers shows has been a long tradition of claiming that participation in the arts involves different forms of judgment than the modes of judgment basic to understanding.[3] This distinction establishes an entire domain of reflections that involve capacities quite distinct from the modes of thinking performed by both practical understanding and the Reason that makes ethics possible. Reflecting judgment orients the mind to powers by which consciousness pursues opportunities for complex participation in what artists make and audiences reconstitute. Such judgment traces how purposiveness exhibits complex interrelationships that embody some version of intentional activity on the part of a maker. Then, more generally if we are to appreciate how intentions shape what people make present, we will have to find ways of engaging what is shown but not quite asserted.

Rather than pursue practical purposes that organize sensation, Kant sees aesthetic experience concentrating on how particular objects dispose our sensibilities to a

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[2]Here I hope I am working in the spirit of Terence Deacon, *Incomplete Nature: How Mind Emerged From Nature* (New York: Norton, 2012). I think Deacon coined the term "ententionality" in order to include features of mind stressed by phenomenology and so to reconfigure what materialism might involve.

[3]Participation provides a mode of activity quite distinct from the understanding. The understanding positions the subject as someone who can accomplish something in the actual world. Participation positions the subject to experience who one becomes as one comes to feel identifications with the power of the making to produce inner states.

domain of "inner intuition" (CJ 192). This means attributing purposiveness to how we see relations giving shape and intensity to those particulars. And while Kant never puts it this way, attributing purposiveness directly engages three important aspects of aesthetic agency. It matters that the work is a made thing embedding authorial choices that establish shape and significance which audiences find in the object rather than in themselves. Second, making here entails attention to intentionality: genius gives the rule to nature, and the audience composes the work as "an inexponible idea" that cannot be submitted to causal understanding. Art works not only give pleasure but they open an entire realm of "inexponible ideas" not available if we attend only to the powers conferred by the faculty of practical understanding that difference from the work of understanding involves specifying how other modes of awareness can be basic to human life.

This third concern is crucial. One has to be clear that intention in Kant is not something that reaches out to align the text with some interpretive purpose. Intention is immanent in how purposiveness structures the work. Then because we have to process this emobodied intentionality, we cannot rely on our two major models of organizing world—the practical orientation of the understanding and the purely theoretical domain of reason that makes morality possible. We have to focus on our powers to deal with what is displayed in this immanent intentionality located in structures of relations rather than in purposes. And we have to come to trust that confining ourselves to such modes of responsiveness makes it possible to attune ourselves to a great deal that goes on in life that is neither the work of understanding nor of reason. There is a third kind of idea that deploys the work of example to reach into the core of what subjects see themselves experiencing.

Speaking of a poem by King Frederic Kant clarifies the kind of experience that calls for and rewards aesthetic judgment:

> The consciousness of virtue, when one puts oneself, even if only in thought, in the place of a virtuous person, spreads in the mind a multitude of sublime and calming feelings, and a boundless prospect into a happy future, which no expression that is adequate to a determinate concept fully captures. … [The aesthetic idea allows] the addition to a concept of much that is unnameable, the feeling of which animates the cognitive faculties and combines spirit with the mere letter of language. (CJ, p. 194)[4]

The art object demands distinctive powers of judgment that not only supplement the understanding but establish conditions where understanding has to yield to more sublime modes of attention.

Since I have heaped up generalizations I need the most concise concrete example I can muster as support for this picture of aesthetic agency. Consider then Ezra Pound's two line poem "In a Station of the Metro" as an example of how reading for purposiveness rewards reflexive judgment and invites engagement in how the particular object takes on various kinds of resonance:

> The apparition of these faces in a crowd:
>
> Petals on a wet black bough.

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[4]The passages are taken from *Critique of the Power of Judgment*, translated by Paul Guyer (Cambridge: Cambridge University Press, 2000).

Pound's primary concern appears to be staging an act of attention that blends three worlds easily sundered—an urban world that increasingly produces alienation, a natural world increasingly the object of that alienation, and a sheerly imaginative sense of responsiveness that would be easily dismissed if it could not establish its powers to intervene in how nature and civilization manage to interact.

"Apparition" is a loaded term. It evokes both a sense of illusion and a sense of empowerment deriving from intense appreciation of how states come to appear for an inner life. But the inner life evoked by this poem does not depend on sheer assertion of humanist pieties. It inheres in the capacity to develop relationships that change how we see. Rather than subsume the scary features of "apparition" into the directness of appearance, Pound makes apparition coexist in a state of nature that is itself extended into the psychological and the mythical. Sheer condensed juxtaposition positions the reader as participating suddenly in a state that can treat the mythic impulse as inhering in concrete perception. The poem evokes for the metro a domain of descent into Hades that is at the same time recuperable as a figure for a dynamic nature breeding relationships that do not fit the categories of the understanding. In this poem nature is rendered timeless, and the audience is invited to recognize how imagination can adapt nature to states of feeling that have as their object forces extending beyond nature. Now nature has to be treated as what imagination can make inescapably present—less in order to understand what happens than to allow identifications with the kinds of forces that make manifest an inner life.

II

The art work becomes a bid to participate in a manner of construction for the purposes of grounding imaginative life in reflecting on possible worlds and the intricacies that make them worthy of attention. My fourth power of agency in Kant's rendering of aesthetic judgment then derives from his grappling with two problems that haunt the assertions I have made so far. What is it about the experience of the art object that calls for the differences from the understanding and moral reasoning? And what kind of discourse can provide any stability at all once one rejects the authority of those two basic models for understanding experience.

Kant not only provides plausible answers to these questions but deploys these answers in order to shift his focus from reflecting judgment as the negotiation of pleasure to reflecting judgment as the work of processing a distinctive kind of "idea" that brings the "supersensible" into play.[5] And in so doing he establishes a sense that aesthetic agency's relation to an "inexponible" object provides a crucial social

[5] I have to relegate to a footnote the specifics of Kant's moving art from the domain of pleasure to the domain of the aesthetical idea, where he can make good on his claims about the epistemic force of what cannot be gathered by the understanding. He first gets the domain of content into his vision of aesthetic purposiveness by treating genius as both a mode of making and an activity seeking to complement the understanding, so its difference from the understanding is built in from the start:

dimension for aesthetic agency—the need to act in terms of a crucial difference between the pleasure of liking and the pleasure of specifying the terms of approval by which one thinks one's aesthetic experience can make claims on how other agents respond to the same work. Perhaps aesthetic experience establishes a form of sociality much less severe than moral reasoning and perhaps therefore capable of gently expanding how people can respect one another.

If our judgments in art do not derive from the understanding (although they can cooperate with understanding) the theorist must suggest how these works produce relations to the world of understanding that call distinctive powers into play. The theorist has to show why particulars matter without subsuming them under purposes provided by the understanding. So theory must find languages for what cannot be processed by understanding. A conceptual space enters where one can talk about what can be seen but not said in propositional forms. The inexponible can be tied to the world by the work of exemplification, a concept later to be elaborated by philosophers like Nelson Goodman and Richard Wollheim:

> [In cognition] the imagination is under the constraint of the understanding and is subject to the limitation of being adequate to the concept; in an aesthetic response, however, the imagination is free to provide, beyond that concord with the concept, unsought extensive undeveloped material for the understanding, … (CJ 194)

The art object demands distinctive powers of judgment that not only supplement the understanding but establish conditions where understanding has to yield to more sublime modes of attention. Genius ultimately becomes a mode of expression inhabiting worlds rather than describing them:

> The mental powers, then, whose union (in a certain relation) constitutes **genius**, are imagination and understanding. … Thus genius really consists in the happy relation … of finding ideas for a given concept on the one hand and on the other hitting upon the **expression** for these, though which the subjective disposition of the mind that is thereby produced, as an accompaniment of a concept, can be communicated to others. The latter talent is really that which is called spirit, for … [expressing} what is unnameable in the mental state in the case of a certain representation and to make it universally communicable. (CJ 194–5)

"Genius is the exemplary originality of the natural endowment of a subject for the **free** use of his cognitive faculties" (CJ 195) because it invents what turns out to stand on its own as a purposive particular that takes on the status of an aesthetic idea. This idea is something anchored in subjective experience that nonetheless has inexponible objective engagement with the cognitive order. The free work of genius demonstrates something close to self-interpreting cognitive status.

Then Kant returns to the status of pleasure in order to stage an antinomy that only dialectic can resolve. And because dialectic sets reason against understanding, it has immense ontological consequences. The aesthetic is raised from a mode of experience to a mode of engaging ideas. And because the work retains the particularity making it "inexponible" the idea has distinctive powers, precisely because it does not submit to the cognitive or the moral mode of discourse. The antinomy serves as a fundamental display of the limitations of the understanding. Aesthetic theory has to argue both that "the judgment of taste is subjective and not based on concepts" (CJ 215) and that the judgment of taste is based upon concepts because we manage to argue about it. The only way out is to take the antinomy itself as requiring a dialectical movement into an apparently paradoxical argument that the judgment of taste is based on a concept but nothing can be cognized because the concept is not involved in the activities of the practical understanding. We must invoke an indeterminate concept that can only be located in terms of this supersensible substratum of appearances:

> Rather as a necessity that is thought in an aesthetic judgment, it can only be called exemplary, i.e., a necessity of the assent of all to a judgment that is regarded as an example of a universal rule that one cannot produce. (CJ 121)

I think there is here a brilliant conjunction by which reference to the real comes not from what the art pictures but instead from its capacity to elicit responses that make one concerned for the capacity of one's response to solicit agreement with other people. One's explanation of one's judgment sponsored by the experience of the particular elaborates what might be exemplary about the how the work engages experience. And that elaboration preserves both the work's particularity and its inexponible nature, while staging the work as soliciting a common response to the pleasure it affords. So exemplification need not be simply a fable in order to escape the language of cognition. Rather it suggests that aesthetic judgment operates by placing one's experience of the object within a social matrix that tests the value of how the sense of exemplification is embodied within the experience of the work. Then one can say that this kind of knowledge by example expands one's repertoire for recognition and elaboration and so makes clear the limitations inherent in the work of empirical understanding.

Take Hamlet as our example of the work example can do it in art. We cannot claim determinate meaning for the adjective Hamlet-like, even though the character Hamlet articulates and elaborates many intricate modes of behavior. But we can use our reading of Hamlet's character as a proposed model for appreciating what can be involved in melancholic behavior or in the strange transformation he undergoes on his sea journey. Particular texts can clarify conditions of experience by functioning as models but they cannot take on the presence of explanatory ideas because their

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> The subjective principle, namely the indeterminate idea of the supersensible in us, can only be indicated as the sole key to demystifying this faculty which is hidden in us even in its sources. … Thus one sees that the removal of the antinomy of the aesthetic power of judgment takes a course similar to that followed by the *Critique* in the resolution of the antinomies of pure practical reason. (CJ 217)

The theorist is compelled against her will "to look beyond the sensible and to seek the unifying point of all our faculties a priori in the supersensible" (CJ 217). Having reason take responsibility for what it cannot cognize is the only way to make reason "self-consistent."

Calling on Reason here seems a bit of overkill for dealing with intuition, but that move allows Kant to secure the status of "idea" for the work of art. Operating in terms of ideas allows entry into a transcendental dimension called for by our interest in what remains uncognizable. Treating the aesthetic as involving ideas makes it possible to see works of art as bringing to the surface deep features of subjective life that in fact can be shared because of how experiences coexist in a supersensible dimension. Art intuits the supersensible because it appeals to free subjectivity in relation to materials that have objective existence in their ways of resisting the satisfactions of a cognitive domain. If one is made uneasy by this language of the supersensible, it may be possible to replace Kant's model of hidden depths for a model of adjacency based loosely on Wittgenstein: the supersensible can be thought of in terms of what can only be seen but not characterized, except as adjacent to what is amenable to causal explanation. This supersensible affords a distinctive social space where agreement is possible despite the lack of determinate truth. For Kant argues that if we probe the subjective principle we find aesthetic experience fundamental to appreciating what social being can be for humans, precisely because we can seek language for the substance of indeterminate concepts so long as we do not demand determinate proof (CJ 217).

ultimate concern is to deepen particularity rather than serve as stable elements in the work of understanding. Our effort to put *Hamlet* within public discourse affords it its particular hold on the world.

Imagine a response to *Hamlet* that tries to work out what sees as exemplary. We could emphasize how the features of the play fit together into a powerful complex experience. Then we would connect that experience to the world as a kind of thinking and feeling by trying to convince others of what it becomes in the act of aesthetic judgment. The connection to the world depends now less on mimetic principles than on social ones connected to how one articulates one's approval. And this articulation takes the shape in does because Kant adapts and modifies the structure of moral thinking to conditions of pleasure rather than of straightforward obligation. Practical Reason for Kant has the capacity that anyone can function impersonally, bound by a commitment to rationality. Approval in art involves an analogous impersonality where subjective pleasure submits itself to standards based on reasons rather than preferences.

When dealing with an art object, one can adapt the form of moral discourse without its categorical nature because there too we encounter something that makes us want to distinguish our approval from simple pleasure. We want to engage the work with a sense that we can appeal to an audience in order to establish what approaches objectivity for our approval. There is a dimension of our pleasure in art that leads us to think of how others might share our response, and in so doing validate our sense that our reasons for our pleasure are compelling. [6]

For my purposes the particulars of Kant's account of what approval involves matter much less than its overall psychology that provides an alternative to stopping with subjective pleasure. Because there is an objectivity to the work as purposive, there are states of mind that can attune themselves to those objective qualities and try to offer accounts that involve the prospective agreement with other people. We can recognize a social dimension of art where we see others as capable of appreciating our reasons and being lead to pleasure by means of them. Because these potential bonds do not have the absoluteness of moral law, they represent a much more fluid sociality where pleasure can be negotiated. And it turned out modernist artistists cultivated impersonality in the production of art as well as the reception as one way of combatting the emphasis on subjectivity that artists and writers took from Kant's celebration of genius.

[6]I think the best social vision deriving from Kant is Max Schelers's distinction between subjective pleasure as entering us into a zero-sum game and the activity of approval as making possible the kind of pleasure in a symphony that is enhanced by the obvious pleasures taken by other members of the audience. See Scheler,

III

There are several problems in Kant's account. But by focusing on idealizations of agency we can treat later philosophers as engaging those problems in order to modify how certain human interests are served by their efforts. Hegel is a useful model for this enterprise. No one has been a sharper critic of Kant's vague ideas about form and his notorious claim for disinterest as the basis for distinguishing between pleasure and approval. These criticisms all stem from Hegel's conviction that dealing with works of art involves the audience in projecting how a work becomes an objective expression of subjective states. The objectivity stems not from the act of judgment but from the qualities of genius that demand self-knowledge. Then art need not be disinterested at all, although our response can still honor Kant's sense of that the interests served by art involve the development of intricate awareness rather than becoming more fluent in the processes governed by the understanding. The engagement with this effort at objectification introduces new levels of self-conscious intensities.

Hegel's usefulness as a theorist of the arts is immediately evident in his basic enabling question: "what is man's need to produce works of art?"[7] Hegel's response has to do with manifestations of agency quite close to Kant's concerns: art addresses distinctive mental capacities that function differently from the workings of the practical understanding. In art we engage sensuous details because they dramatize the mind's activities to grasp particularity while at the same time grounding a metaphoric dimension by which the mind enacts its own propensities to universalize. Art's basic role in life involves a domain of aesthetic judgment where "the thinking spirit" can know itself again "when it has surrendered its proper form to feeling and sense, to comprehend itself in its opposite" (LA, p. 13.). This comprehension of what is surrendered to sense intensifies and focuses self-consciousness. The "I" responding to the work takes responsibility for the state of the subject rendered objectively within the work.

Thus for Hegel the focus shifts from demands for explanation to a willingness to engage the kind of thinking that involves "reflection on the mode of its productivity and practice" (LA, p. 27). Hegel affords a model of response to art that is not so much judgmental as identificatory. And he stresses what powers those efforts at identification make possible—as modes of attunement and as modes of concentration on "inner intuition" that show us how we can meet the demands of what has become objectified. Art is the way humans bring the self before itself "by practical activity" that enables a person to alter "external things whereon he impresses the seal of his own his inner being and in which he now finds again his own characteristics" embodied in his passions: "Only by this active placing of himself before himself" does a person make visible the quality of spirit's engagement with the world (LA, 31).[8]

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[7] G. W. F. Hegel, *Hegel's Aesthetics: Lectures on Fine Art*, Translated by T. M. Knox, (Oxford: Clarendon Press, 1975): 30.

[8] Should I lapse into Hegelian language I want to mean by "spirit" only this: the felt challenge of having to respond to the placing of oneself before oneself. Hegel's most concise generalization about

IV

Can we embody these ideals in our teaching of literature? Is there a real need for how imaginative writing can elicit the work of self-consciousness? I think a secularized Hegel establishes the needs that warrant such idealizations. The fundamental need for self-consciousness is to have people strive to lift "the inner and outer world into spiritual consciousness as an object in which he recognizes his own self" (LA, p. 31). Expressive sensuous activity, represented and doing the representing, allows an impersonal grasp of what the subject becomes as it submits itself to conditions in the world that extend far beyond the individual's immediate sense of its own subjectivity. Hegel's richest metaphor for this process takes the form of an equation: expressive activity engages in a continual process of trying to make "I = I."

The "I" at the subject pole has to recognize how it can take responsibility for what the "I" has come seem as an object for observers of its history. The subject has to modify its sense of itself to maintain an equation with how its world seems to those outside its allure. So art does not concentrate on pleasure arriving from the discovery of form, but produces the kind of pleasure that accompanies a mode of action by the mind that tries to attune subjectivity to an "I" that has taken from history an objective existence. Wordsworth's "Tintern Abbey" makes this process especially striking because the narrator views himself first from the perspective of his past "I", then struggles to make these reflections open to objectivity so that they can serve as emblems for his sister and future readers.

The task of the audience then is to try to participate in the decision-making process of the artist because that orientation provides a means of transforming the desiring subject into forces that take on objective historical significance in their negotiating sensuous environments. In effect art establishes why the maker is of interest. It invites us to explore that interest by examining further the nature of the sensuous conditions we attend to. And at each step of the way we have to ask how and why we are disposed to feel what we feel. Our interest in the work is not so much in the craft or the form as the conditions of self-consciousness that underlie our attention to the sensuous details.

V

In my final section of this paper I want to show the need for these aspects of agency by engaging briefly what seems to me an oppressive reductionism in the new theoretical emphasis on extended cognition as a model of mind at work. I will assert that three valuable aspects of readerly agency get lost when art is subsumed under even the

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the spiritual in the sensuous is probably this one: "Spirit does not stop at the mere apprehension of the external world by sight and hearing; it makes it into an object for its inner being which then is itself driven, once again in the form of sensuousness, to realize itself in things, and relates itself to them as desire" (LA 36). (see also 35, 38) most sophisticated cognitive concerns. (1) By attempting to align art with all sorts of materialisms, especially extended cognition theory, theorists diminish the modes of authorial agency captured in Kant's account of purposiveness and Hegel's account of expression. And by diminishing the author's role, theory inevitably simplifies what it might take to appreciate the full complexities of individual works. Art keeps proving the need for a concept of genius in order to understand the labors it transforms into pleasures. (2) Diminishing the role of purposiveness embedded in particulars makes irrelevant a distinctive category of judgment specific to acts of approval. There is in contemporary theorizing little importance to how specific art objects communicate the kinds of pleasure that make acts of approval possible. (3) Stressing the cognitive aspects of art's engagement with the world ignores how what I have called the presence of exemplary display makes demands on the mind. Cognition enters every human relationship. But there are many aspects of those relationships that cognition cannot take account of fully because it can see what is happening but not judge what is displayed in the expressive process materialized by specific media. Making those judgments involves an attention to the particularity of display that is at our level of knowledge incompatible with the demand for explanation in terms of the laws of physics. With no distinctive mode of judgment, the effort to explain one's approval gets replaced by the celebration of differences in response. Then it is tempting to explain those differences in terms of cognitive psychology rather than in terms evoked specifically by a purposive maker. The cost of switching languages for apprehension is the loss of any appeal to the kinds of self-consciousness that accompany taking pleasure in a complete, fully imagined action. The reflective mind collapses into the capacities for active cognition caught up in the moment and bereft of many dimensions of historical self-consciousness.

In the service of brevity I need an extreme version of how contemporary cognitivism views agency. So I will turn to how David Chalmers talks about judgment—talk that ignores Kant and the long tradition of discourse about judgment elaborated by commentators on the arts. Chalmers sees clearly that the only way he can save consciousness from being reduced to roles that Kant confined to the understanding is to establish a separate faculty that handles responsibility to the rules of physics. This task he assigns to judgment. By having judgment make coherence out of sensation and bring conceptual order to bear, Chalmers can free consciousness to attend to qualia as qualia, with no innate interpretive demands at all. If judgment organizes cognition, states of consciousness can be treated as direct, self-evidential, and unmediated.[9]

[9]Chalmers is intensely Cartesian. He is one of the few thinkers who insist that consciousness not be erased into the analysis of causal functions called for by those who trust only the language and the principles of physical explanation. His version of consciousness performs by directly intending a world and asserting its own presence. One is immediately aware that one is conscious so there is no derivation of that fact from any kind of causal change. But there is also very little more that can be said about consciousness in such an isolated position. Chalmers sets off what is radically different about Husserl (and probably Wittgenstein): we risk peril when we separate consciousness from its involvements in forging an orientation within the world of praxis. Not consciousness alone but consciousness as an aspect of some kind of intentional process or disposition for entering some domain of experience. This is clearest when we talk about Intentionality in art—in the making

It may seem that this treatment of consciousness allows theory openness to the domains of free play explored by the arts. But art is not just free play. There are two large problems with Chalmers' psychology. Consciousness can do nothing but accompany qualia without yielding to judgment; it cannot produce self-conscious ways of dealing with the kinds of values that might enter an account distinguishing pleasure from approval. And his version of judgment cannot provide the needed supplement because it is reduced to what Kant would call the conditions imposed by understanding. Consciousness gets to roam like a randy bachelor while judgment is tied to keeping the cognitive household. Neither domain opens itself to the other.

The content of a judgment becomes simply "what is left of a belief after any associated phenomenal quality is subtracted" (174).[10] So while all phenomenal judgments are expressions of behavior and hence subject to the language of physics, consciousness itself involves a domain that is not logically supervenient on the physical world (181). How we feel ourselves in the world is not a matter explicable by causal statements because such feelings have no material correlate: all we can say about consciousness depends on our observations of its modes of emergence (187). Neither self-evidential consciousness making the world and the self present, nor the judgment bound to the rules of physics, are set up to engage the gorgeous mediacy that comprises fusions between sense and inner sense in our processes of judging works of art or orienting ourselves toward the possible complexities of other human beings.

Chalmers seems to honor phenomenology in his privileging modes of emergence, but in fact he deprives it of any direction of force. His cognitive interest absorbs all description into dealing with causal relations, while intentionality and other states of consciousness become irrelevant because they are not a part of any explanation (177). This is Chalmers on ultimately replacing phenomenal judgments by invoking "perceptions instead":

> When a concert-goer sighs at a particularly exquisite moment, one might have thought that the experienced quality of auditory sensations might be central to an explanation of this behavior, but it turns out that an explanation can be given entirely in terms of auditory perception and functional responses. Even in explaining why I withdraw my hand from a flame, a functional explanation in terms of the psychological notion of pain will suffice. … It is this correspondence between phenomenal and psychological properties that makes the explanatory irrelevance of phenomenal properties not too serious a problem.

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and in the responding—because we can then focus on a relation of display between the senses and processes of reflection that can establish significant affinities between the maker's offering the work as serious art and the audience's possible satisfaction with how they experience it.

[10]For Chalmers there are three kinds of judgment in terms of their content. All three kinds are "not strictly about consciousness" but "are parallel to consciousness and generally about objects and properties in the environment" (175). First order judgments involve the content of the experience stated as a cognitive claim: "I am sensing something red." Second order judgments also involve cognitive claims, but about the agent experiencing the sensation as a kind of consciousness experience, like a particularly intense shade of red. Finally, third order judgments "are judgments about conscious experience as a type. …We make third-order judgments when we reflect on the fact that we have consciousness experience in the first place, and when we reflect on their nature" (176).

Where does one begin unpacking the problematic features of this piece of reasoning? There are sighs and "sighs." Perhaps most sighs can be explained "in terms of auditory perceptions and functional responses." Some sighs though are elicited less because of what the body is doing than because of what the piece of music is doing structurally and tonally. What makes a "particularly exquisite moment" occur? Certainly it is not just auditory or functional. The exquisite moment is likely to make special aesthetic demands on a responding consciousness. And these demands involve not just the senses but the self-conscious responsiveness to how the senses are deployed relative to some kind of purposiveness. Attentiveness at a concert is sadly misdirected if it can be characterized in the same ways that we characterize withdrawing our hands from flames. The response to flame seems immediate because it is driven by direct awareness of pain. To claim the same immediacy of the auditory sensations is to ignore their being sponsored if not caused by responsiveness to the music. That music is highly mediated by a score and by activities of performers, so to claim sensory immediacy is simply to foreclose everything that may make aesthetic experience a challenge to our theorizing about the mind. Chalmers ends up simply invoking the authority of the sciences without even trying to recognize the actual activities comprising the inner sensuousness that goes into processing those mediations.

Now compare the conditions of agency called for by the fourth and final stanza of John Ashbery's succinct lyric "As We Know":

The light that was shadowed then
Was seen to be our lives,
Everything about us that love might wish to examine,
Then put away for a certain length of time, until
The whole is to be reviewed, and we turned
Toward each other, to each other.
The way we had come was all we could see
And it crept up on us, embarrassed
That there is so much to tell now, really now. (CP 661) [11]

In one respect this poem shares with many contemporary critics a deep suspicion of any belief in the inner life. There is only a set of expressions characterizing how two people might review a love affair. Yet the review leads to a strikingly elemental judgment, acutely different in function from the descriptions preceding it. So the poem enacts crucial differences between what can be known explicitly and what can be displayed or performed as significant action inviting reflection. Ultimately the contrast between the two versions of "now" invites us to speculate on the kind and quality of self-consciousness the speaker wants the couple to share

[11] Because I think this poem offers so striking an example of "inner sensuousness" without an ontology claiming an inner life, I modify my essay, "How John Ashbery Modified Stevens' Uses of As," in Bart Eeckhout and Lisa Goldfarb, eds, Poetry and Poetics After Wallace Stevens. New York: Bloomsbury, 2016: 183- 2000.

because of recognizing this difference.[12] Ashbery indulges in a mode of Hegelian self-objectification despite his commitment to locating it entirely in how language is deployed.

Here the implied state of self-consciousness does not emerge from anything picturing an inner life that the individual agents might perform. The speaking simply adapts to how “really now” makes use of English grammar in order to establish a surprising relation to time, which in turn offers a new means of valuing an ongoing relationship. Before this stanza, time had been staged in the poem only as the enemy of any possible bliss involving the sense of home as a place “to get to, one of these days.” Now the pronoun “we” expands into an affirmation of the difference between ordinary time and the kind of time that can warrant the adverb “really.” It is not important what details allow for that new sense of reality, so long as the agents feel the difference from the kind of time that simply passes. What is important is that the lovers become exemplary readers of their own expression, “Really now.” Then they would be capable of affirming, with the audience, the possibility of a charged sense of the present tense in which “telling” can replace “reviewing” and the moment of being replace any need for meaning beyond the sense of plenitude afforded by this telling. That this sense of plenitude emerges primarily from grammatical force is the poem’s fullest guarantee that psychological spaces can come into play for an audience who can will what they are living.

The most elemental art can embody intricate invitations to explore powers of mind that contemporary audiences are increasingly at risk of denying.

[12]Commentators rarely notice that “seeing as” for Wittgenstein activates the force of “Now” as a psychologically active state. “Now I am seeing it as a rabbit” makes the attribution “now” a vital force in time enabling “as” to change what the mind then takes as occupying the space of perception.

The Birth of Modernism: How the Science of Aesthetics Created One of the Most Popular Periods of Art

Barbara Larson

Despite contemporary post-modernist decades the still relatively recent paintings of Whistler, Gauguin, Van Gogh, Picasso, and Ernst Ludwig Kirchner remain in the ascendant in popularity. We think of these artists as Modern, but just when and how did Modernism in art come about? What defines Modernism with its distorted or evocative figures and painterly, colorful, or multi-perspective deconstructed forms that tend to linger in the mind? There have been plenty of discussions about industrialization, the modern environment, and a developing taste for the instant. However, when we take a close look at those would-be defining criteria we are confounded by the return to the classical we see in Albert Moore, much of late nineteenth century Symbolism, several periods by Picasso, or mid-twentieth century Surrealist André Masson's *Gradiva*. Even Monet's celebrated love of the here and now and new urban structures falls into question when we see that his period of interest in industrial subjects such as train stations is relatively brief and expected figures in modern dress are cast aside for landscape and frequent prolonged studies of cathedrals and ancient rock formations. Yet Monet is Modern. Abstract paintings such as those by Kandinsky with their symphonic titles and semi-hidden references to apocalyptic scenarios or Rothko's meditative clouds of deep colors with tragic overtones remain compelling because they are not about specific moments such as historical incidents from 1910 to 1930 (in the former) or 1950 to 1970 (in the latter).

What defines Modernism as a whole is not modernity as a lived condition (though this can be a subject from time to time) or the instantaneous, but a commitment to the experiential–the neurological, physiological process of taking in a subject and being activated by it, both by artist and by viewer. Even the classical subjects, given art historical explanations about contemporaneous conservative politics or interwoven references to mind (Freud, Jung) and mythos, are compelling because of an unexpected play with form, color, texture, perspectival shifts, or location of

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subjects. These formalist concerns are rooted in aesthetics, which narrowly entails a study of beauty, but more broadly refers to sensory response to form and color.

How and when did the experiential turn in art happen and, therefore, what brought about Modernism? The answer is both simple and complex. The simple answer and the one we will explore is 1860. The more complex answer lies in the period before this, when scientific investigations began to challenge ideas on how we see and experience the world and questions were raised about whether or not art should be a mirror of what we thought was the world we knew (realism), or strike ideal fictions (past heroic deeds, for example), or sweep the passive viewer along on an emotive journey of turbulent seas and wistful views over a vast, pantheistic nature (Romanticism). Modernism as it came about around 1860 replaced the passive if empathetic viewer with an actively engaged and individualized person of experience who held a veritable dialogue with the work of art. The transformation is both subtle and profound. Romanticism is surely concerned with the experiential (J. M. W. Turner, after all, strapped himself to the mast of a ship in a storm in order to convey believable sublime drama in painting), but a difference in Modernism lies in its refusal to close the loop of anticipated viewer response. Romanticism, carrying the viewer along beneath the wing of the artist, often points out what one should see and feel from a dramatic perspective; it assumes, Modernism usually does not. Mid-century Realism holds up a mirror of detailed surfaces or the specifics of social disarray; Modernism does not. Modernism opens up the picture plane as a site of the indeterminate. And the resonance and appeal Modernism continues to have for its audiences today largely lies in the way it continues to galvanize the individual spectator. What occurred to precipitate Modernism with its experimental forms and play with color or line was a transformation in the way the relationship between body and mind was reconfigured—a transformation that would reverberate in art for one hundred years.

Before 1860 the mind was often inextricably linked with the notion of a soul and thus, essentially considered separate from the body, its vessel. The eye as the window to the soul could take in the visuals of the world and resulting thoughts could be relatively undisturbed by the living, breathing body. But by 1860 psychology, which had previously been a metaphysical, philosophical discipline was coming into its own as a true science and the duality of mind and body was replaced by an increased awareness of the body's physiological processes upon which the mind was now seen to depend. In earlier decades of the nineteenth century there had been significant interest in physiology along with the materiality of the brain, but a vitalist conception of living matter as ultimately mysterious, compatible with spiritual notions, lingered. Significant work on the brain as the material conveyer of thought was promoted by François Magendie, Franz Joseph Gall, Charles Bell, and Claude Bernard. These scientists were fascinated by the electrical response within nerves, but neurons (nerve cells) within the brain were not yet well understood. Historically, it had been the brain, not the heart, that was thought of as the home of the soul and gray matter retained much of its mystery. The relationship of aesthetics to the soul does not entirely disappear from Modernism (Kandinsky), but it was not until the middle of the nineteenth century that the science of neurology reached the kind of maturity that allowed aesthetics to be recast as a sub-discipline of psychology. Modernism responded to a modern science of aesthetics, the result of psychophysiology.

The psychological turn in aesthetics borrowed ideas from even earlier eras—it had roots in seventeenth and eighteenth century sensationalism. The sensationalists such as John Locke had believed that thought was essentially formed by experience provided by the senses (such as touch) and then combined with memories formed throughout one's lifetime that were bound with these sensations, especially those that produced pleasure and pain. The twin poles of pleasure and pain at the root of human response remained a viable interpretive device for modern psychophysiologists and aestheticists as we shall see. Such was the case with empiricist Alexander Bain, often credited as the founder of the science of psychology (and editor of the first journal of psychology, *Mind*); Bain was also interested in the role of aesthetics in art. The importance of aesthetics to response was underscored from another arena of science—evolutionary theory, wherein Darwin (also influenced by Bain) became increasingly drawn to the important role he believed aesthetics played in the history of species in the 1860s.

In his influential writings of the 1850s, Bain demonstrated an interest in neurological research where the fine arts were concerned. He was mainly concerned with the more traditional interpretation of aesthetics—the definition of what is beautiful. Harmony and proportion produced pleasurable sensations, as did artistic variety. Forms with straight lines necessitated attention to proportion and symmetry to produce pleasure, while curving shapes led to immediate pleasurable sensations associated with ease and abandon based on the freedom from restraint experienced by the muscles of the eye (which trace an arc and experiences the joyous effect of release). Forms cause waves of emotion in the viewer, affecting muscles and nerves. But the more forms one sees the more complex the chain of neurological responses that results in the complete aesthetic response. The basis then of aesthetics was tied to physiology and not to ideas; the implication of the physical movement of the body to the mind and its experience of aesthetics was part of his perspective. Frederic Leighton and Albert Moore's sinuous, languorous paintings of Greek girls of the 1860s and 1870s despite their antique content demonstrate the principle of pleasure-producing elliptical contours. The British artists Leighton and Moore belonged to the first truly Modern movement, appropriately named Aestheticism.

In addition to discussing the physiology behind the experience of the beautiful, Bain also contributed to Aestheticism through foregrounding the importance of specific impressions, remembered through novelty or surprise. He wrote, "The brain is more sharply stimulated…by reason of novelty of the impression…Different things that strike us…are the very foundation of our intellectual development" (Bain 1865, 571–72). Notably, Walter Pater, the best known of the literary critics of Aestheticism wrote about the importance of the impression from the perspective of Bain. He called upon artists to adhere to a strong impression in their quest for beauty and "burn" with a "hard, gem-like flame" (Pater 1868, 311). He reiterated the importance of the subjective and of psychology in the context of a world that impresses itself upon the artist in his 1873 book *The Renaissance.* His writings, given Pater's central importance as a critic within Aestheticism, are examples of the familiarity with the ideas of Bain among the artists associated with the movement.

Aestheticism as an art movement emerged around 1860 and included figures like James McNeill Whistler, Moore, Dante Gabriel Rossetti, and Leighton. Subjects ranged from the classical to the contemporary (Whistler's well known scenes of the Thames River). Aestheticism distanced itself from traditions wherein content was considered the most important aspect of art such as narrative, literary paintings or high-minded references to the heroic or other moral messages or impossibly detailed landscapes. Aesthetes prided themselves on their credo, "Art for Art's Sake." Whether the subject was classical or contemporary, they created compelling works of art based on holistic corporeal response to form and color. The approach varied. Rossetti's Aesthetic paintings feature sensual, often contemporary female heads in luscious oil paint created with glazing and layering techniques, while Moore's languorous statuesque classical females in diaphanous, classicizing gowns make use of muted, harmonious tones and Whistler's Aesthetic works of the Thames sometimes appear laden in a liquidly fog so thick the viewer can readily imagine its dampness on the skin.

Aesthetic response was being contemplated by Darwin and his evolutionist followers as well at this time. Darwin felt aesthetic response accounted for a surprising number of factors in evolution of species from the value of camouflage in avoiding the tendency of the eye to focus on attractants, bright colors in flowers that attracted birds or insects, part of the web of life, and most notably perhaps in the context of this essay, to sexual selection (wherein animals, including humans, choose the most attractive mate). As was so often the case with the Aesthetic artists Darwin contemplated the sensual and pleasurable appeal of beauty; he had read his Bain. As Gowan Dawson has noted, critics of Darwin and of Aestheticism linked them, found them immoral, and complained about their "fleshy" agenda (Dawson 2007).

Darwin's main focus was on species survival, and the avoidance of pain was another pole of experience that became bound with aesthetic theory for the evolutionist. He had read Edmund Burke's *A Philosophical Enquiry into the Origin of Our Ideas of the Sublime and Beautiful* (1757) when he was a student and returned to it again after the Beagle voyage as he contemplated species transformation. (Larson 2013). Burke's ideas developed as part of the "culture of sensibility" in the eighteenth century, when a science of the senses was being formulated and applied to many areas of society, from manners to aesthetics. According to Burke, the sublime created "unnatural tension in the nerves." Darwin identified with Burke's ideas on a rapacious nature, the central drive of self-preservation, and the mind-body relationship in emotional expressions. Obscurity, a sense of danger, and imposing forms created a sense of fear (the sublime). Burke had also held much appeal for artists of earlier decades of the nineteenth century, particularly in regard to landscape aesthetics, but Darwin was especially drawn to Burke's discussion of the physiology and psychology of danger.

In considering sexual selection in the animal world Darwin grew increasingly interested in investigating the concept of beauty in the 1860s. There is an echo perhaps of Aestheticism's credo "art for art's sake" (that is, art's lack of moralizing necessity) when he wrote of the sometimes capricious taste for form and color by female creatures in considering mating partners in his 1869 edition of *Origin of Species*, ten years after its original publication. He happily noted, "I willingly admit that a great number of male animals have been rendered beautiful for beauty's sake" (Darwin 1869, 247). At this time one of the creatures that was associated with Darwin's ideas on aesthetics and sexual selection in the public mind was the peacock (with its magnificent train of feathers), which also made its way into Aesthetic decorative devices of the period. Perhaps the most famous example is Whistler's peacock room, a decorative interior for a wealthy industrialist featuring large painted golden peacocks, but peacock feathers as a motif could be found from fans to stylized decorations for elegant interiors within the movement.

In the 1860s, artists and scientists were sometimes involved in the same cultural circles and artists had ready access to scientific ideas through interdisciplinary journals or the current openness between the philosopher-scientists of the time and artists. An example would be the philosopher/amateur physiologist George Lewes whose life partner was the novelist George Elliot. Lewes had many artist friends along with scientists such as Darwin, about whom he wrote four lengthy articles in the 1860s for his own journal the *Fortnightly Review*. Artists and poets also published in this journal such as Rossetti.

By 1860 in art and science the time was ripe to consider aesthetic attraction to formal elements over detail or the unfolding of a scenario (in art, this would be foregrounding a historical narrative or other event) for a number of reasons, one of which was the cumulative evidence of innate imperfection of the eye as discussed by scientists including the most famous optical physiologist of the day, Hermann von Helmholtz (1856–67). Helmholtz believed the eye to be so faulty (Darwin humorously quoted Helmholtz that had the German scientist been presented with any instrument as poorly constructed as the eye he would have returned it; Darwin 1874, 441) that it was constantly dependent upon information supplied by the mind (psychology) to make sense of the world. Helmholtz also applied his experiments on neurological response to the importance of the impression in art: In "On the Relationship of Optics to Painting" he considered color and light from "the physiological study of the manner in which the perception of our senses originate, how impressions from without pass into our nerves, and how the consideration of the latter is thereby altered" (Helmholtz 1995, 279).

Lewes was one of the influential cultural figures that read Helmholtz on optical physiology and became convinced that seeing was essentially psychological and part of individualized mental perception. Impressions stimulated sensations that might be localized or more generalized within the body. Sensations via sensory nerves then transmitted the message of the impression to the brain. He addressed these ideas in his "Prolegomena" of his book *The History of Philosophy* (1867, xvii–xcv).

The fallible eye, investigated by newly emerging psychologists, physiologists and evolutionary theorists, underscored the importance of a coordinated sensorium in viewer response. Aesthetic artists as we have seen jettisoned an interest in detail, narration, or moral messages as had been present with the Pre-Raphaelites or contemporaneous Victorian artists or academic painters; Aesthetic artists were interested in color harmonies, texture, the curvaceous appeal of the body, and the relationship of forms that did not foreground specifics.

Physiological aesthetics began to attract considerable attention among scientists and newly minted art critics along with artists who took up new ideas on the mind and aesthetics. They found a resource in the many physiological laboratories proliferating in Europe, most notably in Germany. The early English physiological aesthetic theorist James Sully, for example, admired by artists and scientists, including Darwin, spent time studying in Helmholtz's laboratory. Sully responded to Bain, Darwin, and Helmholtz in his subsequent publications.

The evolutionary history of the organism was central in explicating physiological and psychological theories of response to the environment. While Darwin followed Bain, Locke, and Burke on the importance of pleasure and pain in aesthetics, he acknowledged the evolutionary history of these experiences. And from Darwin's perspective, first and foremost vision was part of a coordinated sensorial response in which sensibility was tied to self-preservation—averting harm on the one hand (pain) and positive excitation of the tissue on the other (pleasure). Based in the vital qualities of cell structures, in which both plants and animals share protoplasm, all organic beings responded to sensory stimuli in the environment in a holistic manner. The eye, though limited, developed as it had to the extent that survival and reproduction were ensured. Thus, in the animal world vision responded strongly to stimulants such as markings, coloration, or such secondary sexual characteristics as size of antlers or the overall impression of an animate form such as that which is far larger than the individual and potentially threatening. These stimulants varied among species and through time. And physiological processes evolved along with mental faculties.

Darwin supporter Herbert Spencer was one of the most influential of the psychologists on developing physiological aesthetics in the 1860s. Like Bain, he tied physiology to psychology in his influential *Principles of Psychology* of 1855. Spencer had already demonstrated in this text an interest in evolutionism before Darwin's landmark *On the Origin of Species* was published in 1859, though he had Lamarck's brand of teleological evolutionism in mind. From this position he maintained the idea that aesthetics, rooted in animal behavior, had an increasingly complex history through evolutionary time. He began to write about aesthetics in the 1850s, but is best known for his explanations concerning art from the second edition of *Principles of Psychology* (1872). Here he elaborated on human aesthetics as surplus energy once used for survival and play. Aesthetics as indulged upon in painting was, in its expenditure of energy, a form of adaptation to the present moment. In *Principles of Psychology*, he acknowledged that his original publication, steeped in "The Doctrine of Evolution," was ridiculed in the mid-1850s, but in the last ten years (presumably since Darwin's *Origin of Species* was published) he felt that evolutionary applications of physiology to the mind were now taken seriously; perhaps this is the reason that he now addressed art specifically. Spencer also found that pleasure and pain were fundamental to evolutionism; art (as the elimination of pent up energy no longer needed in survival) was a site of pleasure. Bain had been interested in the older concept of Associations or past memories where aesthetics were concerned; Spencer also added

Associations to his theories of art. The artist and viewer draw upon associations and the impression at first perceived is enhanced through individual experience: Bain for example had written, "The mind supplies from the past what the eye does not distinctly see at the time, so that the picture realized is not the bare optical impression of the moment, but a much fuller picture which that impression suffices to suggest" (Bain 1855, 246). Positive and negative memories are attached to aesthetic aspects of pleasure and pain. Spencer believed that art accompanied the evolutionary advance of culture; the more advanced the culture (both in terms of physical evolution and the advance of society) the more complex the art and the greater the pleasure it gave the viewer. In this way, evolutionism might be used to confirm elite sensibilities and refined taste in Victorian Britain.

After 1860 a number of artists including landscape painters moved away from detailed painting towards optical impressions of the world in Great Britain and in France. The kind of exacting perfection found in academic art or even that of experimental artists like the Pre-Raphaelites or compiling of social information among the French Realists and Victorians was not in line with new science of aesthetics from which true Modernism dates.

The English position on psychophysiology with a focus on Spencer and Bain was introduced into France by psychologist Théodule-Armand Ribot, sometimes called the founder of French experimental psychology. He represented a key transitional personality in reconsidering a still pervasive trend towards Cartesian dualism (of body and mind) in France. Ribot published *La Psychologie anglaise* in 1870 and translated Spencer's *Principles of Psychology* into French. He was also an early French supporter of Darwin. The influence of psychology on vision was also the subject of important writings by historian Hippolyte Taine, who became Professor of Art and Aesthetics at the Ecole des Beaux-Arts in Paris in 1864.

The concept of the impression had begun to circulate in France in the 1860s. In 1860, that grand lexicographer philosopher Emile Littré (author of the *Dictionnaire de la langue française*) wrote an essay on perception and the impression, and in 1863 the poet and art critic and galvanizer of modernism Baudelaire used the phrase "impressions upon the mind" in praising an artist of modern life (Baudelaire, 2: 155).

Psychophysiology developed as a field of study in France, inclusive of the work of Ribot, Alfred Binet, Charles Féré, Charles Richet, and Charles Henry. While experiments in aesthetics and psychophysiology would bear their greatest fruit in the art of France in the last two decades of the century, Impressionists were pursuing corporeal effects of light and weather as early as the 1860s and 1870s. The Impressionist Monet dispensed with detail and began to apply paint in a way that suggested in its tactile and fluid aspects a holistic response to the environment. Impressionist artists sometimes painted side by side, coming up with different results (colors, expression of lighting, focus or lack thereof on one or another object) demonstrating not that they painted what anyone would see, but rather how individual psychology in combination with optical physiology "sees," with open-ended results for the viewer to bring his or her perspective. An example can be found in Renoir and Monet's side by side paintings of the floating restaurant and its surround *La Grenouillère* of 1869. In these paintings Renoir's preference for pastels and focus on the life of people and animals (the ladies in gauzy gowns and dogs lazing about or stepping precariously and unseen into a boat) seems to be on show while his companion Monet telescopes outwards to the sparkling water while trees, bathers, and elegant figures are comprised of daubs and strokes of less blended color.

By the 1860s the idea that subjects of art were not precise objects to be clearly described, but rather were part of an optical field of responsiveness had gained traction among Modernists. Wave theory of electromagnetic fields, color and light, suggested that these forces were vibrating energies interweaving within the atmosphere or ether. Edmond Bequerel's extensive *La Lumière, ses causes et effets* (1867–68) which investigated wave and particle theories of light operating within the ether is one example of literature available to artists on this subject. The idea of a thick, but transparent and all pervasive field (ether) that transported the multiple and competing waves of energy was a popular concept throughout the nineteenth century and is perhaps the source of Monet's much referenced "envelope" that existed between himself and the motif portrayed.

Precious little remains in published discussions by the Impressionists that demonstrate the influence of aesthetics from the perspective of current science, but art critic Jules Laforgue, who wrote enthusiastically about the Impressionists during their lifetimes, claimed the style follows the new science of aesthetics. In an essay entitled "The Physiological Origin of Impressionism," referred to by art historian Richard Brettell as "the single most important piece of theoretical writing on the subject of rapid painting in Third Republic France" (Brettell 2000, 49 n. 29), Laforgue wrote that Impressionist forms were obtained "not by contour but solely by means of vibrations and contrasts of color" (Laforgue 1903). He wrote about the eye from an evolutionary perspective, and praised the Impressionists visual acuity: "The natural eye succeeds in seeing reality within the living atmosphere of forms, differentiated, refracted, reflected by beings and objects in constant variation." Laforgue took to task old-fashioned aesthetics of "Objective Beauty" and the "Subjective Taste of Absolute Man." Instead, "now we have a more exact idea of life within and outside of ourselves." There is an echo of Bain's theories of novelty or surprise followed by the need for the strained nerves of the eye to seek rest when he writes, "Note the three main stages of the physical state of the artist's [Impressionist's] eye before a landscape: the increasing acuity of optical sensitivity under the stimulus of a novel view, the summit of acuity, followed by a decrease in sensitivity due to fatigue of the nerves." While the artwork was absolutely unique to the artist, so it is to the viewer: "Each viewer brings to the work an individual sensitivity made up of an infinity of unique moments of sensitivity.... My instrument is perpetually changing and there is none identical to mine." Like the Aesthetic artists, Impressionists dispensed with any kind of moralizing or specific, historical scenario. And like many of the Aesthetic artists they fixed on a motif that struck them, referred to by art historian Richard Thomson as "emotive naturalism" (2010, 33). Monet seemed to confirm the uniqueness of his choices and responses: "I always work better in solitude and according to my own impressions" (1884, 2: 232).

While artist and viewer both play roles where the impression is concerned, there was an attempt to situate the Modern artist as a special type of person. The idea that the artist was a neurologically superior being was held by materialist scientists like Herbert Spencer, Ribot, Pierre Janet, and Taine. But when it came to Modernists this sensitivity could be read in one of two ways: for Laforgue, for example "The Impressionist eye is in short the most advanced eye in human evolution, the one that has succeeded in grasping and rendering the most complicated of nuances known" (Laforgue 1903). Gauguin claimed for artists of his generation a great intellectual capacity that provided "the vehicle of the most delicate and the most invisible emotions in the brain." However, the critic Albert Aurier, a great supporter of Gauguin, saw his friend Van Gogh in a different light. He was "a distinctly characterized hyperaesthetic perceiving with abnormal, perhaps even painful intensities the imperceptible and secret characters of lines and forms, but even more so the colors, the lights, the nuances invisible to healthy pupils, the magical irritations of shadows" (Aurier 1890). Using the language of psychophysiology, Max Nordau famously saw all Modernists as having a neurologically degenerate system, wherein evolution becomes degraded. But even this could work both ways. Having read Aurier's article on his supposed abnormality and aware of the recent revival of the "mad genius" theory of artists with frazzled nervous systems, the epileptic Van Gogh acknowledged, "The emotions that grip me in front of nature can cause me to lose consciousness…" but applied neurotic tendencies to other Modernists as well, "If we want to face the real truth about our constitution we must acknowledge that we belong to the number from those who suffer from a neurosis that has its roots in the past" (cited in Sheon, 175). Even Impressionists like Monet or Renoir could be discussed as having aberrant vision. Critic Félix Fénéon and writer Joris-Karl Huysmans accused them of "seeing blue" (creating paintings with a bluish cast) due to the force of extreme excitement which supposedly caused momentary color-blindness (Ward, 128).

Just how much the early Modernists themselves knew about the new science of aesthetics is found less in direct statements than through examining their work and looking at their conversation with others. When a young artist came to imbibe the brilliance of the reclusive Cezanne, a former Impressionist living in the south of France, Cezanne advised him "sensation above all else" (Denis 1957–59, v. 2, 29). Cezanne's Impressionist mentor Pissarro left behind commentary describing "the sensation" as that which the artist both sees and feels. Of his time painting with Cezanne he said, "Each one kept the only thing that counts. His own sensation" (Pissarro 1950, 391). In his later style, Cezanne developed deliberate and insistent brushstrokes that communicate touch, movement relative to the motif, and sight, along with the emotive appeal of even the simplest of objects. His subjects were invariably still lifes, landscapes, or the occasional portrait. Cezanne's cohesive approach to painting galvanized followers as disparate as Matisse and Picasso, who counted him as a precursor. Picasso was affected by Cezanne's breakdown of traditional perspective in the direction of a world experienced through prolonged and unprocessed vision, but he also noted Cezanne's emotionalism before the motif (Zervos, 36). The Symbolist Maurice Denis who liked to paint religious scenes, including angels, was an admirer and a visitor. In his famous painting *Homage to Cezanne* created during Cezanne's lifetime, contemporary late nineteenth century Symbolist artists, who rarely painted the here and now, are never-the-less crowded admiringly around one of Cezanne's paintings of a bowl of apples. This suggests that they recognized the importance of the older artist's awareness of subjective response and its reorganization through the formal means of line and color, whether one painted what might exist in the world or not, a direction that interested them greatly. A few years later, after Cezanne's death, Denis acknowledged Cezanne's constant references to "petite sensations" and that this had begun with the aesthetics of his youth (bringing us back to the 1860s).

That the new scientific aesthetics with its roots in the 1860s is of great consequence for artists of the imagination (Symbolists) as well is also suggested by theorist-artist Denis's insistence that the group of painters he was specifically associated with, the Nabis, found their inspiration in sensation and materiality. He claimed the artists drew upon scientific philosophy (neurology and sensation), not mere ideas. He wrote of the Nabis, "The movement [Nabi] represented a strictly scientific approach to art…. If the Nabis were brought to distort, to compose, and finally to invent surprising formulas, it is because they wanted to subordinate themselves to the laws of harmony that govern the relationship between colors, the arrangement of lines, and to imbue the relationship of their sensations with more sincerity" (Denis 1896, 36–7).

In particular Denis cited the importance of the research of psychophysiologist Charles Henry on aesthetics to the Nabis. Henry's experiments were based on the principles of pleasure and pain as reconfigured by the influential physiologist Charles-Édouard Brown-Séquard. Brown-Séquard used the term "dynamogeny" (pleasure) in reference to stimulants that create nervous irritation and a powerful response whereas "inhibition" (pain) is a response to that which is enervating and makes nervous power disappear. In addition, dynamogenous or inhibitory responses, for example to color or sound, seemed to correspond to wavelength theory of invisible fields of energy. Wave lengths of light, color, and within electromagnetic fields were thought to vibrate not only through the air (ether), but within the nerves as well. Denis's one-time mentor, Gauguin, said of his own painting: "Color like music is a vibration and like music attains what is most general and consequently what is vaguest in nature—its interior force" (Gauguin 1899, 227).

Originally a librarian with an interest in aesthetics and psychology, Henry engaged in serious scientific study including on electromagnetism and eventually became director of the Laboratory of the Physiology of Sensations. He had developed friendships with artists and was interested in fixing the effects of line and color through experiments on the nervous system. For example, he and fellow aesthetician and scientist Charles Féré conducted color experiments not just on the eyes, but the whole body through an instrument held by hand called a "dynamometer." Red and orange caused a heightened response in the neuromuscular system, whereas blue and violet were inhibitory. These kinds of experiments were thought to bring scientific insights to both artist and viewer. Neo-Impressionists like Georges Seurat were determined to bring greater control to the world of sensations and turned to Henry for direction. The Neo-Impressionist Signac even helped Henry illustrate his lectures. The respect for psychophysiology was such that some former Impressionists like Camille Pissarro joined the Neo-Impressionists in creating a style that made Henry's principles fundamental.

While this essay focuses on the beginnings of Modernism largely in the 1860s, it is worth noting that psychophysiology was considered such fertile ground for artists that three important directions in the immediate aftermath of our period should be noted: its application to art and politics, its use in considering occult energies that certain artists wished to capture in their paintings, and its value for abstraction. Neo-Impressionists, unlike the Impressionists, were directly engaged in politics and felt that Henry's findings, which suggested that responses to color, line, and sound were universal, could be applied to paintings to suggest a harmonious, even utopian future for all of humanity. Henry also had an interest in politics and felt the artwork could transmit communal messages. To this end he suggested as further reading to artists the writings of his follower Jean-Marie Guyau, notably *L'Art au point de vue sociologique* (1887). Guyau believed that the aesthetic phenomena of painting could expand from one person to another like a "vibrating, magnetized wire." He opened his book with these words: "The transmission of nervous vibrations and related mental states is constant among all living beings, but especially those that are grouped in societies or families" (Guyau 2001, 16).

As curious as "transmission of nervous states" may seem as the method to social harmony, Guyau here hints at another avenue in which the new aesthetics could be applied, occult energies, such as thought or brain waves. In occult applications of psychophysiology artists were interested in transferring their thought through color and line or expressing "emanations" or moods from human subjects. Even some physiologists believed that the body could be a site of psychic materializations. The very notion of oozing ectoplasm, captured in spiritist photography, was interpreted as excess nerve stimulation leaking out of body orifices.

Later nineteenth and early twentieth century "sensitive" artists continued the legacy of having a unique ability to capture what was invisible to the ordinary eye, now venturing into occult phenomena. The Symbolist Redon, a science enthusiast, began to paint fields of luminous color surrounding portrait heads as if referencing their auras, a popular concept during this period. Expressing his interest in these ideas he said upon leaving an electrifying piano concert he attended, the pianist had "a kind of fluidium hanging around him." Important early twentieth century modernist František Kupka was also a practicing medium. He believed his painting might be able to directly transfer thought to the viewer as if through telepathic waves. Linda Henderson has demonstrated that even among Futurists, celebrated for their love of technology, the present, and the future, its leading figure Boccioni believed he was an "ultrasensitive" who could perceive energies others could not, including emanations or states of mind (Henderson, 133). One of his best known series is entitled *States of Mind*.

The psychological power of line and color and their embeddedness in nature played an important role in the emergence of abstraction in art as well. Kupka, the first to exhibit an abstract painting, is an example of one of the earliest abstract artists who was influenced by new experiments in sensory perception. John Hatch has noted Kupka's indebtedness to psychophysicist Ernst Mach, who taught at the University of Vienna and Prague in the 1860s (Hatch). Mach's interest in sensations was such that he rejected the theory of atoms in favor of the unique importance of the role of sensory data in understanding the world. He did support wave theory of energy. Mach had been influenced by his predecessor Gustav Fechner whose 1860 *Elements of Psychophysics* addressed the threshold of stimulation necessary to the senses for human awareness. Mach posited that information about the world is constantly dependent upon understanding the relationship of the senses as data is gathered, then synthesized. He positioned this within a framework of continual evolution. His interest in the sensory resulted in the book *Contribution to the Analysis of Sensations*. Kupka believed in the fundamental importance of the senses in responding to the invisible forces in nature, which is never an objective entity, but always changing. The multiple impressions one experiences need to be carefully disentangled before synthesizing them in a painting. Sensory systems are embedded within nature's own pulsating energies whether invisible waves of energy or visible waves such as water; therefore, abstract forms in art should be used to convey that reality. In turn, the painting should trigger sensory responses in the viewer. Kupka wrote, "As a sensitive being open to all impressions, the artist experiences within himself the whole movement of the universe" (Kupka, 207). For Kupka, waves of energy and resulting vibratory effects on the neurological system might be translated into abstract loops or curves of color or planes of color that also suggested the up and down motion of waves. Echoing Mach on the relationship of sensations, he wrote, "The radiation of the vital energy found in nature…always manifests itself in terms of relationships of vibrations" (Kupka, 141). The wave forms that Kupka felt are most in sync with human impressions are reminiscent of Bain.

The new science of aesthetics that considered the relationship of body to mind and the role of individual temperaments provided experimental information for Modern artists. It gave them direction in moving beyond any desire to depict impossibly detailed scenes or irrelevant idealized scenarios. It also validated formal means of expression through the expressive use of line and color or the physical application of paint. The scientific discussions and experiments concerning aesthetics coming out of the 1860s laid the groundwork for the emergence of Modernism in art.

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Panofsky as an Epistemologist

Nathalie Heinich

The essay "Galileo as a Critic of the Arts" moves with tremendous ease between a variety of fields of Renaissance culture. It includes the theory of art and music, numerology and anamorphosis, Mannerism and poetry, cabinets of curiosity and astronomy, the trajectories of the planets and muscle movement, physics and marquetry, scientific Platonism and classical aesthetics. The reader encounters Galileo and da Vinci, as well as Michelangelo and Tasso, Holbein and Kepler, Ariosto and Arcimboldo. As a result, Erwin Panofsky's essay seems difficult to categorize, at first, be it within an academic discipline or in his own work.

However, this "exercise in methodological virtuosity" (to use the term applied by Pierre Bourdieu to "Gothic Architecture and Scholastic Thought") cannot be reduced to an erudite game, nor to the incoherent mixture typical of the heterogeneous cabinets of curiosity so offensive to Galileo's taste, which he described so nastily, much to the delight of Panofsky. For in his essay, Panofsky attempts to highlight the very peculiar relationship that exists between the multiple facets of Renaissance culture. The relationship, in Panofsky's view, is not one of mere juxtaposition, as Galileo's aesthetic tastes have other elements in common with his scientific view of the world. Neither is it based on similitude—the different elements belong to varying fields of perception. Nor can the relationship be ascribed to cause and effect, nor even to networks of influence—as there is no reason to consider that one element generates the others. The relationship is one of equivalence, where the elements obey the same deep or generative structure. Whether it is related, individually, to a "habitus" (the "grammar of conduct", according to Bourdieu's definition) or, collectively, to a "paradigm" (to use the concept applied by Thomas Kuhn to the history of science) a common structure can be found—if like Panofsky, one takes the trouble to look for

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it—in the different strata of the intellectual personality of one individual, just as it can be seen in the different domains of the same culture at a given time.

This mental structure or, to use Panofsky's own words, these "controlling tendencies", identified in Galileo's work can be summed up by the expression "critical purism". In other words, the readiness to "demand a clear and distinct separation of the values and processes that, at the time, were commonly considered inseparable". This attitude is best expressed in the debate on the *paragone*, in which Galileo intervened via a letter to Cigoli (published in the appendix). Panofsky makes the *paragone* debate the starting point for his own commentary. The debate developed in 16th century Italy, when the respective merits of painting and sculpture were discussed by means of comparison ("paragonare"). At the time, painters and sculptors found themselves in competition for princely or clerical patronage, and the patrons were as likely to favour the imposing nature of statues as they were frescos, and galleries of sculptures as much as paintings.

In this debate, Galileo's position in favour of painting is based on the "the petition of principle for the least memorable" according to which "the farther removed the means of imitation are from the thing to be imitated, the more admirable the imitation will be". This firm distinction between the sign ("the means") and the referent ("the things to be imitated") is extremely modern. At the time, figuration was still largely subject, both in theory and probably in perceptual practice, to the regime of mimesis, which subordinated the value of representation to the truth of the imitated object. Such a truth which could be found at the highest ideal level or pre-formed within its categories of reference be they anatomical, geometric or, especially, literary.

In the gap between the "things to be imitated" and the "means of imitation" (a gap that the supporters of sculpture tried to close by proclaiming the proximity of their art to nature in order to strengthen its excellence), the possibility of a strictly aesthetic regime, a form of autonomy of the "the art of drawing" emerges, more strongly than any idea of the supremacy of painting. In the letter, Galileo undertakes the same work of "empowerment" with regard to music ("empowerment" and not rehabilitation, as that would imply the prior existence of a golden age). He underlines the elements that belong to music in its own right, in contrast to those elements connected to heteronomous, non-specific components. In this he includes things such as textual references which, as was the case for painting, served as guarantors of the "dignity" of art and the "liberality" of its practitioners.

The aesthetic modernity of Galileo in the musical and pictorial fields is not unrelated, says Panofsky, to this equally modern form of scientific rigour which again, for reasons of critical purism, separated what had been considered indistinct; it isolated genres, dissociated poetic activity from scientific activity, fiction from reality, fable from experience, legend from anatomy, mysticism from algebra, philosophy from physics, religion from astronomy. And, by virtue of this same principle, Galileo also loathed allegory in poetry, or anamorphosis in painting, for all these things deployed double meaning, confusion, mystification.

However, according to Panofsky, these poetic or plastic forms were characteristic of Mannerist aesthetics, against which Galileo and his contemporaries reacted by rehabilitating Renaissance art. We can thus understand Galileo's equally clear-cut position in another famous controversy between Ariosto and Tasso, where, just as he defended painting against sculpture, he took the side of the author of the *Orlando furioso* against that of the author of *Gerusalemme Liberata*, by virtue of the same refusal of confusion. Thus, Galileo condemned the pre-aesthetic confusion, among the supporters of sculpture, between that which is represented and the representation itself; the Mannerist confusion between the fake and the fictional or between the unreasonable and the imaginary; and the confusion between fabrication and invention in the work of Tasso.

Can the kind of rationalism demonstrated by Galileo in his aesthetic tastes be attributed, as some of his biographers claim, to his scientific turn of mind? Panofsky does not give a definite answer to this question. He simply asks another, somewhat provocative question—what if it were the opposite? What if his scientific positions were guided by his aesthetic choices?

It took the openness and curiosity of a mind like that of Alexandre Koyre's to react to this suggestion—which was all the more provocative as it came from an art historian and not from an historian of the sciences. Better still, in the review of the book he published the following year, he went so far as to explain what Panofsky had not attempted to write: "One could almost say, although Panofsky did not say it—and perhaps it is not even necessary to use the "almost"—that Galileo had the same cast-iron aversion to ellipsis as he had to anamorphosis; and that Keplerian astronomy was, for him, a Mannerist astronomy"; or again: "it is likely that Kepler's symbolism and his use of cosmotheological reasoning aroused the same aversion in Galileo as that inspired by the allegorism of Torquato Tasso".

Investigating the epistemological enigma of Galileo's failure to take Kepler's planetary laws into account, Panofsky concluded that if Galileo could not integrate the elliptical character of the orbits of the planets into his astronomical theory, it was because of the prevalence of the circular form. This "obsession with circularity" ["hantise de la circularité"], in Koyre's own words, was more "Renaissance" than Mannerist, and was common to all his contemporaries including Kepler. However, in Galilean thought, it could not remain limited, to the world of "ideas", as in Keplerian thought, thus leaving "matter" free to deviate from this perfect form. The reason being that Galileo's "progressive empiricism" and, in this case, his "geometrization of nature" prevented him from accepting any law other than that of "matter". This was in contrast to Kepler's "conservative idealism", which allowed Kepler to maintain an "ontological difference" between idea and matter. Galileo as a result had to project the circular form, which was paradigmatic in all fields at that time, be they mathematical or aesthetic, on to his astronomical theory. This circular form would later become a mere outlier.

In other words, it was Galileo's own modernity in science, associated with the classicism of his tastes, which pushed him to dissociate metaphysics from science. Paradoxically, this stance prevented him from making, or even assimilating, one of the great astronomical discoveries of his time.

Koyré again adds to Panofsky's interpretation, emphasizing the eminently conservative nature of Kepler's metaphysics: "for Kepler himself the acceptance of elliptical trajectories was linked to a dynamic conception, which, in turn, was based on astral or at least solar animism". However as Kepler was writing for technicians and not, as Galileo did, for the common man, he could not neglect empirical data and thus had to give himself a concrete and not a general theory. Kepler did so only "after having vainly sought to conform to tradition"; and "no more than Galileo, he never succeeded in seeing in the ellipse anything other than a distorted circle".

Koyré remarked on the fine illustration of the complexity of innovation, which meant that an innovative researcher, like Galileo, was unable to comprehend what a conservative one, like Kepler, was able to discover. "The paths of human thought are curious, unpredictable, illogical," Koyré concluded. Panofsky speaks of "one of the strangest paradoxes in history". However, the same remark could apply to the way in which Panofsky himself managed to shed light on this fact. For in doing so, he reversed intellectual hierarchies and habits of reasoning in an astonishing manner, and dared to adopt an approach which is itself eminently paradoxical—giving an aesthetician's answer to an epistemologist's question.

Nonetheless, this does not mean that Panofsky wanted to reverse the causal or hierarchical relationships between aesthetics and epistemology, art history and the history of science. He was not a man to bear a grudge. On the contrary, Panofsky goes beyond the very notion of causality—with all the problems of priority and the anteriority of the factors it presupposes—to highlight the equivalences and the structural identities common to different fields. In a similar vein, he outlines what could become a sociology or an anthropology of culture. This innovation would put an end to the tendency whereby "art" moves ever farther from "society", "science" is cast adrift from the "social", the "individual" from the "collective", and the notion of "taste" from "social causes", not to mention the interlinked and inevitably endless quarrels of status that such a situation has generated today, quarrels that will quickly become as outdated as the *paragone* controversy. This sociology or anthropology of culture would seek to highlight, via the historical reconstruction of the logic of action and representation, that which is common to the different levels of understanding of reality, as well as to the different fields of knowledge and culture. It would underline the fact that they are part of the same structural schemes, rather than mere processes of imitation, influence or imposition.

In such a situation, erudition can no longer be viewed as the fetishization of knowledge, a means of showing off, or a way of avoiding intra-disciplinary clashes. Rather, it is an instrument to be used in research, making it possible, through the pluri-disciplinary nature of the references cited, to identify similarities, affinities and logical links based on structural constants. When overcoming disciplinary compartmentalization and academic strategies, there is a need for intellectual freedom so as to maintain an awareness of the historicity of mental strictures. Otherwise, one allows oneself to be governed by the false evidence of the intellectual dogma of today—which declares, for example, that art and science should not mix. In doing so, one risks misunderstanding what intellectual life was during the Renaissance, a time when such a distinction had neither the same force nor the same meaning as it has today.

It is therefore surprising to note that the elements Panofsky had to bring together in order to identify the principles governing Galileo's thinking were in opposition to the intellectual codes of our time; just as those very elements were what Galileo himself had to pull apart, in opposition to the intellectual codes of his own era. This is another one of the "strange paradoxes of history" where, at a distance of three and a half centuries, the stories of two extraordinary researchers mirror each other. They display the same clarity and perspicacity in their use of language, and the same freedom of thought, acquired because of their intellectual curiosity, a curiosity freighted down with as much culture and erudition as it is lacking in obedience to tradition.

Art and Science in the Thinking of Rudolf Arnheim

Ian Verstegen

What is normative in our evolved knowledge of the world? Just as models of mind decide whether to respect phenomenal experience or the apparently more secure findings of physics, we have to decide to give relative importance to *art* or *science*. The constructivist or culturalist world view argues that even if science has some transfactual reality, in practice there is wide berth in how these facts are instantiated or clothed in human culture. The scientific viewpoint instead pleads that physical and in general natural constraints give rise to relatively invariant social and cultural formations results.

In regard to the first question, the Gestalt school of Max Wertheimer, Wolfgang Köhler and Kurt Koffka provided a novel answer: neither phenomenal experience nor physical facts should be given ultimate authority.[1] Phenomenal experience did provide the departure point for any scientific inference. However, what can be called genetic subjectivity is just as much a construction as the derived worldview of the sciences.[2] To create a schematism, if in our phenomenal experience we understand certain phenomena to be "objective" and a part of the external world, and another part to be "subjective" and subject to our own acts of perceiving, then both of these data serve the creation of two kinds of knowledge, the scientifically Objective and the personally Subjective:

Datum	**Construction**
Phenomenal objectivity>>>>>>>>>>	Objectivity
Phenomenal subjectivity>>>>>>>>>	Subjectivity

As Paul Richer writes,

[1]Epstein and Hatfield (1994).

[2]Richer (1979), pp. 33–55.

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> Physicalism demands the priority of Objectivity over the world of immediate experience, calling the latter an epiphenomenon. On the other hand, classical phenomenology demands the priority of Subjectivity over the objectivities of the natural attitude, calling the latter 'quasi-given' in comparison with the absolute immanence of Subjectivity. Gestalt psychology demands a priority for neither but allows both as constructions.[3]

In practice, this means that the Gestalt school adheres to a programmatic reduction to science (in the future) but seeks phenomenal and transcendent scientific facts to mutually constrain each other in mental explanation.[4] For this, the Gestaltists developed the idea of psychophysical isomorphism, which sees the form of brain processes as developing the contours of phenomenal experience, collapsing the two into each other.[5] This philosophical solution stands on a delicately balanced razor's edge, and it has been almost uniquely occupied in the 20th century by those following Gestalt theory. While it takes effort to sustain it, because habits of mind cause us to default to one or the other binary of mind or body, it is a uniquely powerful way of orienting ourselves toward the intractable problem of the relation between the incorrigibility of lived experience and physical facts that are the existential cause of those experiences.

Over his long career, Gestalt psychologist Rudolf Arnheim (a pupil of Wertheimer and Köhler) adhered to this philosophical position.[6] His own elaborations of the psychology of art gave the same deference to phenomenal experience with the same recognition of the need to anchor events in brain processes. Perhaps this is best illustrated in his theory of expression, in which the stresses and strains found in the phenomenal experience of directed tension or dynamics of visual forms, are posited to be the byproduct of tensions in neural events.[7] The brain event does not override experience; rather, the phenomenology of the experience constrains the nature of the physical process that can be posited as part of its explanation.

I want to use this metaphor of a razor's edge to explore the relationship between art and science in Arnheim's thought. Because Arnheim's teachers did not write systematically about art it is more difficult to find this symmetry in their works, but it is infinitely clear in Arnheim. The reality of culture and the arts has a kind of authority akin to phenomenal experience in the philosophy of mind. However, science is not thereby discounted. Science too is another way of knowing the world that has some kind of long-term authority that underwrites lived cultural experience but is in its formal elaboration just as much a construction as culture. In other words, genetic Art grows from art and genetic Science grows from science:

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[3] Richer (1979), p. 50.

[4] Hatfield (2000).

[5] The classic statement of isomorphism is Köhler (1938). See further Köhler (1960); reprinted in Henle (1971) and Metzger (1954). For a discussion, see Henle (1984).

[6] See, e.g., Arnheim (1994).

[7] Arnheim (1966, 1974), Verstegen (2005), ch. x.

Datum **Construction**
Scientific practices>>>>>>>>>>>>>Science
Artistic practices>>>>>>>>> >>>>>Art

As a psychologist, Arnheim identified strongly as a natural scientist. But he was a scientist whose object of study was art. How were the two related? In his estimation it is first of all important to recognize their similarities: "Both art and science are bent on the understanding of the forces that shape existence."[8] In other words, the world is conceived of forces—physical and mental—and in different ways we try to register these through our organized knowledge. When we are acting as both scientists *and* artists we seek to record these forces as they relate to the world and the organism. The scientist seeks to discover those forces external to herself and communicate them indirectly. The artist also discovers and also intuits forces to create primary communications that are indirectly about them.

> In science the appearances of things are mere indicators, pointing beyond themselves to hidden constellations of forces…In the arts the image is the statement. It contains and displays the forces about which it reports. Therefore, all of its visual aspects are relevant parts of what is being said.[9]

In other words, science goes through sensation to infer underlying structures whereas the arts' message are those sensuous structures themselves.

Forces are generated by structures, other features shared by both art and science. That is, in seeking to characterizing those forces, we pass invariably to the structure, the *Gestalt*, that generates them. Structure is "what the thing is about," and its nature reflects the above distinctions elaborated for forces. However, in regard to structure it is more important to stress that the same kinds of organization typical of the arts are also found in the natural world. Indeed, it was the possibility that nature could be organized, articulated, formed, or *gestaltet*, that gave the Gestaltists hope that natural phenomena could serve as the bearers of complex mental contents in the first place. Therefore, Gestalt theory formed part of that current of twentieth century thought that sought complexity in natural phenomena from Ludwig von Bertalanffy to René Thom and Hermann Haken.

Nevertheless, as we would expect there are also differences in the kinds of structures and forces contained in art and science. There is a great value in elaborating this difference because the razor's edge persists here too. It is too easy to explore the "style" of scientific explanation and slip into relativism, a one-sided culturalist error. And it is too easy to reduce cultural expression to rigid expressions of psychological or neural mechanisms, the physicalist error. As I will outline, a rigorous conception

[8] Arnheim (1969a), p. 300.

[9] Arnheim (1969a), p. 301. Arnheim wrotes something similar in his contentious review of Nelson Goodman's *Languages of Art*, "science employs and consumes sensory data in order to arrive at the principles governing the operations of physical and mental forces. In art, the sensory data themselves are the ultimate statement because what we are made to see and hear lets us experience the play of forces that govern our existence".

of the notion of structure allows us to specify exactly how to understand science and art and weigh their relative contributions.

It is possible to elaborate on Arnheim's theories in a way that I have done for media theory by using the ontology of Roman Ingarden.[10] If Ingarden's teacher Husserl, and Arnheim's own teachers themselves, were students of Carl Stumpf, that makes Arnheim and Ingarden theoretical "cousins" and indeed one finds that in combining their works together one achieves a descriptive richness and philosophical rigor that is not possible with either alone.

If "structure" is the key to unlocking the fundamental kinship between art and science—structure in a different locus relative to sensuous presentation—what more can be said about it? Following Ingarden, I will argue that structure can be defined with patterns of ontological *determinacy* and *indeterminacy*. By examining and comparing the ontological structure of works of science and art, we are able to understand better their fundamental structure and their basic kinship and differences.

In particular, I will argue that science constructs partially indeterminate theories and models to stand for the basic structure of the world whereas the arts are forms of artifacts that are by their nature indeterminate. Science improves its theories by closing determinacies to arrive at a worldview, while art projects determinacies to give one version of a worldview. The procedural indeterminacy of theories is the unknown that science deals with. The indeterminacy of an artistic world, and its direction toward a possible world, are the unknowns that the arts deal with. What both share is a utopian orientation to the inherent indeterminacy of the future.

Some First Distinctions—Kinds of Heteronomy

Although it is not true of much of the history of philosophy, many philosophers are reluctant to grant phenomenal experience the status as a part of the world.[11] Similarly, works of art are unusual creations, partly objective and partly subjective, which because of their "heteronomous" (non-autonomous) status become things "empiricists do not like."[12] Nevertheless, in acknowledging both we have a richer view of the world that goes beyond the empiricist's description of it. In fact, it is the very idea of indeterminacy that allows us to recognize borderline ontological objects within a general ontology of the world.

The world is entirely determinate in the sense that for every interrogative there is a possible answer. It is not important whether or not we can epistemologically gain access to that answer but rather the brute fact that the object has a complete ontological nature. For example, a mineral that we hold in our hand was formed somewhere. It

[10] Verstegen (2019).

[11] Hatfield (2004).

[12] von Wachter (2005).

has features of its composition. Someone may have mined that mineral but the fact is lost to history. No matter, the mineral came from *someplace*. One hundred years ago, we may not have had the means to identify the features of the mineral; today we may. But at both times those features were a part of that mineral.

It can be argued that something like "science" is a basic feature of human existence because humans have to infer, even in small-scale societies, to the causes of events in the natural world. People reflect and take into account perceptual effects wrought by distance, the intervening medium of water, and so on, arriving at lore regarding the mediation of the environment. Many societies do not develop organized scientific activities, but their own life cannot go contrary to the properties of objects. For example, no set of beliefs can make water into something that "cannot drown us."[13]

When, however, organized science develops, its characterizations of the world seek to capture in an artificial medium of words and pictures the underlying determinacies of the world, including its powers and proclivities. A model is indeterminate until confirmed, and then we say that the artificiality of the model now reflects something objective about the world. It turns out to be true. The changing or "transitive" element of science is this artificial part, bound by indeterminacy.

Scientific theories and models have something in common with works of art in that they are created by people and are existentially dependent on them for their existence. But there is another feature of the world that is radically indeterminate, and that is the future.[14] There are elements of matter, physics, chemistry that are determinate but not yet known. But there is nothing determinate about the future, because it has not come into actuality yet and its contours remain mere empirical possibilities.[15] When it does come into being, its objects will be fully autonomous. Before it does, it is ontologically heteronomous.

Following Ingarden, we can actually define the artistic as another kind of anomalous or heteronomous ontological object with indeterminacy. It is not the kind having to do with empirical possibility like the future but instead radical non-actuality because its creations by definition *cannot come to pass or be actualized*. In regard to indeterminacy, the future is *not yet* actualized; art is *never* actualized.

The arts, according to Ingarden, are indeterminate in two ways. In the first case, the act of consciousness that forms the work of art has no reference to an autonomous object. In the second case, the strata of aspects that create and name heteronomous (fictional) objects are incomplete, possessing "spots of indeterminacy" (*unbestimmtheitsstellen*). When an invented individual is described in a work of fiction, unlike a real individual for whom each and every aspect of his being has determinate features (hair color, height, weight, a father's name, etc.), it only has determinateness that has been described by the author. We only can state that a fictional character has a spouse, nationality, if the author found it important to do so.

[13]Brereton (2005).

[14]Johansson (2009).

[15]Ingarden (1964).

An artist or author can imagine a world completely without reference to the real world (and its determinacies). But more often they use elements of the world as basic props around which their agents act, such as Dickens' invented characters in real London. For example, a work of fiction can be set in a locale with a particular political context. What is determinate is the geography of the city, and the political realities that constrain and enable action in that society. Upon that bases however we can begin asking the question: what do we do?

The utopian element of art regards what we can call object indeterminacy. For the artist or writer has the ability to stress what exists and what does not exist, to stress different styles of completeness and incompleteness regarding what is interesting to her. The utopian element of science relates instead to theory indeterminacy. The scientist wonders what fuller picture of the world lies beyond observation and hypothesizes it. The answer is tied to what the scientist thinks the future will hold in regard to the use of those eventual findings, just as the artist's world is tied to dis/utopian imagined possibilities.

The Style of Science

As Arnheim writes, "the scientist, like the artist, interprets the world around him and within him by making images."[16] These are hypotheses and theories, as translated by perceptual models, analogies and metaphors. In order to join the disparate data and observations a sensuous, intuitive image or model is necessary to construe the underlying facts and mechanisms.

Arnheim was quite willing to suggest that in very broad strokes cosmologies follow the human mind in conceiving of simple elementary forms that are increasingly differentiated by thought and observation. This might suggest that Arnheim felt that art and science were essentially alike. Of course, this theoretical commitment was commonly selected in the twentieth century. Thomas Kuhn in *The Structure of Scientific Revolutions* argued that the criteria for theory change were in many cases *aesthetic*.[17] More radically, Paul Feyerabend wished to extend ideas of style and *zeitgeist* from art history to science itself.[18] Arguing in this way, scientific theories would amount to creating non-objects as we just defined for the arts, a radical solution indeed.

Less radical is to affirm the underdetermination of theory by evidence, when the model stands pars pro toto for the mechanism it seeks to explain. Duhem and Quine argued that because of this dilemma in many cases it was impossible not only to make

[16] Arnheim (1969a), p. 274.
[17] Kuhn (1970).
[18] Feyerabend (1983), pp. 16–46.

affirmative judgments in science (Duhem) but all knowledge generally (Quine).[19] In this case, the determinacies dictated by observation have a number of apparent spots of indeterminacy that are impossible to fill at the time and therefore leave space for varying interpretations. However, the inability to supply a determinate solution does not mean that the underlying structure is not determinate. It is determinate but unknown, so it is the *model* that lacks determinacy. An analogy would be a photograph (unlike a painting), which has been poorly shot. The subject of the photograph existed at its creation but we have no way to link the signs in the imperfect photograph to the determinate individual that was its putative subject.

This is also Arnheim's argument because he argues that models are limited because they are "only simplified approximations of the actual state of affairs in the physical world."[20] Both art and science seek to convey perceptual forces but the scientist will be seeking to reflecting those uncovered by theory and the model can never be mistaken for reality. Conversely, for art the model *is* the reality.

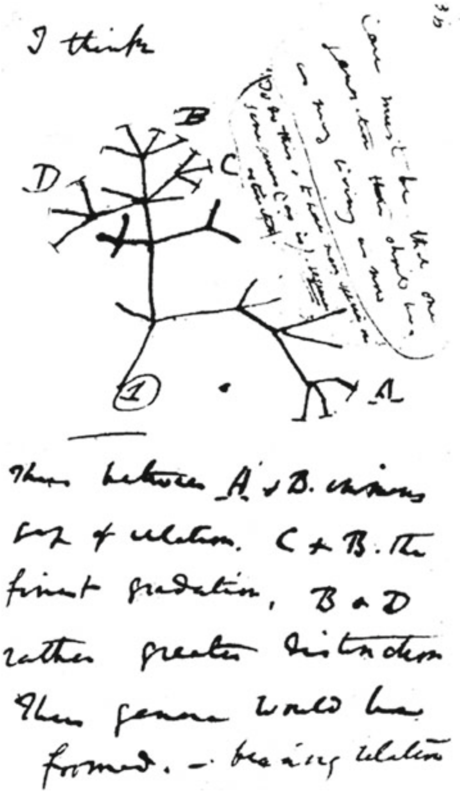
Therefore, the role of investigation ought to clarify the difference between the creative models and scientists and those of artists. The more we learn about a fictional universe ought not change it. Only the author can introduce these spots of determinacy. Even if we read an author's notes and get a sense of the significance of certain details that inspired her in creating that fictional universe does not really change that universe. In science, however, the model can lose its creative function once it is found to be empirically described or overwhelmingly confirmed due to experimental control. What was creative, analogical, ideal disappears. It remains a poetic mnemonic. What were indeterminate holes in the model (not reality) are filled up and one is then able to match, point to point, the models determinacy and that of the world.

Another way to put this would be to say that with the model, the statements that we make in regard to its predications are true judgments, that is, they can be either true or false. This is not possible in any simple sense, as explained below, in regard to judgments made about fictional worlds.

When Arnheim investigated the creation of Picasso's *Guernica*, he followed the artist's exploration of symbols and figures—like the bull—that could communicate his idea, which was the final reality.[21] Something different happens, however, when investigating the psychology of scientific inference. For example, in discovering the nature of natural selection, Charles Darwin used the metaphor of a "tree of nature." He was seeking to explain the way in which blind natural selection favored the survival of some species and not others, which became extinct. For that biological reality, he needed to indicate how a primitive species gives rise to later species, which might persist today, whereas others could lead to a dead end.

[19] Duhem (1991), Quine (1961).
[20] Arnheim (1969a), p. 282.
[21] Arnheim (1969b).

In the early sketch in his notebook, he indeed draws a tree, but it is irregular.[22] It radiates outward, rather than perfectly upward:



Charles Darwin, Notebook B, 1838

Darwin begins his page with "I think," and improvises a series of species marked with letters, which he seeks to relate spatially in regard to survivorship and extinction.

For German art historian Horst Bredekamp, the coral is a better model than the tree because it captures the role of past species in the dead parts of the coral (as opposed to the living tree) and branches outward (in Deleuze's parlance, "rhizomatically") rather than upward, thereby evading the unfortunate teleology suggested by the upright tree. Bredekamp goes further to argue that one of Darwin's early sketches was actually based on a specimen of algae (which he thought to be coral) he himself collected on his travels.

What is more interesting for this discussion is Bredekamp's suggestion that "Darwin formulated his theory of evolution not as a description of nature, but as the

[22] Gruber (1974).

commentary of a diagram."[23] One senses the ghosts of Duhem, Quine and Kuhn here, because the model of the coral is not a transparent means toward an ulterior reality but is chained to the explanation itself.

Howard Gruber had earlier noted a number of models used by Darwin to circle around the phenomenon of natural selection—among them the "tree, tangled bank, wedging, war and artificial selection"—each imperfect or incomplete in its own way.[24] We can see that Darwin's "tree," is already not a tree but an "image of wide scope," intended to capture the general dynamics in a merely tree-like form. In this sense, it is incorrect to afford the model-tree the determinacy of a real tree, including its attribute like perfect uprightness, etc.

Darwin's tree of nature then is a generic image that captures a number of features that approximates as a sensuous surrogate for the reality of natural selection he was seeking to explain. The artistic or stylistic element of science, then, exists as a provisional element in the service of a deeper truth about reality. The scientist's theorizing refers "out there" (or maybe "in there") somewhere, in the structure of the world, whereas the object of expression is in the artist's head.

The Truth of Fiction

Aristotle is well-known to have put poetry above history: "the one relates actual events, the other the kinds of things that might occur. Consequently, poetry is more philosophical and more elevated than history" (*Poetics*, 9, IX, p. 59).[25] For Aristotle, poetry relates to the universal and not the particular. In other words, poetry can connect to higher truths of humanity. Arnheim's and Ingarden's theories show how to bear this out.

While Ingarden has sketched the most profound way in which the pluralism of metaphysics is a feature of humanism, his technical theory of the work of literature allows further clarifications. When a character in a fictional novel utters a statement, it can be called a *quasi-judgment* (*quasi-Urteil*). When Arthur Conan Doyle writes that Sherlock Holmes lit a cigarette, we treat it "as if' it is a judgment with a truth value, yet it has none. It constructs the world of Arthur Conan Doyle but does not pass judgment on it.

For Ingarden, there is a pretty safe distance between reality and fiction. But there is another kind of judgment, the "apparent judgment," which is true relative to the fictional world that has been created by an author. In this case it is not the author making a quasi-judgment about a character but rather the character himself—Sherlock Holmes—making a judgment. Ingarden perfectly well knows that these exist

[23] Bredekamp (2005); quoted in Rampley (2012).

[24] Gruber (1981).

[25] Halliwell (1995).

but he is not clear about a similar kind of judgment that is more “poetic,” in which people judge the fictional world itself. They are not occupied with building it up as a quasi-judgment but rather judging it as already formed.

Josef Seifert and Barry Smith have explored this class of “poetic judgments of the narrator or author which judge about the constituted world as if it were real.”[26] They reflect bona fide judgments and therefore make truth claims. In the most important cases, the author makes statements that are somehow transcendent to the action of the novel. Ingarden, however, wants to argue that the author, insofar as she appears in the fictional work, loses her purchase on reality. According to Seifert and Smith, in ignoring this possibility, Ingarden loses sight of a potential source of the deep moral significance of fiction, its poetic truth.

In the first case, authors can describe fictional characters in a way that rings true for a certain type. The author may also characterize a time or place that is very apt. The examples suggested by Seifert and Smith are Manzoni’s insights on contemporary Italian society in *I promessi sposi*.[27] An example of the previous phenomenon is Manzoni’s account of divulging secrets in Chap. 11, which rings true of human nature in general. Similarly, one can find deep reflections on contemporary Soviet life in Solzhenitsyn’s *Gulag Archipelago*.[28] In both cases, the authors express truths about historical situations. The apparent judgments made by authors express truths that transcend the indeterminate worlds of their author’s creation.

But the transcendence can also extend further than a historical situation to general states of affair in human life. These poetic truths are quite general and reveal the nature of reality itself. Examples mentioned by Seifert and Smith include ideas of mercy and justice in Shakespeare’s *The Merchant of Venice*, communicated through Porta, or in *Measure for Measure*, with Isabel. Obviously, what is significant is that artists undertake such works in the first place, and construct their series of apparent judgments, to plumb these values of the nature of human nature. They seek to address these truths in the first place by creating these works. These truths are inaccessible with different cognitive instruments. As Aristotle wrote, merely recounting history reveals the particular but if the writer wishes to address what “might occur,” she must turn to “poetry,” i.e., fiction.

Ontologically, poetry trades in determinacies related to real individuals (history) in favor of generic determinacies that are not relevant to the fictional world itself (allowing only quasi-judgments about their quasi-truth or falseness) but rather to the world in general, our generic understanding and truths about the way of the world, human nature, how we achieve wisdom. Therefore, the indeterminacies align in some way with the those of the real world in a significant way, and we discover in the fiction something profound about nature in general. The poet is not shying away from reality but capturing—by moving beyond the concrete individual—something

[26]Seifert and Smith (1994).

[27]Manzoni (1842).

[28]Solzhenitsyn (1973).

true in a deeper way. Hence, there is the frequent observation that novelists are keen observers of psychological reality and personality.[29] But they could also—in the manner of Robert Musil—intuit deep truths about causation and the physical world.

To repeat, in such cases we would no longer be dealing with quasi-judgments because those that we make could have full truth-claims. In other words, those truth-claims would have truth-makers, or regions of the world corresponding to the claim or able to serve as evidence to support their truth. These regions would be heterogeneous because among the generally fictional structure of the literary (or simply artistic) work, there would still be patterns of indeterminacy that somehow add up in their correspondence to the judgmental claims made on their behalf.

For specific ontological reasons, Arnheim (and Ingarden too) would argue that pictures have different kinds of truth claims that they can make than the sequential arts: poetry, music and pantomime. An example from his writing on film, then, suggests what Arnheim thought about deeper truths that might be achieved. Describing Chaplin's signature tramp character, Arnheim writes that:

> He is a poor man, not conscious and certainly not proud of his state, pathetically eager to imitate the smart elegance of the rich that he admires as his superiors. His vain attempts to pass for a dandy, with a swagger cane and a fop's moustache – the sharp contrast between a vain intention and a miserable effect – this is the essence of Chaplin's comedy.[30]

While Chaplin's character was created for entertainment, it remains popular because each one of us recognizes something of our own vanity in the tramp, at the same time that it is grotesquely exaggerated beyond everyday reality.

Manzoni's more general observations, those which go beyond the sketching of his fictional world and cast of characters, elliptically reach out into the real world. The parallel fictional world that he has created is not then hermetically sealed but asks us to judge its truths both internally (as quasi-judgments) and externally as bona fide judgments of reality. Even so, these judgments are not the primary work of the artist or author, who predominantly creates a work that is ridden with spots of indeterminacy. One could call the reality component of the fictional work the inverse of the stylistic feature of the scientific work.

Conclusion

The preceding essay has sought to investigate the division between art and science using the writings of Rudolf Arnheim. Connecting his observations with Roman Ingarden's paradigm of ontological in/determinacy, I have used the notion of structure to enlighten the fundamental differences between artistic and scientific knowledge. Both works of art and scientific have structure, but their in/determinacies relate to the world in completely different ways.

[29] For example, by Heider (1941).

[30] Arnheim (1940).

As I summarized, epistemic items of science can *become determinate*. In art they can *never* be determinate. In science, the model *stands for* (a region of) reality. In art the model *is* the reality. Science tracks reality, incompletely and imperfectly, but the underlying forces and structures of the natural and biological worlds are ultimately mirrored by theories. A highly successful theory, with its models and analogies, becomes transparent to reality; the predictions of the theory reflect the determinacies of the world.

If, by its definition, art lacks full determinacy, nevertheless the stratum of objects that it projects by pinpointing various determinate elements (relative to its fictional world) does have determinacies. Even so, truths about those element are only true relative to its world, not the determinacies of the world. But this is the virtue of the arts because what is presented is its world, completely, without ulterior reference.

The borderland between art and science is the most interesting because there *is* indeterminacy in models while there is *determinacy*, artistic "truth," in the arts. There is a sense in which the scientist like Charles Darwin must allow his imagination to play freely, so that he may arrive upon the intuitive image that can fire his continued investigations. Similarly, amidst a fictional activity, the writer like Manzoni may arrive upon observations that conform in some significant way with the world—that of the mind, social or physical reality.

One thing that both art and science share that has only been hinted at is a utopian/dystopian potential, relating to the indeterminacy of the future. This function is most clear-cut in the arts. The arts often envision an alternative, counterfactual reality, one which is deemed better than the present one, or which erases its flaws. Or conversely they envision a terrible end, serving as a warning for our actions in the present. With spots of indeterminacy the author can create a particular brand of reality and in a non-trivial sense that world, in its visionary guise, seeks to change the indeterminate future toward (or avoid) a new determinate reality.

The literary theorist Wolfgang Iser, a close reader of Arnheim and Ingarden, very nicely captures the way in which fictions stake out a relationship to the possible:

> The semblance, however, gives vivid presence to intangible states of affairs so that they may penetrate into the conscious mind as if they were an object of perception. What can never become present, and what eludes cognition and knowledge and is beyond experience, can enter consciousness only through feigned representation, for consciousness has no barrier - as Freud has remarked - against the perceptible and no defense against the imaginable. Consequently, ideas can be brought forth in consciousness from an as yet unknown state of affairs, indicating that the presence of the latter does not depend on any preceding experience.[31]

Another way to put it is that it is only by creating alternate images of reality that people can *recognize* those alternatives, or work toward them as meaningful ends.

The scientist knows that her investigations do not change the world. But often scientists hope that a particular line of experimentation will confirm the image of humanity that they believe their investigations have supported to that point. Such question are related to the question of: What kind of science do we want? Where do

[31] Iser (1993).

we want to put our scientific resources? What kind of world can we bring into existence (or destroy) by our human (technological) actions today? More philosophically, the most evident way that scientists have reflected on the question of the future is regarding whether we have freedom of our wills and actions. In sum, the sciences have "artistic" elements related to their *visions of the future*—as when Einstein counsels us that "you cannot simultaneously prevent and prepare for war."[32] Hence, despite their differences art and science are reunited once again by their orientation to the future and the possible.

To conclude, while Arnheim articulates essential similarities in the aims of art and science to portray forces and to construct their messages through structure, he also wishes to maintain their differences. Science cannot be collapsed into art, and art cannot be collapsed into science. Rather they will continue on a parallel track, science aware of its own stylistic foibles, and art sensing its contact with deep reality.

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Interpreting Scientific Images: Aesthetic Considerations at Work

Otávio Bueno

Introduction

The production of scientific images is a significant feature of scientific practice. Images from various kinds of electron microscopes (such as transmission electron microscopes and scanning electron microscopes), probe microscopes (scanning tunneling microscopes and atomic force microscopes), or functional magnetic resonance imaging instruments constitute an important source of visual evidence in the sciences. But it is not always straightforward to determine exactly what these images convey, and suitable interpretations of the relevant images need to be provided.

In many instances, however, it is no easy task to develop proper interpretations of these images. In these cases, it is a delicate process to make sense of them: What exactly do they state about the world? How could the world be if these images represented accurately the way things are? How can these images be misleading? Can they potentially confound features that should be separated, or suggest contrasts that are not appropriate? How accurate are they?

The history of art offers one of the richest sources of approaches, techniques, convention codes, and ideas involved in the interpretation of images. In this paper, I argue that attention to these elements can be useful to the interpretation of scientific images, particularly given the role of convention codes in their interpretation. Interestingly, this also suggests a way in which scientific images can be illuminating to art, especially regarding the cognitive role that art can play in scientific imaging. In the end, the close connection between aesthetic and cognitive considerations in the constitution and interpretations of scientific images is emphasized.

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Images: Content and Phenomenology

Scientific images are diverse and multifarious. Diagrams and micrographs are very different in their mode of presentation and in the roles that they play in scientific practice. In order to evaluate such images, it is important first to be clear about their content so that the kind of image and their central function is determined. I should emphasize that the considerations below are by no means exhaustive, but they provide a context in which the assessment of scientific images can be performed.

Images are distinctive given the mode of presentation they provide: they offer, as Noel Carroll highlights, a *detached display* (Carroll 2008, pp. 56–58). When we see a mountain, we are spatially connected to it and can position our bodies in the direction of the mountain. It is part of the experience of seeing such an object that we can direct our bodies toward it: the mountain is in our vicinity. Even though it may not be close by, it needs to be close enough for us to be able to see it. In contrast, when we see an image, no intrinsic information in the image allows us to position ourselves relative to the object displayed in it. When we see a photograph of Mount Everest, we cannot direct ourselves toward the mountain just by considering the photograph. In order to do that, we need additional, extrinsic information about the environment, which is not given only by the image in question (Carroll 2008, pp. 56–58). In this respect, images are *detached* from the viewers, in the sense that the objects displayed on them are phenomenologically separated from the viewers.

Images also convey information about the objects by displaying visually salient features of these objects. Hence, they are *displays*, and thus, contrast with other modes of presentation of information that are *not* visual in nature, such as linguistic or sonic representations. A cat can be displayed in a drawing or in a photograph, but not in a linguistic description. A cat cannot be seen in such a description, since no visually salient features of the cat are manifest or shown in it. A cat can be imagined on the basis of such a description, but to imagine a cat is very different from seeing one, given that, in contrast with sight, imagination is not causally depend on the objects that are imagined. One can imagine a cat flying unaided across the Atlantic, even though this is not physically possible.

As these considerations suggest, images can be thought of as *detached displays* (Carroll 2008, pp. 56–58), and this specifies their mode of presentation: they offer visually salient features of objects that are spatially disconnected (detached) from the viewers.

In addition to a mode of presentation, images also have *content* and a particular *phenomenology*. An image's content is the information it provides about the world. A photograph of Yosemite Valley gives information about how the valley looks: this is its content. The photograph yields a particular phenomenology: what Yosemite Valley was like when the picture was taken. In the case of images, content and phenomenology typically go hand in hand. The content of an image is accessible because seeing the image yields a particular phenomenology in viewers; it is through the phenomenology that one can have access to the content of the image. In this way, what links the content of an image and its phenomenology is experience: *seeing* the image is the only way of having access to its content.

A description of an image, no matter how detailed it is, does not convey the image's phenomenology, and, thus, does not present its content. After all, a description provides verbal information about the content of the image, and that information is generic with regard to the visually salient features the image presents (see Lopes 1996; Hopkins 1998). For instance, the description "The cat is on the mat" is generic in the sense that it does not specify anything about the cat (its color, kind, posture, or position) or the mat (its shape, size, location, or the material it is composed of). In contrast, since they are visual in nature, images need to specify each of these features in some detail: otherwise, it would not be possible for viewers to recognize the objects (or the kind of objects) that are displayed in the images. One can represent the Empire State Building as a dot on a page, but that is not an image of the building, given that none of its visually distinctive traits are made salient by the dot. Images are, thus, a very special kind of representation, whose content is displayed and made manifest visually. Since descriptions are ultimately unable to disclose the phenomenology of experiencing the image, they fail to transmit the relevant content.

Both scientific images and images in art have content and a distinctive phenomenology. These two features are closely tied to the way particular images are constructed or obtained. A painting of a room in a seventeenth-century Spanish palace presents visually salient features of the palace's room as part of its content. This generates, in turn, given the way the room was painted, a distinctive phenomenology, which allows viewers to access the image's content.

Consider, for instance, some of the choices made by Diego Velázquez when painting *Las Meninas*: in particular, the self-portrait he included in the painting; the representation of the royal couple as a reflection on a mirror at the back of the room; the series of paintings that dominate the background of the scene. These choices involved aesthetic options on the artist's part: the framing of the scene, the position of Velazquez's self-portrait in the painting, the texture of the reflected image on the mirror. Corresponding to each of these traits, there is a distinctive phenomenology. There is something that is like to see, on the surface of the painting, the particular texture of the reflection on the mirror that is portrayed, in the image, as being at the back of room. The content of this portion of the painting, similar to other portions of it, is given through the corresponding phenomenology. It is by experiencing the objects depicted on the surface of the image that one has access to the image's content.

The same goes for scientific images: their content is also given by the image's phenomenology. A crucial difference between scientific and fine art images is that for those images that can be used as a source of evidence, they are obtained as a result of a particular interaction between the sample under study and the relevant scientific instrument that was used (such as various kinds of microscopes, including electron microscopes, scanning tunneling microscopes, or atomic force microscopes). In this sense, the images are causally produced as the result of the interaction between the sample and the scientific instrument. Hence, scientific images provide a record of the interaction: a particular measurement that makes manifest salient traits of the sample (those that the relevant instruments were designed to track and highlight).

By seeing the surface of the resulting scientific image, researchers can then identify those features of the sample that the images made manifest. By experiencing these images, one can access traits of the sample that one would otherwise be unable to access. The phenomenology of experiencing these images give researchers access to these images' content, highlighting what the images display about the sample. When the word 'IBM' was written at the nanoscale (that is, 10^{-7} to 10^{-9} m scale) using a scanning tunneling microscope (Eigler and Schweizer 1990), it was the particular position of xenon atoms that researchers could see in the resulting atomic force micrograph. It was eventually through the phenomenology of the relevant image that access to the content of the sample was made possible. (I will return to this example in more detail below.)

Hence, content and phenomenology are crucial for both scientific and fine arts' images. A key difference, in certain cases, is that scientific images, in contrast with those in fine arts, are generated in order to provide evidence regarding the sample under study. However, as will become clear shortly, some images in fine arts, such as photographs and moving pictures, can be similarly produced (although they typically are used beyond such evidential contexts). It is important to examine more closely the relations between such images.

Transparency and Counterfactual Dependence

What is distinctive about certain scientific images, such as those generated by microscopes and telescopes, and some mechanically generated images in the arts, such as photographs and motion pictures, is the particular kind of dependence that is established between the sample under study or the scene under consideration and the corresponding images. The dependence is counterfactual in the sense that had certain features of the scene before one's eyes been different, the resulting perceptual experiences would have been correspondingly different. (I will elaborate on this point in more detail below.) If a mechanical shark were not in front of the camera when *Jaws* was being filmed, there would not be a (mechanical) shark on the surface of the resulting image. The image is counterfactually dependent on the scene before the camera.

An image is transparent in the sense that, by seeing the image, for instance, a still picture of *Jaws* in which the (mechanical) shark is shown, one sees the relevant object (for discussion, see Walton 2008; Lopes 2003). I do not think that one literally sees a (mechanical) shark when one looks at the relevant still picture. Rather, one sees an *image* of a (mechanical) shark, which is, of course, something quite different from a shark. However, given the counterfactual dependence between the (mechanical) shark and the still image of it (the visually salient features of the shark are preserved in the still picture), I will keep using the expression 'transparent' when referring to images that are counterfactually dependent in the relevant sense, with the understanding that no assumption is being made about seeing the objects in question, but only seeing images of them. Of course, one can see a (mechanical) shark *in* a (suitable) still picture, but this is also different from seeing a shark, given that it involves interpreting the image *as* an image of a (mechanical) shark, independently of actually seeing the shark. For my purposes, what matters for transparency is just the counterfactual dependence relation between the scene before the camera (or the relevant scientific instrument) and the corresponding image.

If we consider that transparency is a crucial feature of photography, the outputs of certain scientific instruments are similarly transparent. Images of bacteria that are obtained by using transmission electron microscopes provide access to visually salient features of these microorganisms. One can have a sense of how they look by examining the surface of the relevant images.

But this is not the case for every scientific instrument. Several such instruments fail to produce transparent results. This need not to a problem for these instruments as long as their outputs do not depend on the way the objects under study look. But if the point of using these instruments is to indicate the look of the objects under study, transparency becomes crucial. For example, optical and electron microscopes typically provide transparent images, within the limits of the particular instruments and the methods of preparation under use. These methods often transform the objects in the sample, for instance, via staining, drying, and slicing. All of these features may change the way the objects in the sample look. However, the instruments do capture accurately the appearance of the objects, perhaps transformed by the relevant methods of preparation.

Some scientific instruments, however, do not provide transparent images: the way an object in the sample look is not a relevant parameter to be captured. Images generated by functional magnetic resonance imaging (fMRI) techniques provide a clear illustration. Certain patterns of brain activity are represented by fMRI images, but these images do not offer a guide for the way the relevant activity *looks*. In fact, it is not even clear that to consider such looks makes much sense. Researchers are primarily interested in the location of the brain activity rather than in the representation of visually salient features of the activity itself.

Other instruments, however, produce importantly transparent images, since these instruments have been designed to detect visually noticeable attributes of the objects under study. A micrograph generated by a transmission electron microscope illustrates this situation. The image is created in order to enhance and reproduce visually salient features of the sample—after the latter is suitably prepared so that a beam of electrons can pass through it. Part of the preparation techniques involves careful slicing of the sample. So, what is found on the surface of the image is a reproduction of those features in the sample with which the instruments interact—suitably prepared. (The images do not provide exact information about the way the objects in the sample actually look like in vivo, although one can *infer* some of the features that may be expected in the latter from the images produced by the electron microscope.) Transparency is satisfied, and it has to be satisfied in order for the image to have the epistemic status it has, namely, as evidence for what is going on in the sample—even if only in vitro.

Transparency is needed as a condition for the proper access, detection, and augmentation of the visually salient features of the sample. It may be complained that talk of "visual salience" in this context is misleading. Given that we are dealing with objects that are significant smaller than the wavelength of visible light (which range roughly from 390 to 750 nm), no one can literally *see*, without the use of suitable instruments, several of the objects that are studied at the relevant scale, such as ribosomes (which range around 20 nm for prokaryotic ribosomes or from 25 to 30 nm for eukaryotic ribosomes). In what sense can we speak of visually salient features of objects that cannot be observed with the naked eye (see van Fraassen 1980)?

Here is a way of making sense of this situation. Observation provides a form of access to objects that satisfies the following two counterfactual dependence conditions (condition (c_1) comes from Lewis 1980; condition (c_2) needs to be added given that counterfactual conditionals cannot generally be contraposed; see also Bueno (2011, 2018):

(c_1) Had the scene before one's eyes been different (within the eyes' sensitivity range), the visual experience would have been correspondingly different.
(c_2) Had the scene before one's eyes been the same (within the eyes' sensitivity range), the visual experience would have been correspondingly the same.

These two conditions ensure that observation is sensitive to changes in the environment around the observer, and as I argue shortly, there is a straightforward extension of this account that includes observation mediated by instruments.

Visual experiences involve sensations (non-intentional sensory information), intentional features and, in some cases, conceptual components. It is important to distinguish simply seeing an object (which requires sensations and intentional traits) from seeing that the object is thus and so (which demands concepts). The former is a simple (non-epistemic) form of seeing, whereas the latter is conceptual in nature. I can see an okapi without realizing that it is an okapi that I see. This would be the case if, for example, I do not have the concept of *okapi*, but there is an okapi in front of me and I see it. (Fred Dretske has presented and defended this distinction on a number of occasions; see, for instance, Dretske 2000). Moreover, certain features of the visual experience remain invariant as the observer moves in the environment. Although the observer has different sensations, certain features of the visual experience remain the same (Smith 2002). As I move around my desk, the sensations I have, the contents that occupy my visual field, change. But the length of the table, its size, and its shape remain invariant. In fact, it is due to this invariance that I am able to recognize the table: if the table's size, shape, and length changed as I moved around it, I would no longer be able to determine whether it is the same table that I was seeing. I would, most likely, not even suppose that it was a table! We rely on these regularities so that we can be in a position to perceive the world around us.

For the same reason, we also rely on the counterfactual dependence conditions, which are here understood as changes in the actual world rather than in some other possible worlds. Suppose there was no table in front of me. The scene before my eyes would then be different. It would also be different if there were a table of a different size or shape than the one that was in front of me some time ago. Given the counterfactual dependence conditions, the changes in the scene before me yield correspondingly different visual experiences. I would conclude that the table was no longer in front of me or that another table replaced it.

Observation has three significant epistemic properties (Azzouni 2004). It gives us access to objects that is *independent* of our beliefs—at least in the case of simple (non-conceptual) seeing. Observation provides access to objects that is *robust*: we blink, we move away and the objects are still there. Finally, observation allows us to *track* the objects around us in space and time.

Each of these properties of observation emerges from the counterfactual dependence conditions (see Bueno 2018). With regard to independence, when I open my eyes, what I experience does not depend on me. Assuming that my eyes are working properly, the experiences I have depend on what is there in front of me. Had there been different objects before me, I would have had correspondingly different experiences. Similarly, regarding robustness, if nothing changes in the scene before my eyes, my visual experiences will remain the same. The robustness of my access to the world then emerges, since it is not up to me what I will then see. Finally, with regard to tracking, the reason why I am able to track objects in space and time is because any changes in these objects (that take place within my eyes' sensitivity range) produce corresponding changes in my visual experiences. I am then able to track the objects, spatially and temporally, through these changes.

In the same way as observation, good scientific instruments also satisfy suitably reformulated versions of the counterfactual dependence conditions, which can be formulated as follows (see Bueno 2011, 2016, 2018):

($c_1{}'$) Had the sample been different (within the instrument's sensitivity range), the image produced would have been correspondingly different.
($c_2{}'$) Had the sample been the same (within the instrument's sensitivity range), the image produced would have been correspondingly the same.

And just like observation, the counterfactual dependence conditions for instruments also ensure that the access to the sample provided by the instruments in question (a) is *independent* of the researchers' beliefs, (b) is *robust*, and (c) allows researches to *track* in space and time the objects in the sample. Just like what happens with observation, for each of these three properties, if a scientific instrument satisfies the counterfactual dependence conditions, that is, ($c_1{}'$) and ($c_2{}'$) above, then it will also satisfy the three epistemic properties (independence, robustness, and tracking). It is in virtue of these properties that observation, including observation aided by certain scientific instruments, provide a special sort of access to the world.

Several scientific instruments satisfy the counterfactual conditions ($c_1{}'$) and ($c_2{}'$) as well as the three resulting epistemic properties. Optical and electron microscopes provide clear examples. In the case of these instruments, there are also *good grounds* to the effect that the conditions in question are indeed satisfied: by changing the inputs of the instruments, one changes their outputs accordingly (Bueno 2011, 2016). The result is an important form of transparency: the instruments provide information about visually salient features of the sample. After all, the instruments are not only sensitive to variations in the sample, but they also enhance and reproduce visual information about the latter, given the way in which the images are produced.

In other words, observation has the same epistemic properties than the experiences yielded by certain microscopes (such as electron microscopes) with the access they provide to what is only observed via the mediation of instruments. As a result, it makes perfectly good sense to extend the status of observation to those scientific instruments for which not only the counterfactual dependence conditions are satisfied, but also for which there are good grounds to the effect that they are indeed satisfied.

Transparency emerges in the case of suitable scientific-imaging instruments in virtue of the contribution of two components: (i) the counterfactual dependence between the sample under study and the images produced by the instrument, which ensures that the resulting images are sensitive to appropriate changes in the sample, and (ii) the particular mechanism of image generation that constitutes the instrument, and which preserves and enhances visually salient features of the sample and transfers them to the image.

Untouched photographs satisfy both of these components. They are, after all, images that are sensitive to visually salient features in the environment, and are produced as the result of an interaction with the latter (within the sensitivity range of visible light). It is in virtue of these components that (untouched) photographs can be used as visual evidence that something is so and so. It is for the same reason that certain micrographs (outputs of certain kinds of microscopes) similarly provide visual evidence, even of objects that cannot be seen with one's naked eyes alone. Both photographs and certain micrographs, being the outcome of something that satisfies the appropriate counterfactual dependence conditions, share what can be called the *witness principle*: these images are *witness* to certain traits in the environment that produced them, namely, the visually salient features in the scene before the camera or the sample inserted into the microscope. Both express a form of empiricism about these traits (the empiricist is typically realist about the observable; see van Fraassen 1980; Bueno 2018).

In order for photographs to be counterfactually dependent on the scenes before them, image manipulations that violate the counterfactual dependence conditions cannot be allowed. As a result, digital manipulations of photographs that break the counterfactual dependence conditions produce outputs that no longer can be considered photographs.

The transparency of both photographs and micrographs is a crucial component that allows one to extract visually salient information from the resulting images about either the scene before the camera or the sample under the microscope. As will become clear, aesthetic considerations are crucial in this context.

It might be argued that the transparency of both photographs and micrographs undermines the possibility that aesthetic considerations can play any role at all. With transparency in place, it becomes difficult to focus on the images as objects of aesthetic consideration. The difficulty is that the transparency of the images takes the viewer to the objects the images represent rather than to the properties of the image's surface (for a critical discussion of this point, see Carroll 2008, Chap. 1).

But this consideration is not very persuasive (as Carroll 2008 also emphasizes). Despite the transparency of the images, the viewer can certainly focus on the latter's aesthetic properties. Nothing precludes the viewer from considering certain traits on the image's surface: the way in which it is framed, whether it includes unexpected colors, a special light source, or is taken from an unusual point of view. These are just obvious instances of aesthetic considerations that can be attended to despite the transparency of the images in question.

In fact, photographs, understood as satisfying the counterfactual dependence or transparency conditions, are assessed in part by the way in which they present the objects: they provide a record of the objects as they were located in front of the camera. The challenge is to capture such objects in the fleeting moment in which some of their visually salient features can be highlighted, often allowing viewers to see something that would otherwise be missed with their unaided eyes.

It turns out that aesthetic considerations are also crucial in the interpretation of scientific images. I will now turn to this topic.

Aesthetic Considerations in Scientific Imaging

Once transparency is in place, aesthetic considerations become crucial for scientific imaging. With the transparency requirement, scientific images provide a particular sort of information about the objects under examination, namely, information regarding visually salient features of the sample under study. This information is made manifest by invoking aesthetic considerations. Depending on the way in which scientific images are constructed and obtained, aesthetic considerations will figure differently.

For instance, suppose that the relevant image is constructed to convey information about the position of certain objects in the sample. That information can be made more salient by differentiating more clearly the objects that are represented on the surface of the image and those in the background. It may well be that by making such a change the resulting image will be altered in an important respect. However, without this change, the central point of the image—the particular kind of information it aims to convey—may be entirely lost. In this case, modifying the image accordingly seems to be justified.

In other cases, certain diagrammatic elements are added to the images in order to highlight certain traits that may not be as salient. Such elements may emphasize, for instance, certain symmetries in the sample that would otherwise not be as noticeable.

More generally, what roles do aesthetic considerations play in the construction of scientific images? (a) Aesthetic considerations can increase the informational content of a scientific image by strengthening relevant features in the image that need to be made salient, and can be made salient, by exploring aesthetic features in the construction of the image. Choice of contrast, saturation, and exposure can all contribute to enhance the informational content of the image.

(b) Aesthetic considerations can also be central to produce the right image, the image that transparently exhibits the behavior of a selected class of phenomena (see Galison 1997; Frankel 2002). The image should be obtained in such a way that the salient features of the phenomena are made manifest on the surface of the image. Once again, aesthetic considerations are central to the construction of the resulting images. The content of certain images can be refined and made more salient via suitable image adjustment techniques. For instance, by changing the contrast used in certain scientific images, it is possible to produce images whose central point is far clearer than it would otherwise be. Depending on the point of the image, and the instrument that has produced it, the changes can either be such that the increase in contrast yields a worse image (one for which part of the content has been lost), or improves it (its content becomes more salient).

(c) Aesthetic considerations are important in the interpretation of scientific images. Convention codes are crucial to the stabilization and understanding of such images: depending on the codes that are in place, different implications are drawn about the content of the images in question. Consider the first micrographs produced by a scanning tunneling microscope in which black and white colors denote depth. Of course, there are no colors at the nanoscale (a scale that is substantially smaller than that of visible light). So, colors in nanoscale images have their own particular conventional meaning, and in this respect, aesthetic considerations involved in the relevant convention codes are central to stabilize the images (settling on the way such images look) and for their understanding (allowing for adequate interpretations to be articulated in order to avoid potential misunderstanding).

Convention codes play a double role: (i) they are involved in the construction of scientific images, and (ii) they are invoked in the interpretation of such images. With regard to (i), depending on the convention codes that are used, different images are produced. For instance, micrographs produced by electron microscopes are constructed on the assumption that the point of view of the viewer is the same as the one that was used to obtain the micrograph in the first place. It then makes good sense to use the same point of view to interpret the resulting image. Viewers would not make good sense of the micrograph if they adopted a different point of view than the one used in its construction. Mistaken inferences could result in such a case. I may think that there are several mitochondria in the cell I am visualizing using a given micrograph. This is because I see several spots on the micrograph and I take each of them to be a mitochondrion. The convention code invoked at this stage shapes the understanding of the micrograph. Suppose a different convention code is invoked, however. I realize that a mitochondrion may be a long object, shaped as a snake, and the way in which the micrograph was built produces only a slice of a transversal cut of the mitochondrion, which is then shown on the micrograph as certain spots. A clear understanding of the convention codes in the construction of the image is crucial.

With regard to (ii), it becomes clear that the interpretation of a scientific image also relies on convention codes. If these codes are changed, different ways of interpreting the images emerge. The mitochondria example just mentioned clearly illustrates this point too.

The same remark also applies to photography. Typically, convention codes in ordinary photography emerge from the fact that photographs are produced and interpreted as resulting from being taken from the perspective of the camera. Ordinary photography is always taken from a particular point of view, and is therefore interpreted by the viewer as presenting the scene before the camera as it would have been seen by the viewer had he or she been where the camera was when the shot was taken. This positioning of the camera relative to the scene and the positioning of the viewer relative to the surface of the photograph is analogous to the relationship between the positioning of the tip of the microscope relative to the sample under study and the positioning of the researcher relative to the micrograph. In both the case of photographs and micrographs we have a perspectival element: there is a point of view from which such images are produced, and it is on the basis of this point of view that information can be extracted from both types of images. The perspectival element indicates how these images should be interpreted: it provides the point of view that the viewer should use to understand the spatial relations among the objects represented on the surface of these images.

In this way, convention codes constrain the construction and interpretation of photographs. Given the way in which photographs are taken (having the perspective they have), they encode the convention codes that are used to interpret them. And since photographs are taken in a way that preserves the counterfactual conditions between the scene before the camera and the corresponding images, these conditions are also crucially invoked in the construction of the resulting images.

Aesthetic considerations in scientific imaging play a significant role in the production of visually salient information about various subjects of study. Choosing a suitable coloring of certain scientific images, where no colors can literally be found in the subject matter under study (because the objects in question are smaller than the wavelength of visible light), or deleting certain constituents on the surface of certain scientific images, are significant ways of highlighting certain features of the images in question. Aesthetic considerations are here cognitively relevant: in virtue of their use more informative presentations of the relevant scientific images are produced. In fact, without such aesthetic considerations the point of the images (the key piece of information they conveyed) could not be made salient: the images in question would not be as intelligible or their central point would not be conveyed as effectively if aesthetics considerations were not in place.

Consider, for instance, the widely discussed image obtained in 1990 by physicists Donald Eigler and Erhard Schweizer, in which the letters 'IBM' were written with 35 xenon atoms (Eigler and Schweizer 1990). By carefully manipulating and positioning particular atoms with the help of a scanning tunneling microscope, the team of physicists managed to write 'IBM' at the nanoscale, one atom at a time.

An important constraint was involved, however, in the construction of the image. There are several atoms in the background. If all of them are shown on the image, the 35 xenon atoms that are manipulated will not be made salient, and will not be distinguished from all the other atoms in the background. In this case, the image—thought of as an image of 'IBM' composed out of atoms—would not be intelligible. In fact, it would be difficult even to visualize the manipulated xenon atoms and distinguish them from those in the background. The untouched image would only display a bunch of atoms, none of them being salient in any particular way, and the point of the image would be lost. To prevent this outcome, the researchers *deleted* from the surface of the microscopic image all of the representations of the atoms in the background. This is a radical use of a device that is common in photography and film: by changing the focus of the camera, and blurring the background, one makes manifest relevant features on the surface of the image, to which the viewer's attention is driven (it is called *bracketing*; see Carroll 2008, Chap. 5). In the case of the scanning tunneling microscope image, even though importantly manipulated, it is significantly more salient and informative in the way it is presented. Aesthetic considerations are fundamental to the expression of the information conveyed by scientific images.

But this particular sort of image manipulation also comes with a price. Strictly speaking, transparency is violated once the surface of the microscopic image no longer carries the original information about the atoms in the background. In fact, it is not clear that the idea of a *background* can be applied in this context, given that the untouched image displays an array of atoms uniformly distributed on the surface of the sample. (It would be similar to searching for the background in an extreme close-up shot of a brick wall.)

As noted, the capacity of highlighting certain informationally-sensitive aspects of scientific images provides a significant role played by aesthetic considerations in science; but it is not the only role. As discussed above, aesthetic considerations are also involved in the interpretation of the images in question. Depending on the salient features that the images have, they are interpreted in different ways. These salient features emerge, in part, from aesthetic considerations, since these considerations shape the presentation and constitution of the relevant images. This feature emerges from the fact that the interpretation of scientific images is a function of the way in which such images are constructed. And the construction of such images, as noted, is typically guided by convention codes, which highlight the visually salient features of the images in the first place.

Which manipulations of scientific images are acceptable and which are not? Transformations that violate transparency are typically problematic. Adding colors to images can be problematic if the coloring is understood as providing information about how the objects in question look. If the added colors are not misunderstood as representing visually salient information and no risk of misinterpretation of the image is involved, then the additional colors would not be taken to violate the transparency of the image. After all, the colors are then not interpreted as standing for some visually relevant property of the objects studied in the sample.

More generally, image manipulation and aesthetic considerations typically go hand in hand. Which kinds of image manipulation are acceptable depend, in part, on the sorts of aesthetic considerations that inform the construction of the relevant images.

I noted that, in the scanning tunneling micrographs, colors cannot be interpreted via their qualitative character, since there is no color in the scale in which such micrographs are taken. In this case, the contrast between black and white represents how deeply the tip of the microscope moved down on the surface of the sample (which is indicated by a black region on the micrograph), or how high the microscope's tip moved up away from the sample (which is indicated by a white region on the micrograph). As the tip of the scanning-tunneling microscope crosses the surface of the sample, it moves up or down, depending on the topography of the sample's surface. The resulting image (assuming that the term can be used in this case) then reflects the topography of the sample's surface in a way that is analogous to the way in which a blind person forms a sense of the surface of an object by systematically touching it. Colors, in the case of scanning-tunneling micrographs, are convention codes that do not track the same properties that they are normally taken to be tracked in ordinary instances of seeing.

There is, thus, an epistemic role to convention codes in that the choice of these codes indicates the way in which information is presented and conveyed. By highlighting certain features on the surface of images and by making it possible to extract certain bits of information from them, convention codes enhance one's access to the informational content of the images, thus playing a crucial, although not always recognized, role in scientific practice.

Aesthetic Considerations: Photography and Scientific Imaging

In which ways is the aesthetics of photography similar to the aesthetics of scientific imaging? For both photography and scientific images transparency plays a decisive role. Transparency is central to photography given that photographs provide information about visually salient features of the scene before the camera, and transparency entails that these features are properly conveyed in the corresponding photographs. Similarly, scientific images are also transparent given that these images yield information about visually salient features of the sample under study, and transparency is instrumental in yielding the proper outcome.

The aesthetics of photography emerges, in part, from photography's transparent character: a particular photograph may have aesthetic value precisely because of the transparency of the photograph. It is in virtue of transparency that certain photographs have the features they have: they convey information about the visually salient features of the scene before the camera by carefully exploring the way in which such photographs are produced. Aesthetically valuable photographs obtain their value, in part, due to the way in which they were taken. Such photographs register the outcome of the interaction between the scene before the camera and the camera itself in unique, particularly telling, surprising or illuminating ways: they emerged from occasions in which such interaction was explored in a powerful manner.

For instance, certain photographs highlight the sources of light in the scene before the camera thereby enhancing certain features of the objects that are being photographed. Some photographs are particularly informative about the relevant scene due to the way in which transparency was explored. They display the visually salient features of the scene in a unique way: by registering a slice of a particular event and carefully framing it, a photograph can allow viewers to see something that they could not see with their naked eyes (the event in question can be too fleeting or too complex for that).

Similarly, aesthetic considerations in scientific imaging also rely on the transparency of the images in question. Since informativeness plays such a significant role in scientific imaging, it is not surprising that aesthetic considerations emerge from transparency as well. Being the outcome of a particular interaction between a microscope and the sample under study, a micrograph provides information about what was going on in the sample. Displayed on the surface of the micrograph is the output of that interaction, which represents a particular configuration of the sample within the sensitivity range of the microscope. Just like photographs, viewers of a micrograph can see something they are unable to see with their naked eyes. The aesthetic value of scientific images emerges from the exploration of the details involved in the sample, as transparency allows for, by highlighting the cognitive and informational aspects of the relevant process under study.

Conclusion

In this paper, I argued that aesthetic considerations are important both in the construction and in the interpretation of scientific images. At the construction stage, these considerations are involved in certain types of image manipulation, such as change in contrast, brightness, saturation, or color scheme, and they guide, in part, the kinds of image manipulations that are allowed for. This helps, in turn, to improve the intelligibility and effectiveness of scientific images as a vehicle of information about the sample.

At the interpretation stage, convention codes are crucially invoked. After all, similarly to images in the arts, scientific images rely on a certain point of view from which they are supposed to be looked at. Convention codes provide assumptions from which the information about the sample under study can then be extracted. The interpretation of colors, shapes, brightness, and textures in scientific imaging, for instance, emerges from the relevant convention codes.

The result is the close interaction, in scientific image making, of aesthetic and epistemic considerations, in a way that highlights central traits of the construction and interpretation of scientific images.

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Complexity and Chaos Theory in Art

Jay Kappraff

Introduction

Kauffman and Varela propose the following experiment: Sprinkle sand or place a thin layer of glycerine over the surface of a metal plate; draw a violin bow carefully along the plate boundary. The sand particles or glycerine will toss about in a rapid dance, swarming and forming a characteristic pattern on the plate surface. This pattern is at once both form and process: individual grains of sand or swirls of glycerine play continually in and out, while the general shape is maintained dynamically in response to the bowing vibration.

Hans Jenny in his book *Cymatics* (Jenny 1967) has noted from this experiment:

> Since the various aspects of these phenomena are due to vibration, we are confronted with a spectrum which reveals patterned figurate formations at one pole and kinetic-dynamic processes at the other, the whole being generated and sustained by its essential periodicity. These aspects, however, are not separate entities but are derived from the vibrational phenomenon in which they appear in their unitariness.

These are poetic ideas, metaphoric notions, and yet they have reflections in all fields from the wave/particle duality of quantum physics, to oscillations within the nervous system to the oscillations and distinctions that we make at every moment of our lives. Complexity and self-organization emerge from disorder, the result of a simple process. This process also gives rise to exquisite patterns shown in Fig. 1.

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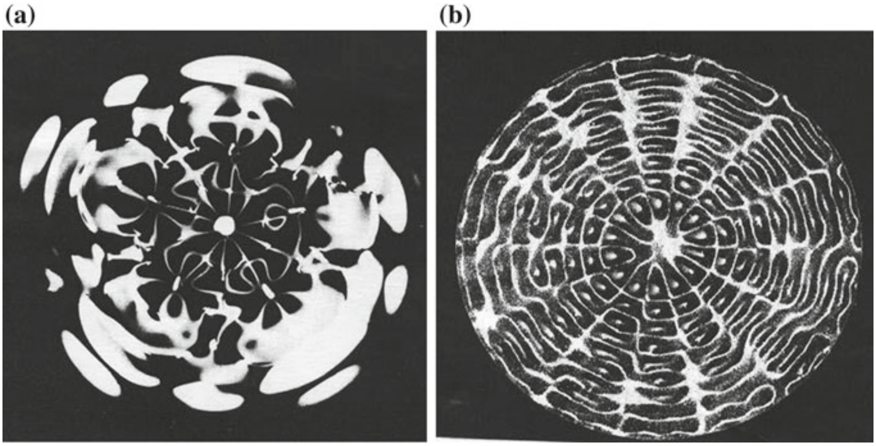

Fig. 1 **a** Pattern formed by the vibration of sand on a metal plate; **b** vibration of a thin film of glycerine. From *Cymatics* by Hans Jenny

G. Spencer Brown in his book *Laws of Form* (Spencer-Brown 1969) has created a symbolic language that expresses these ideas and is sensitive to them. Kauffman and Varela (1980) has extended Spencer-Brown's language to exhibit how a rich world of periodicities, waveforms and interference phenomena is inherent in the simple act of distinction, the making of a mark on a sheet of paper so as to distinguish between self and non-self or in and out (see Fig. 2). There is nothing new about this idea since our number system with all of its complexity is in fact derived from the empty set. We conceptualize the empty set by framing nothing and then throwing away the frame. The frame is the mark of distinction.

I have found that number when viewed properly reveals self-organization in the natural world from subatomic to cosmic scales. The so-called "devil's staircase" shown in Fig. 3 places number in the proper framework and reveals a hierarchy of rational numbers in which rationals with smaller denominators have wider plateaus and lead to more stable resonances. The devil's staircase is a representation of the limiting row of the Farey sequence the first eight rows of which is shown in Fig. 4. The n-th row is simply a list of all rational fractions with denominators n or less.

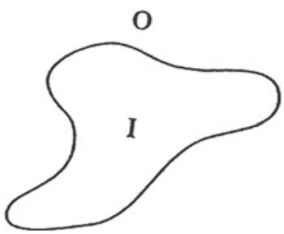

Fig. 2 A mark of distinction separating inside from outside

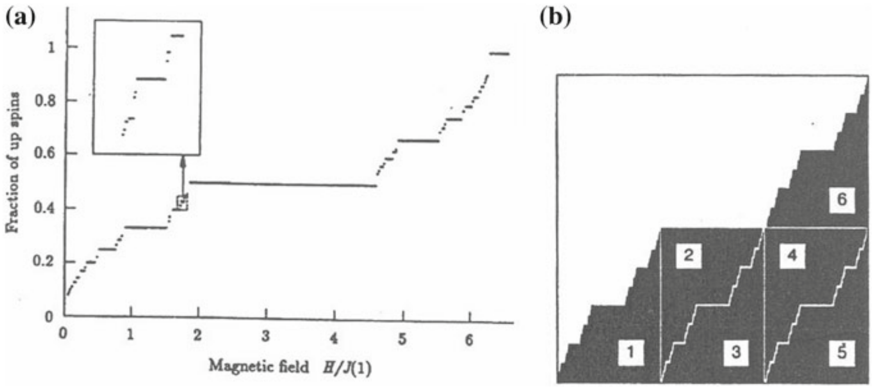

Fig. 3 **a** The devil's staircase exhibited in the Ising model from Physics; **b** the devil's staircase subdivided into six self-similar parts

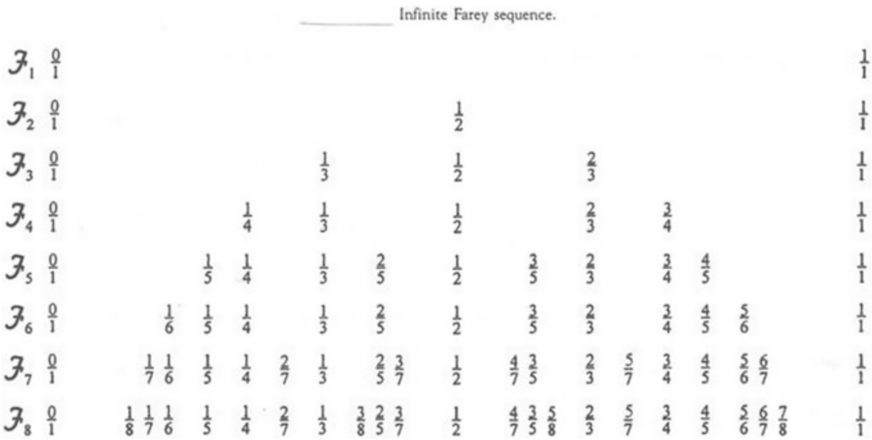

Fig. 4 The first eight rows of the Farey sequence

Notice that row 8 on the interval from 0 to ½ contains all of the critical points on the Mandelbrot set, important for describing chaos theory, where the rationals are fractions of a circle when the Mandelbrot set is mapped from a circle (see Fig. 5). On the other hand, the interval from ½ to 1 contains many of the tones of the Just musical scale shown on the tone circle in Fig. 6, including the tritone (5/7) and the diminished musical seventh (4/7) used in the music of Brahms. Only missing are the dissonant intervals of the semitone and the wholetone (Kappraff et al. 2003).

In Fig. 7 the number of asteroids in the asteroid belt is plotted against distance from the sun in units of Jupiter's orbital period Notice that sequence of gaps in the belt are

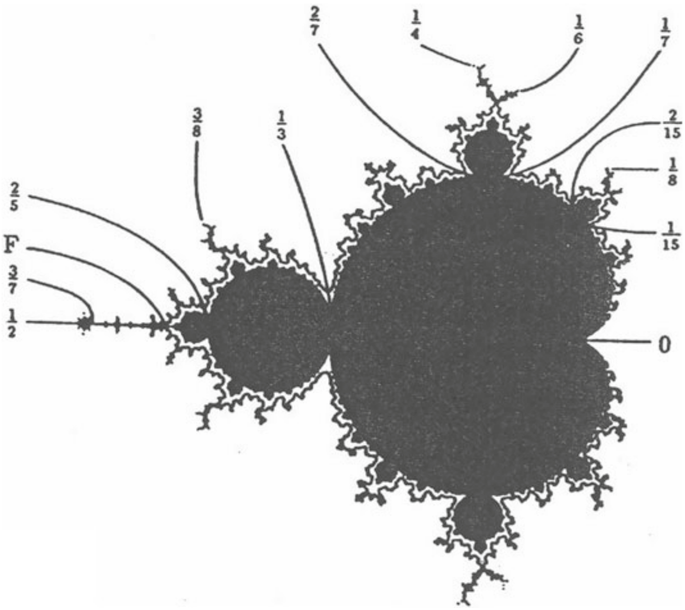

Fig. 5 The Mandelbrot set showing critical values of the external angles at fractions from row eight of the Farey sequence. The fractions determine the period lengths of the iterates z_n for a given choice of the parameter c. The point "F" (Feigenbaum limit marks the accumulation point of the period-doubling cascade. A. Douday: Julia sets and the Mandelbrot set)

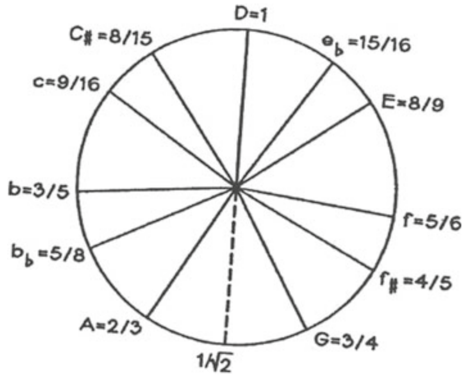

Fig. 6 The Just scale shown on a tone circle. Note the symmetry of rising (clockwise) and falling (counterclockwise) scales

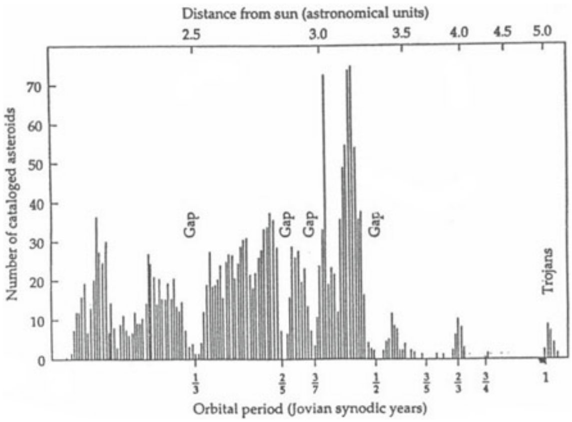

Fig. 7 Number of asteroids plotted against distance from the sun (in units of Jupiter's orbital period). Gaps occur at successive points in the Farey sequence. From *Newton's Clock* by I. Peterson Copyright 1992 by I. Peterson

at the rational numbers: 1/3, 2/5, 3/7, 1/2, 3/5, 2/3, 3/4 and that these are consecutive entries to rows 6 and 7 in the Farey sequence. I have found (not shown here) that this same Farey sequence also expresses the hierarchy of phyllotaxis numbers that dictate the growth of plants from pinecones to sunflowers (Kappraff et al. 2003).

We see here that without a telescope or without a living bud or the sound of a musical instrument, our very number system already contains the objects of our observations of the natural world and is capable of reproducing phenomena in all of its complexity. How did this come to pass? Are we observing an objective reality or are we projecting our own organs of perception onto the world? These are deep questions for philosophical study.

From the earliest times humans have tried to make sense of their observations of the natural world even though they often experienced the world as chaotic. Their very existence depended on reliable predictions of such events as the arrival of spring to plant, fall to harvest, the coming and going of the tides, etc. The movement of the heavenly bodies provided the first experiences of regularity in the universe and the application of number to describe these motions may have constituted the earliest development of mathematics. In ancient times, astronomy and music were tied together. The earliest cultures were aural by nature and music played an important role as confirmed by the many musical instruments found in burial sites of ancient Sumerians from the third and fourth millennia B.C. There is evidence that the Sumerians were aware of the twelve tone musical scale in which tones were represented by the ratio of integers or rational numbers placed on a tone circle with 12 sectors similar to the positions of the planets in the zodiac (McClain 1994). In the East, the pentatonic scale of five tones chosen from the twelve was prevalent corresponding to the five observed planets. In the West, seven tones were the norm since the sun and moon were added to the planets.

Expressing the musical scale in terms of rational numbers has certain problems associated with it. It was well understood that a bowed length of string has a higher pitch when it is shortened. For example, if a string representing the fundamental tone is divided in half it gives an identically sounding pitch referred to as an octave. Also the inverse of the string length gives the relative frequency, so that the octave has a frequency twice the fundamental. The key interval of the musical scale is the musical fifth gotten by taking a length of string whose tone represents the fundamental tone say D and reducing it to 2/3 or its length. A succession of twelve musical fifths placed into a single octave gives rise to the twelve tone chromatic scale known as "spiral fifths" as shown in Fig. 8. Its serpent like appearance leads the ethnomusicologist, Ernest McClain, to suggest that this scale lies at the basis of the many serpent myths in all cultures.

On a piano which is tuned so that each of the intervals of the 12 tone scale are equal in a logarithmic sense (the equal-tempered scale), if we begin on any tone and play twelve successive musical fifths, the result is the same tone seven octaves higher. Referring to Fig. 8, the first and thirteenth tones in spiral fifths,

A_{flat} and G_{sharp}, the tritone or three wholetones located at 6 o'clock on the tone circle, are the same tone in different octaves. However, in terms of rational fifths they differ by about a quarter of a semitone, the so-called Pythagorean comma. This is true because in order for $(2/3)^{12}$ to equal $(1/2)^7$ it would follow that $3^{12} = 2^{19}$ which is certainly false. Unless a limit is placed on the frequency of the tones, the use of rational numbers to represent tone would require an infinite number of tones. This presented ancient civilizations with a kind of 3rd millennium B.C. chaos theory.

Similar problems faced early astronomers as they sought to reconcile the incommensurability of the cycles of the sun and the moon. The solar cycle of 365 days does not mesh with the lunar cycle of 354 days. A canonical year of 360 days was chosen as a compromise between the two. It turns out that the ratios 365 ¼: 360 and 360: 354 are both approximately equal to the Pythagorean comma so that the musical scale had some roots in astronomy. Also if an octave is limited by relative

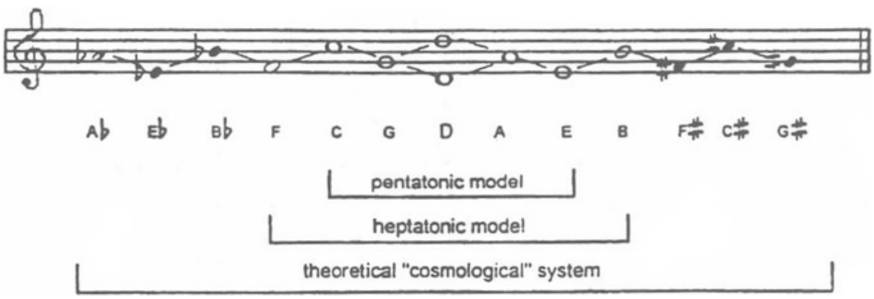

Fig. 8 Serpent power: the spiral tuning of fifths. Courtesy of Ernest McClain

frequencies of 360–720 eleven of the tones of the Just scale can be placed as integers within this limit missing only the tritone. You can verify this comparing the intervals of the following sequence with Figs. 6 and 9 (the rational numbers represent relative string lengths).

D	Eflat	E	F	Fsharp	G	A	Bflat	B	C	Csharp	D’	
360	384	400	432	450	480	540	576	600	648	675	720	(1)
1	15/16	8/9	5/6	4/5	3/4	2/3	5/8	3/5	9/16	8/15	2	

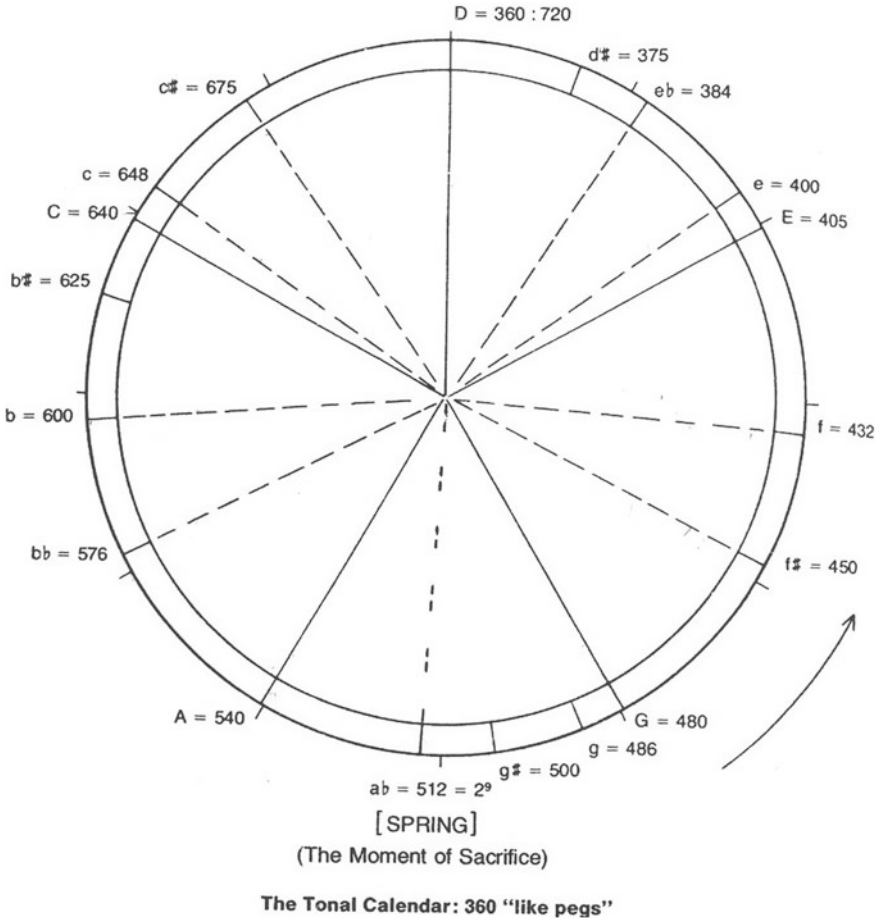

Fig. 9 The Just scale shown as integers on a tone circle. Note the symmetry

All ancient scales were expressed in terms of integers with the integers of the Just scale divisible by primes 2,3, and 5 while the scale of "spiral fifths" were expressed by integers divisible by primes 2, and 3. Notice in Figs. 6 and 9 that the tones of the Just scale are placed symmetrically around the tone circle. This is the result of symmetrically placed rational fractions in Sequence 1 being inverses of each other when factors of 2 are cancelled, e.g., $5/6 \equiv 5/3$ as compared with 3/5. But factors of 2 result in the same tone in a different octave. Compare the limit of 360/720 with the limit of 286,624/573,268 required for spiral fifths. So the Just scale embodies the two great lessons of the ancient world, the importance of balance and limit in all things. Ernest McClain has traced the use of music as metaphor in the Rig Veda, the works of Plato and the Bible (McClain 1976, 1978, 2001).

To ancient mathematicians and philosophers, the concept of rational number was thought to lie at the basis of cosmology, music, and human affairs. On the other hand, while the concept of an irrational number was not clear in the minds of ancient mathematicians, it was understood that rational numbers could be made to approximate certain ideal elements at dividing points of the tone circle into 12 equal sectors, what is now known as the equal tempered scale with $\sqrt{2}$, $\sqrt[3]{2}$, $\sqrt[4]{2}$ at 6, 4, and 3 o'clock respectively. The battle between rational and irrational numbers was dramatized by the imagery of the *Rig Veda*. Ernest McClain says (McClain 1976):

> The part of the continuum which lies beyond rational number belongs to non-being (Asat) and the Dragon (Vtra). Without the concept of an irrational number, the model for Existence (Sat) is Indra. The continuum of the circle (Vtra) embraces all possible differentiations (Indra). The conflict between Indra and Vtra can never end; it is the conflict between the field of rational numbers and the continuum of real numbers.

This battle between rational and irrational numbers continues into the present where it lies at the basis of chaos theory and the study of dynamical systems. In chaos theory no rational approximation to an irrational number is good enough in terms of yielding closely identical results as I shall demonstrate.

Three decades ago scientists began to realize that many of the phenomenon that they thought toe deterministic or predictable from a set of equations were in fact unpredictable. Changing the initial conditions by as small an amount conceivable led to entirely different results. For example, a rational approximation to an irrational initial condition, no matter how good the approximation, would lead eventually to totally different results. The system of equations predicting weather was one such set of equations. In fact as soon as the equations were more complicated than linear, built into them was chaotic behavior. In other words the fluttering of a butterfly's wings in Brazil could, in principle, over time affect the weather patterns in New York.

The growth of plants is another natural system that appears to exist in a state of incipient chaos (Kappraff et al. 2003). When the cells of a plant are placed around the stem successively at angles, known as divergence angles, related to the golden mean of $2\pi/\varphi$ radians the spiral forms reminiscent of sunflowers appear. Change the divergence angle to a close rational approximation of the golden mean and the spiral is lost and replaced by a spider web appearance (see Fig. 10).

Consider the simple map governing the Mandlebrot set (Peitgens et al. 1992),

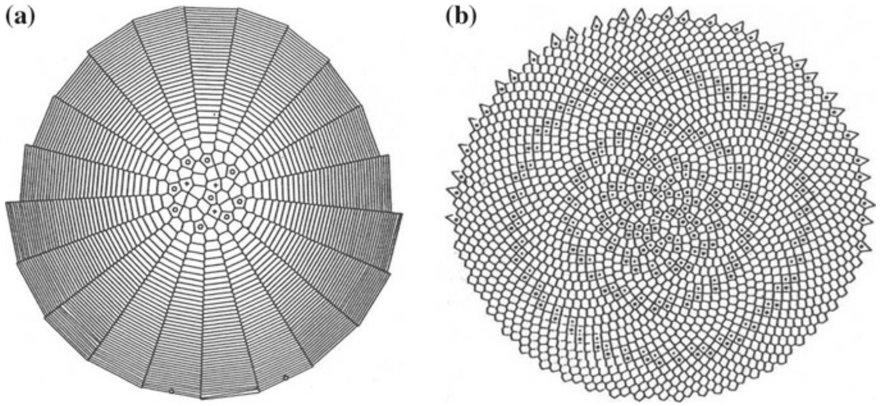

Fig. 10 **a** A computer generated model of plant phyllotaxis with rational divergence angle $2\pi x13/21$. Note the spider web appearance; **b** irrational divergence angle $2\pi/\varphi^2$. Note the daisy-like appearance

$$\mathbb{z} \rightarrow \mathbb{z}^2 + c$$

for z and c complex numbers.

Beginning with an initial point z_0 and replacing this in the map leads to the trajectory $z_0, z_1, z_2, \ldots$ The Mandelbrot set constitutes all values of c that lead to bounded trajectories. This sensitive dependence on initial conditions holds for values of c outside of the Mandelbrot set. If the value of c is taken internally and away from the boundary of the Mandelbrot set, the behavior of the trajectory is simple, leading either to a fixed point or a periodic orbit. The Julia set is the boundary of the set of points of the trajectory that do not escape to infinity. For example, when $c = 0$, the Julia set is a unit circle. Points outside the Mandelbrot set lead to chaotic behavior of the kind just mentioned. Points near the boundary of the set have the most interesting behavior. One such Julia set for a point near the boundary of the Mandelbrot set is shown in Fig. 11. This is somewhat like the state of affairs that exists at the shoreline between land and ocean. The frozen character of the land as opposed to the chaotic nature of the ocean is mediated by the tide pools at the interface between the two. This is where life has its greatest diversity. Stuart Kauffman referred to this region of great differentiation as the "edge of chaos" (Kauffman 1995).

There is a strong relationship between chaos and fractals. In fact, Julia sets generally have a fractal nature. The study of fractals had its beginning with the research of Benoit Mandelbrot into the nature of stock market fluctuations. However, such structures were noticed earlier by Lewis Richardson in his study of the length of coastlines. Richardson noticed that there was a power law relating the apparent length of coastlines when viewed at different scales. When viewed at a large scale such as the scale of a map, the coastline appears finite. But if the scale is reduced so that all of the idiosycracies of the coastline are evident, the ins and outs of the coastline have

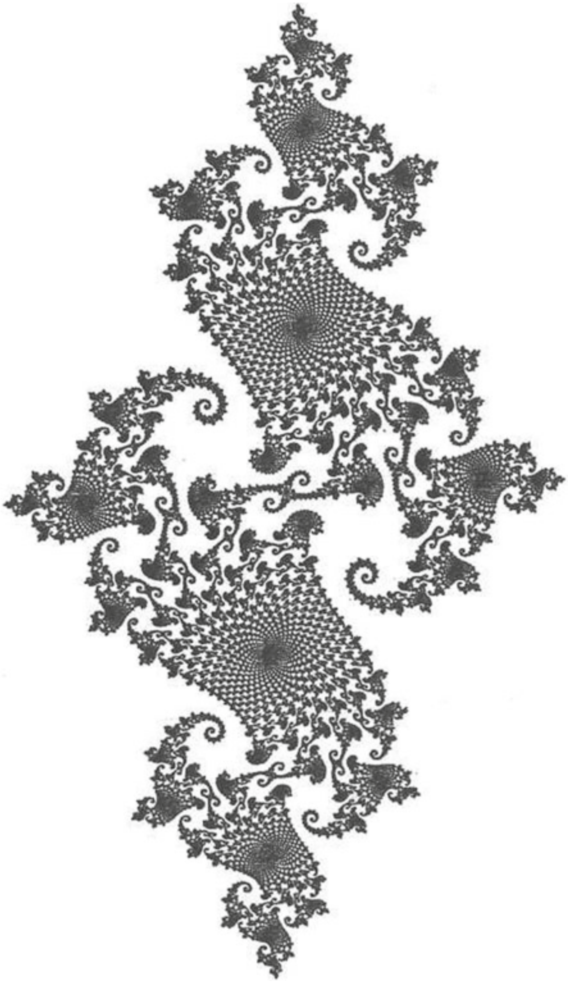

Fig. 11 A "dragon" shaped Julia set for a value of c at the boundary of the Mandelbrot set

no apparent limit and its length is effectively infinite. Furthermore, a small stretch of coastline is similar to the whole when viewed in a statistical sense.

Robert Cogan and Pozzi Escot have shown that music also has a fractal nature (Cogan 1976). For example, they show that musical structures appear and reappear throughout the musical score at different scales. This is the consequence of the music also satisfying a power law referred to as 1/f noise found in the structure of the music of Bach and Mozart (Gardner 1978). 1/f noise has a spectrum of sound between the spectrum of Brownian motion in which the next note is completely determined from the previous notes resulting in a frozen quality in the music; and white noise is when the tones are randomly chosen leading to a chaotic sound. So we see that good music is again the result of finding the "edge of chaos."

Good art also strives to incorporate the elements of self-similarity although this is generally done subtly. In a great work of art each image must relate to the others in terms of its geometry and metaphorical themes. Artists and sculptors have always been inspired by the complex forms of nature. For example, the vortices in Van Gogh's famous painting, "Starry Night" in Fig. 12a appears to be taken directly from the meandering stream winding through separate vortices in Fig. 12b. Trains of vortices also appear in the knarled cypress trees found in many of Van Gogh's late paintings such as "St Paul's Hospital, (1889)" of Fig. 13a and perfectly embody the bark and knots of the cypress tree in Fig. 13b. On the other hand, the design on a palm leaf from New Guinea represent yet another set of vortices shown in Fig. 14a, b. Figures 12b, 13b, and 14b were taken from the beautiful photos of complexity in nature found in Theodor Schwenk's book, *Sensitive Chaos* (Schwenk 1976).

Manuel Baez (see this issue) creates sculptures reminiscent of complex forms from nature out of bamboo sticks and rubber band connectors (Baez 2001) resulting in structures whose whole is greater than the sum of its parts. Baez describes his system as follows: "These dynamic processes are inherently composed of interweaving elemental relationships that evolve into integrative systems with startling form and structure generating capabilities". Beginning with a simple shape such as a square or pentagon, a module is created which is replicated over and over. Since the sticks are flexible, the model inter-transforms into amazing shapes illustrating the order which exists within apparent chaos. Three structures from his "Phenomenological Garden" all made with 12" and 6" bamboo dowels and rubber bands are shown in Fig. 15.

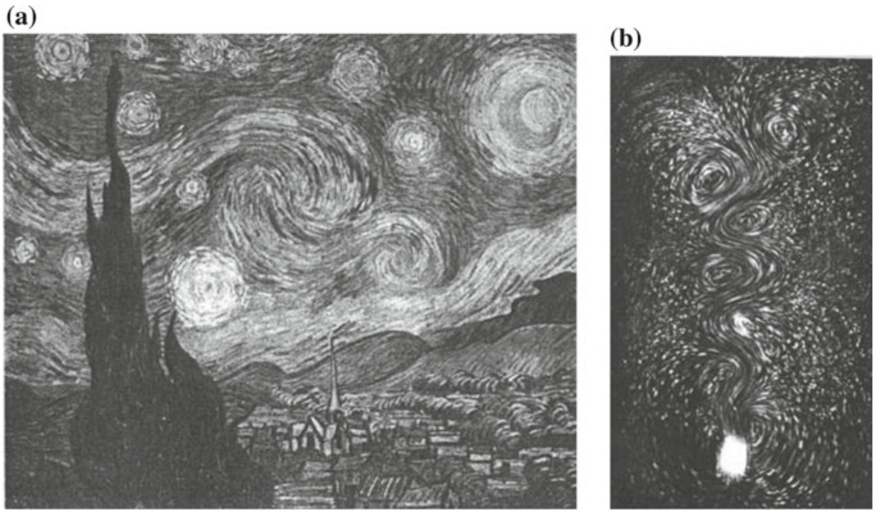

Fig. 12 **a** Van Gogh's painting, "Starry Night". About this painting Van Gogh wrote, "First of all the twinkling stars vibrated, but remained motionless in space. Then all celestial globes united into one series of movements…Firmaments and planets both disappeared, but the mighty breath which gives life to al things and in which all is bound up remain (Purce 1974)."; **b** a meandering stream winding through separate vortices. From *Sensitive Chaos* by Schwenk (1976)

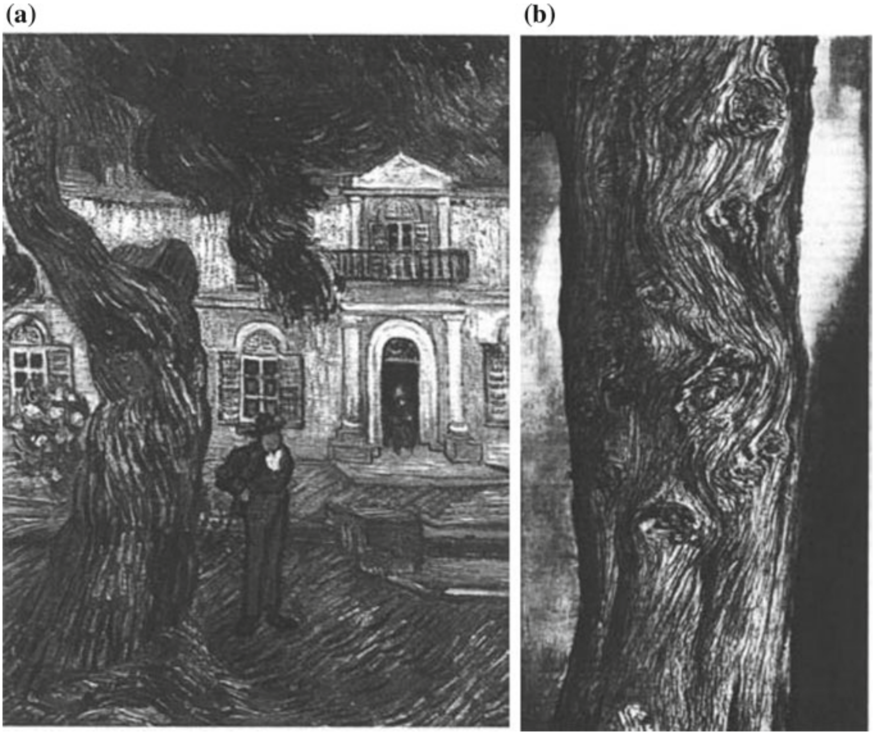

Fig. 13 **a** Van Gogh's painting, "St. Paul's Hospital, (1889)". Van Gogh wrote, "The cypress are always occupying my thoughts—it astonishes me that they have not been done as I see them."; **b** The bark and knots of a cypress tree from Schwenk (Gardner 1978)

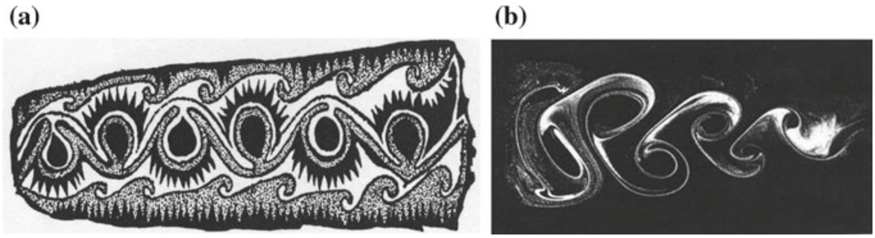

Fig. 14 **a** Design on a palm leaf (May River, New Guinea) Volkerkundliches Museum, Basel; **b** a vortex train from Schwenk (1976)

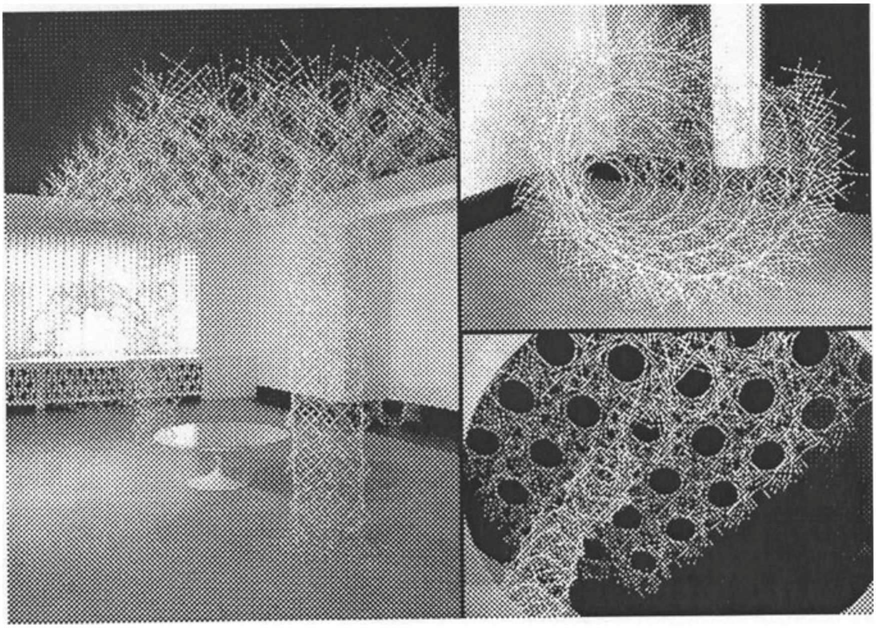

Fig. 15 The Phenomenological Garden of Manuel Baez

They were all generated from a simple square pattern.

Bathsheba Grossman invites scientists and mathematicians to send her complex images from their work such as proteins or globular clusters from astronomy or complex geometrical forms and recreates them as three dimensional sculptures in a variety of medias. Her "Cosmological Simulation" (see Fig. 16a) was created from simulated scientific data and illustrates the fractal nature of the universe. "Ferritin Protein" (see Fig. 16b) is a three-dimensional model in laser etched crystal made from a protein data bank file. Her bronze sculpture "Metatron" is shown in Fig. 17. It is made by a lost wax process and created from an operation upon a cube and an octahedron. It appears to be as a singular vortex fixed in time and is evocative to me of frozen music.

Barnsley (1988) has shown that fractal images can be created by subjecting an initial seed figure to the following transformations: contractions, translations, rotations, and affine transformations (transformations that transform rectangles to arbitrary parallelograms). For example, Barnsley's fern is created by repeatedly transforming an initial rectangle to three rectangles of different sizes, proportions, and orientations and one line segment as shown in Fig. 18. This approach to generating fractals is leading to revolutionary ways of understanding how complex structures arise from simple ones. It is being applied to many applications from image processing to generation of fractal scenes for movie sets such as that shown in Fig. 19 generated by Kenneth Musgrave.

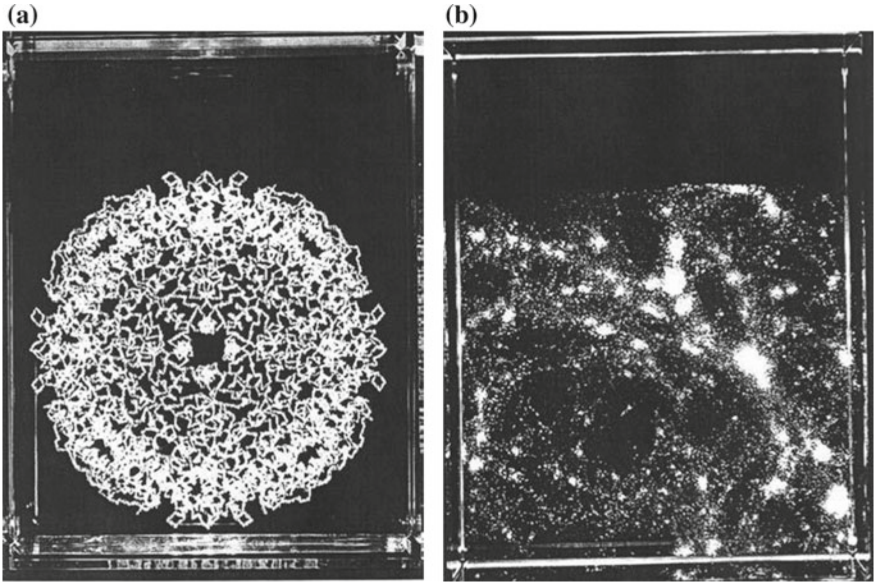

Fig. 16 **a** Large scale model of a cosmological simulation; **b** ferritin, a symmetrical protein. Courtesy of Bathsheba Grossman

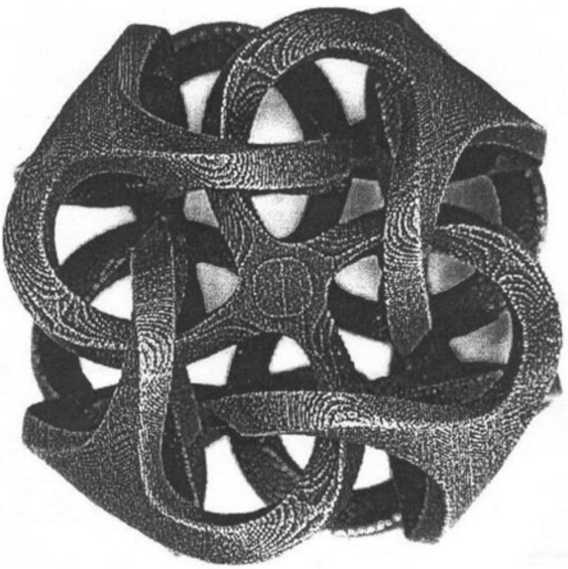

Fig. 17 The Metatron. Courtesy of Bathsheba Grossman

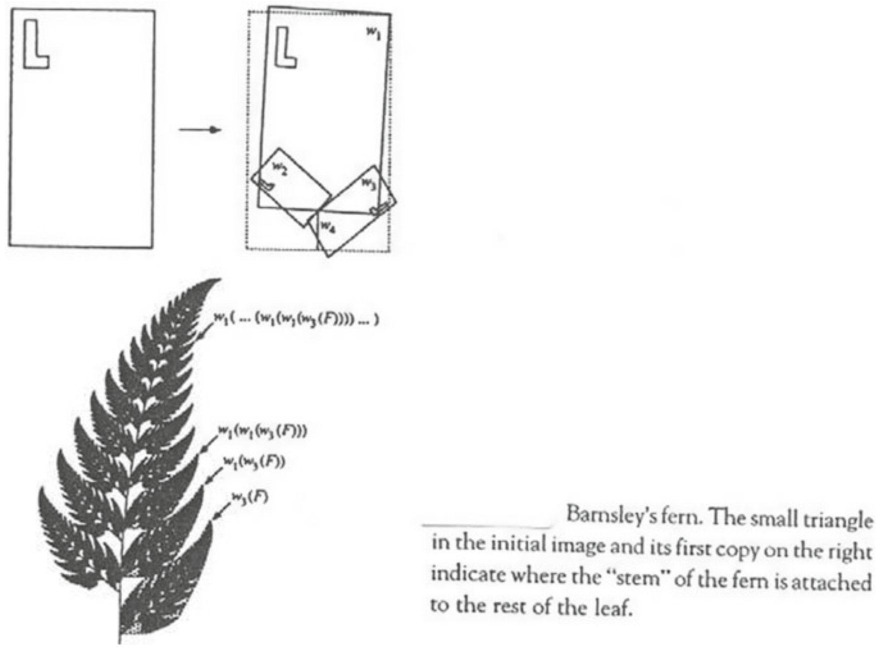

Fig. 18 Barnsley's fern. Created by repeated transformation from a rectangular seed pattern

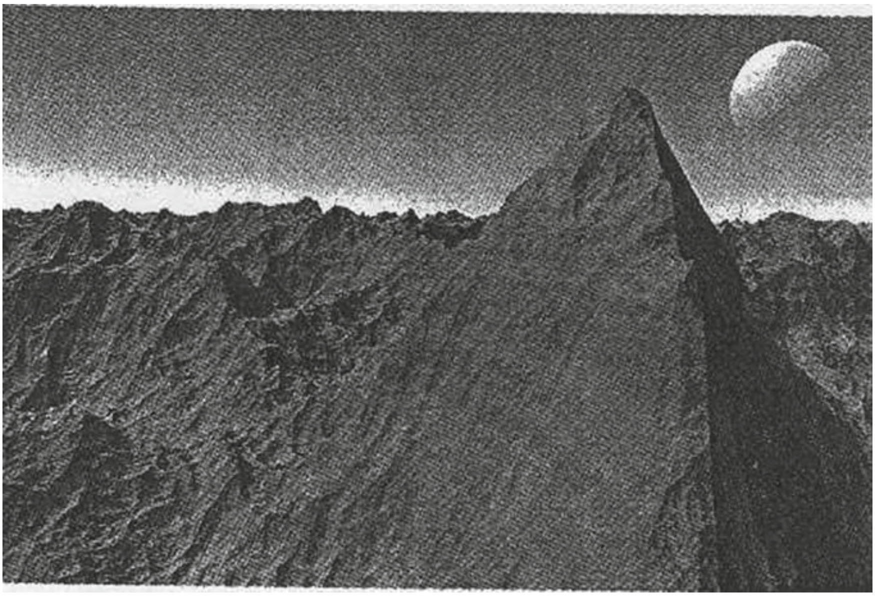

Fig. 19 A fractal scene by Kenneth Musgrave

Structures and designs with fractal properties appear quite naturally in many cultures. I will present two examples from Ron Eglash's book *African Fractals* (Eglash 1999). In the western part of the Cameroons lies the fertile grasslands region of the Bamileke. Eglash describes their fractal settlement architecture (see Fig. 20).

> These houses and the attached enclosures are built from bamboo—Patterns of agricultural production underlie the scaling. Since the same bamboo mesh construction is used for houses, house enclosures, and enclosures of enclosures, the result is a self-similar architecture—The farming activities require alot of movement between enclosures, so at all scales we see good-sized openings.

Many of the processional crosses of Ethiopia indicate a threefold fractal iteration (see Fig. 21). Eglash suggests that the reason that the iteration stops at three may be for practical reasons. Two iterations is too few to get the concept of iteration across, while more than three presents fabrication difficulties to the artisans.

The twentieth century was a revolutionary time in the history of mathematics and science. First the deterministic nature of physics was replaced by the strange

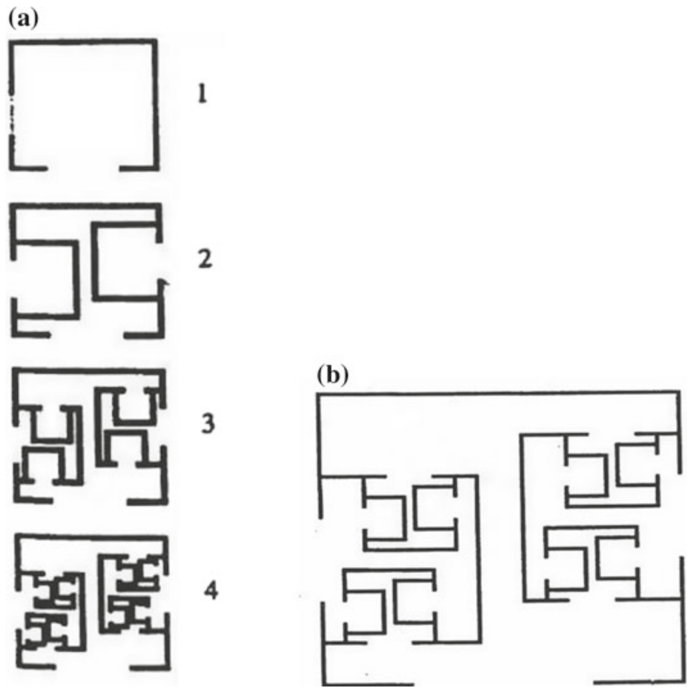

Fig. 20 **a** Fractal simulation of Bamileke architecture. In the first iteration ("seed shape") the two active lines are shown in gray. **b** Enlarged view of the fourth iteration. From *African Fractals* by Ron Eglash (Baez 2001)

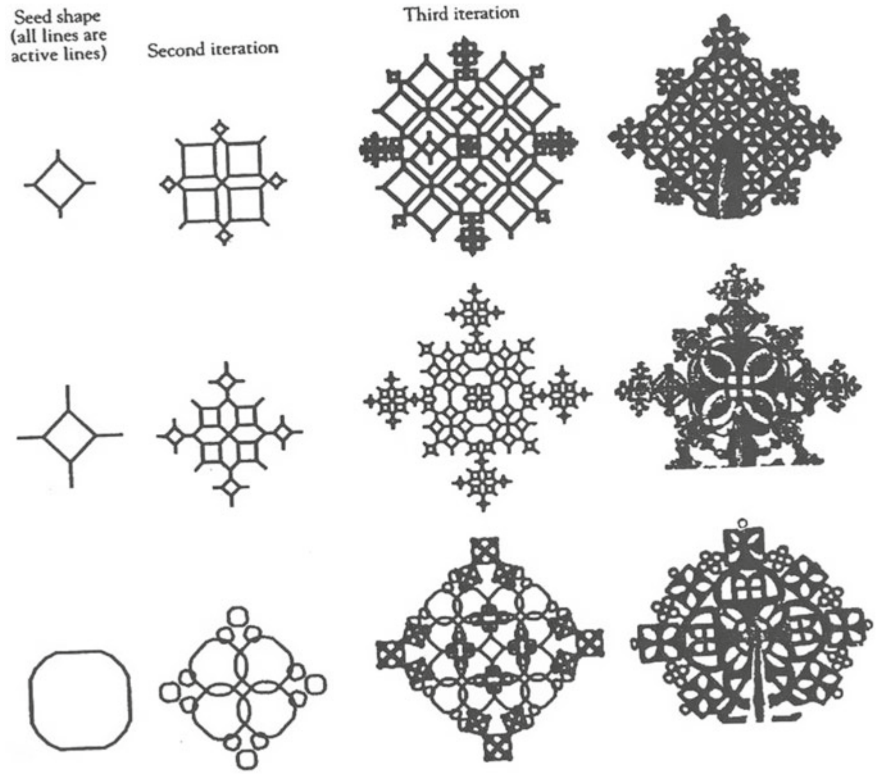

Fig. 21 Fractal simulation for Ethiopian processional crosses through three iterations. From *African Fractals* by Ron Eglash (Baez 2001)

world of quantum mechanics where the outcomes of an experiment depended on probability counter to the intuition of Albert Einstein that "God does not play dice." Then the foundations of mathematics were shaken by Kurt Godel who showed that a mathematical system could not be both consistent and complete while Alan Turing discovered that there was no way of determining whether a computer program would halt once given some initial data.

Mathematical and scientific theories are created by observing symmetries of all sorts. This enables the information inherent in the physical system to be compressed into a theory or set of equations. For example, all of the possible motions of celestial or earthbound bodies are governed by Newton's laws which is elegantly stated as $F = ma$. Knowing only a few facts about the initial motion, in other words only a few bits of information, the theory can predict the ensuing motion. What if the system exhibited no such symmetry? Then each specific instance would have to be observed in its entirety. In other words, no information would have been compressed for us to unlock by a theory. All we could do would be to observe each orbit and record what we saw. Systems generated by rules in which the next state is determined by the flipping of a coin is an example of a system devoid of symmetry. There is no way to determine the final state of the system except by following the coin flips to their conclusion. Similarly, in mathematics, a mathematical system is generally compressed by stating several axioms representing a finite number of bits of information from which an unlimited number of theorems follow. Without axioms mathematics would not be concerned with judging truth or falsity but rather with generating patterns.

Chaitin (2000) has recently shown that rather than being an irrelevant curiosity, this state of affairs, reflected in Godel's and Turing's discoveries, is central to the representation of nature by mathematics and science. He created a number from number theory with the property that the determination of its digits was equivalent to flipping coins. We can now say that, it may be that only narrow islands of observation may be derivable from our standard equations and theories. As a result mathematicians have begun to realize that other approaches would be needed to characterize natural phenomena and to coax information from nature. One such program is being explored by Stephen Wolfram in his book *A New Kind of Science* (Wolfram 2002).

Wolfram studied the behavior of a large class of systems governed by rules in which the next state of the system was determined by the previous state, so-called cellular automata. In response to simple rules and starting with simple initial conditions, complex forms would emerge such as the one in Fig. 22a. Compare this with one of the network of veins of sand created by the interplay of sand and water shown in Fig. 22b by Schwenk. Wolfram discovered that all such automata could be classified as being one of four types and that naturally occurring systems of growth from plants and animals to blood vessels to crystals (some of which are shown in Fig. 23), were themselves cellular automata exhibiting the same properties as the artificial ones he created. Furthermore, he discovered an astounding principle which he refers to as the Principal of Computational Equivalence: that all processes, whether they are produced by human effort or occur spontaneously in nature, can be viewed as computations. Furthermore, in many kinds of systems particular rules can be found that achieve universality, in other words, the ability to function as a computer in all of its generality, e.g., a universal Turing machine. The dramatic discovery of his book was to show that rather than being a rare event, such universality could be created out of simple rules.

This new approach to science is an invitation for artists and scientists to draw closer to one another. After all, the examples of ornamental art have patterns similar to ones generated by cellular automata. For example, Fig. 24 illustrates several examples generated by cellular automata reminiscent of the Ethiopian designs of Fig. 20. Hans

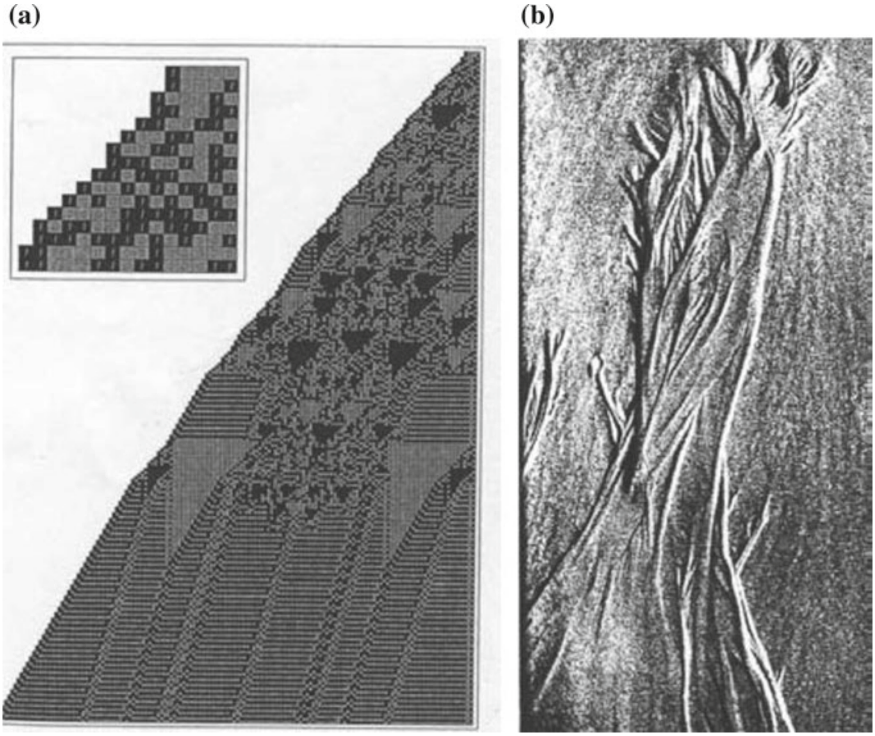

Fig. 22 **a** An example of a system defined by the following rule: at each step, take the number obtained at that step and write its base 2 digits in reverse order, then add the resulting number to the original one. Dark squares represent 1 while light squares 0. For many possible starting numbers, the behavior obtained is very simple. This picture shows what happens when one starts with the number 16. After 180 steps, it turns out that all that survives are a few objects that one can view as localized structures. From *A New Science* by Wolfram (2002); **b** a network of veins of sand created by the interplay of sand and water. From Schwenk (1976)

Jenny's and Theodor Schwenk's vibratory patterns offer another link between art, science and nature. Figure 25a from Jenny (1967) shows particles of sand in a state of flow being excited by crystal oscillations on a steel plate. Compare this with Fig. 25b from Schwenk (1976) showing the ripple marks in sand at a beach.

We are heading into an exciting new era of scientific and mathematical explorations in which artists, musicians and scientists will be joining hands to help each other and the rest of us understand our universe in all of its complexity. More and more the question will be asked: Is it art or is it science? Mathematics will serve

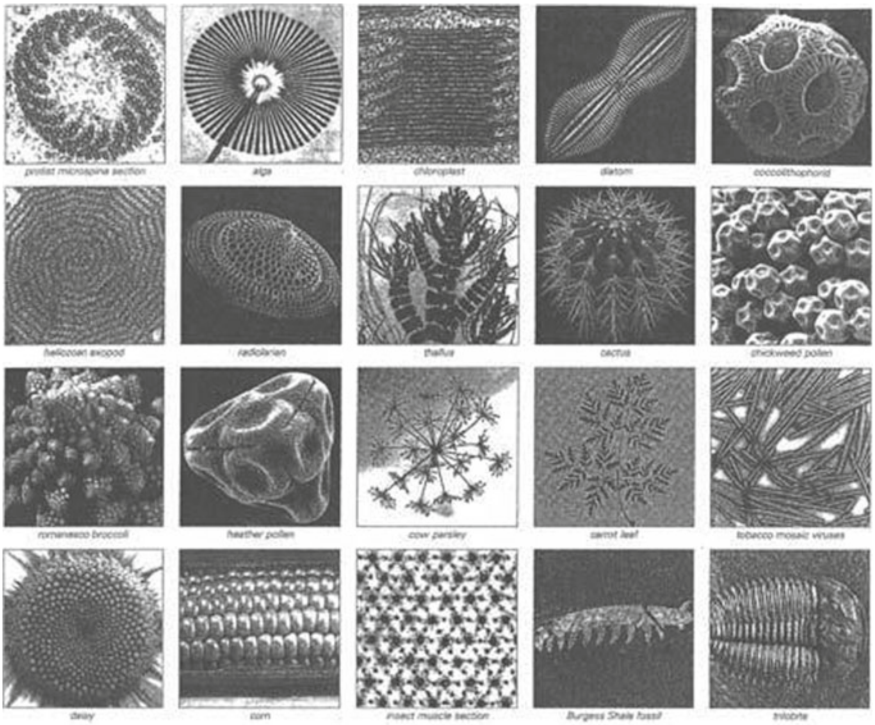

Fig. 23 A collection of patterns from nature suggesting natural cellular automata. From *A New Science* by S. Wolfram

as the common language, scientists and engineers will create the technology, and artists and musicians will provide the spirit. These new approaches will suit our age and society much as ancient systems of thought met the needs of those cultures. Just as ancient systems of numerology were incorporated into the myths, religious symbolism and philosophy of those ages, the new science of complexity and chaos theory is certain to spawn its myths and metaphors for our age.

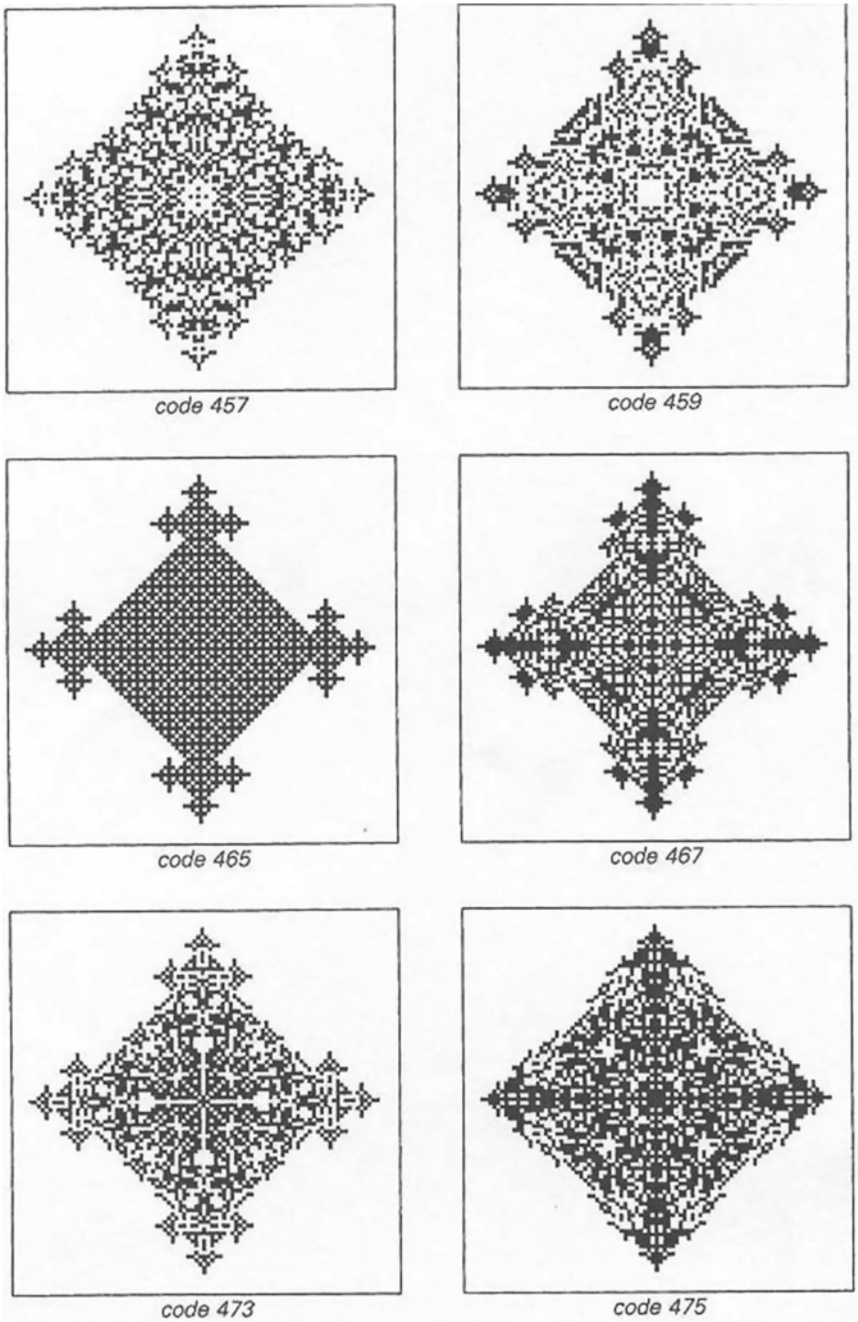

Fig. 24 Cellular automata generated by simple rules with the appearance of Ethiopian crosses. From *A New Science* by Wolfram (2002)

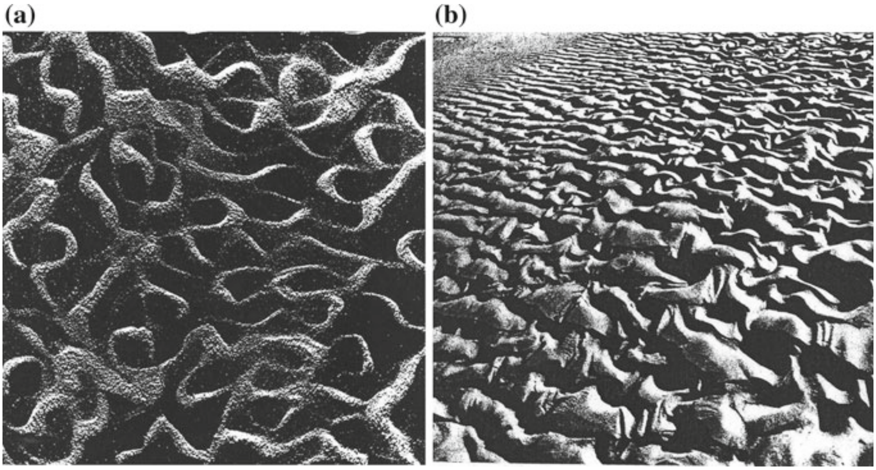

Fig. 25 **a** Particles of sand in a state of flow excited by crystal oscillations. From Jenny (1967); **b** ripple marks of sand on a beach. From Schwenk (1976)

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The View Through Glass

Painters' Science, Mathematicians' Art, and the Magic of Shadows

Rossella Lupacchini

In his *De pictura*, Leon Battista Alberti used the tale of Narcissus, who was turned into a flower, to present painting as the flower of arts: "What is painting but the act of embracing by means of art the surface of the pool?" (Alberti 2004, p. 64). Indeed, the view through the surface of the pool, as through the windowpane, gives evidence of a theory of knowledge, involved in *artificial perspective*, which mathematics and the philosophy of nature were not ready to accommodate. On the one hand, the view through glass contrasts with Euclid's constructions, on the other hand, acting as a semi-transparent mirror, the surface of the pool triggers a subject-object interaction between the seer and what is seen, questioning the (classical) scientific representation of isolated systems.

Narcissus' metamorphosis calls attention not only to the critical function of a see-through plane for *visual* knowledge, but also to the magic of shadows. Narcissus did not fall in love with his own specular-image, but with a shadow that he believed to be someone else. At first, the mirror was invisible to him. Then, he realized: "I burn with love of my own self; I both kindle the flames and suffer them" (*Metamorphosis*, 3. 454). If the seduction of the *other* is the first step towards the recognition of the self, the magnetism of the shadow is the first step on the road to knowledge.

The shadow was a challenge for painters. As a picture of reality, each painting is a 'still life' where shadow is essentially a changeable form. Leonardo was aware of the problem, which also arose in depicting the continuous transformation of nature. His talent for drawing, however, allowed him to demonstrate how motion should affect geometry. While the artificial perspective led mathematicians to conceive of a *visual geometry,* which extends Euclid's, a *reverse perspective*, namely a "doctrine of shadows," led Leibniz to address Leonardo's demand for a geometry "which is done with motion" (*Codex Madrid*, II, 107r).

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In this article, we will discuss how the dialogue between art and science, starting in the Renaissance, transformed our view of geometry and our understanding of natural processes.

The Flower of Arts

Among the events told in his *Natural History*, Pliny includes the origin of painting. Seeing her lover off, a young woman "drew in outline on a wall the shadow of his face thrown by the lamp" (*Nat. Hist*., 35, 151). The young woman cleverly used a natural process—the casting of the shadow—to draw the silhouette of her lover that would help her remember him. The geometrical laws of projection lead the girl to trust the outcome more than her memory. Do they also make the outcome an 'art work'? In his *De Pictura* (1436), Leon Battista Alberti emphasizes that his task is not "writing a history of painting like Pliny, but treating of the art in an entirely new way" (Alberti 2004, pp. 61–62). He also uses the metaphor of shadow in describing painting as a "shadow of sculpture" in his *De statua* (1464). But here the shadow is not needed to take a record of a statue, but rather free the *shape* from the marble and make painting an *art*. Indeed, for Alberti, painting is the flower of all the arts; even the "art of building" grows out of it.

> Painting was honoured by our ancestors with the special distinction that, whereas all other artists were called craftsmen, the painter alone was not counted among their number. Consequently I used to tell my friends that the inventor of painting, according to the poets, was Narcissus, who was turned into a flower; for, as painting is the flower of all the arts, so the tale of Narcissus fits our purpose perfectly. What is painting but the act of embracing by means of art the surface of the pool? (Alberti 2004, p. 61)

The "entirely new way" of treating art, in Alberti's view, couples the visionary power of the architect Filippo Brunelleschi and the natural sensibility of the painter Leonardo da Vinci: a conception of building as 'gambling' and a conception of painting as a science. Unlike sculpture, which is a "very mechanical art," painting, Leonardo remarks, "uses the power of its science to display the greatest landscapes with their distant horizons" on a flat surface (Leonardo 1890, p. 23, § 31).

It was the invention of *artificial perspective*, conventionally credited to Brunelleschi, to give painting the power of a science. Whether or not the inventor of perspective, Brunelleschi must be credited for providing clear evidence of its power, namely, the power of generating 'virtual reality'. In the dedicatory letter of his *De pictura* to Brunelleschi, Alberti expresses his amazement for the completion of the cupola of Santa Maria del Fiore; "a feat of engineering," he writes, "that people did not believe possible these days and was probably equally unknown and unimaginable among the ancients" (Alberti 2004, p. 35).

How could people sustain the project? Although the rules of perspective allowed the spectator to appreciate the scene as if it were real, they could not guarantee the solidity of actual buildings. Who could trust the design of an enormous construction, to be realized "without the aid of beams or elaborated wooden supports," to the point of funding it? Perhaps only Cosimo de' Medici (*il Vecchio*), a merchant of alum who became one of the richest and most powerful men of Europe not because of his properties and gold, but thanks to his expertise in moving 'virtual money' as a banker. He made his fortune handling letters of exchange and credit, facing the risks of hazardous investments and insecure moneylending.

The Mirror of Self

The *problem of form* emerges in the Renaissance culture as a crucial issue for both the theory of art and the theory of science. What Alberti recognized as an unmistakable sign of Brunelleschi's genius was his giving credit to an *artificio certo*, which it to say, his thriving on the cultural hazard that combines the uncertainty of pragmatic activity with the certainty of mathematical demonstration. From this point of view, the traditional boundary between practical and productive knowledge, on the one hand, and theoretical and scientific thought, on the other, tends to disappear. Here a double hazard is involved, as the problem of form concerns also the relationship between the subject (to be read as the *Self*, the mind, the reason, the eye, as well as the project itself) and the object (to be read as the *Other,* the external world, as well as the work itself). The problem originates at the crossroads between the freedom of the subject (painter or mathematician, philosopher or merchant, craftman or politician) and the necessity of the objective world, that is, between the ideal design (Alberti's *lineamentum*), which the artist foresees on the screen of imagination, and the concrete work, which makes that project real. Far from being marginal as well as exclusive to the artist or to the geometer, the problem of form is a matter of common concern within a culture grown out of constructive interferences between abstract and concrete, creativity and experience, 'artful nature' and 'human species'.

Ernst Cassirer argues that the marriage between art and science was celebrated in Leonardo's artistic work and his scientific achievement. It is not only because of the unique sensitivity of his eye, but rather in virtue of a "really essential union" that Leonardo attains "a new vision of 'freedom' and 'necessity', of 'subject' and 'object', of 'genius' and 'nature'" (Cassirer 1963, p. 161). Such an essential union can be thought of as a kind of specular relation between the self and the world, which is to say, as a "coincidence of opposites," or, "identity through the otherness." This might suggests reading Narcissus' story as an expression of the "contradictory identity" inherent in painting or, more generally, in art. Narcissus' discovery of himself depends on his facing an 'otherness' that cannot be dissolved, although he tries to neutralize it by embracing it. Such an otherness appears to be a necessary condition of knowledge itself. In contrast with the "natural history" of painting told by Pliny, Narcissus' experience is suitable for illustrating aspirations and risks of that *perspectival culture,* peculiar to the Renaissance, upon which not only art and science, but also commercial trades and different areas of social and civic life, meet and dialogue.

Narcisssus not only likes the image in the pool, but also feels that the image likes him. His confidence in the *other* can be compared to that of the *perspettivo*, sure to be able to impose one's own will on the outside world and share the result with the others. As Ovid tells us, when Narcissus tries to hug the other, the *imago formae* stretches its arms towards him, as if it would come out to meet him, and returns his smile too. Yet, just like Narcissus' embrace turns his ardent passion into nothing (*nil*), perspective's spell might turn virtual reality into illusion. The mutual love through the surface of the pool does not permit Narcissus to join his lover, nor the simulacrum to let itself be seduced (*ducere a se*). The more Narcissus approaches the image, the more the image blurs and dissolves into the water surface; the more Narcissus moves back, the more the image withdraws into the bottom of the pool.

The distance between Narcissus and his reflected image is false (*ficta*), like the distance between the eye and the painted image. The same distance separates the painting from the mind's eye of the artist and commends it into the painter's hand. Indeed, "perspective is by nature a two-edge sword," according to Erwin Panofsky. "Perspective," he writes, "creates distance between human beings and things (…); but then in turn it abolishes this distance by, in a sense, drawing this world of things, an autonomous world confronting the individual, into the eye" (Panofsky 1991, p. 67). Thus, one might also observe that the *perspettivo* ignores, or deletes, the distance between oneself and the other, bringing one's eye into the mirror. While the eye that sees and the object seen lose importance, the virtual reality of the image comes into 'existence', autonomous from the real subject and object. Such a virtual reality, however, does not (re)present the picture taken by a naked eye amongst many, but the image captured by means of a lens that filters out minor sensible details to reveal the soul's gaze of the artist. The position of the lens must be well defined but not absolute; only God's point of view can be thought of as absolute, for God sees everything, although his perfection is immovable. In the artist's hand, a lens can deform, dilate, reduce, sharpen, blur. From this point of view, the painter's art appears to be similar to the Florentine banker's ability to deform the capital value by handling letters of exchange, carrying out operations on virtual amounts of money. It also paralles the architect's design in giving shape to a model that does not follow a given archetype, but what Alberti's called a *lineamentum*, i.e., a tentative scheme of lines, angles, and figures in the site of mind. In need of the other to see himself, Narcissus "remains unmoved with the same countenance, like a statue formed of Parian marble" (*Metamorphosis*, 3, 419) facing the image that he would like to join. He remains petrified, notwithstanding his desire to embrace the image prompts him to move on. The object fatally vanishes through the movement of the subject, like Ovid warned, "it comes and stays with thee; with thee it will depart if thou canst but depart thence" (*Metamorphosis*, 3, 435). By contrast, movement, like that of a "truck shifting" (*carriuolo*) or that of the design (*lineamentum*), from the depth of soul to a world thought of as a worksite (*cantiere*) (Alberti 1969, pp. 205–206), is a basic ingredient of the Renaissance painting as well as of the success of the banker's operation. But how does *perspectiva pingendi* confer movement to its image?

Visual Geometry

If to give shape means to create a sense of three-dimensionality on a flat surface, a mirror image should provide the model to be followed. Accordingly, if the imitation of natural things (*cosa naturale*) fundamentally asks for giving depth to bodies (*far parere le cose rilevate*) (Alberti 2004, p. 46), the mirror becomes the competent authority.

> When you wish to know if your picture be like the object you mean to represent, have a flat looking-glass, and place it so as to reflect the object you have imitated, and compare carefully the original with the copy. You see upon a flat mirror the representation of things that appear real. (Leonardo 1877, p. 150)

It is "only by giving tactile values to the retinal impression," according to Bernard Berenson, that the painter can create a sense of space and give substance to one's mental images (the *rilevanza* of Leonardo and Alberti). It is by producing "ideated sensations" that the painter can give "existence" to things in coherent and constant forms, and therefore distinguish them from mere ghosts.

In one of his most insightful essays, Berenson drew attention to "the ineloquent" in Piero della Francesca's art. In particular, it can be appreciated in his human figures. Piero depicts bodies more than individuals, faces devoid of emotion, of any rethoric tone, and yet their consistence can be compared with the one of Euclidean constructions. A paradigmatic example is given by the Diptych of the Dukes of Urbino at the Uffizi Gallery in Florence. The geometry of elements—the cylinder of the Duke's chest and of the Duchess' neck, her face and hairstyle oval, their standing in a space where what is infinitely distant and what is infinitely close appear balanced—remove the two individuals from the time of history and from the specific place to transmute them into ideal models. Notwithstanding the two figure do not resemble each other, they appear as if one were the reflection of the other.

For Berenson, "impersonality" is Piero's distinct method. His goal is not to represent the whole of phenomenic universe, but to "present" a certain phenomenon that has produced an impression upon him in such a way to make us feel as he felt it. If the goal is to show a phenomenon in its essential significance, the artist must avoid reproducing his own feeling, "for the feeling is not the original phenomenon itself, but the phenomenon, … , as refracted by the personality of the artist" (Berenson 1909, p. 71). According to Berenson, Piero was not only impersonal in his method: he loved impersonality as a quality in things. And yet, Berenson remarks, no *Flagellation* is more impressive than his. In what does Piero's unique charm consist? What makes so attractive Piero's art is that 'virtual' image produced through a lens that, by cancelling any expression of feeling, any special emotion, reveals the soul's gaze of the artist. Is such a lens that makes the difference between Narcissus' failure and the effectivenes of Renaissance art?

It would seem that the rationalizing abstraction, made possible by perspective, is crucial for making depicted scenes ineloquent. The perfect visual geometry of Piero's painting seems to be willing to correct the irregularity of phenomen, the unreliability of sense, the occasion of historical event. In its essential significance, the *Flagella-*

tion expresses 'incommensurability': no adequate speech, no measure can relate the figures standing in the foreground, unconcerned, impassive like rocks, with the situation in the background. Nevertheless, the very impersonality of those forms transmits the artist's gaze with crystal clarity. The more ineloquent a painting is, the more the painter speaks of himself through his work: he does not show a momentary passion or an occasional emotion, but his "mental set," where perceptions become *forms*, filtered through subjective impressions. Not surprisingly, "it is in his architecture that Piero betrays something like lyrical feeling," when he paints "what he cannot hope to realize, his dream of surrounding worthy of his mind and heart, where his soul would feel at home" (Berenson 1954, p. 5).

Abstract from any contingency, idealized as models, the two figures of the Diptych of the Dukes of Urbino do not stand in front of one another like Narcissus and his reflected image. They are rather reminiscent of the nymph Echo, as they are dematerialized through an echolalia in tune with the one of the painter. Indeed, it is Piero's voice or, better, his gaze that mirrors itself in the two panels of the diptych and takes shape in the portraits of the Duke and the Duchess. We are presented with a kind of self-portait of the artist; not of his semblances, but a soul's portrait, visible to the sensible eye of the spectator only through the mirror of the artwork.

Piero della Francesca: The Duke and Duchess of Urbino, *c.* 1465–72. *Florence, Uffizi Gallery*

Reflected in the mirror or reproduced on a canvas, using Alberti's veil or Dürer's grid, the image is conform to the seen thing when one can appreciate the volume. In this "stage of the mirror,"[1] the *perspectiva artificialis* appears to be legitimated by two authorities reciprocally involved: a strictly static, geometrical conception, which accepts motion only as a result from overlapping congruent geometrical figures; the authority of the ego, which overlaps with and absorbs the observer's ego. Actually, what painting presents on the plane is always a 'still life'. As a matter of fact, this artistic conception can accommodate the *chiaroscuro*, able to render the "tactile values" of volumes, but not shadow moving continuously.

The painter's eye sees geometrically.[2] This is relevant for Leonardo as well as for Piero della Francesca, but their conceptions of geometry are different. Piero's geometrical gaze seems to be willing to capture the reflections of a divine *scientia visionis* in the harmony of perspective spaces, whereas Leonardo's, by pursuing the continuous metamorphosis of living forms, sees the need of more refined means to attain a "science of nature."

The Invention of Reality

If the invention of "artificial perspective" drives the painter to grasp the intelligence of nature and to simulate its forms accordingly, Leonardo asks the painter for more: "the mind of the painter must transmute itself into the very mind of nature and be the interpreter between it and art" (*Trattato,* I, 24v). Letting imagination take control of the perspectival means, "painting is a second creation made with imagination." As Leonardo (1890) explains:

> Such a proportion is between the imagination and the effect as between the shadow and the shadowed body, and the same proportion is between poetry and painting, since poetry set its things in the imagination of letters, and painting set them out of the eye from which it receives the similitudes as if they were natural. (*Trattato*, I, 2)

In his praise of painting as the most sophisticated form of expression, Leonardo issues painting with the power of "virtual reality." His theory of art pursues a "visual synthesis" between natural sensibility and mathematical understanding, what he calls *saper vedere*. This leads him to see, on the one hand, that the mathematics of his time is not apt to describe nature's living forms in their constant transformations, on the other hand, that "a veil or a flat glass" cannot be of any use in shadowing.

> It requires much more observation and study to arrive at perfection in the shadowing of a picture, than in merely drawing the lines of it. The proof of this is, that the lines may be traced upon a veil or a flat glass placed between the eye and the object to be imitated. But that cannot be of any use in shadowing, on account of the infinite gradation of shades, and the blending of them, which does not allow of any precise termination. (Leonardo 1877, p. 67)

The above passage is particularly instructive as it points to the difficulty for painting to simulate the *intelligence of nature.* Impermanence is the essential character

[1] The expressione is borrowed from Lacan (1949, p. 449).

[2] For more details, see Kemp (2011).

of shadows as well as of living forms, but numbers and geometrical figures are still. Leonardo's approach to geometry is both visual and dynamic.[3] He uses his unique talent for drawing to compensate for the deficiencies of mathematics, his anatomical drawings as "demonstrations." His engagement with nature's visual magic not only urges perspective to be released from the fixed view-point, it also creates the demand for what he calls "geometry which is demonstrated with motion" (*geometria che si prova col moto*), or "done with motion" (*che si fa col moto*) (*Codex Madrid* II, f. 107r).[4] As for a mathematical science of nature, Leonardo's concerns about shadows and motion ought to wait for projective geometry and infinitesimal calculus to be addressed.

The Mechanics of Nature

The experience of Narcissus has tended to be seen as an expression of a theory of knowledge forged by the Renaissance art. But which theory of knowledge is intended? How does the artistic vision affect the scientific representation? At first, Piero's impersonal attitude might be felt to advocate a vision via windowpane in tune with classical physics, where the observer is kept physically distant from the object of inquiry. It appears to convey dispassionateness, maintaining a special autonomy for the object seen. But in fact the flat glass, which perspective drawing sets at "the intersection between the eye and the thing seen," performs as a *semi-transparent mirror*, for it lets light rays through (from the scene to the eye), and reflects the eye on to the vanishing point. This 'dual' faculty of glass makes it explicit the *entanglement* of the seer with the thing seen in the artistic vision. Does it also apply to the scientific worldview? Can the observation of physical quantities be divorced from the 'lenses' available for its execution? To which extent can the observer be kept separated from the object of inquire?

The ideal determinism of the Newtonian classical mechanics conjugates the continuous evolution of an isolated (or closed) physical system with the complete description of its state at any given time. It follows that for each physical quantity one can assign a well-defined value to a system at a given time. Accordingly, classical *indeterminism,* hence probability, is a consequence of 'incomplete knowledge'. By contrast, quantum probability flows from Heisenberg's *uncertainty principle*, according to which the values of *incompatible quantum observables* cannot be simultaneously precise. Therefore, incompatible observables of a quantum system, such as path and interference, position and momentum, or the spin components, cannot be measured simultaneously with accuracy. This means that no experimental

[3]"The line—he writes—is similar to a length of time, and as the points are the beginning and end of the line, so the instants are the end-points of any given extension of time" (*Codex Arundel*, f. 190v).

[4]In some of his beautiful drawings, he manages to trace trajectories of complex motions, and to render figures in local movement through a sequence of images similar to film-frames (see Kemp 1990, p. 52).

arrangement which provides an answer to a yes–no question concerning one of them can also provide an answer to a yes–no question concerning the other. Thus, quantum physics creates the demand for a deeper understanding of the notion of "physical entity." Glass may help us see how.

A glass is a *semi-transparent mirror* that can either reflect or transmit light with the same probability. Consider a photon travelling horizontally rightwards that impinges on a glass inclined at an angle of 45° and propagate via two different paths. Quantum theory describes the photon as travelling in both paths. The state of the photon is given by the superposition of the two states associated with the two components of the original beam. Any observation, however, results in either the photon reflected or the photon transmitted, with the same probability. The photon does not split in two. Now, consider that two ordinary mirrors deflect the two components towards each other, while a second semi-transparent mirror at the intersection of the two paths combines the original beam. Such a mirror system, where two ordinary mirrors and two semi-transparent mirrors are placed alternately at the vertices of a rectangle, is called "Mach-Zehnder interferometer." If a photon enters horizontally and is not observed on its way through, it appears to emerge horizontally with probability one. This certainty measures *quantum interference*.[5] If the photon is observed in one of the two paths (within the interferometer), it will emerge randomly (either reflected or transmitted by the second glass). *Interference is lost*.

By providing evidence of quantum interference effects, this kind of experiment also raises questions about the nature of quantum interference. How does it take action to deflect the photon? Which path can be attributed to a photon inside the interferometer? How can a single (indivisible) photon travel both ways? It would be hardly wrong to admit that a single photon requires a counterpart to trigger interference. Might it be plausible to think of photons interacting with some 'virtual' counterparts? Within a perspectival view, this is not to say that real photons would interact with merely abstract possibilities. With his gift for pregnant expressions, David Deutsch called "shadow photons" what is involved in the interference phenomena: "If the complex motions of the shadow photons in an interference experiment were mere possibilities that did not in fact take place, then the interference phenomena we see would not, in fact, take place" (Deutsch 1997, p. 49). Actually, those shadow photons draw attention on the difficulty of discerning what is 'real' from what is 'virtual'. Does a real photon lose its 'reality' travelling through the interferometer? Or does quantum interference shed more light on the entanglement of the real with the virtual at the foundation of our knowledge?

[5] Classical thinking would expect the photon emerging randomly from the second semi-transparent mirror, either upwards or rightwards.

Shadows of the Multiverse

The idea that a photon or some other physical object could succeed in doubling its state and simultaneously travelling two paths brings to mind scenarios of science fiction. A number of fascinating films and novels treat the subject with remarkable truthfulness, presenting various kinds of "replicants" living their lives, unaware of having "doppelgängers" dwelling in other worlds. The simple mirror system considered so far can be made more complex and functional adding semi-transparent and ordinary mirrors, which open a great number of mutually alternative paths. Also, the distance between mirrors can be thought of as measuring a few meters or several light years. According to one interpretation of quantum physics, the universe is in fact a multiverse in which participates, beside the world of our experience, an infinite number of other worlds. All of the other parallel worlds, however, are not accessible to our inspection, they are not "observable" but through interference effects.

After the philosophy of nature was warned to beware of imagination (*fantasia*) by Galileo, and to lend credence to ghost-waves by Einstein, following science fiction might appear bizarre. Economy undoubtedly appears more reliable. Thus, David Deutsch (2011) calls attention to the "fungibility" of money and explains how quantum physics could refine the notion of fungibility, namely, of being identical for certain purposes. While different banknotes are fungible entities because they are identical in their function (when lending an amount of money no one requires having back the specific borrowed banknotes), photons' fungibility is subtler: it involves their being identical and yet distinct. Do they challenge Leibniz's principle of identity of indiscernibles? In fact, photons are more similar to dollars in bank accounts; unlike specific banknotes, they are not thought of as "physical objects," but rather as *states of things* or configurations of objects. Deutsch suggests calling them "configurational entities."

Returning to the interference experiment described above, now the photons can be regarded as configurational entities. When the photon encounters the first semi-transparent mirror, a configurational entity travelling two paths is generated, hence two parallel histories go on. The configurational entity is active until the photon is observed, which is to say, registered through an irreversible amplification act. In this sense, to observe means to let the virtual-real entanglement collapse, or to shift it to another level. Recalling what happened when Narcissus' embrace reached the pool or the Gorgon's gaze encountered Perseus' shield, it seems not unreasonable to conjecture that a "virtual" image could be so much effective as a "real" body. Can the rules of mythology be applied to physical reality? Quantum interference effects encourage a positive answer.

Perhaps the most convincing evidence of the reality, whether or not virtual, of the multiverse emerges from the key role of quantum interference in quantum computation. This "extension" of the classical theory of computation was an answer to the question about how to simulate efficiently a quantum evolution with a computing machine. The task was reckoned beyond the capacities of any Turing machine, even *probabilistic,* for the amount of information involved in describing the evolution of quantum states in classical terms grows exponentially with time. While the Renaissance painting encouraged geometry to explore the world of vanishing points beyond Euclid's elements, quantum physics has prompted computation to investigate the ways of quantum interference at the boundaries of Turing's world.

Considering the computational resources required to predict the outcome of a complex interference experiment, Feynman (1982) realized that the very act of performing the experiment could be tantamount to a complex computation. This led him to conjecture that it might be possible to simulate efficiently a quantum evolution, provided the simulator itself is a quantum system. Beside Feynman's conjecture, Deutsch (1985) proved that a *universal quantum computer* (universal simulator) could perform any computation that any other quantum computer could perform. Quantum computation exploits a multiplicity of parallel computational paths in superposition as well as quantum interference to amplify the probability of correct outcomes of computations. As mentioned above, quantum interference can make it possible to attain certainty by combining uncertainties. Mathematically, this possibility comes from complex numbers: since the *probability amplitudes*, which determine *real* probabilities, are complex numbers, they may cancel each other and produce *destructive interference* or enhance each other and produce *constructive interference*.

The basic structure of a quantum computer can be derived from the Mach-Zehnder interferometer. It provides a model of a computing machine operating on a single "qubit" that in two steps produces the logical identity. Like a photon can be in a coherent superposition of travelling in two paths, a *qubit*, which is the "building unit" of quantum information, can be in a superposition of the two logical states 0 and 1. The two semi-transparent mirrors, acting independently as *logical gates*, implement the two computational steps. Computational processes of this kind, however, have no classical analogs. Their power stems from the capability of letting mutually exclusive computational paths interfere and measuring the outcome at the convenient time. How can one trust the result?

If Brunelleschi's design asked Cosimo to trust the outcome of a computation never performed before, quantum computation asks mathematics to trust its design. In fact, to trust the result of quantum computing means to trust quantum physics. Bringing about the efficiency of *quantum algorithms,* what is called "quantum speedup," quantum interference also casts shadow over computational procedures. No quantum computation can be checked step-by-step; no computational path can be followed by the mathematician's eye. To some extent, a quantum computational path appears to be reminiscent of Leibniz's notion of "perception." As he writes in his *Monadology* [6]:

> If we imagine that there is a machine whose structure makes it think, sense, and have perceptions, we could conceive it enlarged, keeping the same proportions, so that we could enter into it, as one enters into a mill. Assuming that, when inspecting its interior, we will only find parts that push one another, and we will never find anything to explain a perception. And so, we should seek perception in the simple substance and not in the composite or in the machine. (*Mon.*, 17)

[6] All quotation of *Monadology* are taken from Leibniz (1989).

The “simple substance” is the monad and perception is the stuff that monads are made of. Similar to photons or qubits, monads can be thought of as “configurational entities” which are both identical and distinct. In fact, monads required Leibniz to test his “principle of the identity of indiscernibles”. As simple substances, monads have no parts, hence cannot differ in magnitudes. Their “natural changes” must come from an internal principle, and their “diversity must involve a multitude in the unity.” Such a multitude appears to be spanned by a changeable set of perceptions. As an example of a simple substance with an internal diversity, Leibniz alluded to “incorporeal automata” (*Mon.,* 18). Actually, if the idea of a universal computer can be traced to Leibniz’s visionary dream of a universal characteristic (Davis 2000), monads’ cosmos can be viewed as an ancestor of the multiverse:

> Just as the same city viewed from different directions appears entirely different and, as it were, multiplied perspectively, in just the same way it happens that, because of the infinite multitude simple substances, there are, as if were, just as many different universes, which are, nevertheless, only perspectives on a single one, corresponding to the different points of view of each monad. (*Mon.,* 57)

In its attempt to transmute itself into the mind of nature, the Renaissance painter made it clear that our three dimensional visual experience cannot flow from our sense of sight, since the picture taken by the eye and the picture created by painting are both two dimensional “virtual images.” In the age of artificial intelligence, quantum physics might suggest the three-dimensional experience of the world conveyed by our senses to be only one perspective of the multiverse, participating in a state of coherent superposition.

Seeing In

Although Ernst Cassirer (1963, p. 158) emphasizes that “it was artistic ‘vision’ that first championed the rights of scientific abstraction and paved the way for it,” the ways of art and science soon began diverging. Once numbers were assigned to geometrical points by Descartes and mathematics was ‘naturalized’ by Newton, the mechanical structure of the physical world replaced Alberti’s ideal architecture. After Alberti’s and Piero’s treatises on painting, the first mathematical account of the painters’ visual geometry was Girard Desargues’ *Brouillon project* (1637). The ‘light rays’ were replaced with a family of lines from a point (the ‘eye’), and Alberti’s vision through an open window became a projective space. Challenging the fifth Euclidean axiom, parallels met: the “vanishing points” were filled by the points at infinity. But Desargues’ *Brouillon project* would lay dormant for almost two centuries, whereas the developments of algebra, analytic geometry, and calculus sank the interest in this branch of geometry. However, there were some exceptions.

One exception was Abraham Bosse who, in 1648, first published Desargues’ theorem of homologous triangles. Bosse was not a mathematician but an engraver, fellow of the Paris *Académie Royale de peinture et de sculpture*. It might be interesting to recall that shortly after his *Manière universelle de M. des Argues pour pratiquer la perspective par petit-pied comme le géométral*, which included Desargues' theorem, was published, the 1651 edition of the *Traité de la peinture* by Leonardo went to press. Leonardo's writings chosen for the French edition could effectively support the idea that painting must rely on the 'judgement by eye' and can derogate from perspectival constructions. Such an argument was clearly against Bosse's insistence on geometrical analysis as a pre-requisite for proper 'seeing', shared by Bernard Lamy. Approximately in the same years, in a seemingly different cultural milieu, Leibniz distinguished the "verisimilitude" judged by the eye of the body (*Auge des Leibes*), from the "intelligibility" determined by the eye of the mind (*Auge des Verstandes*) (Leibniz 1906). What the mind's eye pursues are not only observable quantities, but primarily relations and processes independent of sensible experience. It seems plausible that Leibniz, like Abrahm Bosse and Bernard Lamy, wished to revise the *perspectival vision* of Leonardo and of the Italian painters of the fifteenth and sixteenth century in the light Desargues' geometry. Their goal was to move from a foreshortened view, always partial and imperfect, to a planimetric orthographic view from a point at infinity. Not surprisingly, a correspondence between Leibniz and Henry Oldenburg, secretary of the Royal Society, concerning a *nouvelle manière géométrique* related to Desargues' projective geometry, dates from the same period.

Through the Looking-Glass

The discussion between Leibniz and Oldenburg was about a booklet by Desargues, published in a few copies in 1641, titled *Léçons de ténèbres*. Their main interest appears to be in the method developed by Desargues in his study of the conic sections. In a letter to Leibniz, Oldenburg wrote:

> Suppose the Eye be at the Center of a sphere which is touched by a plaine at the Zenith, and beholds the plaine of a segment of the sphere, the side plaine at the Zenit, and beholds the plaine of a segment of a Center of a sphere, the said plaine is the base of a Cone whose vertex is the Eye. If the said circle be above the Horizon, and Parallel thereto, ye section on the touching plaine is a circle; but if not Parallel of the Horizon, it is an Ellipsis, if it toucheth the Horizon, and all other parts of it be above the same, it is a Parabola; etc. Seing many such elevated circles may touch the Horizon in the same point, their projection will be all *congruentes Parabolae*; but if one or more circles be partly above and partly beneath the Horizon, their projections are hyperbolas; and if they have the same common Chord in the Horizon, their projections are *congruentes hyperbolae*; if they be quite beneath the Horizon, they cannot be projected at all. (Oldenburg 1973, p. 559)

The point at issue in conceiving of conics as projective transformations of a circle is that, imagining the eye at the centre of the celestial sphere and a plane tangent to the sphere at the Zenith, the Euclidean space 'stretches' into infinity. Looking at any horizon point, one cannot reach the Euclidean plane tangent at the Zenith. The geometric figures release from the static Euclidean-Platonic models and transform into one another through continuous movements from one point of view. Accordingly, in Leibniz's thought, it is the principle of continuity that allows qualitatively different cases to be unified.

Looking for the *Geometric Characteristic*, Leibniz sees continuity as the general principle of geometric construction. Continuity does not concern things, but order: "it inheres in the order according to which everything can be allotted [*assignari*] its location [*locus*] at a given time." The concept of space is also transformed: "Space is the continuity in the 'order of co-existence' according to which, given the co-existence relation in the present and the law of changes [*lege mutationis*], the co-existence relation in any given time can be defined." Hence a line is the extension described by a point's motion (*linea est extensum quod describitur motu puncti*). In the light of continuity, what is shared by two points ideally separated becomes clear and distinct: "what the mind determines is called *direction*" (Leibniz 1995, p. 278). Conceiving of the Euclidean points as 'viewpoints', Leibniz[7] replaces the *res extensa* of the Cartesian space with a "subject extending oneself" (*sujet qui s'étende*):

> As the extension is just something abstract, it requires a thing to be extended. It needs a subject, as it is something concerning this subject, like the duration. It also presupposes something in this subject. It supposes a quality, an attribute, a nature that extends itself, stretches itself, that continues in this subject. The extension is the diffusion of such a quality or nature. (Leibniz 1840, p. 692)

When continuity allows a point to stretch out and extend over a line, it also allows the embryonic concept of 'quantity' to be brought about in its intuitive form. Whereas the intuitive interpretation regards a point as an 'ultimate unit', not further divisible into parts, Leibniz regards a point as a 'direction mark'. He draws from the point the direction of the tangent and, therefore, the movement of the curve. In his view, the rationale behind the law of continuity demands both unfolding the infinite multiplicity of possible cases and holding the logical value of the quantity while its intuitive meaning vanishes into a point at infinity, namely, in the concept of 'limit'.

The *lex continui* does not require dismissing the mirror of perspective, but breathing life into the glass out of which it is made. The mirror of Alberti and Piero della Francesca must be transformed not only to single out Euclid's or Plato's forms, *précises et arrêtée*, but also to take hold of the infinity of Desargues' configurations through all possible directions (Leibniz 1854, p. 244). The flat glass must be processed into a lens. It is by following the painter "into the very mind of nature" that the mirror *senza ragione* of Leonardo's *Atlantic Code* (f. 207r) can transmute itself into the "living mirror" of Leibniz's *monad*. Like Desargues (1864, p. 78), Leibniz viewed the infinity as the matrix of Euclid's geometric constructions as well as of Poussin's painted appearances.[8] In his philosophical and scientific reflection, he did not pay much attention to the mimetic representation but rather focused on the notion of "expression" which allows meaningful correlations to be recognized. For Leibniz, what is needed to establish a 'correlation function' is an *idea*, a particular

[7] In his essay *Examen des principes du R. P. Malebranche* [1711], in Leibniz (1840).

[8] Nicolas Poussin was the most appreciated French painter of the era. Although he did not take part in the debate on the need to use or to release perspectival constructions in painting, his work constituted a notable blenchmark.

direction of mind, connecting the thing with the cognition of thing. As he wrote to Arnould: “One thing expresses another, in my usage, when there is a constant and regular relation between what can be said about one and about the other. It is in this way that a projection in perspective expresses a geometric figure” (Leibniz 1969, p. 339). Accordingly, as for the conic sections, a circle can be expressed by an ellipse, a hyperbola, a parabola; as for the monads, they express the mutual relation of “all created things to each other, and each to all the others.” Since monads are thought of as simple substances endowed with an internal principle of change, which determines a multitude in the unity, each monad has relations that express all the others, and consequently, “each simple substance is a perpetual *living mirror* of the universe” (*Mon.,* 56).

In some sense, Leibniz’s idea plays the same role of Piero della Francesca’s lens in driving the soul’s gaze. Thus, the idea is a *medium,* inherent in human mind as well as in the universal substance, which brings about the rationale of all things behind their phenomenal accidents. It can be viewed as a ‘lens’ that focuses on geometrical shapes through algebraic equations, or that recognises the essential structure of conic sections through different projections from the same circle. All this implies a loss of confidence in a criterion for knowledge based on ‘verisimilitude’ and guaranteed by the sight, namely, by the *Auge des Leibes* and, in some way, a vindication of shadow.

As perceivable physical entities, bodies are “well-founded phenomena,” whose “moral certainty” is superior to that of phantasms or dreamlike visions, but such a certainty cannot be demonstrated. Like Desargues’ geometric projections and the shadows cast by illuminated objects, all bodies are devoid of material substance: they are nothing more than different appearances of the same substance. By reversing perspective, Leibniz suggests, when the light replaces the eye, the opaque body replaces the (three-dimensional) object, a different appearance of a phenomenon results, which, nonetheless, is “well founded” too. Moreover, moving the light cone, a multiplicity of appearances can be produced, all of them equally well founded. It is by embodying both the law of continuity and the geometry of vision that shadow acquires its cognitive power as expression of the *Auge des Verstandes*. Like the idea, the *lineamentum* of the Albertian architect, or the letter of credit of the Florentine banker, the shadow draws its value from its capability of performing under different guises, transmuting itself into the shape which is called to express. Its shape depends on the surface that it meets and on the angle of the light source: it can increase, diminish, stretch, shorten, deform, while the original relation, which forges its ‘identity’, is preserved.

The Doctrine of Shadows

For Renaissance artists, committed to facing the great challenge of reconciling Plato’s ideal order with the ‘authority of vision’, shadow remained elusive and ungraspable. Once released from a static, closed world, however, the shadow becomes an added value that continuously redefines itself through the variety of changeable relations projecting it into the visible world.

From a philosophical point of view, the shadow is what negates material substance to physical bodies. Hence, as a negation of "tactile values," it posed a 'technical' problem for the artistic representation. As a matter of fact, Leibniz overcomes a major stumbling block of central perspective, where shadow was absorbed in the perspective cone. Thinking of shadow as complementary to the perspective projection, Leibniz is led to recognize a *perspective renversée* in the *doctrine of shadows*.[9] Thus, perspective teams up with the science of shadows in dealing with motion and change, which Renaissance painting, tied to Narcissus' mirror, was not able to cope with. Now Narcissus can be freed from the embrace of his simulacrum, and art—not solely the art of drawing but, more generally, the *ars combinatoria* that, for Leibniz, is the key of the *scientia universalis*—can be released from the obligation to mimesis. An infinite universe unfolds and reflects itself in the infinity of monads' perspectives. Indeed, the monads' universe appears as a kaleidoscope of partial perspectives, unified through the continuous movement of their inner perception. Like shadow, a monad seems to extract images from its own essence. It does not mirror the visible, but expresses both the infinite multiplicity of forms and their unit.

Leibniz realized that Desargues' geometry and method derived from a more general theoretical standpoint, which questioned the egocentric attitude of one-point perspective. While in perspective drawing there is one central vanishing point, in which all parallel lines converge, and such a point mirrors the viewer's eye, Desargues' projective geometry adds points at the infinity along the whole circle of horizon: any point defined by a pair of parallel lines is a point at the infinity.

As shown by the passage of Oldenburg's letter mentioned above, a philosopher like Leibniz and an artist trained in projective geometry like Bosse were both fully aware of the capabilities of Desargues' method. This method allowed one to *demonstrate*—not simply to express in algebraic terms—that hyperbola, parabola, ellipse are all 'shadows' of a circle, projected on to the plane tangent to Zenith. It allowed the *Auge des Verstandes,* placed at the center of the sphere, to capture the substantial unit in the multiplicity of changeable forms. Desargues' method also validated that perspective switch from the eye to the light, or from the *Auge des Leibes* to the *Auge des Versatandes,* suggested by Leibniz in his *Précepts pour avancer les sciences*. Thus, it showed that a mimetic representation, when it is not a mere duplication of appearance, is a particular case of expression; more precisely, it is the expression of that who has been able to locate one's eye in the center of the infinite celestial vault, in the "right point of view." This creates the demand for a regulative idea "clear and distinct" to see beyond the similarities and differences of aspects: a lens within the mind.

[9]Cf. his *Préceptes pour avancer les sciences*, in Leibniz (1840, p. 170).

Conclusive Remarks

Mathematical principles and demonstrations involved in the construction of pictorial space, on the one hand, bring painting closer to scientific knowledge, on the other, take freedom away from art, by diverting the artist from the sphere of impulsive subjectivity. The 'flat glass' of *perspettivi* provides a metaphor for an intermediate plane, which appears to correspond neither to a mirror capturing all visual evidence of phenomena and flinging it back, independently of mind, nor to an imagination's screen unfolding all possible forms created by the individual mind.

The theoretical investigation into the notion of form as something continuously changing and, therefore, detached from the motionless abstract figures of Euclidean geometry, was initiated in the *artificial perspective* and carried out through Leonardo's studies on motion and shadows. Then, it reached full accomplishment in the *perspective-projective* model that pervades the Leibnizian *corpus*. Putting aside the image of an unchangeable, inert world, according to which shadows, in their evanescent mutability, could be conceived of as false appearances, or as effects of adventitious circumstances, the *perspective—shadow science* couple urges geometry to dispense with the static contemplation of rigid forms and paves the way for that process of transformation which would be completed by the Erlangen program. And yet, in Leibniz's world one can already appreciate a coherent model, both scientific and philosophical, compatible not only with the 'virtual reality' on which Brunelleschi and the Renaissance *perspettivi* placed their bets on, but also with the multiverse which poses a challenge to contemporary physics.

Indeed, Leibniz's *living mirror* does not encourage contemplating a fixed image captured on a flat glass, but passing through the glass to follow the mind's eye (*Auge des Verstands*) in its continuous search for the "right angle of vision," namely, for a certain point where it is possible to grasp, through the plurality of perspectives, through the anamorphoses, or through the opacity of shadow cones, a substantial unity and harmony; hence, to see "the purpose of him who has caused [it]" (Leibniz 1996, II.8). By putting Leibniz's monads in the place of Desargues' points at infinity, the very idea of space was changed. As a "co-existence order," space could be thought of as continuously transforming together with the shapes dwelling in it. Those shapes make it worth to replace the image of a unique reality drawn from the realm of visual evidence, with the image of a virtual reality emerging from symbolic structures. More precisely, all this leads to dismiss the flat glass related to one-point perspective, and to see reality through a lens capable of recognizing as scientific objects even those "configurational entities" whose temporary existence can only be ascertained bringing into focus their interference effects.

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Finally Fresh Air: Towards a Quantum Paradigm for Artists and Other Observers

Julian Voss-Andreae and George Weissmann

Introduction

More than a hundred years have elapsed since the early 20th century Relativity-Quantum revolution of physics, but a malaise about its meaning, and a deep search for clarity persists. Quantum Theory (QT) works extraordinarily well in every of the countless fields in which it has been applied, with stunning accuracy and with no exceptions to its validity in predicting statistically the observed behavior of physical systems. But at the same time, it has stubbornly defied any conventional model of what a physical system could possibly ''be like" in order to exhibit such behavior. QT has defied any attempt to model what quantum systems "are". This predictive success of a theory without an accompanying single coherent and visualizable model of what entities the theory is about is a novel situation in science, and the time it is taking to make sense of it is a testimony to the monumental challenges we face in this endeavor. It is for this reason that QT continues to be seen as a weird, spooky, inexplicable picture of reality.

For many decades after the heady and exhilarating period 1900–1935 most physicists shied away from the fundamental questions and the philosophical inquiry of the founders, who had thought so profoundly about the meaning of QT and asked such penetrating questions. This was partly because of the seeming impasse this kind of inquiry had encountered. Another factor was that there was so much work to be done to apply QT to all kinds of phenomena, that the challenge of understanding the foundations receded. The focus on practical applications led to a "shut up and calculate"[1] mindset that became the motto of those times (approximately 1935–1970), characterized by great progress in applications to various fields of study and technology, but

[1] David Mermin: "If I were forced to sum up in one sentence what the Copenhagen interpretation says to me, it would be 'Shut up and calculate!'".

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few new insights into the implications of QT for our understanding of the nature of reality. Then, in the 1970s, there came a renaissance of research into quantum foundations and quantum philosophy. Weissmann co-founded the 'Fundamental Fysiks Group' at the University of California, Berkeley, which played a role in kickstarting that renaissance.[2] That newfound interest in the theoretical foundations of quantum physics coincided with the emergence of a number of experimental groups that performed research driven by those fundamental questions. Today, a growing field of inquiry into the quantum foundations is producing important new insights, theoretically as well as experimentally, and appears to be preparing the ground for an emerging Quantum Paradigm. Books and other media, both technical and popular, are springing forth shedding light on many aspects of this.[3] The main obstacle impeding this thrust is the persistence of old presuppositions—unquestioned assumptions—and concepts built on these. Yet despite their shortcomings, in their totality these attempts bear testimony to the profound influence quantum insights are already having on our culture, even in the absence of a fully formulated, matured and consistent Quantum Paradigm.

The Classical Paradigm

Classical (or Newtonian) physics, the physics of the 16th to 19th centuries, is built on a set of unchallenged presuppositions, so self-evident that they are often considered 'common sense': The key presupposition of these is that I and the world are fundamentally separate, a concept known as *subject-object dichotomy,* made explicit by Rene Descartes in the 17th century. Accordingly, I, the individual "subject", experience myself as an actively knowing self which experiences a passively known, external, "objective" world outside and independent of being observed. The price of this Cartesian bargain was that the unity of being was sundered at the root of scientific thought. Initially, this did not seem to impede the development of science, which experienced 300 years of rapid growth, in a process of unification toward beautiful simplicity, accompanied by corresponding technological advances which greatly enhanced the control of humanity over nature, for better or for worse.

Moreover, the external world appears to consist of separate objects, which are thought to "exist" in a three-dimensional space. Their "existence" excludes the possible existence of other objects occupying the same space. These objects are considered to be existing continuously in every moment of time. A simple example is

[2]Kaiser (2011).

[3]Gary Zukav: "Dancing Wu Li Masters", Fritjof Capra: "The Tao of Physics", Nick Herbert: "Quantum Reality", Fred A. Wolf: "The Spiritual Universe", "The Dreaming Universe", Michael Talbot: "Mysticism and the New Physics" and "The Holographic Universe", Heinz Pagels: "The Cosmic Code—Quantum Physics as the Language of Nature", Itzhak Bentov: "Stalking the Wild Pendulum", Bohm and Hiley: "Implicate Order", Victor Mansfield: "Synchronicity, Science, Soulmaking", Carlo Rovelli: "Reality is not what it seems", Philip Ball: "Beyond Weird", Henry Stapp: "The mindful Universe" and "Quantum Theory and Free Will".

a ball flying through the air: Operating in the classical paradigm, we assume there is a 'real ball out there', and the light scattered off it and into our eyes, produces in our nervous system and brain the impression of a continually changing image of the same object at different points on its trajectory. But already the technology of a movie shows us that a series of discrete images ("frames") slightly changing from image to image can produce the illusion of continuity. And TV technology shows us that the illusion of continuity can even be achieved through a fast succession of momentary events, such as an electron beam hitting fluorescent chemicals causing discrete, localized flashes of light on a screen. The ball flying through the air is an example of a perceptual-conceptual paradigm creating a familiar reality, namely an object, out of an underlying process, namely a discontinuous series of events. This can serve as an introductory metaphor of how the operation of our classical paradigm gives rise to our familiar world of objects and people from a very different underlying reality.

Another important presupposition of the classical paradigm is that "observation" or "measurement" is assumed to be a passive process, through which we merely find out experientially what the objective situation is. Measurement is assumed to allow the gathering of information without affecting the observed. It is imagined as an objective process, which can be carried out either by direct sensory perception and subsequent mental recording of the outcome, i.e. using our body and its sensory organs as a measurement device, or by an insentient measurement and recording device. 'Objective' refers to the assumption that the observer's state of mind, for example his or her intent, are not assumed to play a role in the measurement.

The Classical Paradigm has no place for awareness, consciousness, mind or free will; it considers them as "epiphenomenal", only simulated by corresponding behavior.[4] Devoid of existence or meaning, they are not considered to be legitimate categories of scientific discourse, but merely terms of ordinary discourse, remnants of pre-scientific thought. One of the implications is that my physical body is all there is to me, and that when I die, everything that is "me", disappears together with my body's biological functioning.

These presuppositions which form the core of the Classical Paradigm, together with a corresponding classical (Aristotelian) logic, are "embodied", i.e. fully internalized and operating below the level of conscious thought. Our classical concepts, language and logic then keep us stably locked into this paradigm, and the resulting social consensus seals this confinement.

But it was only a question of time before science would have to face the unrecognized limitations of its basic presuppositions. That moment came at the beginning of the 20th century, when classical physics ran into its terminal crisis with decades of irreconcilable paradoxes and confusion.

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[4]The basic assumption of behaviorism.

Paradigms and the Structuring of Reality

The great wisdom traditions, for example Buddhism, Taoism, Vedic traditions, or Kabbalah, have investigated the nature and workings of human consciousness for millennia, and found that our experience is heavily conditioned by presuppositions. These presuppositions in their entirety determine a *paradigm*, an embodied world view within which the whole of life plays out. A paradigm, in this most fundamental sense, structures our experiential reality, including what we perceive and how we think. Our paradigms can have a severely limiting effect on us, a condition Buddhists refer to as "ignorance" and see as contributing to an unsatisfactory, alienated way of being, suffused by suffering, selfishness and conflict. The limitation is not so much the result of operating in a paradigm: it is the consequence of not being aware that we are operating in a paradigm, and what its presuppositions are. The traditions developed teachings and practices with the goal to lead the practitioners to free themselves of these limitations.

Presuppositions can be built on top of one another, which leads to a hierarchical structure of paradigms, with more specialized paradigms rooted in more general ones, and used for more specific domains. In general, the more fundamental a paradigm and its presuppositions are, the more unchallengeable these presuppositions seem. They may seem unchallengeable because they appear to be self-evident due to long term familiarity and habituation, making them not consciously noticed, and so not even subject to challenge at all. Thus, paradigms can form a "prison" that keeps our perceptions and thinking, our very sense of being, in tight limits. This is especially acute and problematic in the case of fundamental paradigms, which tend to operate at a conditioned, unconscious level, most especially since we are generally attached to them, i.e. "believe" them. The Classical Paradigm is an example of such a fundamental paradigm.

Einstein understood this and pointed out that our '*common sense*' presuppositions are nothing more than a culturally shared collection of prejudices, unchallenged assumptions programmed into the mind from an early age on. Every new idea one encounters in later years must combat this accretion of "self-evident" concepts. And it is because of Einstein's unwillingness to ever accept any unproven principle as self-evident that he was able to penetrate closer to the underlying realities of nature than any scientist before him.

In the context of science, it was Thomas Kuhn, in his groundbreaking work "The structure of scientific revolutions"[5] who introduced the concept of a *paradigm* as "a comprehensive model of understanding that provides a field's members with viewpoints and rules on how to look at the field's problems and how to solve them". By reviewing and analyzing the way science had historically developed, he showed that the traditional idea of science progressing through a steady accumulation of knowledge was inaccurate. Instead, science makes its greatest advances in discrete, revolutionary steps, so-called *paradigm shifts*, which are necessitated and prompted by the gradual accumulation of insoluble inconsistencies and other deficiencies within

[5] Kuhn (1962).

the old paradigm. A new paradigm then emerges by a stroke of genius, usually first resisted by the field but gradually gaining ascendancy and, in time, near-universal recognition. The new paradigm recontextualizes the whole field of knowledge to which it pertains, and opens up an explosion of new insights, research methods, and results. The phase of science between such revolutions, which Kuhn calls "normal science", consists of filling in the details of the new map, until eventually it approaches its own limits.

Such scientific paradigms are of an intellectual, conceptual nature, more than of an embodied, experiential one.[6] Their explicit formulation is usually the task of philosophers of science. Such paradigms determine the concepts in which the theories are to be formulated, what is to be observed and how it is to be conceptualized, the kind of questions that can be meaningfully asked, the possible form of answers in relation to this field, and how the results of scientific experiments should be interpreted.

As such, paradigms are by their nature frameworks. They are not true or false; instead they can be more or less useful for specific purposes. All statements of fact are relative to a given paradigm, and their truth or falseness is therefore strictly relative to that paradigm, and not absolute. In fact, the same statement can sometimes be understood in completely different ways in different paradigms, or make no sense in yet another paradigm. This makes inter-paradigmatic communication challenging, and yet vital for our survival as a species. A basic openness, and willingness to listen, try it out, are necessary, but still not sufficient conditions for inter-paradigmatic communication. Metaphoric or poetic use of language, and art in general, can help bridge the gap.

A Quantum Physics Experiment: Buckyballs Reveal Wave Behavior and Inspire Art

George Weissmann and Julian Voss-Andreae met at the ETH Zürich's *Cortona Week* in Italy in 1999 where Weissmann presented his research on *Quantum Physics and Parapsychology*. Voss-Andreae made his very first sculpture at this interdisciplinary workshop intended for natural scientists who want to explore beyond the confines of their fields.[7] Voss-Andreae was at that time a graduate student in physics participating in a seminal experiment[8] led by Markus Arndt in Anton Zeilinger's research group in Vienna, Austria. Originally proposed by Roger Penrose,[9] the experiment probed the

[6]However, when scientific paradigms are adopted, internalized, believed and embodied, they may, and frequently do, have experiential implications.

[7]Cortona Week was an annual seminar taking place in Cortona, Italy, during the years 1985–2017. Created to foster transdisciplinary and intercultural competence in natural scientists and engineers, the seminar extended their expertise to a much broader scope of other domains such as spirituality, literature, psychology, fine arts, bodywork, and intercultural knowledge.

[8]Arndt et al. (1999).

[9]Markus Arndt, private communication.

wave aspects of the then largest particles to ever reveal quantum mechanical wave properties, Carbon-60 “Buckminsterfullerenes” or *buckyballs*. We will describe this experiment in some detail to illustrate how insights leading to the Quantum Paradigm are gained and how this experiment has inspired Voss-Andreae’s artistic path.

While Newton assumed that light consists of particles, Thomas Young demonstrated in 1802 light’s wave-like properties. His famous ‘double-slit experiment’ masks a beam of light to allow only two small portions of it, typically in the shape of rectangular slits, to fall onto a screen to allow observation of the resulting light pattern. Light imagined as consisting of a stream of bullet-like particles would be expected to create two separate areas of local brightness, the images of the two slits, but that is not what is seen when we perform the experiment. Instead, the light emanating from the slits creates a distinct striped ‘interference pattern’ with more than just two separate areas of maximum local brightness (Fig. 1).

All features of the interference pattern can be predicted by modeling the light as the sum of two electromagnetic waves, one emanating from each slit: in the center of the screen, where the distance to each slit is exactly the same, the two light portions arrive exactly in phase; whenever one wave’s electric field is at its maximum so is the other wave’s, and if one wave’s electric field is at its minimum so is the other one’s—the observed sum of the two contributions is an area of maximum brightness. If we, however, move a little bit to the left or right on the screen, away from the exact middle, we soon get to a point where the two wave trains are shifted by exactly one half of the light’s wavelength with respect to each other. Now, whenever one wave is at its maximum, the other one is exactly at its minimum and vice versa—what we observe in such an area is the absence of light because the two oscillating electric fields of each wave cancel each other out exactly, at every moment in time. If we move away from the screen’s center yet a little bit further, the situation is reversed again—the difference in length of the two wave trains is now exactly one

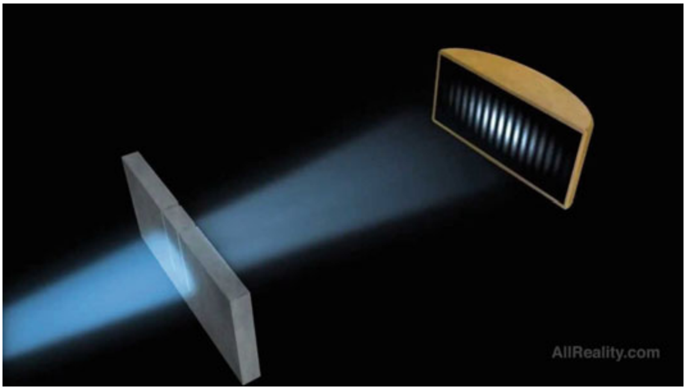

Fig. 1 The double-slit experiment. A light beam, coming from the lower left, penetrates the double-slit and the interference pattern is observed on the screen (top right)

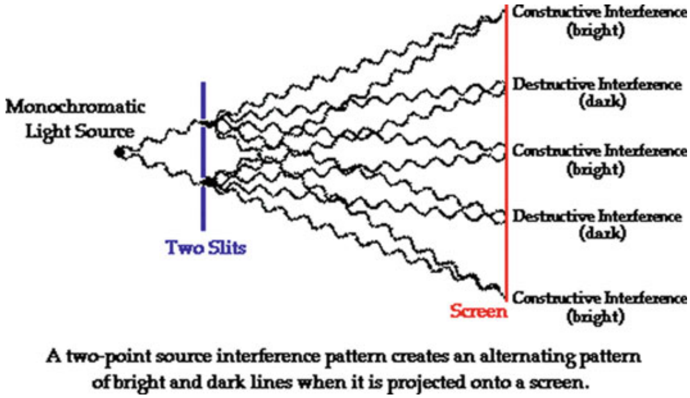

Fig. 2 How the wave property of light and matter explains the appearance of the interference pattern

whole wavelength so the waves arrive in phase yet again, resulting in another area of maximum brightness (Fig. 2).

This experiment seemed to have settled the issue of whether light consisted of particles, as Newton had hypothesized, or had wave nature, in favor of the latter. But a hundred years after the double-slit experiment with light was performed for the first time, Albert Einstein established that even though it remains true that the propagation of light through space and time is perfectly modelled as a wave, its observation can only be modelled if imagined as a particle: If we replace the screen in the above experimental setup with an extremely sensitive light detector and dim down the light to almost darkness, we will observe discreet 'clicks' in the detector, each corresponding to the detection of a single photon, the particle of light. Even though the light can be so weak as to allow passage of an arbitrarily long time between the detection of each photon, the pattern that will be recorded over time will still satisfy the distribution of the same interference pattern—if we just wait long enough, the single photon detections will accumulate to create the same statistical pattern as seen on the screen in Fig. 1 (Fig. 3).

In the years leading up to the year 1999, the development of several atom optics techniques and advances in the field of semiconductor technology, as well as the unexpected discovery of Carbon-60 buckminsterfullerene all contributed to the possibility of using buckyballs to demonstrate quantum mechanical wave properties on that unprecedented scale, two orders of magnitude more massive than anything ever before. The buckyballs, soccer ball-shaped molecules consisting of 60 carbon atoms with a diameter of about 1 nm,[10] were subjected to a double-slit-type experiment. The screen with the slits,[11] about 1 m away from a source that evaporates a beam of

[10]One nanometer is 10^{-9} m or one billionth (=1/1,000,000,000) or 0.000000001 m.

[11]The slits in our experiment are for technical reasons not just two, but a "diffraction grating" with many slits. The concept of the double-slit can be expanded in a straightforward fashion to a series of slits, not changing any of the reasoning above that leads to the interference pattern.

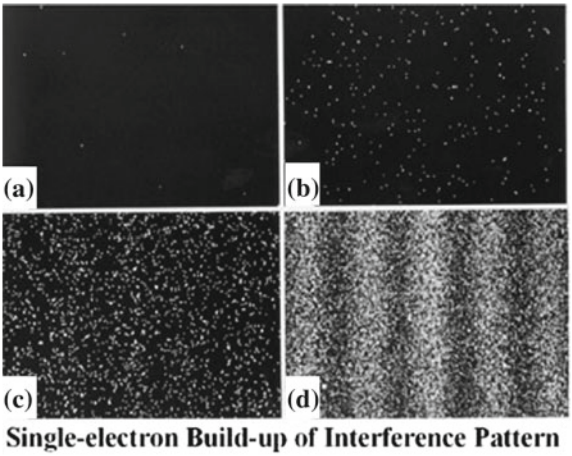

Fig. 3 Successive accumulation of observed particles (here electrons) shows that the individual 'events' (light dots) adhere to the overall probability distribution as predicted by Quantum Theory. The individual events collectively create the interference pattern. QT does not, however, predict the exact position of each individual particle observation

hot buckyballs into a vacuum, has 50-nm wide slits, 100 nm apart from each other (Fig. 4).

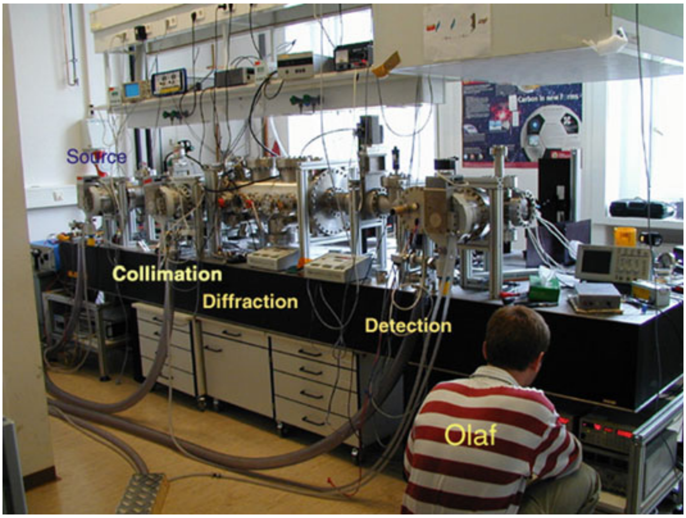

Fig. 4 Photo of the experimental setup used to reveal quantum mechanical wave behavior of Carbon-60 buckyballs (Vienna 1999)

The molecules fly at typical airplane speeds[12] through the vacuum, one at a time,[13] and fall about one millimeter in the gravitational field while traversing the apparatus, just as a macroscopic ball would at that speed. If we mentally scale up the experiment so that the buckyballs assume the size of normal soccer balls, they would be detected at the moon and the distance from one slit to the next would be about the size of a soccer field. What corresponds to the detection screen in Young's 1802 experiment is, in the 1999 Vienna experiment, a movable stage that scans the width of the molecule stream with a laser beam pointing upwards along the direction of the slits (Fig. 5).

Focused to a narrow width of a few micrometers, the molecules passing through absorb the light and eject an electron in response. The now charged molecule can be controlled via electric fields and is accelerated into a particle detector to be counted individually. And the accumulated individual events indeed conspire to create an interference pattern that perfectly matches the predictions of QT (Fig. 6).

The fact that the count rate drops down next to the central maximum and then goes up again is the telltale sign for wave interference. The only way to explain the experimental results in terms of the Classical Paradigm would be to conclude that a single buckyball (or, more accurately, the entity that is later detected as a single buckyball) goes through two openings at once—two openings that are a hundred times farther apart than the diameter of one buckyball.

The shape of the buckminsterfullerene, called 'truncated icosahedron' in mathematics, was first classified by Archimedes around 250 BCE and the oldest image existing today is a print from about 1500 AD by Leonardo da Vinci for a renaissance book on mathematics (Fig. 7).[14]

This image of a truncated icosahedron with open faces inspired the first sculpture Voss-Andreae made after graduating from art college in 2004: Recreating the structure from bronze sheet, the cutouts inside the faces were used to create a sequence of buckyballs of diminishing size, nested inside each other. The buckyballs where attached in place by running thin rods radially through the 60 vertices. Intriguingly,

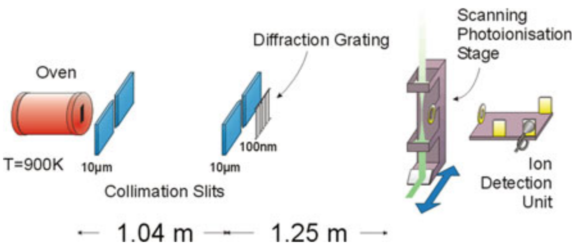

Fig. 5 Schematic of the Vienna experiment setup

[12]Typical velocities of about 600–800 km/h corresponding to de Broglie wavelengths of about 3 pm (3×10^{-12} m).

[13]The detected buckyballs are separated by a typical distance of 0.1 mm or 100,000 times their diameter.

[14]Luca Pacioli "Divina proportione" (Divine proportion), composed around 1498 in Milan and first printed in 1509.

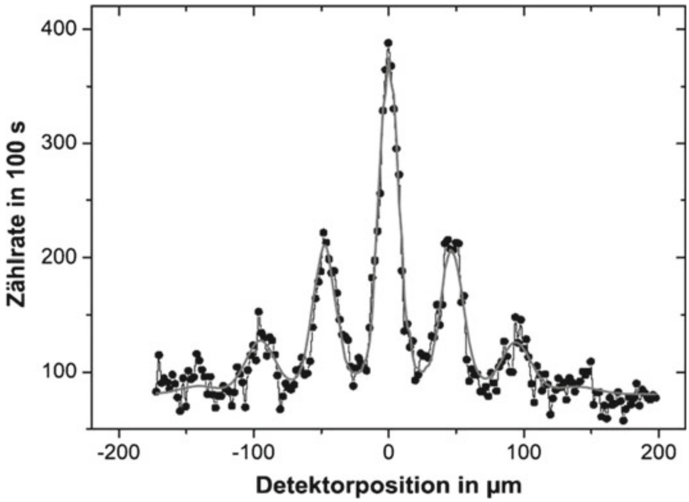

Fig. 6 The interference pattern of buckyballs [Image taken from: Arndt et al. (2001)]

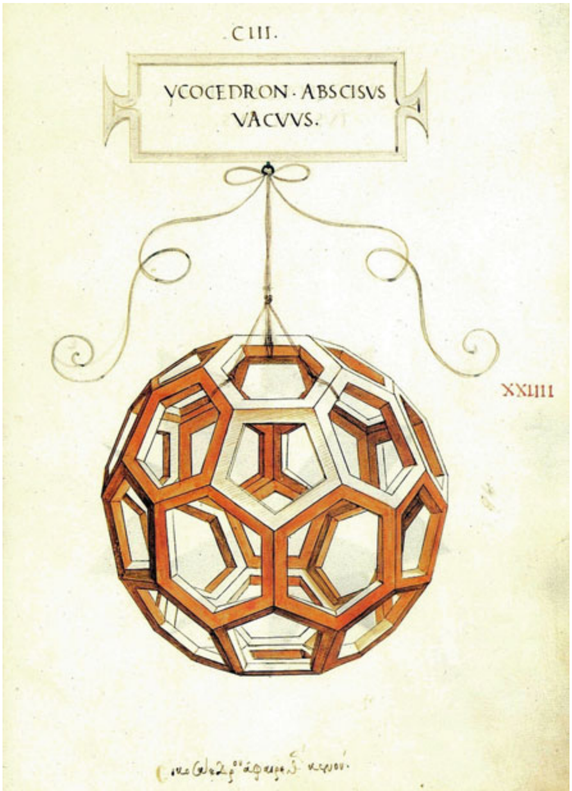

Fig. 7 The shape of the buckyball. A truncated icosahedron drawn by Leonardo da Vinci

the resulting shape of "Quantum Buckyball" echoes the mathematical structure of the wavefunction encoding our knowledge of the potentialities of the buckyballs in the Vienna experiment: the wave fronts are a series of concentric spheres, moving outwards (Fig. 8).

A sculptural object occupying a considerable volume of space while consisting of comparatively little material is an apt metaphor for matter—the ephemeral energetic dance that gives rise to our experience of matter as solid, impenetrable and lasting. Voss-Andreae subsequently created larger buckyball sculptures from steel consisting only of the solid's edges, culminating in a 30-ft (9-m)–diameter piece first installed in 2006. Now permanently sited in a picturesque private park in Oregon, the buckyball hovers above arm's reach over a sloped terrain with a small creek running under it. Suspended by three majestic Douglas firs that grow through the structure, the buckyball's orientation was chosen such that two opposing hexagons, one at the bottom and one on the top, are lying between the trees on horizontal planes. As of this writing, the sculpture has been at that location for over 10 years, growing slowly upwards together with the trees. The reason that such a basic shape succeeds as a piece of art is its placement within nature. Despite its considerable size, the structure's visual impact is quite subtle due to the relatively thin 2-in (5 cm) tubing and the natural color of the corroding steel. The trees intersecting the buckyball dissolve the mathematical shape, symbolizing quantum physics' revelation that our common-sense perception of matter as having well-defined boundaries is ultimately an illusion (Fig. 9).

Fig. 8 Julian Voss-Andreae. *Quantum Buckyball*, 2004. Bronze with patina, diameter 24″ (60 cm). Location: Private Collection, Portland (Oregon)

Fig. 9 Julian Voss-Andreae, *Quantum Reality (Large Buckyball around Trees)*, 2007. Steel and trees, diameter of the steel structure 30 ft (9 m). Location: Private collection, Portland (Oregon)

Special Relativity associates a specific amount of energy with each portion of matter.[15] QT assigns this energy a specific frequency[16] which, by virtue of relativity, becomes a wave when moving. Therefore, any portion of moving matter is mathematically described as a wave, with a specific *de Broglie wavelength*.[17] Anton Zeilinger once remarked jokingly during one of the weekly meetings of his research group in 1999, that the fact that the de Broglie wavelength associated with a walking person of fairly typical mass and velocity happens to be approximately the Planck length,[18] cannot possibly be a coincidence. Zeilinger's remark highlighted a yearning, often expressed in the group's discussions, to understand what the unobserved wavefunction 'really is' and how it feels like—"it would be great" was an often-heard wish, "to send a philosopher though the double-slit experiment". The philosopher could, after diffraction and subsequent detection, tell us what exactly happened in there. While completely out of current technological reach, this wish led to the idea of using larger biomolecules as probes in future experiments. Voss-Andreae spent some time researching viruses and proteins as potential candidates for such a follow-up exper-

[15] $E = mc^2$.

[16] $\omega = E/\hbar$ from $E = \hbar\omega$.

[17] $\lambda = h/(mv)$ from $p = \hbar k = h/\lambda$.

[18] A very small distance (1.6×10^{-35} m) generally assumed to be of fundamental importance in physics.

iment[19] and, getting excited about protein structure, he embarked two years later on his career in art by creating sculptures based on these molecular building blocks of life.[20,21] Soon after that, the old dream of sending a person through the double-slit, to experience for oneself what it feels like to fly through space as a delocalized wave package in a ghostly superposition with oneself, inspired Voss-Andreae to dream up such a sculptural metaphor. Modeled on the shape of a stylized human walker, "Quantum Man" consists of numerous vertically oriented parallel slabs of steel with constant spacing reminiscent of the wavefuntion's mathematical structure.[22,23] Like a quantum-age update of classical, monolithic and solid sculpture, this style creates an impression of a three-dimensional topological map, evoking the fundamental scientific act of the measurement, imposing the Cartesian coordinate system onto the organic structure of the world. The slabs are connected with short cylindrical pins of steel. These seemingly irregularly positioned pins between the regularly spaced slices evoke the random-appearing, indeterminate events encountered in quantum physics (Fig. 10).

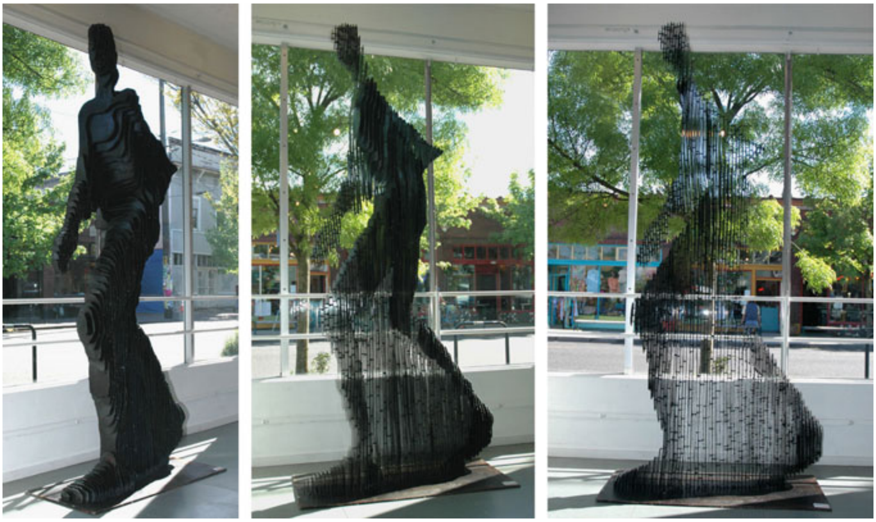

Fig. 10 Julian Voss-Andreae, *Quantum Man*, 2006. Steel with patina, 100 × 44 × 20 in (2.50 × 1.10 × 0.50 m). Public collection of the City of Moses Lake, Washington

[19]Frank Grotelüschen: "Die Quantenwelt wird sichtbar. Anton Zeilingers physikalische Experimente stoßen an die Grenzen des Vorstellbaren" Berliner Zeitung (Wissenschaft—Seite W01) December 6, 2000. https://julianvossandreae.com/wp-content/uploads/2000/12/2000_12_6_BZ.pdf.

[20]Voss-Andreae (2005).

[21]Voss-Andreae (2013).

[22]Ball (2009).

[23]"Dual Nature," Science **313** (2006) p. 913. https://julianvossandreae.com/wp-content/uploads/2006/08/2006_08_18_Science.pdf.

When approached from the front or back, “Quantum Man” seems to consist of solid matter, but when seen from the side it virtually disappears because only a small fraction of material can be seen at this angle. The visual effect this style produces is striking and echoes quantum physics’ paradoxical nature and its critical dependence on the observer’s point of view. The effect is even more pronounced in the second version, using laser-cut stainless-steel slabs: the light zig-zagging between the polished slices lets the viewer perceive moving objects behind the sculpture even at angles where no direct line of sight exists. In addition, the light reflecting off the laser-cut edges draws the sculptural volume into space. Through its highlights and shadows still clearly reading as the depicted body,[24] the sculpture becomes a ghostly ‘after image’ of the body, now completely unified with its surroundings.[25]

Voss-Andreae experimented with different ways of representing the human figure through parallel slices, including more realistic rendering as well as exploring other slicing directions.[26] In 2012, he made his first work in a series that continues to endure to this day, rendering the human body naturalistically and in vertical slices oriented along the direction of the gaze.

This orientation results in the sculptures’ disappearing exactly when the viewer crosses the figure’s ‘line of sight’. Instead of a literal analogy to the mathematics of quantum physics, this new body of work, while using the same formal device of creating a solid body from thin parallel slabs of metal, now speaks to the conscious mind observing his or her world. It is not enough to look at a static image; the viewer must actively experience the work by surrounding it and allowing the full image of the work to emerge through continued observation. A 2014 installation for the University of Minnesota’s Physics and Nanotechnology Building titled “Spannungsfeld” (literally “tension field”[27]) places two monumental figures in meditative kneeling poses, a man and a woman, facing each other. Sliced in the same direction of their gaze the two figures emerge as a pair of polar opposites, like manifestations of a single underlying oneness, a ‘quantum field’, as it were. Object and subject appear as symmetric, as merely different sides of the same coin (Fig. 11).

Voss-Andreae’s 2018 work “Elective Affinities”[28] takes the next step toward symbolizing our underlying connectedness by merging two human bodies into one. A standing male and female figure leaning against and pushing each other, in a pose

[24]This effect even allows to clearly discern faces and facial expressions despite the drastic reduction of visual information this approach entails.

[25]A good visual introduction can be found at https://www.facebook.com/thisisinsiderart/videos/719258618244705/.

[26]Voss-Andreae (2011).

[27]The German title of the installation originated in physics but is used in contemporary German almost exclusively in a metaphorical sense, implying a dynamic tension, often between opposites, that permeates everything in its vicinity.

[28]“Elective Affinities” (German: “Die Wahlverwandtschaften”) is a novel by Johann Wolfgang von Goethe, published in 1809. The title is taken from a scientific term once used to describe the tendency of chemical substances to combine with certain other substances in preference to others. The novel is based on the metaphor of human passions being governed or regulated by the laws of *chemical affinity*.

Fig. 11 Julian Voss-Andreae. *Spannungsfeld*, 2014. Stainless steel and granite, 12′ × 70′ × 6′ (4 × 21 × 2 m). Physics and Nanotechnology Building, University of Minnesota (Minneapolis, Minnesota). The two figures manifest as a pair of polar opposites from an underlying oneness. Object and subject are merely different sides of the same coin

suggesting opposition as much as attraction. The hands, pushing into the opposite figure, seem to merge with the other body. The heads morph into one, with the faces touching, sharing common metal slabs which makes full visual separation of the two bodies impossible.

Elements of an Emerging Quantum Paradigm

The Wavefunction

All the measurement information which an observer has gained about a physical system through past measurement interactions is encoded in a mathematical object called the wavefunction.[29] All physical questions the observer could ask within the context of QT about his[30] possible future measurements can be answered from knowing this

[29]The general term is 'state vector'.

[30]Or 'her'. Let us assume, for the sake of brevity and without loss of generality, that this and the other hypothetical observers we use in this article, identify as male.

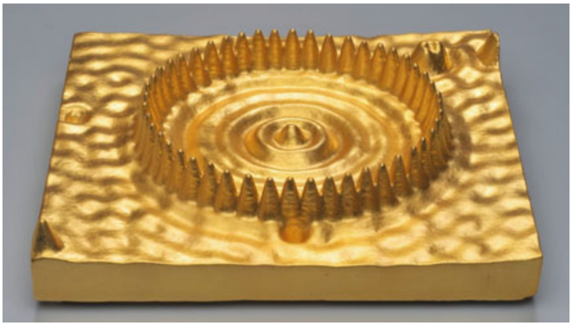

Fig. 12 Julian Voss-Andreae. *The Well (Quantum Corral)*, 2009. Gilded wood, 3″ × 13″ × 12″ × (6 cm × 34 cm × 31 cm). This object was made by using data from a 1993 landmark experiment [Crommie et al. (1993)] arranging single atoms into a circle

wavefunction. Let us exemplify this with the simplest case of a quantum system, a single particle such as the buckyball in our experiment described above. The "wavefunction of this particle"[31] is the quantum mechanical equivalent of the function describing the motion of the center of mass, in Newtonian physics an infinitesimally small point. In QT, the wavefunction is not point-like but spreads out over space, giving it for example the ability to penetrate two neighboring slits in our experiment. But QT does not tell us what the system's ontic[32] properties are, if such even exist. The wavefunction cannot be considered to be representing what the system itself "is", only how it manifests to an observer via its interaction with him. The common shorthand notion of the wavefunction being the "wavefunction of a particle" is misleading, suggesting that such a particle exists even when not observed. It creates a false duality between observer and observed and imputes properties to a particle which that "particle" in fact only "has" when it is observed. The idea that the particle exists, in and of itself, and has definite properties "between" observations, is incompatible with QT. What the wavefunction does do, however, is to inform the observer what values a possible measurement can yield, and what probabilities to expect for these values to be measured (Fig. 12).

Measurement Problem and Information

One of the paradoxes of QT that has doggedly bedeviled a self-consistent interpretation of QT, namely the so-called "measurement problem", is based on the fact that a measurement instrument is just another physical object like any other and should be treated as such by QT. Then why does the wavefunction of a quantum system S evolve continuously in time according to the rules of QT, while when S interacts with a measuring instrument, its wavefunction "collapses", i.e. changes discontinuously? According to the laws of QT, the wavefunction of S becomes correlated with that of the measuring instrument when they interact but should never collapse. That would,

[31]Representing its position, the so-called "center-of-mass-wavefunction".

[32]Real, or factual existence.

however, entail that a measurement, with a determinate outcome, is not possible. But since measurements obviously do occur, and have determinate outcomes, the collapse had to be postulated as an ad hoc rule in QT. Most physicists who thought about these issues felt uncomfortable with this "measurement problem"; that there should be two kinds of time evolution of the wavefunction, a continuous evolution dictated by the Schrödinger equation 'while no one looks' and a discontinuous 'collapse' if a measurement is performed—despite the fact that any measuring instrument is in all other respects just another macroscopic quantum system.

But if we interpret QT within the Quantum Paradigm, where the wavefunction is regarded as a mathematical construct encoding past measurement information and not an ontological objective reality, then each new measurement calls for a substitution of the previous wavefunction with the current one encoding the new information gained by the measurement. The mysterious "collapse" is now recognized as simply an information update. This understanding of the wavefunction as representing *information*, and therefore of QT as a theory of information, is now considered by most researchers in quantum foundations the most promising and practically useful interpretation of QT. But most of them still don't take the final logical step and relate information to experience; when the fullness of experience is reduced to conceptual abstractions, then experience reduces to information, void of meaning. The informational interpretation which is becoming dominant as an interpretation of QT, while close, is still one crucial step removed from the Quantum Paradigm, from making contact with existential reality.

In this, and many further examples which we elaborate elsewhere,[33] the Quantum Paradigm solves the foundational inconsistencies and paradoxes of QT that result from interpreting it classically, in particular with the presupposition of objectivity. What all this implies existentially is that the world is not "out there" with us (our mind) being "in here". The classical dualism between external objective reality and our internal subjective experience of it is generated by the inappropriate application of the Classical Paradigm.

Relationality

The second fundamental "paradox" of QT when interpreted within the Classical Paradigm with its Cartesian subject-object split is the "Wigner's friend paradox",[34] a scenario involving an indirect observation of a quantum measurement. In QT, an observer O treats not only the system S that he is observing, but also any other observers (along with their measuring instruments) as quantum systems. If we analyze the quantum treatment of a situation where a second observer O' is observing O in the process of observing S, and apply the usual quantum rules, it turns out that

[33] Weissmann and Larson (2017).

[34] Also known as the "second observer" paradox.

O' and O end up with different wavefunctions for S.[35] This "paradox" is inevitable, given the rules of QT for construction of wavefunctions on the basis of data. As long as we are trying to interpret QT within the Classical Paradigm, which regards the wavefunction as objectively given, this is indeed a paradox, because the wavefunction should then be unique, and not observer-dependent. The conclusion from the above considerations is that the wavefunction is always relational, i.e. relative to a given observer. There is no objective or absolute information about S itself, and in fact, the assumption that there could be (possibly as yet unknown) objective properties[36] of S is irreconcilable with observed quantum behavior. This simple and elegant resolution of the "Wigner's friend paradox", discovered in the 1990's by Carlo Rovelli and others, is a generalization of the relativity of space and time which Einstein discovered and formalized in his special relativity theory.

The Observer-Participator

The purely passive observer of classical physics, who just observes what was already the case before the observation, is in QT elevated to the observer-participator[37] who plays an active role in creating the event history of the system, and in the process, of himself. John A. Wheeler used the suggestive terminology of question and answer: The observer asks a question of the universe[38] by means of his measurement operation, and the universe answers this question by yielding the outcome of the measurement. This process of question and answer creates something genuinely new in the universe and is therefore truly 'creative'; the observer has the freedom of choice what question to ask, and the outcome of the measurement is in principle not predictable from the state of the system before the measurement.[39] The observer is thus a co-creator of his reality.

Entanglement and Wholeness

Let us consider a "composite" quantum system consisting of two separate subsystems S_1 and S_2 described by a common wavefunction. We measure the observables of each subsystem separately. If S_1 and S_2 are not interacting, then a measurement of one subsystem will not affect the portion of the wavefunction describing the other one; the two systems can be thought of as independent. But if the two subsystems do interact,

[35] For a time at which O has already observed S but O' has not yet, only the wavefunction belonging to O has yielded measurement results for S that are definite.

[36] Other than conserved ones.

[37] A term introduced by John A. Wheeler.

[38] The whole observable universe is ultimately one large quantum system.

[39] And cannot even be thought of as determined at all, a property of QT called *contextuality*.

then the wavefunction will become an inseparably connected wavefunction of both subsystems. A measurement of the observables of one of the subsystems will in that case also affect the expected measurement probabilities of the other one. Even if S_1 and S_2 are far enough from each other to exclude any causal influence between them,[40] a measurement of one system will affect the other one's measurement outcome. S_1 and S_2 are called 'entangled'. Every time two quantum systems can interact, they become entangled, even if they were initially not entangled.

Entangled systems cannot be considered to be separate, since their respective observables are mutually correlated. Quantum systems have an aspect of wholeness which would not be classically suspected on the basis of being "separate, independent particles". This wholeness extends to any quantum system, even the whole observable Universe. Separateness thus turns out to be a classical illusion, rendering the concept of reductionism, the assumption that a whole is nothing but a sum of its parts and that the behavior of complex systems can in principle be understood by considering their separate components and interactions, obsolete. Separateness and reductionism are replaced by holism, the recognition of wholeness as a basic feature of reality (Fig. 13).

Fig. 13 Julian Voss-Andreae. *Elective Affinities*, 2018. Stainless steel, 89″ × 82″ × 26″ (226 × 209 × 66 cm). Private collection (Palm Springs, California). Two human bodies merging into one symbolize our fundamental connectedness—our apparent separateness is an illusion

[40]Causal influences cannot spread faster than the speed of light.

Quantum Indeterminacy, Randomness and "Psi"

All the laws of classical physics are deterministic. Once the configuration of a classical system is given at one moment in time, its whole past and future is completely determined and in principle calculable. For human existence this seemed to imply a complete lack of free will: human and animals were just automatons, with completely pre-determined reflexes. Full embodiment of such a worldview would obviously have grave consequences for human societies, for then no one is responsible for their actions. Quantum theory demolishes this determinism: knowing all that can be known about a system now, namely its wavefunction, does not allow us to predict, even in principle, the outcome of the next measurement. While the probability of any possible outcome is determined by QT, the outcome of any specific measurement we make, is not (see Fig. 3 for an example). The only regularity we can predict is that if we repeat the same experiment, measuring the same observable many times, then the average outcome will be the one predicted by QT. There is no other regularity or order in the individual measurements. This *quantum indeterminacy* is characterized by the impossibility of influencing the probability of measurement results by any causal means. This indeterminacy is typically interpreted as randomness, i.e. any pattern or predictability is thought to be absent from the sequence of individual measurement outcomes. But randomness is not the only alternative to determinism, as can be seen by considering the concept of free will: An action caused by free will, as we usually understand it, is neither causally determined, nor is it random.

Let us consider an experiment, where a quantum system is prepared in the same way every time and a specific observable is measured every time. An example would be the measurement of the spin of electrons in a beam, which has a binary result: spin 'up' or spin 'down'. Randomness of quantum events in this case would mean the absence of any pattern or predictability in the sequence of measured 'ups' and 'downs'. Quantum indeterminacy denies the possibility of any causal influence on individual measurement outcomes. Randomness implies there is no pattern in the sequence of repeated measurements, causal or not. If there are any (non-causal) factors that influence such a pattern, then that would contradict randomness, but not quantum indeterminacy. There are a number of very carefully executed experiments, by a number of different researchers, who have set up such an experiment but, in addition, asked participants to "influence" the outcome of the binary sequence and to somehow temporarily "shift" the pattern of 'ups' and 'downs' away from the, say, 50:50 probability, the ratio expected for very long experimental runs. It turns out that the presence of a person with focused intent can make a statistically significant impact.[41] Here, like in most other fields, some people are better at it than others—interestingly often people skilled in activities such as meditation, yoga or martial arts. Physics tells us that there is no causal mechanism to explain such "psi" phenomena—

[41] A good starting point to explore this interesting topic outside the current scientific mainstream are the books of Dean Radin. "Entangled Minds" and "The Conscious Universe", for example, present exhaustive meta-analyses of the existing literature.

but our conscious mind co-creates the world, and the quality and specifics of that co-creation are at least in part of our own mind's making.[42]

Embodying the Quantum Paradigm

Understanding the Quantum Paradigm intellectually does not, in and of itself, transform our experience. In order to achieve that, the new paradigm must be embodied, so that it structures our experience and informs our actions.

What does it mean to live as a quantum being in a quantum world? By reintroducing us to the centrality of experience, it will awaken us from the trance of living in a reductionist world of concepts into the fullness of life; by its insights into the oneness underlying the apparent separateness it will sensitize us to our kinship with all of life and Nature, where compassion and commitment to the common good becomes the foundation of all ethical behavior. It will re-introduce us to the aboriginal but now long-lost realization that the Universe is alive, and sacred. We would recognize the deeper truth of the ancient insight that "Life is a dream": all manifestation, all beings, the whole world, are seen as the dream of one Cosmic Consciousness (Fig. 14).

Fig. 14 Julian Voss-Andreae. Quantum Buddha, 2016. Bronze, 25″ × 19″ × 11″ (62 × 47 × 28 cm). Private collection (Taipei, Taiwan)

[42]The phenomenon of such "non-causal co-occurrences" was studied in a collaborative research by one of the great founders of QT, Wolfgang Pauli, and the renowned psychologist Carl G. Jung, who named them "synchronicity"—meaningful coincidences.

Conclusion

Most of us, scientists as well as laypeople, are unaware of the deeper layers of presuppositions that underlie our own experience. Through the rise of classical science this materialistic-reductionist, deeply internalized worldview has given us great powers and put us, at the same time, at great risk. The urgent need for a paradigm shift is most obvious in our reckless attitude toward our environment; we are jeopardizing our future by rapidly making our planet uninhabitable. The global crisis we are collectively creating calls for a revisioning of our reality, for a refocusing of our energies towards the common good, grounded on an embodied knowledge of our fundamental connectedness. This connectedness has been recognized by the world's great spiritual wisdom traditions, but in our current age, with (classical) science having become the ultimate arbiter of truth for many, this insight no longer holds sway over us. It is intriguing that through the natural progression of that very same human endeavor, the natural sciences, those ancient insights now appear in a new light, imbued with renewed meaning, which will be of crucial help in changing our way of being.

Before our future unfolds, we have dreamt it up. The central place where we, as a collective mind, dream up our future, is in art. Therefore, art has an important role in harnessing the transformative powers we need to get to the future we want. Like the Quantum Paradigm, art is holistic in its very essence. Artists and other keen observers tend to have a natural affinity toward the elements of this emerging worldview and there are many examples of art, including the sculptures presented here, that offer glimpses into this view, helping us to intuit its qualities. Our hope is to plant these seeds into the cultural mainstream to help transcend the paradigm of old, such that science, spirituality and art can become partners, rather than foes, in the dream of discovery and illumination.

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Of Barrels and Pipes: Representation-as in Art and Science

Roman Frigg and James Nguyen

Introduction

A flame is moving along a fuse. It reaches a tire, which starts rolling down a slope. It reaches the ground and moves horizontally for a short while before it starts climbing a tilted balance, its speed being just sufficient to pass the midpoint. This tips the balance to the other side and the tyre rolls down again. After having gone up and down another smaller balance it hits a board that is tied to a ladder. The ladder falls, hitting another board, which kicks the tyre in the direction of an oil barrel on top of which there is a small trolley with a burning candle. The trolley starts moving and soon gets stuck under a metal grid with sparklers, which catch fire. This lights another fuse, setting off a small firework. A spark of the firework ignites a puddle of oil, and so on.

[1] A sequence of the movie can be seen at https://www.youtube.com/watch?v=GXrRC3pfLnE.

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This is the opening sequence of the 1987 film *The Way Things Go* by Swiss artists Fischli & Weiss.[1] In the 29 minute long film we see a seemingly endless sequence of events involving physical objects such as tyres, ladders, oil barrels, shoes, and soap. The events are carefully arranged and subtly calibrated. They unfold according to exceptionless laws and yet there is an element of surprise in them. The sequence of events fascinates and even creates a sense of suspense about what's next (a reviewer for *The Independent* enthusiastically reported that watching *The Way Things Go* was like watching a Hitchcock movie). Yet there is no purpose, no cause, no finality, and no meaning to either the events themselves, or to their progression. What happens is aimless and eventually pointless.

The movie is not just a piece of somewhat unusual entertainment. The title of the movie, "The Way Things Go", has an unmistakably existential ring to it and can be seen as making reference to the fate of human ambition, the purpose of social struggle, and the search for meaning in life.[2] In this way the film uses the sequence of physical events to comment on the human condition. By likening life to the sequence of events in the film, it projects some of the properties of the sequence of film-events onto human life and represents the *conditio humana* as sequence of carefully calibrated, but ultimately aimless, events.[3]

Revert three decades. In 1953 the economists in the Central Bank of Guatemala set their Phillips-Newlyn machine (PN-machine) in motion, a system of pipes and reservoirs with water flowing through it.[4] US corporation Wrigley, one of the largest buyers of Guatemalan chicle gum, had announced that it would stop imports from Guatemala in protest to a recent land reform. The economists in the Central Bank were concerned about the effect that this would have on the national economy. They adjusted the machine to account for the macroeconomic conditions in Guatemala and let the machine run. They then closed the valve marked "exports" and watch what happened. The flow marked "income" started falling, and the water level in a tank marked "surplus balances" rose, which in turn caused a fall in a graph marked "interest rates".

But how can a machine that pumps water from reservoir to reservoir provide insight into what's happening in the Guatemalan economy? The crucial factor is that the PN-Machine is not just any system of pipes and reservoirs. It was built so that it implements principles of Keynesian economics if the reservoirs are interpreted as elements of an economy such as the central bank and privately invested savings, and the flow of water is interpreted as the flow of money through an economy. By using this machine to study economic conditions in Guatemala the economists take the machine to be a model of that economy, and the model ends up representing the Guatemalan economy as a Keynesian economy.

The PN-machine, a scientific model, and the artwork *The Way Things Go* have something in common: they both *represent* their respective targets (or subjects) *as*

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[2]This is even clearer in the original German title *Der Lauf Der Dinge*.

[3]We briefly mention alternative interpretations in Section "Representation in Art and Science".

[4]Our discussion of the Phillips-Newlyn machine draws on our (Frigg and Nguyen 2018). The machine can be seen in action at https://www.youtube.com/watch?v=k_-uGHWz_k0.

thus or so. The PN-machine represents the Guatemalan economy *as* a Keynesian economy and *The Way Things Go* represents life *as* sequence of carefully calibrated but ultimately aimless events. The question then is: what establishes this sort of representational relationship? More specifically: in virtue of what does a scientific model or piece of art (X) represent a target system or subject (Y) as thus or so (Z)?

We take as our point of departure Nelson Goodman and Catherine Z. Elgin's discussions of representation-as in the context of artistic representation (Section "Goodman and Elgin's Analysis of Representation-as"). We then generalise their notion of representation-as so that it also covers scientific representations, which results in what we call the DEKI account of representation (Section "The DEKI Account"). Throughout these sections we use visual art and material models as examples. We continue by indicating how the account can be generalised to apply to non-concrete models and artworks (Section "Non-concrete Objects"). Our approach is premised on the proposition that representations in art and science share essential traits, namely the ones identified in DEKI. We defend this claim against the view that representation in the two domains is fundamentally different and submit that differences are ones of degree rather than kind (Section "Representation in Art and Science"). We end by summing up our arguments (Section "Conclusion").

Two caveats are in order. First, when discussing scientific representation we mainly focus on models and only occasionally touch upon other kinds of representation (graphs and diagrams and so on). This limitation is owed to limitations of space and we do not imply that models are the only (or even most important) medium of scientific representation. Second, we only discuss models and artworks *in as far as they are representational*. Models can perform many functions beyond representation, and it goes without saying that not all art is representational. The aim here is not to offer a general analysis of art and science; we only intend to analyse how models and works of art represent *when* they represent. Finally, we delve right into the account that we deem to the most promising account of representation, namely representation-as. For a review of alternative accounts of representation see our (Frigg and Nguyen 2017a).

Goodman and Elgin's Analysis of Representation-as

Goodman and Elgin's (GE's)[5] notion of representation-as is composed of two essential ingredients: the distinction between something being a representation-of a Z and something being a Z-representation, and the notion of exemplification. We discuss each of these in turn, and then explain how they combine to form the complex representational relation of representation-as. We illustrate their account with their own example of a caricature showing Winston Churchill as a bulldog.

[5] When referring to views shared by Goodman and Elgin, we use the acronym "GE" to refer to them jointly.

Representation-of and Z-Representation

Denotation is the two-place relation between a symbol and the object to which it applies. According to GE for X to be a representation of Y it is necessary (and sufficient) that X denotes Y because "denotation is the core of representation" (Goodman 1976, 5). For this reason denotation is "representation-of" (Elgin 2010, 4).[6]

A number of qualifications need to be added about this use of "denotation". First, denotation is usually restricted to language, where a name is understood as denoting its bearer. This restriction is neither essential nor helpful. Signs other than words can denote. A portrait can denote its subject; a photograph can denote its motif; and a scientific model can denote its target system. There is nothing in the notion of denotation that would restrict it to language (Elgin 1983, 19–35).

Second, even though proper names are the paradigmatic example of denoting expressions, denotation is not limited to these. Definite descriptions, indexical terms, sentences, pictures, graphs, diagrams, and many other symbols can also denote. In particular, at least according to GE, predicates also denote: they denote all the objects in their extension (Goodman 1976, 19; Elgin 1983, 19). The predicate "red" denotes all red things and a picture of the hydrogen atom denotes all hydrogen atoms.

Viewing denotation as the core of representation may seem innocuous, but it has important consequences. If denotation is necessary for representation-of, then not all pictures represent in this way. Pictures showing Pickwick or unicorns do not denote anything simply because neither Pickwick nor unicorns exist. Such pictures are therefore not representations-of anything.

This seems counterintuitive and invites the following objection: if we recognise a picture as portraying a unicorn, then surely it represents something, namely a unicorn. GE respond to this objection by pointing out that we are misled by ordinary language into believing that something is a representation only if there is something in the world that it represents:

> What tends to mislead us is that such locutions as "picture of" and "represents" have the appearance of mannerly two-place predicates and can sometimes be so interpreted. But "picture of Pickwick" and "represents a unicorn" are better considered unbreakable one-place predicates, or class terms, like "desk" and "table". [...] *Saying that a picture represents a soandso is thus highly ambiguous between saying that the picture denotes and saying what kind of picture it is*. Some confusion can be avoided if in the latter case we speak rather of a "Pickwick-representing-picture" of a "unicorn-representing-picture" [...] or, for short, of a "Pickwick-picture" or "unicorn-picture" [...] *Obviously a picture cannot, barring equivocation, both represent Pickwick and represent nothing. But a picture maybe of a certain kind – be a Pickwick-picture* [...] *– without representing anything.* (Goodman 1976, 21–2, emphasis added)

This leads to the introduction of the notion of a Z-representation: X is Z-representation if it portrays a Z, where we use Z as a placeholder for the motif of a representation (for instance Z = unicorn). Derivatively one can then also speak of Z-pictures, Z-statues,

[6]We put systematicity above grammatical correctness when we write "X is a representation-of Y". For a detailed discussion of GE's view on representation-of see our (Frigg and Nguyen 2017b).

Z-paintings, and so on, to emphasise what kind of *Z*-representation one is dealing with: a *Z*-picture is a *Z*-representation that is a picture, etc.

Some *Z*-representations are also representations-of *Z*s: Guido Reni's *Portrait of Cardinal Roberto Ubaldini* is a man-picture and it denotes a man (namely Cardinal Ubaldini). It is one of GE's crucial insights that cases like these are, if not exceptions, then certainly not the rule. In fact there is a complete disconnect between what kind of representation something is and what, if anything, it is a representation-of (cf. Goodman 1976, 25–31). *Z*s do not have to be denoted by *Z*-representations and, vice versa, *Z*-representations do not have to denote *Z*s. This is obvious enough in the case of language: the word "sunflower" is not a sunflower-representation yet it is a representation-of sunflowers (because it denotes sunflowers). The observation carries over to pictures. The upper half of Adriaen Coorte's *Three Medlars with a Butterfly* is a butterfly-representation while being a representation-of the transformations of the soul; Lovis Corinth's *Innocentia* is a women-representation yet it represents innocence; and Sandro Botticelli's *The Birth of Venus* is woman-representation and it is not a representation-of anything (because the goddess Venus doesn't exist). The divorce of *Z*-representation and representation-of *Z* is in no way an anomaly, contrived by the exalted imagination of unworldly philosophers. A lightening-bolt-representation denotes the fastest dog at the races without being a dog-representation; public restrooms aren't usually denoted by restroom-representations; and a map of the Hundred Acre Wood associated with the *Winnie the Pooh* stories is a territory-representation without being a representation-of anything.[7]

What does it take to be a *Z*-representation? In the case of pictorial representation this is a much-discussed issue. So-called *perceptual accounts* hold that a picture *X* portrays a *Z* if, under normal conditions, an observer would see a *Z* in *X* (Lopes 2004). GE take a different route and explain *Z*-representation in terms of what they call genres (Elgin 2010, 2–3; Goodman 1976, 23).[8] Nothing in what follows depends on how this notion is unpacked and so we keep operating with an intuitive understanding of how pictures are categorised according to what they portray. Our preferred take on this in the context of scientific models is discussed in Section "The DEKI Account".

Exemplification

An item exemplifies a property *P* if it at once instantiates *P* and refers to it. To instantiate *P* without referring to it is merely to possess *P*, and to refer to *P* without instantiating *P* is to represent *P* in a way other than by exemplifying it. An item that exemplifies a property is an exemplar (Elgin 1996, 171). Straightforward examples

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[7]This map is piece of paper in the real world; it's not a fictional object in the story. In fact it's so real that a collector recently paid almost half a million Pound Sterling for it (https://www.independent.co.uk/news/uk/home-news/winnie-the-pooh-map-auction-record-breaking-eh-shepard-a8440406.html).

[8]Other options are also available. For a survey see Kulvicki (2006).

of exemplification are the sample cards supplied by commercial paint companies. These cards instantiate various colours, and refer to the colours instantiated (Elgin 2007, 39; 2017, 187–188).

Instantiation is a necessary condition for exemplification. But the converse does not hold: not every property that is instantiated is also exemplified. Exemplification is selective (Elgin 1983, 71). The chip card exemplifies redness, but not rectangularity, or being an inch long, even though it instantiates these properties. Only selected properties are exemplified. There is nothing in the nature of an object that determines the selection; no properties are intrinsically more important than others. Turning an instantiated property into an exemplified one requires an act of selection, which usually depends on the relevant context. The same sample card can exemplify rectangularity if used in geometry class. The specifics depend on the context and the case at hand. One aspect, however, is crucial: exemplars provide epistemic access to the properties they exemplify (ibid., 93). So to be exemplified a property not only has to be selected; it also has to be epistemically accessible. We say that a property that satisfies these criteria is *highlighted*. These considerations can be summarised in the following definition:

Exemplification: *X* exemplifies property *P* in a context *C* iff

(i) *X* instantiates *P*, and
(ii) *P* is highlighted in *C*.

Where *P* is highlighted in *C* iff

(α) *C* selects *P* as a relevant property, and
(β) *P* is epistemically accessible in *C*.

A sample card exemplifies, say, a certain shade of red because it instantiates it and, in the context of a paint shop, is selected as relevant and is epistemically accessible (a sample card too small to see with the naked eye would not exemplify red, nor would one that is used in a context in which colour is irrelevant).

Many works of art do not literally instantiate the properties they exemplify. Pictures and statues cannot instantiate properties like speed and elegance—after all they are made of paper or bronze. GE acknowledge this and say that these are examples of *metaphorical exemplification* (Elgin 1983, 81). A painting can literally instantiate the property of being grey; it can metaphorically instantiate sadness (Goodman 1976, 50–52). Metaphorically instantiated properties can be exemplified in the same way in which literally instantiated properties are: by being highlighted. In the next section we provide a development of GE's notion of metaphorical exemplification that emphasises the importance of the literally instantiated properties in grounding non-literally instantiated, yet still exemplified, properties.

Representation-as

A key insight on the way to a definition of representation-as is that *Z*-representations can, and often do, exemplify properties associated with *Z*s. A racehorse-picture can (metaphorically) exemplify speed; a ballerina-statue can (metaphorically) exemplify grace and elegance; and air-crash-film can (metaphorically) exemplify engine failure. One could then say that an *X* represents *Y* as *Z* if *X* denotes *Y* and is a *Z*-representation exemplifying certain *Z*-properties. This is on the right track, but one last step is lacking: the exemplified properties have to be imputed to *Y*. Thus we arrive at the following definition of representation-as (Elgin 2010, 10):

Representation-as (RA): *X* represents *Y* as *Z* iff

(i) *X* denotes *Y*,
(ii) *X* is a *Z*-representation exemplifying *Z*-properties $P_1,\ldots, P_n$, and
(iii) *X* imputes $P_1,\ldots, P_n$, or related properties, to *Y*.

Consider GE's example of a caricature representing Churchill as a bulldog, where the caricature portrays Churchill as tenacious and ferocious. RA offers the following explanation of how the caricature does this. The caricature (*X*) denotes Churchill (*Y*). The caricature shows a bulldog (*Z*), and hence is a bulldog-representation. The bulldog-representation (metaphorically) instantiates a host of bulldog-properties. Among these tenacity and ferocity are highlighted in the context in which the caricature is shown. Hence the caricature (metaphorically) exemplifies tenacity and ferocity. Finally, these properties are imputed to Churchill himself.

We now see how *The Way Things Go* manages to represent the *conditio humana* as a sequence of carefully calibrated but ultimately aimless events. The film (*X*) denotes the *conditio humana* (which it does mainly in virtue of its title). The film shows a burning fuse triggering a tyre to roll down a slope etc. (*Z*), and hence is a burning-fuse-tyre-rolling-down-a-slope-etc.-representation. The film metaphorically exemplifies *Z*-properties: the careful calibration of events and their ultimate aimlessness. Finally the film imputes these to what it denotes, the *conditio humana*.

The natural suggestion would be to generalise RA to the scientific context by letting the *X* range over scientific models, and *Y* over their target systems, and *Z* over the content or character of models. This points in the right direction, but conditions (ii) and (iii) need to be further developed in a number of ways to be able to account for what happens in the case of scientific models (and indeed some cases of artistic representation, as we shall see).

The DEKI Account

In this section we develop our preferred account of scientific representation, which, for reasons that will become clear later, we call the DEKI account.[9] Our account, which builds on RA, is primarily designed to handle scientific representation, but, as we discuss in more detail below, the way that we develop RA into DEKI also helps shed light on artistic representation.

The second condition of RA stipulates that *X* be a *Z*-representation. The notion of a *Z*-representation has intuitive appeal in the case of visual representations.[10] We readily categorise Pierre-Auguste Renoir's *La Première Sortie* as young-women-in-the-theatre-representation or a sequence of *Skyfall* as car-chase-representation. But a system of pipes and reservoirs isn't classified as a Keynesian-economy-representation in the same way. On what grounds, then, is the PN-machine classified as a Keynesian-economy-representation? And this problem is not specific to the PN-machine. Lengths of plasticine are used as myoglobin-representations; oval shaped blocks of wood serve as ship-representations, mice are used as animal-representations; balls connected by sticks function as molecule-representations; electrical circuits are studied as brain-function-representations; and autonomous robots are used as insect-cognition-representations. In virtue of what does a material object become a *Z*-representation? Neither reference to visual appearance nor appeal to genres explains how these objects come to function as *Z*-representations.

A representation, *X*, is first and foremost, an object with an associated set of properties: being of such and such a size, being made out of such and such materials, and so on. The material constitution of a representational vehicle matters and so we introduce a term of art to classify them; we can call them *O*-objects. As used here, *O* is simply a specification of what kind of thing *X* is. Derivatively we speak of *O*-properties to designate properties that *X* has qua *O*-object. The PN-machine is a water-pipe-object and having a flow of one litre of water through a certain hose per unit of time is one of its *O*-properties.[11]

O-objects are turned into *Z*-representations by *interpreting* their *O*-properties in terms of *Z*-properties. In the PN-Machine the *O*-properties include the flow of water, the capacity of tanks, and so on. These are then associated with economic properties: the production flow of a commodity, and a quantity of stocks for example. More generally, let $\mathcal{O} = \{O_1, ..., O_n\}$ be a relevant set of *O*-properties pertaining to *X*, and let $\mathcal{Z} = \{Z_1, ..., Z_n\}$ be a set of relevant *Z* properties. An *O-Z-Interpretation* *I* then is a bijective function $I : \mathcal{O} \to \mathcal{Z}$. If an *O*-property is quantitative (for instance, being *x* metres long), the interpretation also contains a function associating the values of the *O*-property with the values of the corresponding *Z*-property (for further discussion about how an interpretation handles quantitative and qualitative prop-

[9] For more details about the DEKI account see our (Frigg and Nguyen 2016, 2018).

[10] This is not to say that this concept needs no further analysis; it's just to say that there is at least a pre-theoretic intuition we can build on.

[11] *X* does not uniquely determine *O*. The PN machine could also be described as a metal-and-plastic-object, or as post-war-production-object. Any property instantiated by *X* could ground *O*.

erties see our (Frigg and Nguyen 2018, 212–213)). Hence, an object becomes a Z-representation when its properties are interpreted in the appropriate manner. We therefore say that a *Z-representation* is a pair $\langle X, I \rangle$, where X is an O-object, and I is an O-Z-interpretation.

We now identify scientific models with Z-representations in the following manner: a *model* is a Z-representation where X is an O-object that is used as the vehicle of the model in a certain context (either due to convention or the stipulation of a scientist, or group thereof) and I is an interpretation. We then write $M = \langle X, I \rangle$ and also speak of a Z-model. So the reservoir-and-pipe system becomes a Keynesian-economy-representation when, in a certain context, it is used as the vehicle of the model and it is endowed with an interpretation that maps its hydraulic properties to economic properties.

It is a deliberate choice that this definition of a model contains no reference to a target system. There are models that don't have target systems, and therefore we should distinguish between the notions of being a scientific model and being a scientific representation. Some Z-models are also representations-of a Z, others aren't. The PN-machine is a representation-of the Guatemalan economy. But Maxwell's ether-model is not a representation-of anything (there is no ether!) despite being an ether-representation. Crucially, targetless models need not be failures. In some cases models are constructed without being intended to be representations-of systems in the world, and an account of modelling that undercuts such an enterprise gets started on the wrong foot (we return to such models in Section "Representation in Art and Science", where we also give examples).

It pays noting that O and Z, while often distinct, can coincide. In such cases the interpretation I is the identity function. The architect's cardboard house is a house-object that is used as a house-representation and when studying ships engineers often use small ship-shaped objects as ship-shaped-object-representations. Such representations are usually considered to be *iconic models* (Black 1962).

Models, understood as Z-representations, exemplify selected Z-properties. The PN-machine, for instance, exemplifies rising surplus balances and falling interest rates. But, just as a painting does not literally instantiate sadness, the PN-machine does not literally instantiate falling interest rates (it's a water-pipe system!). The problem is that if $O \neq Z$, then the model-object X will not, at least in general, instantiate properties associated with Z, and thus cannot exemplify them. It's at this point that GE rely on the notion of metaphorical instantiation: although the painting doesn't literally instantiate sadness, it does metaphorically instantiate it, and can therefore exemplify it. GE are right in pointing out that it is not necessary that X *literally* instantiates P. But rather than relying on the somewhat vague, and to some philosophically suspicious, notion of metaphorical instantiation we turn to the notion of an interpretation to define a precise sense of non-literal instantiation. Given that an interpretation establishes a one-to-one correspondence between O-properties and Z-properties it is natural to say that a model $M = \langle X, I \rangle$ *I-instantiates* a Z-property P iff X instantiates an O-property P' which satisfies the following condition: P' is mapped to P by I (and if the property is quantitative, the relevant values of P' are mapped to the relevant values of P).

The introduction of *I*-instantiation specifies precisely how objects can exemplify properties they do not literally instantiate and it does so in a way that emphasises the importance of the properties literally instantiated by models (their *O*-properties) in establishing the exemplification of the relevant *Z*-properties. Exemplification of *Z*-properties only happens under an interpretation, and for this to happen a model must instantiate the relevant *O*-properties that the interpretation function takes to the exemplified *Z*-properties. Notice that all of this can be made sense of without the need to appeal to metaphorical instantiation (although those happy with the notion of metaphorical instantiation can see the notion of *I*-instantiation as regimenting how scientific models metaphorically instantiate properties: they do so in virtue of a combination of literally instantiating *O*-properties and interpretations).

I-instantiated properties can be *I*-exemplified if they are *I*-instantiated and highlighted (as described in Section "Exemplification"). The PN-machine, then, *I*-instantiates falling interest rates and the flow of money while instantiating particular meter readings and flows of water, and it *I*-exemplifies falling interest rates and commodity flows if they are *I*-instantiated and highlighted. However, it is important to note that not all of the properties that *X* *I*-instantiates need to be *I*-exemplified in any given context of investigation. It is the context which determines which of the *I*-instantiated properties are highlighted: for example, it could be the case that a researcher has to determine which of the *O*-properties *X* instantiates before these can be highlighted (by performing a measurement on *X* say), and the related *Z*-properties may only be exemplified once this is known (thus allowing us to learn from models by investigating their behaviour). In other contexts certain *I*-instantiated properties may not be highlighted at all if they are irrelevant for the task at hand, even though they are covered by the interpretation (for example, if the PN-machine was being used to answer intra-national macroeconomic questions and the tank marked "foreign exports" was ignored). Whether or not a *Z*-property covered by the interpretation is *I*-exemplified depends on whether we have epistemic access to the corresponding *O*-property and on whether the context selects that *O*-property as a focal point of the investigation. The adoption of an interpretation in no way determines that this has to be the case. *X*, together with the interpretation, provides a "menu" of *Z*-properties that the model *I*-instantiates. Whether or not any of these properties are exemplified depends on the epistemic purposes of those using the *Z*-representation.

The next question to ask is: what makes the PN-machine represent the Guatemalan Economy? Or more generally: what makes a model, construed as a *Z*-representation, represent a target system as a *Z*? For a model to represent a target as a *Z* two further conditions have to hold. The first is that the model must denote the target system. Denotation is the core of representation. It establishes representation-of. Nevertheless, as we have seen above, it is only necessary and not sufficient for representation-as. This is where the second condition comes into play. The basic idea is that properties exemplified by the model are imputed to the target. Imputation can be analysed in terms of property ascription. The model user may simply ascribe the exemplified properties to the target system, and this is what establishes that the model represents the target as having those properties.

But the properties imputed are rarely exactly those exemplified by the model. The model could, for instance, exemplify being frictionless, but the property imputed to the target is something like "having sufficiently low friction to be negligible in the current context". In some cases the imputed properties could diverge significantly from those exemplified by the model. It is therefore crucial that the relation between them is articulated with precision. For this reason we build an explicit specification of how the exemplified properties are related to properties imputed into our account of scientific representation by means of a "key". Let P_1, ..., P_n be the Z-properties exemplified by the model, and let Q_1, ..., Q_m be the properties that the model imputes to the target (n and m are positive natural numbers which can, but need not, be equal). Then the representation must come with a key K specifying how exactly P_1, ..., P_n are converted into Q_1, ..., Q_m. Borrowing notation from algebra (somewhat tongue-in-cheek) we write the key as a function K taking a set of exemplified properties as the arguments and mapping them to a set of to-be-imputed properties: $K(\{P_1, \ldots, P_n\}) = \{Q_1, \ldots, Q_m\}$.

P and Q properties are often different, but it's worth noting that it needn't be the case that the P properties are mapped to distinct Q properties: the key can be the identity. This would allow for models to exemplify "relevant properties" which they are hypothesised to share with their target systems, which amounts to the claims of those who defend versions of the similarity account of scientific representation (Giere 2004, 2010; Weisberg 2013). Moreover, since we place no restrictions on the sorts of properties that are exemplified, we do not rule out structural properties being exemplified and then imputed onto their target systems in virtue of hypothesising that there is some structure-preserving mapping that holds between the two (such as isomorphism (van Fraassen 1980, 2008), homomorphism (Bartels 2006), or a partial-isomorphism (French 2003; Bueno and French 2011)).

Gathering together the pieces we have discussed yields the DEKI account of representation:

DEKI: Let $M = \langle X, I \rangle$ be a model, where X is an O-object that serves as the vehicle of the model and I is an O-Z-interpretation. Let T be the target system. M represents T as Z iff all of the following conditions are satisfied:

(i) M denotes T.
(ii) M I-exemplifies Z-properties $\{P_1, \ldots, P_n\}$.
(iii) M comes with key K associating the set $\{P_1, \ldots, P_n\}$ with a set of properties $\{Q_1, \ldots, Q_m\}$: $K(\{P_1, \ldots, P_n\}) = \{Q_1, \ldots, Q_m\}$.
(iv) M imputes at least one of the $\{Q_1, \ldots, Q_m\}$ to T.

The account owes its name to the main ingredients: denotation, exemplification, keying up, and imputation. Figure 1 shows how the various aspects of the account fit together.

Understanding how these conditions are met in the case of the PN-Machine illustrates how the account works. The machine (X) is conceptualised as a water-pipe-object (O). Z is a Keynesian economy. The machine is endowed with an O-Z-interpretation (I), mapping hydraulic properties to economic properties. The

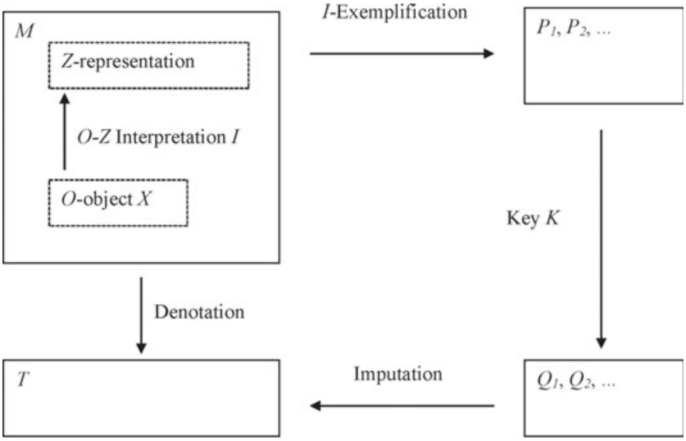

Fig. 1 The DEKI account of representation

machine so interpreted is a Keynesian-economy-representation, and as such it is a model *M* (a Keynesian-economy-model). The Guatemalan economists used *M* as a representation-of the Guatemalan economy by letting the model denote the Guatemalan economy (i). The machine instantiates a number of water-pipe-properties and, via *I*, it *I*-instantiates a number of economy properties. Some of them—the effect that a decrease in foreign exports had on income and the interest rate for instance—are exemplified because they were highlighted (ii). We can presume that the economists used an interval-valued key, which moved from specific changes in value for the interest rate in the machine before and after the change in foreign exports to values of, say, ±10% around them (iii) and imputed the result to the Guatemalan economy (iv).

The above-mentioned examples of models (the plasticine myoglobin-model, etc.) can be analysed along the same lines.[12] The introduction of keys was originally motivated by maps, which therefore (unsurprisingly) can also be analysed in terms of DEKI. A map, considered as an object, is a paper-with-colour-print-object. Under an interpretation that takes certain lines to indicate borders, blue to designate water, and black dots to signify cities, the map becomes a territory-representation. Through the introduction of denotational relationships between the map and parts of the word, usually by borrowing denotation from language (by saying that the map denotes the world, that a certain dot denotes Paris, etc.), the map becomes a representation-of the world. The map exemplifies certain properties, for instance that the points labelled "Paris" and "New York" are 29 cm apart. The map comes with a key specifying the scale of the map (for instance 1:20,000,000), which translates 29 cm into 5800 km.

[12]For want of space we cannot discuss each case individually. For useful discussions of the model of myoglobin see (de Chadarevian 2004), model of ships (Sterrett 2002; Leggett 2013), model organisms (Ankeny and Leonelli 2011), molecules (Toon 2011), brain functions (Sterratt et al. 2011), and robots (Webb 2001).

There being a distance of 5800 km between the two cities is then imputed to Paris and New York.

Certain measurement devices function in this way too. After a short immersion in a solution, a strip of litmus paper exemplifies a certain shade of red, and, via a key that converts a colour spectrum into levels of acidity, ascribes a pH value of 3.5 to the solution. Some graphic representations also fit the DEKI mould. In the representation of the Madelbrod set, a key is used that translates colour into divergence speed (Argyris et al. 1994, 660 and 695). The square shown is a segment of the complex plane and each point represents a complex number. This number is used as parameter value for an iterative function. If the function converges for number *c*, then the point in the plane representing *c* is coloured black. If the function diverges, then a shading from yellow over green to blue is used to indicate the speed of divergence, where yellow is slow, green is in the middle and blue is fast.

Interpretation is crucial in visual arts too. The fact that we readily recognise Edgar Degas' *The Rehearsal of the Ballet Onstage* ("*Rehearsal*" for short) as a ballet-representation may mask the fact that this recognition is the product of an interpretation. Symbolist painter Denis (1909/2003) famously reminded his fellow-artists that a painting, before being a battle horse, a nude, or some anecdote, is a plane surface covered with pigments. A painting per se is a welter of lines and dots, a bounded collection of curves, shapes, and colours. Assume that we make a temperature measurement at each point of a surface (for instance the bonnet of a car) and use a colour-coding similar to the one used for the Mandelbrod set to record the outcomes in the form of a plot. Further assume that it so happens that the temperature distribution is such that the resulting temperature plot is visually indistinguishable from *Rehearsal*. Would we say that this plot is a ballet-representation? No. A coloured surface that looks like *Rehearsal* is a ballet-representation only under an interpretation that takes the colours of the surface to be representations of a visual experience we have when seeing ballet dancers.[13]

Emphasising the importance of an interpretation in understanding a visual pattern is more than just an academic point. Much confusion can be avoided by bearing in mind that visual patterns are not "natural" depictions of something just because they look like something, where "natural" is taken to mean that there is some objective relation between the depiction and the depicted that does not depend in any essential way on the role of onlookers and observers.[14] This point is brought home by the case of Putnam's ant, which traces a line through the sand that ends up looking like Churchill (Putnam 1981). The trace isn't a Churchill-representation, let alone a representation-of Churchill, unless it's interpreted as such. And although the visual similarity between the trace in the sand and the British politician *can* form the basis of such an interpretation (an onlooker could interpret the shape of the trace as the shape of Churchill's face with a cigar in his mouth for example), they needn't. And

[13]Explaining how this kind of interpretation works is no easy feat. See Kulvicki (2006) for a useful review of the options discussed in the philosophy of art.

[14]Suárez (2003) emphasizes this in the scientific context.

without an onlooker there is no interpretation to begin with and the trace is not a *Z*-representation of any kind.[15]

The importance of an interpretation is highlighted by considering cases where the "obvious" or "natural" understanding of an image is in fact not the correct one. James Elkins discusses striking cases of such images. One of his examples is a widely-reproduced Hubble Space Telescope image of young stars in the Eagle Nebula (Elkins 2007, 10–12). We see an image that looks like an under-water photograph of a rock formation that is covered with a thin layer of brownish seaweed. The unsuspecting onlooker is seduced into thinking that young stars in the Eagle Nebula look like seaweed-covered rock formations, and part of the popularity of such images derives from the seemingly easy visual access they provide to astronomical phenomena. But, as Elkins points out, this reading of the image is profoundly mistaken. The image is a fusion of thirty-two individual images taken with four different cameras. These images were cleaned, stitched together, and given false colours. The colours that appear to represent an ordinary visual impression in fact are a coding for physical properties of the objects (blue, for instance, stands for the emission of doubly ionised oxygen). Unsuspecting onlookers unaware of all this will radically misinterpret the image.

In better cases visual interpretations that are initially misleading at least raise interesting questions. Mandelbort (1982) presents an impressive collection of images that are the result of mathematical algorithms and colour codings of the kind described above and yet look like depictions of mountains and planets, and Barnsley (1993) produced a welter of images of the same kind that look like ferns. These, and similar achievements, were hailed as the discovery of the "fractal geometry of nature" (as Mandelbrot calls it). It is surely remarkable that fern-look-alikes can be produced by mathematical algorithms plus a colour coding scheme, but the announcement of the discovery of the fractal geometry of nature may well be premature. Per se these images tell us more about an onlooker's interpretation than about nature itself. Filling the gap between appearance and an underlying mechanism has become the subject matter of the field of research known as fractal growth theory, which attempts to show that the equations generating the images can be seen as representations of real physical or biological processes, and that therefore the shapes seen in the computer-generated images are reflective of natural process. If true that's a significant discovery, and one that goes way beyond the superficial observation that a computer plot, when seen through a visual-image-interpretation, looks like a fern or a planet.

Returning from cautionary notes to constructive explanation, DEKI has the means to explain the working of symbolic art. Frans Pourbus the Younger's painting of Anne of Austria is, in our parlance, a Princess-with-dog-representation. The painting is also a representation-of Princess Anne, because it denotes the princess. But it is not a representation-of her dog (even if she had one); the part of the painting showing a dog does not denote anything (the painting doesn't function like a portrait of a royal couple where half of the painting denotes the queen and the other half the king). But

[15] See French (2003), Chakravartty (2001), and Bueno and French (2011) for further discussions of this thought experiment in the context of scientific representation.

the dog is an important part of the picture and can't be dismissed as a mere ornament. The dog is exemplified. Under the conventions used at the time the dog was a symbol for fidelity, and so the painting should be read as coming with a key associating a dog with fidelity (in the same way in which litmus paper comes with key associating the colour red with acidity). The painting then imputes the thus keyed-up property to the princess and represents her as faithful.

Non-concrete Objects

Not all models are physical objects, and not all artworks are visible and tangible. Issac Newton's model of the sun-earth system consists of two perfect spheres with a homogeneous mass distribution gravitationally interacting with each other but nothing else, and Leonardo Fibonacci's model of a population consists of immortal rabbits reproducing indefinitely at a constant rate living in an environment that places no restrictions on either food or space. Mark Twain's *The Adventures of Tom Sawyer* tells a story about Huckleberry Finn and Tom Sawyer, two wayward boys exploring the Mississippi, and Louis-Ferdinand Céline's *Journey to the End of the Night* follows antihero Ferdinand Bardamu on his journeys through France and the United States.

These objects don't exist; they can't be seen; and they can't be touched. They are non-concrete. They are often regarded as fictional objects or characters. How to analyse such objects is a formidable philosophical problem (indeed there is a question already whether they are objects at all), and there are more options available than we can mention here.[16] For our purposes it does not matter which options we choose. Since things like Huckleberry Finn and immortal rabbits are accessed through the imagination we refer to them as "imagined-objects". The hyphen indicates that we use this locution as a term of art whose sole purpose (in this context) is to provide us with a convenient way to talk about these things while remaining ontologically non-committal. Imagined-objects can have properties. Bardamu is a gnome and Tom Sawyer is infatuated with his classmate Becky; Newton's planets are spherical and Fibonacci's rabbits are immortal. How such property attributions are analysed depends on which view of fiction one adopts.[17]

What matters for our current purposes is that imagined-objects can be interpreted in the same way in which material objects can be interpreted. Phillips and Newlyn interpreted the hydraulic properties of their machine as economic properties. Newton did the same in the case of his model of the solar system. The basic imagined-object of the model is the so-called two-body system: a system consisting of two perfect spheres with a homogenous mass distribution, one large and one small, attracted to

[16]For reviews of these options see Friend (2007) and Salis (2013). See also French (2010) who argues that we can adopt a "quietist stance" towards the ontology of scientific models and theories.

[17]We favour an anti-realist approach to imagined-objects and analyse property attribution as pretend instantiation; see our Frigg and Nguyen (2016) for details. We emphasise that talk about imagination does not commit us to the view that thinking about models involves mental imagery; see Salis and Frigg (forthcoming).

each other with a $1/r^2$ force. In the Newtonian model the larger sphere is interpreted as the sun, the smaller sphere as the earth, and the force as gravity. So, in the context of the Newtonian model, the two-body system is a solar-system-representation. The interpretation is independent from the basic imagined-object and could in principle be changed. This is what happened in the Bohr model of the atom, which uses the same imagined-entity (the two-body system) but the large sphere is interpreted as a proton, the small sphere as an electron, and the force as electrostatic attraction. Thus, in the context of the Bohr model, the two-body system is a hydrogen-atom-representation.

Some works of literature can be seen as working in the same way. George Orwell's *Animal Farm* tells the story of a farm that is run by the animals. But the novel is not a manifesto for the self-governance of non-humans or a demonstration of the intelligence of pigs. The novel is an allegorical denunciation of Soviet-style communism as an exploitative reign of terror. The pigs are to be interpreted as the party functionaries and other animals—horses, chicken, sheep, and so on—as other segments of society; the happenings on the farm are to be interpreted as political events. Thus interpreted *Animal Farm* is a Soviet-communism-representation. As such it need not be a representation-of any particular country or party apparatus. But in a letter to a friend Orwell described the novel as a tale against Stalin, indicating that the novel denotes Soviet Russia during the first half of the twentieth Century, and a number of characters in the novel denote concrete historical figures: the pig called Napoleon denotes Stalin, Snow Ball denotes Trotsky, Squealer denotes Molotov, etc. The plot exemplifies a number of features like power being built on a cult of personality, loyalty and hard work not being rewarded, decisions being arbitrary, and innocent creatures being sacrificed mercilessly in power games of a ruthless and selfish elite. All these are imputed (with an identity key) to Stalin and his entourage, thus providing a piercing criticism of the phoney pretensions of communism.[18]

Voltaire's *Candide: or, Optimism* tells the story of a young man, Candide, who adheres to the teachings of Professor Pangloss and believes that everything in the world is for the best. But when he starts travelling the world, experiencing hardship, disaster, and suffering, he becomes disillusioned with Pangloss' doctrines, which he comes to see as fundamentally at odds with how things are. On the face of it the book is a story about the adventures of a good-hearted but naïve traveller, and the story betrays Pangloss' optimism as a doctrine that is fundamentally at odds with the course of events in the world. But we miss an important point if we stop here. Voltaire wrote the book as a response to Leibniz's doctrine that we live in the best of all possible worlds, created by a benevolent and omniscient God. In fact, Professor Pangloss is a parody of Leibniz and so we should read Professor Pangloss as denoting Leibniz. The story exemplifies there being an unbridgeable gap between optimist teachings and real-world events, denouncing the optimist doctrine as a piece of bogus philosophy. These properties are imputed to Leibniz's philosophy (again with an identity key),

[18]An alternative analysis would take the story at face value and see the plot as an animal-farm-representation. The conversion of animal-farm-properties into Soviet-communism-properties would then be put into the key. We are not adjudicating between these options here. In our view it is a strength of the framework that it has the flexibility to accommodate different analyses of a work of literature.

and Leibniz himself is portrayed as a promulgator of a delusional and ultimately dishonest vision of the world.

These two examples aren't handpicked exceptions. Satirical and allegorical works can generally be interpreted in the same manner as the above, and so can fables and parables. Realist fiction also fits the mould (as we will see in the next section), and so do historical and biographical novels.

Representation in Art and Science

So far we have stressed the parallels between representation in art and science, and argued that both can be accommodated within the DEKI framework. This does not imply, however, that representation in art and science is the same in all respects. There are important differences. But these, we claim, are often differences of degree rather than kind. An exhaustive treatment of these differences is beyond the scope of this essay (arguably, any discussion of this issue will always remain open-ended) and so we concentrate on few focal issues: the role of targets, the flexibility of interpretation, and the importance of rhetoric and style. To keep the discussion manageable we restrict attention to literature; similar points could be made about other art forms.

A fundamental objection to the project of drawing parallels between representation in art and science is that artistic representations have no well-defined target. Writing specifically about literary fiction, Currie notes that "[w]e have no more than the vague suggestion that fictions sometimes shed light on aspects of human thought, feeling, decision, and action" (2016, 304). Since we don't find real-life analogues of, say, Natasha and Pierre (in Leo Tolstoy's *War and Peace*) we cannot compare the novel and the world, which pulls the rug from underneath the project of likening representation in art and science, because such a comparison is a defining feature of scientific modelling.

The contrast between scientific models and literary fiction is rather less stark. First, not all scientific models have targets. There are famous failures like models involving the ether, phlogiston, and Ptolemaic epicycles. But not all targetless models are remnants of failed scientific projects. Models of three-sex reproduction in population dynamics (Weisberg 2013), the φ^4-model in quantum field theory (Hartmann 1995), the Lorenz model of the atmosphere (Smith 2007), the Kac-ring model in statistical mechanics (Werndl and Frigg 2015), the logistic model of population growth (Hofbauer and Sigmund 1998) and baker's model in chaos theory (Frigg et al. 2016) are all models without targets. Crucially, they aren't failures. They were known all along not to have targets, and they were constructed for purposes other than the exploration of a particular target.[19] Second, not all works of literature lack targets. As we have seen above, satirical novels like *Animal Farm* and *Candide: or, Optimism* can have

[19] It has been emphasised variously in the debate about models that models perform a number of functions other than representation. See Knuuttila (2005, 2011), Peschard (2011) Bokulich (2009) and Kennedy (2012) for a discussion.

clearly specified targets. Biographical novels like Vargas Llosa's *Aunt Julia and the Scriptwriter* are tales about real-world characters. Works in the tradition of social realism such as Émile Zola's *Germinal* and Charles Dickens' *Oliver Twist* offer piercing commentary on social reality and fierce criticism of poverty. Erich Maria Remarque's *All Quiet on the Western Front* and Kurt Vonnegut's *Slaughterhouse-Five* are passionate denunciations of the horrors of World Wars I and II (respectively).

One may argue that the horrors of world wars or Stalin's cult of personality are too broad and unspecific to serve as targets. Maybe they are, and there is a discussion to be had about what counts as a target system and how it is delineated. But it pays to note that also in scientific contexts not all target systems are precisely circumscribed. Economic models represent general phenomena such as unemployment, inflation, business cycles, and exposure to risk; ecologists model general processes such as population growth and predator-prey dynamics; physicists model the approach to equilibrium; sociologists model social exclusion; political scientists have models of conflict resolution. None of these are specific in the sense that they denote a particular target like our solar system. Hence, if there is a difference in specificity between the targets of literary fiction and scientific models, then the difference seems to be one of degree rather than kind, and the dimensions along which comparisons are made is largely uncharted territory.

The grain of truth in Currie's observation is that not all novels have even a vague target. Franz Kafka's *The Castle* or Fyodor Dostoevsky's *Crime and Punishment* are not about anything in particular, at least not in any obvious way. They are not about World War II or poverty. This does not mean, however, that readers cannot take the novels to be about specific things. The plaintiff trying to manoeuvre her way through the endless and often uncooperative positions of a contorted legal system may interpret *The Castle* to be about her legal nightmare; and the remorseful criminal can recognise himself in Raskolnikov. The choice of a target in such cases is ad hoc, and a myriad of other targets are equally possible. Readers are free to choose targets, and when they do so they can use the novel to generate insights about their chosen target. It seems to be correct to say that this kind of underdetermination of targets is more common in literature than in science, but at the same time it should be acknowledged that the phenomenon is not unheard of in science either. The harmonic oscillator is the physicist's favourite workhorse and almost anything from the atoms in the wall of a black body to insulin receptors has at some point or other been modelled as a harmonic oscillator.

A point where the difference between science and art is more pronounced is the flexibility of interpretation (in the sense of DEKI). In scientific cases the Z is usually fixed by the context and the interpretation highly regimented. Someone who doesn't interpret the large sphere as the sun simply doesn't understand the Newtonian model. In literature there is often more flexibility. How much flexibility there is depends on the context and the genre.[20] There is little flexibility in interpreting *Animal Farm* while there are (almost) no limits to an interpretation of *The Castle*. Fischli & Weiss' film, which we described in the introduction, also lends itself to different

[20] See Eco (1994, 1992) for discussions about the limits as to how literary texts can be interpreted.

interpretations. We interpreted it as a *conditio-humana*-representation. Someone else might emphasise the borderline functionality of the arrangement and its constant risk of failure, and therefore see it as risk-representation. Feminists might point to the masculine character of the materials and see the design of the setup as a manifestation of the male preoccupation with mechanical processes; for them *The Way Things Go* could be a gender-ideology-representation. And so on. In artistic contexts the interpretation is often deliberately left open, and coming up with an interesting interpretation is a creative act in its own right. Such freedom is foreign to science, where interpretations are regimented and controlled.

A last point we want to consider is the importance of rhetoric and style in the presentation of a model or a work of literature. Language and rhetoric is a crucial aspect of a work of literature. We admire great authors not only for the inventiveness of their plots, but also (and sometime even more so) for their use of language, the elegance of their expressions, and the fluency of their diction. This importance of language and rhetoric, opponents of a parallelism of modelling and fiction point out, is entirely foreign to science. Currie submits that "[m]odels are not dependent for their value in learning on any particular formulation" (2016, 305), while formulations are crucial in literature. A recounting of the plot of *Hundred Years of Solitude* in the language of a seven-year-old is not the work of art that Gabriel García Márquez created.

There is no question that language and rhetoric play a different role in literature than in the presentation of scientific models, but that does not imply that models are completely independent of their formulation. Everybody who has ever spent time solving differential equations will know that the choice of the right coordinate system for the description of the situation is crucial. In a recent paper discussing models (understood as imaginary entities) Vorms (2011) points out that what she calls the "format of a representation" is crucial to the inferences scientists can draw from the model. The very same model, when presented under a different format, can yield different predictions and offer different explanations. Formulation matters. So, once again, the difference is one of degree and detail rather than kind.

Conclusion

The DEKI account of representation, building on Goodman and Elgin's notion of representation-as, highlights the commonalities between scientific and artistic representation. By understanding how each of DEKI's conditions are met we come to understand how a hydraulic system like the PN-machine can represent the Guatemalan economy as a Keynesian economy, and how a cleverly calibrated sequence of rolling tires and burning barrels can represent the *conditio humana* as ultimately aimless. The account explains, in general, how an object X represents a target Y as thus or so Z. This is not to say that representation-as works in exactly the same way in science and in art (or even to say that it works in exactly the same way across the sciences or across the entire field of art). DEKI's conditions are stated at the appropriate level of abstraction so that they can be met in different ways in different cases, as we have discussed. But the differences that emerge in different instances, or types of instances, of representation-as depend on how the very same conditions, of denotation, exemplification, and so on, are met. We conclude by re-emphasising that our analysis is aimed at cases of scientific and artistic *representation*. We don't want to claim that all scientific models, let alone works of art, play representational roles. But where they do, we hope that analysing them through the lens of DEKI will help us understand how they work.

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Field Experiences: Fundamental Science and Research in the Arts

Mónica Bello

Over recent years various scientific institutions have nurtured novel models of dialog and cooperation between scientists and artists while museums and art centres have increasingly been incorporating art and science explorations into their programs. Currently we are witnessing a heightened interest in the hybrid areas created between disciplines. From the lab to the artists' studio, from urban space to remote natural scenarios, interactions between artists and scientists are being reconfigured. Today it is clear that scientific engagement with cultural practices acts as an important driver for novel scenarios for knowledge exchange between fields. The way we comprehend our environment, the interactions with other beings or the understanding of the way nature works have constituted the common drives of art and science throughout our history. The sense of wonder towards what complex phenomena these events may reveal is a fascination for many artists who are inevitably drawn to the laboratory.

How do we approach knowledge and experience through art and science dialogues? What are the big questions and insights coming out of these exchanges? John Dewey proposed that all interactions that affect stability and order in the whirling flux of change are rhythms. How do we explore these rhythms in the balance and counterbalance of our techno-scientific contemporaneity?

At CERN, the European Organization for Nuclear Research in Geneva, physicists and engineers are probing the fundamental structure of the universe. Infinitely small sub-atomic particles demand that highly advanced technology is stretched to its limit. By founding the first CERN Cultural Policy, the laboratory provided a specific means to reach other communities and to bring non-scientific voices into the research environment. The policy coincided with the founding of Arts at CERN in 2011, the official arts programme of the laboratory, which quickly became an influential platform dedicated to bringing science and art together in mutual inspiration. The vision of the programme was always beyond communication or outreach purposes, instead the goal was raising an awareness of bringing other creative communities with sur-

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prising viewpoints, perspectives and questions into the lab, a re-contextualisation of the practice of the scientists and an incentive for significant conversations between artistic mindsets. Arts at CERN has evolved over the years thanks to solid institutional support and a significant network of international collaborations, now running Collide, Accelerate Guest Artists as the annual schemes that bring artists into the laboratory from all over the world, complemented by the Art Commissions & Exhibitions program, that fosters artistic production after the artists return to their studios.

When the programme was founded, the emphasis was place into the stimulating discussion around the notion that science and its non isolate nature and practice. Interdisciplinarity was an essential part of it, and a motto. CERN Director General Fabiola Gianotti stated in Davos 2018 that she is "very much in favour of a diverse and multidisciplinary culture, we have to break cultural silos, when people talk about humanities in one side and science, art and science, like if they were incompatible and mutually exclusive, but they are the highest expression of creativity, ingenuity, curiosity of humanity". Artists at CERN are currently welcomed at the lab as part of a strategy to open science to society and to invite creators to explore the challenges of imagining a multifaceted world. During the artistic residency programs Collide, Accelerate - named after the big technological devices of the particle physics lab -, Guest Artists or the latest Art Commissions programme artists work alongside scientists and engineers at CERN in order to seek the limits of research in relation to the big questions of contemporary science. What are the conditions and the implications of artists working in this unique and complex research environment? What forms of creation take place in a highly specialised environment? What common grounds can be shared in order to negotiate the limits of contemporary creativity through different fields and experiences? From a curatorial angle, Arts at CERN attempts to respond to a model of institutional cultural practice that nurtures and support artists' engagement with physics and hard sciences, and fosters research and production of deeply informed artworks. The artists are invited to confront and respond to an age of accelerating scientific and technological development and become active with the dynamics and complexities of the fundamental research environment.

When artists arrive at CERN the question of how we make sense of the experience of our world, and how the languages of art and science are applied to such questions, is a common and general motivation. That said, different people will of course bring different approaches, and the dynamics between individual artists and scientists will always follow surprising paths. Peter Jenni, former spokesperson for the ATLAS experiment and one of the fathers of the Large Hadron Collider (LHC) says, "engaging with artists at CERN can enrich the personal motivation and satisfaction for working in the laboratory. Being challenged to have a broader view is ultimately beneficial." Experimental physicist Tamara Vázquez goes slightly further in saying that "the capability of stepping back and appreciating the research topic one is working on as part of a whole [finds] new paths to solve problems or new ways to interpret the results. This is precisely what working with artists does: to remember the scale of the research we are doing and what we are ultimately trying to explain". Thus bringing into focus the importance of cultural contextualisation and reflection that increasing numbers of scientists see as important as regards their own practice. The methodologies of advanced science and technology and its associated instruments situate the artist in an environment marked by a precision and a complexity that is often unfamiliar to the field of arts. As a particle physics lab, at CERN a collective drive exists to set a common goal: uncovering the fundamental constituents of nature. The instruments developed for pursuing this goal take multiple forms and shapes, from discreet microcircuits to the vast scale of the Large Hadron Collider (LHC) and its particle detectors. On entering the lab it becomes clear that it will not be straightforward to comprehend the broad range of experiments, their scale and function, and the models that may represent through deeply specialised theoretical models of our world drawer in mathematical language. Today science and technology play a crucial role in defining the human experience and an understanding of the tools and processes that enable knowledge to advance. In laboratories as well as in observatory environments, where artists are invited to investigate and become part of the research community, a multi-perspectival approach to 'fieldwork' can be applied, allowing for an opening of enquiries for thinking about a new and more relevant art and science practice. The encounter with the experience of 'the remote' lies there: from the observation of the skies, the seas, far-off lands and non-human scenarios, extreme locations and even invisible subatomic realms. All of these become an intrinsic part of the contemporary artistic practise, and sources for inspiration and investigation and fieldwork research within the physical world. At CERN the artists make little attempt to depict the scientific concepts involved in their subject matter. Rather they reveal and explore phenomena, ideas and histories of discovery outside everyday human experience, making us able to sense and experience them or in some way grasp their significance and profoundness.

Japanese artist and composer Ryoji Ikeda spent a few weeks at CERN in 2014 as artist-in-residence. During that time he became close to the theoretical physics research in order to created two major works inspired by his encounters with scientists at CERN. With *the planck universe* launched at the ZKM in Karlsruhe in Summer 2015, Ikeda designed an immersive and synesthetic experience based on principles of particle physics and cosmology. The installation—consisting of two overwhelming projections which unfold on an area of over 375 m^2—explores human perception on the smallest microscopic level as well as the largest level of endless space beyond the observable universe. The Planck scale sets the universe's minimum limit, beyond which the laws of physics break, and is used by scientists to describe the smallest units of our universe. Pictorial worlds which have been enlarged to our proportions by the Planck scale (10^{-35} m) can be perceived on the large-format floor projection of *the planck universe [micro]*. So while visitors enter an immersive area in *the planck universe [micro]*, in *the planck universe [macro]* they experience a macro scale of 10^{26} m, which lies beyond the observable universe, by means of an immense wall projection over three floors with engaging sound. In the second work *supersymmetry* Ikeda expands his research on a 80 screens that forms a corridor in which visitors are enwrapped by mathematical and data images that appear like a flash of blinking light and sounds. A second part of the installation on the second floor directly above shows light boxes on which particles move over microscopic, brightly shining areas. The complex entanglements which ensue within this installation are reminiscent of the supersymmetry principle in physics that predicts a partner particle for each particle in the Standard Model which would eventually help explain why particles have mass.

The use of physics data in a visual form is also explored in HALO, the latest monumental data artwork from British duo Semiconductor (consisting of Ruth Jarman and Joe Gerhardt). This works embodies in an extraordinary way the artistic fascination about the experience of nature through the lens of contemporary science and advance technology. The art piece is a large scale immersive installation which embodies Semiconductor's ongoing fascination with how we experience the materiality of nature through the lens of science and technology. In 2015, the artists participated in a research residency at CERN and began to work with data captured by ATLAS, the largest of the four detectors at the Large Hadron Collider that sits in a cavern 100 m below ground near the main site of CERN, in Meyrin (Switzerland). Beams of particles from the LHC collide at the centre of this detector and generate collision debris in the form of new particles, which fly out from the collision point in all directions. Taking the form of a large cylinder, the structure houses a 360° projection of scientific data while an array of 384 vertical wires are played by the same data, to produce the sound. The work draws the viewer into its centre in order to inhabit the results of particle-collisions, produced by the experiment at CERN—the magnitude of the experiment is such that it intends to probe and enhance our current understanding of the fundamental structure of matter, contributing to new theories that better describe the universe. By using the raw data from the ATLAS collisions, the artists seek to convey the signature of the technology, the mark of the architecture of the experiment, to finally speculate about the man's voice behind it. Their intention is to confront the viewer with the data before it has been processed for scientific consumption. The particle-collision events that form the core data of HALO occur at close to the speed of light, and time frames are measured in millionths of a second. By accessing the metadata with the collaboration of the scientists, the artists have been able to access the time sequences and slow them down. HALO was premiered in Art Basel in June 2018 as part of the Audemars Piguet Art Commission 2018, curated by Mónica Bello. This prestigious commission was founded by the watchmaking company from Le Brassus, Switzerland, to supports new artworks that reflects an artistic unique vision while drawing inspiration from complexity and precision—notions that are inherent to both watchmaking and particle physics.

While HALO presents us with the sublime, an encounter with the fundamental aspects of the universe, other artists invite us to consider the philosophical aspects of the understandings of nature and reality through other means. The use of custom-made scientific devices that pick up signals from cosmic rays are the artistic approach applied in 'Cascade', the new work of Seoul based Yunchul Kim—artist in residency at CERN in 2017. Yunchul Kim's work focuses on the artistic potential that can be found in the unique behaviours and transformative properties of different materials. For Kim—who spent two months at CERN in 2016 as artist in residence—materials are not merely a basis for creating forms and images, but essential elements for viewing and understanding natural phenomena. Cascade explores matter by capturing the pattern of muons—electrically charged subatomic particles. It does so through an installation comprised of three live elements: a muon detector, a complex assemblage of pumps, and an arrangement of tubes through which fluid flows. When muons are detected, lights and connected pumps are activated, triggering the movement of an uncanny, viscous fluid through the sculptural system. In Cascade Yunchul Kim addresses how hidden information in nature can be represented into the physical world crossing the limits of our daily experiences. Cascade stand as scientific and technological mediator of the subatomic world, giving materiality to the particles that cross our atmosphere to transcend the subatomic realm that it represents. The artist's work highlights the ways in which our experiences of nature can transcend to a functional technology and be transformed in a subliminal media, and ultimately question our place within it.

While the experimental realm allows a representation of the intrinsic relations of natural systems, artists are often captivated by theoretical models. British artist Suzanne Treister's singular approach is constructed through eccentric narratives and unconventional bodies of research. In her unifying manner, her work reveals structures that bind power, identity and knowledge. In 2018 Treister arrived to CERN as artist in residence with a question, is the holographic universe principle—the theory that our universe could be a vast and complex hologram—something that has been sought by artists since the beginning of our civilization? In her time at CERN she invited scientists mainly working with quantum gravity and black holes to address this question with her by hypothesising that, beyond acknowledged art historical contexts and imperatives, artists may have also been unconsciously attempting to describe the holographic nature of the universe. The final artwork consists of a video that comprises over 25,000 chronological images of art history from cave painting to global contemporary art, including outsider and psychedelic art that echoes conceptually the actions of CERN's particle accelerator, the Large Hadron Collider (LHC) by accelerating at 25 images per second in a looped sequence. Alongside this colossal library of images is a soundtrack of interviews with, and watercolours by the scientists that collaborated with her at CERN. THUTOAH hypothesises a reality that has perhaps been intuited over the ages, a reality beyond the already documented intentional depictions of spiritual, mystical or transcendent realities or altered states of consciousness; the reality of the holographic nature of the universe.

In similar fashion the Danish artist Lea Porsager begins her work CØSMIC STRIKE within a field-work methodology. This piece is described by the artist as 'a superposition of hard science and loopy mysticism which aims to invoke a repetitive, occult, and oddly interstellar scene'. By disrupting quantum technologies with esoteric propositions she engages through her work with a myriad of impossible and impassable worlds, with a suggestive call for other perceptions and other consciousness states. The work developed out of a short stay at CERN in 2018 explores the neutrino—a subatomic particle with no electric charge and therefore with a very weak interaction and very difficult to detect. An enigmatic, mysterious particle that challenges some of the models currently being researched in contemporary science. A 3 m long 'neutrino horn' found at the CERN storage building during her visit takes most of the space in the gallery. Invented by the Dutch scientists Simon van der Meer this magnetic horn consists in a high-current pulsed focusing devise that select pions and focuses them into a very sharp beam, and once those decay into muons and neutrinos, created an equally well focused neutrino beam. The refine design of this instrument was a source of inspiration for the artist to think about neutrino detection and neutrino's travel through this. Porsager present to the public a 3D animation picturing the inside of the neutrino horn inviting the viewer to experience 'neutrino-imaginations' from the inside of the horn: in the work, the horn becomes a ghostly container of oscillation, vibrations and irritation. In this visual narrative she intends 'to play promiscuously with the spiritual and quantum physics' and filling the experience of her vision with an amorphous realm that combines energies, mantras and stories resulting from her time collecting ideas and experiences at the lab.

An embracing of scientific concepts, strategies and methodologies became foregrounded in the work of Andy Gracie—guest artist at CERN in 2016. Whether this has been through directly engaging with experimental processes or through collaborations with scientists and laboratories, the intention has been the same; through certain focused approaches, to highlight how we go about connecting as humans with new knowledge and how that creates and lends meaning and significance to existence as an organic planetary entity. His work embraces the idea that human beings are creatures driven by curiosity, a desire for knowledge that has propelled their development into the dominant, planet-changing species. This notion extrapolates out into other notions. Humans also ascribe significance to things; to objects and to events. The subtle and shifting balance between knowledge, understanding and significance is played out across the arts and wider expressions of culture. Our investigations and experiments lead us ever closer to an unattainable complete theory of everything. Casting the notion of disciplines aside, whatever it is that we are studying, we are studying the universe. Every facet of our existence and every reflection we make is a factor of the coming into existence of the universe. Creative experiment across disciplines forms the hub of Gracie's approach, making work that is inspired and informed by science, but carried out in the field of art. Each work being an experiment in one way or another in how to understand 'how things work'—their properties, their compositions, their information states, their potentialities or their meaning. They are a process of framing systems as strategies to raise questions; as speculative proposals rather than definitive empirical constructs. Works such as *Drosophila titanus* and the Deep Data series have made use of simulation in various formats in order to allows us to pose questions about how the space environment and terrestrial organic lifeforms might interact. In *Drosophila titanus*, the fruit fly *Drosophila melanogaster* was exposed over a period of years to incrementally intensified elements of the conditions on Titan. The goal was to follow a rigorous scientific process in order to see how close a species could be adapted for survival in non-terrestrial environments. In Deep Data, various model organisms are exposed to space conditions as measured by space probes, landers and robots to see how they adapt in real-time experiments. The test subjects are placed in environments where a minimum of novel stimuli will elicit behaviours and growth patterns which are different from the norm. Where they are recreating space or non-terrestrial environments, they are not rebuilding the universe but re-contextualizing elements of space phenomena within functioning and targeting systems. The notion of space exploration and understanding the space environment is central to most of Andy Gracie's work. For more then 50 years we have been launching robots and devices into space in order to discover more about what space actually is, and to learn about how we came to be here. Gracie sees this plethora of scientific platforms as an extension of our own sensory cortex, allowing us to place our awareness at multiple points throughout the Solar System. This exploration by proxy extends our cognitive boundary to the current position of the last data transmission from the furthest out probe. Further enquiries along this line go into the materiality of space itself. The history and formation of our own Solar System, our immediate neighbourhood, and probably the logical and practical extent of our explorations, provides a rich territory for artistic inquiry. The artist has been working with interplanetary dust particles, fragments of ancient material can tell us much about the formation of the Solar System. They can tell us about how ubiquitous organic chemistry actually is in space, and therefore give us clues about the origins of life on Earth. They can tell also remind us about how our own presence here is the blink of an eye, that we know so little, and that looking up towards the dark is a deep compulsion within us all. Another body of work is forming in collaboration with cosmologists and astrophysicists, and focuses on the moment we theoretically understand as the beginning of the Universe in parallel with the notion of heat death or the ultimate apocalypse and end of everything.

Inspired by the accumulation of materials and the continuos flux of energy and matter that connects the mechanical and the corporeal, the New York based artist Mika Rottenberg has spent time at CERN in 2018. Spaghetti Blockchain is a new work resulting from her time at the lab that is launched at her solo US museum show at the New Museum in June 2019. In this video installation, the artist do a mash-up images of the filming from her time at CERN—mainly from ATLAS experiment, CERN Data Centre, Antimatter Factory and ISOLDE experiment—as well as images from female Tuvan throat singers and a potato farm in Maine. In this complex and fantastical video piece Rottenberg explores absurdist satire while acutely creating allegories for contemporary life: exploration of labor, technology, distance, and matter in relationship to the seemingly immaterial. Through these film locations Rottenberg experiments with the idea of humans as composed of, and as manipulators of matter, revealing the interconnectedness between the mechanical and the corporeal. Intertwining his practice with the role of composer, Haroon considers electricity his main medium and creates atmospheric environments through the linking together of light, sound, music, video and elements of architecture.

In 2017 hrm199—a collaborative platform founded by artist Haroon Mirza to connect people from a diverse range of disciplines can intertwine their practices—was awarded a CERN residency. During the time of Haroon Mirza and Jack Jelfs at the laboratory grime/DJ producer Elijah and artist and musician GAIKA were invited to join them in the laboratory to conceive and produce The Wave Epoch—as a special one-off improvisation created from materials collected at different locations around CERN. The group of artists chose to film and perform at the CMS detector cavern at the Large Hadron Collider at CERN, as well as next to the OPAL detector machine at its predecessor particle accelerator LEP—in operation from 1989 to 2000—and outdoors locations. Added to that, the artists collected extensive video footage of interviews with theoretical as well as experimental physicists where different topics were discussed and explored. With their sound and film recordings the artists created an immersive club experience that brought the audience to a hypothetical scenario where the LHC has been rediscovered by a future civilisation and turned into a ceremonial site, similar to Stonehenge or other ritualistic and yet mysterious sites. Launched at the Brighton Festival in 2018, The Wave Epoch invited to reflect on how perception of purpose-built locations evolve over time and to how the ceremonial and ritualistic tendencies of humankind help to question and reinterpret the scientific and technological landscapes.

one1one is the second art commission produced by hrm199 as an outcome of the residency at CERN. In this case, the artists focused specifically on the interplay between language, consciousness and physical matter to respond to the question about language and what would be the most appropriate language to describe the world, and how does that choice determine what can be known? The artists argue that mathematics is used to describe fundamental physics—but more the knowledge of the fundamental laws of the universe is refined, the less the 'real world' makes sense. Once more, the duo applies a fictional strategy to test this issue: in the year 4250, where spoken communication is rendered archaic and defunct due to supernatural, mystical and spiritual phenomena will be the norm. In the gallery a video manifesto, combined with electric circuits which generate light, sound and disruptions to moving image creates a seemingly synesthetic experience. Through this series of sensorial stimuli, hrm199 aim to scrutinise the limitations of human language, particularly the contradictions of meaning which can occur when it is used to describe fundamental science.

Never have we been in possession of so much knowledge as we are now. Science today has reached unprecedented stages of advancement. Yet as we advance our understanding of our own knowledge and the possibilities offered by technology, we also become aware that the codes of the world no longer appear to depend on us. We find ourselves at a non-human level, a mode where nature, metaphorically, has abandoned us.

Artists at CERN come together with a myriad of ways to question nature, from theoretical models to complex experimental scenarios. The experience of 'making science' not just as a rational thinking process, but as a way to adjust intuitions and to combine knowledge becomes relevant throughout their time in connection with CERN community.

Leslie Thornton, an American avant-garde filmmaker and artist, whose work at CERN begun with a first visit in 2018, is deeply influenced by a unique experimental visual practice combined with deep ties to the sciences of her family history. In an on-going research project Thornton is planning to produce a 'living archive' which would serve as as a substrate, database, or visual/cognitive field out of which a number of works—art and media works, texts, visual images—would be produced. Entitled *Event* the project is based on a series of conversations that emerged during her initial visit to the laboratory. The notion of an 'event,' and the capture of the trace of its presence, as an *image* for example, is a common concern for artists, scientists, and philosophers. There is also an intersection in the register of instrumentation: the camera (or as the artist argues—an expanded idea of what a camera is, or can be). In a joint collaboration with filmmaker Jeff Preiss and Thomas Zummer, Thornton is involved in an examination of the uses and histories of photography in contemporary particle physics, specifically as they developed at CERN. What is an *image*? What is an *event*? What is *evidence*? These are part of the philosophical questions that emerge in both scientific and artistic practice, as well as how science is conducted through history and contemporaneity or the histories of scientific observation. Thornton and her collaborators aim to develop a final piece in late 2019 that compiles these ideas in a series of completed media works, installations and texts.

The artistic projects formerly described tend to focus on the complex and, at times hidden, entanglements between artistic and scientific practices. Both art and science have a profound relation to *knowledge and representation*, to the technical experimentation of nature and the traces, events, phenomena, artefacts and experiments. On close observation, a complex pattern emerges, revealing surprising complicities and difference between various practices in these different disciplines and inextricably linked to each other. The laboratory's modes of working attain their value in the context of CERN, one of the most diverse and widest-ranging scientific environments in the world. Art proposals acquire new character once they come into contact with particle physics and its exploration of the fundamental forms of matter. The phenomena of nature may be explored in unorthodox ways and the greatest experiments, complexity, and technical precision "encourage [the artist] to re-consider the intangible peripheries of micro and macro, the often-elusive transitions between analogue and digital, the model character of time-based experiments, where the present is relentlessly worried with past and future events' affirms Mariele Neudecker, artist-in-residence in 2015–16. The often quoted Marshall McLuhan claimed that "it's always been the artist who perceives the alterations in man caused by a new medium, who recognises that the future is the present, and uses his work to prepare the ground for it". The truth is that both artists and scientists experience the drive to understand what escapes our control. Science and art both seek to raise awareness of these changes which will lead to a future exploration and appreciation of them and hence to a social and cultural engagement.

Without independent and radical thinkers in art and science advances in knowledge would remain glacially slow. Furthermore, alongside independent thinkers we need pioneering ways of bringing together radical modes of thought and strategies for understanding. As put forward by ATLAS physicist Mark Sutton - who collaborate extensively with artistic duo Semiconductor during the production of HALO "increasingly our understanding of the world informs the way in which society functions, so it is important that we learn how to communicate the cutting edge of our understanding as widely and in as diverse a way as possible. And so artistic engagement could help to keep that more in the forefront of our minds. It is another way in which we can keep connected with the real world".

See Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18.

Fig. 1 LHC Tunnel. Courtesy of CERN

Fig. 2 At ALICE Detector. Courtesy of CERN

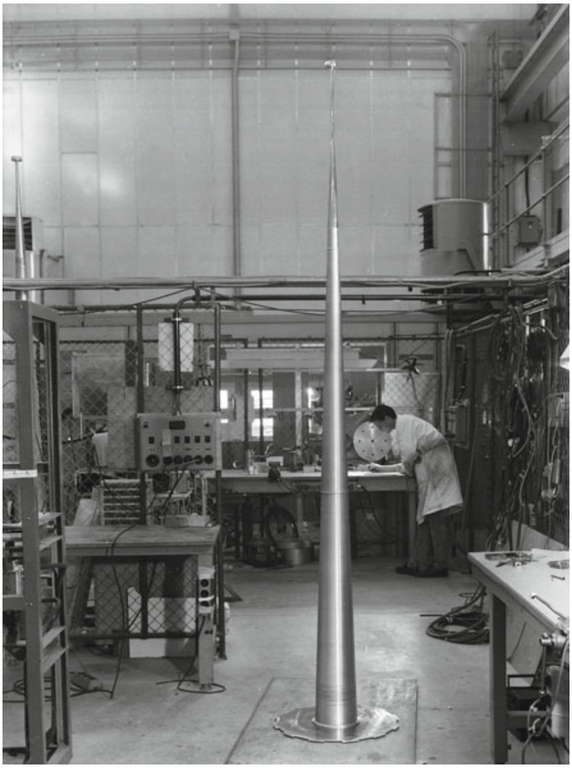

Fig. 3 Neutrino Horn. Archive Image CERN

Fig. 4 Antje Greie Ripatti, artist-in-residence. Archive of CERN

Fig. 5 HALO by Semiconductor. Audemars Piguet Art Commission 2018. *Photo* by Claudia Marcelloni/CERN

Fig. 6 HALO by Semiconductor. Audemars Piguet Art Commission 2018. *Photo* by Claudia Marcelloni/CERN

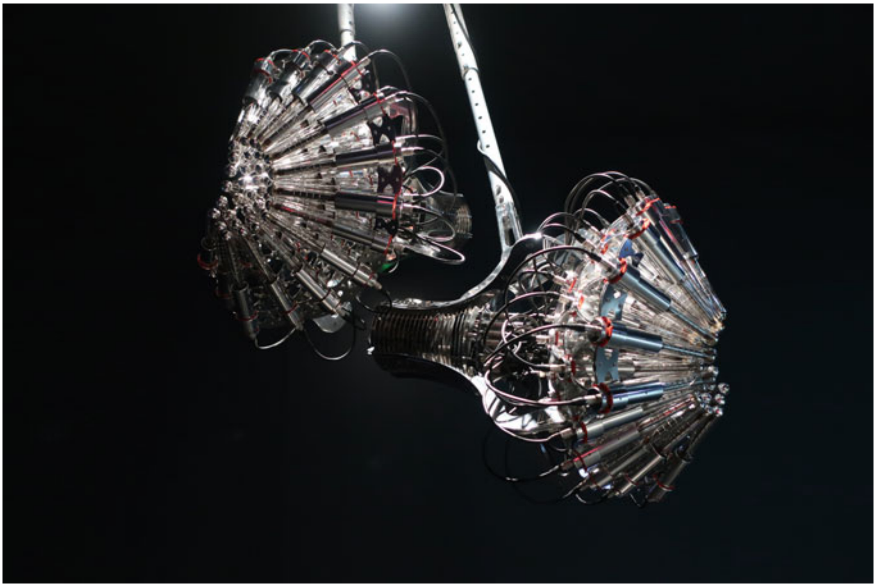

Fig. 7 Cascade/ Argos. Arwork by Yunchul Kim. Courtesy of CERN

Fig. 8 Cascade/ Argos. Arwork by Yunchul Kim. Courtesy of CERN

Fig. 9 Micro Macro. Artwork by Ryoji Ikeda at ZKM. Courtesy of the artist

Fig. 10 ATLAS Model. Courtesy of CERN

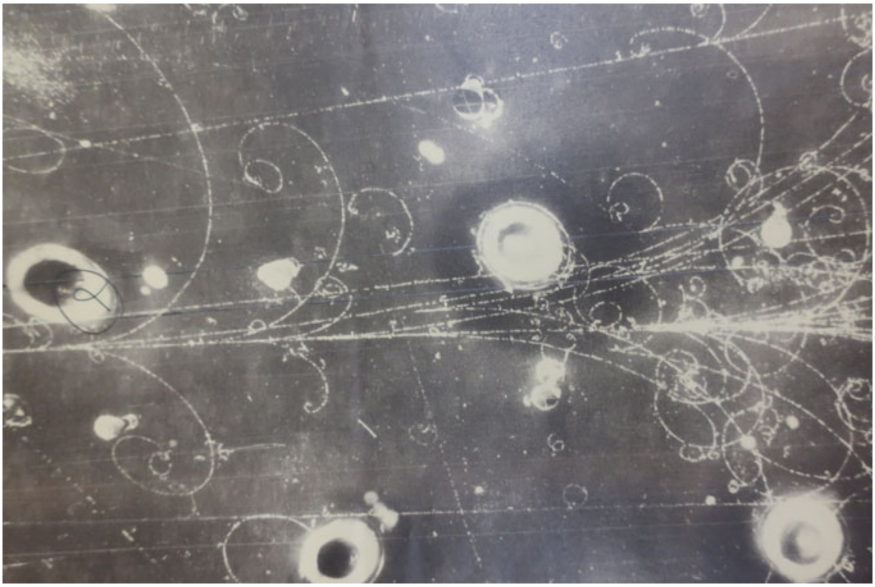

Fig. 11 Cloud Chamber. Courtesy of CERN

Fig. 12 Gaika portrayed at ATLAS experiment. *Photo* by Sophia Bennett/CERN

Fig. 13 Haroon Mirza and Jack Jefls with scientist Diego Blas. *Photo* by Sophia Bennett/CERN

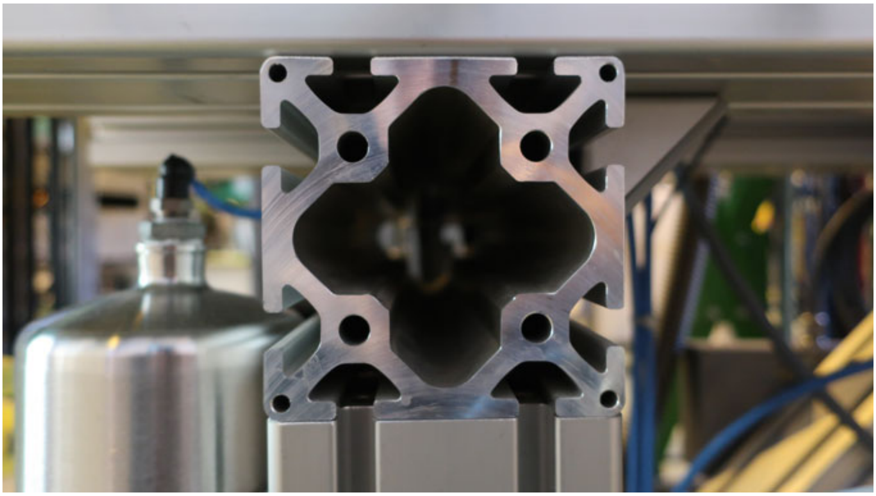

Fig. 14 Caption from CERN experiment. *Photo* Mónica Bello/ CERN

Fig. 15 HALO by Yunchul Kim, at Broken Symmetries FACT, Liverpool. Courtesy of FACT

Fig. 16 CERN Data Centre

Fig. 17 CERN experiment

Fig. 18 Theorist at work, CERN

A Psychohistorical Philosophy for the Science of the Arts

Nicolas J. Bullot

Main Text

Some enquiries into the relations between arts and sciences have engaged with, and sought to overcome the Two Cultures view (Snow 1959). This view rests on the idea that the culture of the arts and the culture of the natural sciences are mutually exclusive and hostile to one another. Adherence to the Two Cultures view leads to scepticism about the prospects of cooperation between the creative arts and humanities, on the one hand, and the natural sciences, on the other. Artists and theoreticians in the humanities who defy and decry science and positivism are promoting ideas and actions that can support the Two Cultures view. Reciprocally, scientists who discredit methods and scholars from the arts with condescending attitudes can contribute to prolonging the influence of that view.

The Two Cultures view is fraught with problems. Along with a number of colleagues, I defended an alternative to the divisive pessimism that leads to, or motivates the Two Cultures view (see Bullot and Reber 2013a; Bullot et al. 2017). The background of this approach rests on the *co-dependence thesis* (Bullot et al. 2017), which posits that dependence relations have tied arts and sciences together in the past and continue to interlink them in the current historical context. These dependence relations have led to the formation of diverse and complex art-and-science nexuses over the course of human history.

Bullot et al. (2017) sketched an argument from shared mental capacities in support of the co-dependence thesis. It rests on the premise that a number of cognitive tools have been shared across both scientific and artistic practices. Arguably, cognitive tools shared by artistic and scientific cognition comprise emotions and heuristics in decision making, imagination and thought experiments, narrative explanations, and a variety of capacities for cultural learning (for example, imitation and teaching).

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From these shared mental capacities, we can infer that creativity and innovation in both natural sciences and the arts depend on a shared toolbox of cognitive tools and brain mechanisms.

In the next sections, I provide further support to the co-dependence thesis in an examination focused this time on the debate about the foundations of the science of art (Bullot and Reber 2013b; Seeley 2011). One of the brainchildren of Two Cultures view is the idea that some intrinsic characteristics of artistic and scientific cultures make it impossible to develop a science of art. This view raises two philosophical questions about the conceptual foundations of the science of art. First, is a science of art—or a science of the arts—feasible? That is to say, are there *fundamental obstacles* to the development of an integrative science of the arts? Second, if a science of the arts is feasible and desirable, what are the principles and methods that should provide its conceptual foundations? In what follows, I review discussions about the first question that also engage with the second problem.

The Contested Natural Sciences of Art

Science, Causal Explanation, and Intervention

To serve as background of this discussion, I will assume a conception of *science* based on three core ideas that have been discussed in philosophy of science. First, I assume that one of the aims of a scientific model—or theory[1]—is to provide good *explanations* of the phenomena that the model seeks to describe and understand.[2] Second, the search for *causal explanation* is of particular importance to scientific thinking and practice. Third, causal explanation in science combined with technology can provide human learners with new ways to make predictions and manipulate the explained phenomenon.[3]

A number of scholars have an interest in scientific research about the arts and artistic projects inspired by science. In the former case, researchers have not reached a consensus on the principles and methods that should subserve a science of art in general, or causal explanation of specific artistic practices. Much theoretical contestation has occurred in relation to research that applies biological methods and models to the study of art. For example, there exists a debate about the conceptual foundations of evolutionary theories of art (Davies 2012; Dissanayake 1988; Dutton 2009). Another contested branch of the science of art focuses on using the experimental methods of psychophysics and psychology to study aesthetic responses to both artistic and non-artistic objects (see, for example, Berlyne 1971; Fechner 1876; Leder et al. 2004). Another field based on methods from biology uses brain sciences

[1]In the present chapter, I use the terms *model* and *theory* interchangeably.

[2]For a sample of influential accounts of scientific explanation, see Hempel (1965), Salmon (1992), Thagard (1992) and Simon (2000).

[3]See, for example, Woodward (2003) and Craver and Bechtel (2006).

to investigate art and aesthetics; this field is known as *neuroaesthetics* (for recent surveys, see Chatterjee and Vartanian 2016; Skov and Vartanian 2009). Let me take as an example the debate about the foundations of neuroaesthetics.

Neuroaesthetics

Neuroaesthetics is a recent field of research. But it is important to be aware of its history and of doctrinal shifts among its champions. To explain these, it is useful to distinguish the statements made by a first wave of research in neuroaesthetics from a second wave, which relies on different claims and is still ongoing as a research program.

First Wave

The first wave of neuroaesthetic research on the visual arts was comprised of a few neuroscientists and allied philosophers of mind. It was paralleled by separate neuroscientific research on music.[4] The contributions focused on visual art were published during a period of twenty years, starting around the last decade of the twentieth century. These works linked optimism about the prospects of a neuroscience of art (often implicitly understood as visual art) with the idea that the main role for neuroscientists in this field was to search for laws[5] and psycho-neural universals of aesthetic experience and art.[6]

The researchers known as defenders of this aesthetic positivism include neuroscientists Ramachandran (2001), Ramachandran and Hirstein (1999), Solso (1994, 2000, 2003), and Zeki (1998, 1999, 2001), Zeki and Lamb (1994). In some works, they introduced their research about art as an inquiry into the ways art 'obeys' the 'laws of the brain',[7] or as a search for neurobiological laws that explain artistic universals (Ramachandran 2001: pp. 11–12; 2011: Chap. 8; Ramachandran and Hirstein 1999). The search for universals of artistic cognition was also a central aim of enquiries developed by psychologist Pinker (2002: p. 404) and allied philosopher Dutton (2005, 2009: pp. 51–59). Both of them argued that there are universal signatures of art, such as virtuosity, pleasure, style, creativity, special focus, and imaginative experience.

A number of critics and art historians (Gombrich 2000; Gopnik 2012) and philosophers (Hyman 2010) have raised objections to the conceptual foundations of first-

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[4]For the discussion of the neuroscience of music, see Peretz and Zatorre (2003), Levitin (2006), Levitin and Tirovolas 2009), Thompson (2009), and Patel (2010).

[5]For a defence of the search for laws in empirical aesthetics, see Martindale (1990), pp. 3–13.

[6]See Aiken (1998, pp. 24–25), Dutton (2005), Fodor (1993, pp. 51–53), Peretz (2006), Pinker (1997, Chap. 8), and Pinker (2002, Chap. 20), Zeki (1998).

[7]See Zeki and Lamb (1994) and Zeki (1999).

wave neuroaesthetics. Some divisive judgments made in these debates might have been indicators of the resilience of the Two Cultures view. In the next section, I discuss the objection from art's distinctness, which is an important objection that challenges the universalist approach to the first wave of neuroaesthetics. This backlash was paralleled by contestations of evolutionary theories that viewed art as an adaptation (Davies 2012; Patel 2010). In spite of occasional acrimonious exchanges, many researchers came to the realisation that these were interesting times to develop interdisciplinary research about the arts and reflect on the conceptual foundations of scientific theories of art.

Second Wave

I propose to identify the *second wave* in neuroaesthetics as the works in neuroaesthetics that attempt to identify and redress the shortcomings of the first wave in a spirit of greater collaboration with art history, philosophy and the humanities. Works of the second wave also include attempts to test hypotheses that have proven important in the debate about the first wave. The works published by Chatterjee (2011, 2013a), Chatterjee and Vartanian (2014), Shimamura (2015, 2012) and their colleagues are representative of this second wave.

Chatterjee and Vartanian (2016) propose a framework for reviewing a number of studies pertaining to neuroaesthetics. The framework is a tripartite model, which posits that both aesthetic and artistic experiences emerge from the interaction between three mechanisms of the human brain: the emotion-valuation system, the sensory-motor system, and the meaning-knowledge system. The framework aims to explain aesthetic processes by identifying components and functions of these three systems. Explanations that seek to explain a phenomenon by decomposing systems into components that cause a to-be-explained phenomenon are typically described as mechanistic explanations.[8] Although mechanistic explanation is not the only type of explanation employed in biology (Dupré 2013), it is a sort of explanation commonly attempted by researchers in the cognitive sciences of art and, more specifically in neuroaesthetics.

Research on the emotion-valuation system provides illustrative examples. Consider empathy. There are reasons to think that the power of some works of art to move audience members can depend on our capacity to *empathise* with others. The capacity for empathy is a component of the emotion-valuation system (Chatterjee and Vartanian 2016). Freedberg and Gallese (2007) have argued that our explanation of responses to artistic works would be incomplete without taking into consideration empathy and the brain systems that cause empathy. In their account, the mirror neuron system is the core mechanism that causes empathy in both social and artis-

[8]Mechanistic explanations in science use the functional decomposition of a mechanism into parts and activities. Thagard (1992, 2006, 2019), Bechtel (2008), Bechtel and Richardson (1993/2010), and Craver (2007) have argued that mechanistic explanations is an important type of explanation in biology in general and neuroscience in particular.

tic situations. Thus, *pace* a number of critics of this approach (Bloom 2016; Casati and Pignocchi 2007; Hickok 2014), Freedberg and Gallese (2007) argue that empathetic responses to expressive paintings (e.g., dramatic works by Caravaggio, Goya and Pollock) depend on a brain system that generates embodied simulations of the emotions expressed by these paintings.

In another study of the emotion-valuation system, Brown et al. (2011) conducted a quantitative meta-analysis of 93 studies in brain imaging (fMRI and PET studies) of appraisal of positive-valence across sensory modalities. As used in psychological and cognitive sciences of emotions, the concept of *valence* refers to the perceived attractiveness (its goodness, or positive valence) or averseness (its badness, or negative valence) of a stimulus like an event, object, or situation. Within each category of sensory modality, the authors analysed studies using a wide range of stimuli. For example, within vision, they selected studies that included evaluations of pictures, artworks, images of food, erotic images, and images of loved ones. Their results suggest that the region activated most consistently across all four modalities was the right anterior insula. This is the region in the brain's core affective system, which is typically associated with visceral perception and the experience of emotions.

Brown et al. (2011) think that their meta-analysis warrants a bold conclusion about aesthetic judgement and the emotion-valuation system. Their conclusion is that, fundamentally, aesthetic judgment consists of the appraisal of the valence of perceived objects—that is, of attractiveness or averseness of objects. On their account, the neural system deployed for this purpose originally evolved for the appraisal of objects that provide survival advantage, which include nutritional food and attractive mates. Subsequently, this system was reused for generating the aesthetic experience of objects that satisfy social needs. Brown et al. (2011) include works of art among these socially useful objects. Following Brown et al. (2011), Chatterjee and Vartanian (2016) suggest that 'the pleasure that people derive from looking at beautiful objects taps into our general reward circuitry' (2016: p. 174).

Chatterjee (2013b) argues that neuroaesthetics can contribute to an interdisciplinary science of the arts by formulating and assessing general hypotheses about the brain mechanisms of artistic creation and appreciation. On his view, 'scientific studies' can even 'investigate the influence of historical meaning on appreciation of artwork' (Chatterjee 2013b: p. 138). Thus, Chatterjee is an optimist about the prospects of science of art understood as a neuroscience of art and aesthetics (neuroaesthetics). That is, his writings sketch a negative answer to the question of whether or not unsurmountable obstacles prevent the development of a science of art. Yet, his optimist account is more qualified than the accounts proposed by champions of the first-wave of neuroaesthetics. For he concedes to the critics of neuroaesthetics that neuroscientific methods can be inadequate to explore the historical dimension of the arts (Chatterjee 2013b; Chatterjee and Vartanian 2016: p. 189). Specifically, he argues that scientific studies 'cannot analyze historical meaning itself embedded in the artwork' (Chatterjee 2013b: p. 138), a methodological view expounded as follows:

> If one believes that a critical level of analysis in art appreciation is understanding the unique information contained in individual works, the way a piece of art responds to its place in time, and is embedded in its local culture, then experimental science will be found wanting. Experiments, by design, draw general inferences from many examples of artworks. Scrutinizing layered historical meanings of an individual work of art is too fine-grained a level of analysis to be resolved by the lens of scientific experimental methods. (Chatterjee 2013b: p. 138)

The Problem of Art's Specificity

Assessments of evolutionary and neuroscientific theories of art greatly vary with respect to method and conclusion. That said, researchers in the humanities and social sciences typically study art in well-defined social contexts. Thus, they regularly opt for *contextualist* approaches, which depend on the 'thick' description of a cultural context or the careful examination of individual and idiosyncratic factors. Methods aimed at describing and analysing cultural and historical contexts therefore take the precedence over the search for universals and mental mechanism.[9]

Stern sceptics and pessimists about the science of art defend an affirmative answer to the question of the fundamental obstacles to a science of art (Gopnik 2012; Margolis and Laurence 2007; Margolis 2000; McFee 2011). That is, they argue that there exist obstacles to the scientific study of art that make such a science a highly unlikely or an entirely impossible endeavour. Other writers are moderately pessimists (Davies 2013), and a number of moderate pessimists have focused their objections on neuroaesthetics (Casati and Pignocchi 2007; Hyman 2010; Langer 2016; Noë 2011, 2015). Scholars who defend critical forms of philosophical naturalism or natural philosophy may be viewed as critical optimists about the science of the arts (Bullot and Reber 2013a; Bullot et al. 2017; Meskin et al. 2018; Seeley 2011, 2013; Thagard 2019).

One of the influential arguments brought forth by both pessimists and critical optimists rests on the idea that a number of scientific theories of art tend to miss an explanation of the factors that make a thing a work of art. This line of reasoning leads to what I will call the *objection from art's specificity*. This objection operates by referring to distinctive properties of the fine arts and then drawing attention to the fact that some generalising scientific methods or hypotheses fail to identify and explain such distinctive properties. The label 'objection from art's specificity' is of

[9] Artists, humanists, and social scientists typically engage with artistic practices with contextualist approaches (Bullot and Reber 2013a; Danto 1964; Harrop and Bullot in press; Hogan 2013; Levinson 2007). Their view is *contextualist* in the sense that they understand works of art within the constraints of the careful interpretation of unique social and historical contexts (or artworlds). Fields such as the continental philosophy of art, art history and visual culture, media studies typically analyse artistic practices as anchored into a cultural and social context. Some contextualists, such as the anthropologist Geertz (1973), claim that the explanation of social practices (e.g., ceremonial and artistic practices) need to be explained by means of 'thick descriptions' that capture the significance of each social practice in its unique cultural context.

my own making. But it is an adequate label to categorise a highly coherent group of like-minded objections, which typically rest on the idea that the science of art is faced by the problem of identifying art. Both moderate optimists about the science of art (Bullot and Reber 2013a; Bullot et al. 2017; Seeley 2011, 2013) and pessimists (Casati and Pignocchi 2007; Davies 2013; Hyman 2010; Langer 2016; McFee 2011; Noë 2015) have discussed this objection or defended some of its versions.

Hyman's Use of the Objection from Art's Specificity

When applied to neuroaesthetics, the objection from art's specificity leads to the idea that neuroscientific studies of the arts have failed to identify and locate art. Hyman (2010) defends this pessimist line by focusing his critique of the first wave in neuroaesthetics on the objection from art's specificity. Ramachandran and Hirstein (1999) propose that the 'purpose' of art 'is not merely to depict or represent reality—for that can be accomplished very easily with a camera—but to enhance, transcend, or indeed even to distort reality' (1999: p. 16). They posit that, fundamentally, artists seek to amplify the essence of an object in an artwork. This is to induce powerful responses by the same type of neural mechanisms than the type that would be activated by the original object. Hyman (2010) aims to refute this hypothesis by presenting one of the versions of the objection from art's specificity.

The central premise in Hyman's (2010) argument is that 'Ramachandran's theory of art (…) doesn't distinguish between a work of art and the kind of object that it represents' (2010: p. 250). To illustrate this point, Hyman states that the theory 'doesn't distinguish between a sculpture that represents a woman with big breasts and a woman with big breasts'. From this, he concludes that 'the theory cannot be telling us what 'the key to understanding what art really is'' (2010: p. 250). The core premise here is that the response to an artistic depiction of a female nude by Ramachandran's amplification mechanism would not fundamentally differ from its response to a non-artistic female nude. If Hyman's interpretation of that mechanism is correct, then the objection could succeed in showing that the mechanism does not explain that which is distinctive of art, and therefore distinctive of our responses to works of art.

Hyman (2010) redeploys the objection from art's specificity in his critique of Zeki's early writings on neuroaesthetics (Zeki 1998, 1999). Zeki's research at that time posits that, in some cases, different genres of art—such as cubism and kinetic art—excite different groups of cells in the brain. In response to this view, Hyman argues that 'it is undeniable that we could not appreciate a painting by Mondrian if the cells in our brains which are excited by vertical and horizontal lines were not functioning properly' (2010: p. 255). But 'this does not explain why the painting is pleasing or interesting to look at, or what it means' and 'it reveals nothing whatever specifically about art'. This is because, Hyman continues, 'it is equally true that I could not see the text on a page or the railing in a fence if the cells in my brain which are excited by vertical and horizontal lines were not functioning properly' (2010: p. 255).

Although it has been presented in diverse versions, the objection from art's specificity tend to rest on two basic claims about that which a science of art is supposed to explain—the *explanandum* of that science. The first is a premise about art's specificity; and the second a premise about shared systems (in the sense of shared mental mechanisms).

The Premise of Art's Specificity

The first idea, which may be called the *hypothesis of art's specificity*, states that humans identify works of art as a distinct category of socially valued entities. Humans refer to distinctive properties of the exemplars of that category to differentiate these works of art from non-artistic objects. To specify the properties that are specific of works of art requires that scholars identify that which is distinctive of art. In philosophy, this task is traditionally associated with an ontological theory of art, which aims to elucidate the nature of art and define what art is (Currie 1989; Danto 1981; Ingarden 1989). Philosophers have proposed a variety of such theories, which range from theories identifying art with adaptive aesthetic processes (Anderson 2000) to opposing accounts that understand art as a purely social and normative historical institution (Dickie 1984/1997, 2000; Shiner 2001), through to accounts integrating both aesthetic and historical criteria (Davies 2015).

No philosophical ontology of art is uncontested. However, both amateurs and experts interested in art typically assume that there exist discoverable properties that set artistic things apart from non-artistic things. Thus, the idea that there are historical and mental facts that explain art's specificity is commonly entertained as a default expectation, or at least as a reasonable assumption.

The Premise of the Shared Systems

The second premise of the objection from art's specificity asserts that a significant number of the theories of art introduced in neuroaesthetics, or more generally biology, posit mental systems for aesthetic responses and artistic decision making that are also engaged by decision making and intercourses with non-artistic things. We may call this idea the hypothesis of *shared systems*.

Neuroscientists tend to adopt or defend the hypothesis of shared systems without seeing it as a threat to the science of art (Ramachandran and Hirstein 1999; Zeki 1999). A representative example is Brown et al. (2011) functional connectivity model (see above), which posits that aesthetic processing is the appraisal of valence of perceived objects by a core brain system connecting four regions (anterior insula, rostral cingulate, orbitofrontal cortex and ventral basal ganglia). According to this model, aesthetic appraisal results from interactions between subjective awareness of current homeostatic state (mediated by the anterior insula) and exteroceptive perception of objects in the environment (mediated by the sensory pathways leading up to the orbitofrontal cortex). That is, recurrent connectivity between the anterior insula and the orbitofrontal cortex can mediate 'homeostatic emotions', which consist in the assignment of valence to objects as a function of current homeostatic state. In an explicit endorsement of the shared system hypothesis, Brown and colleagues write that the core circuit 'is in no way restricted to aesthetic processing, but may be related to all cognitive processes that involve viscerality (…), as shown by the observation that it is active when people evaluate the truth or falsity of religious propositions' (2011: p. 256).

Another version of the shared systems hypothesis is Freedberg and Gallese's (2007) claim that empathetic responses to expressive paintings (e.g., dramatic works by Caravaggio, Goya and Pollock) depend on a 'mirror-neuron' system that generates embodied simulations of the emotions expressed by these paintings. It is clear in Freedberg and Gallese's (2007) conception that such a system is used in non-artistic activities, indicating that it is a shared system.

Adoption of the shared systems hypothesis nonetheless poses a problem for neuroscientists. If the hypotheses of art's specificity and of shared systems are both true, then one might be warranted in concluding that there exists a fundamental obstacle to a neuroscience and biology of art. For, if neuroscientific explanations can only describe brain systems that subserve *both* artistic and non-artistic functions (as suggested by the premise of shared systems), then it might be impossible for such explanations to discover the causal processes that are *distinctive of*, and *sufficient for* artistic functions and practices. This pessimist conclusion simply follows from the fact that the description of multi-purpose mental mechanisms of the human brain does not seem to offer a description of mechanisms that are sufficient to, and distinctive of artistic practices and experiences.

Critical Naturalism and Essentialism

Let us review the lessons that may be learned from the objection from art's specificity. First, researchers engaged in the debate typically agree that models from the biological sciences can describe mechanisms that are *necessary conditions* of artistic experience and artistic practices. To take a simplistic example, researchers typically assume that having a human brain is a necessary condition of acting as an artist and engaging in art appreciation. However, referring to a very general biological condition of artistic practice—such as the brain—does not explain anything that is distinctive of art, understood either as a historically-situated social practice or as set of distinctive aesthetic experiences. Following this line of reasoning, the objection from art's specificity defies scientists by raising a challenge about the explanatory scope of the mechanisms they posit in their explanations. How can a scientist demonstrate that the mechanism she or he posits explains a distinctively artistic phenomenon? How could the scientist demonstrate that the posited mechanism is not simply a general necessary condition to, but not a sufficient condition of art and its specificity?

A number of sceptics about the prospects of a science of art think that neuroscientists and biologists have failed to offer a persuasive response to the challenge posed by the objection from art's specificity. To them, typical models of art from the biological and cognitive sciences do not explain how we create and respond to *art as such*.

Pessimism About the Science of Art Grounded in Social Constructivism

A number of pessimists[10] about the biological sciences of the arts appeal to social norms to justify the idea of art's specificity and the associated objection. On these views, to identify and understand the specificity of art, we need to explain the *social conventions* and *social norms* that govern artistic expertise and inform our responses to particular artworks. The explanation of these social norms in our engagement with art, they argue, lies outside the purview of biology and neuroscience (e.g., of the biology of our sensory-motor and emotion-valuation brain system).

According to some pessimist views, even if neuroscientists were seeking to explain neural correlates of the social rules that govern artistic practices, they could only describe systems of the social brain that function to support both artistic and non-artistic practices. That is the point made by the *shared systems* premise of the objection from art's specificity. So, again, these scientists would not explain how we identify and value *art as such* because they would neither investigate, nor include in their models the social systems that need to be understood to explain how we identify and value art as such.[11]

Among the most radically *pessimistic* assessments of the science of art, McFee (2011: Chap. 8) maintains that contemporary neuroscience is irrelevant to our philosophical reflections upon an art form like dance. Other philosophers opt for less radical forms of pessimism. Among them, Davies (2013) is a self-declared *moderate pessimist* who has engaged with neuroscience. Davies argues that recent psychological empirical research on dance does not directly settle any of the core normative and ontological questions investigated by the philosophy of dance (for example, specifying the factors that make dance an art form).

[10] See Margolis (1980, 1995, 2000), McFee (2011: Chap. 8), Gopnik (2012), Davies (2013), and Langer (2016).

[11] The argument can also be run with a focus on the evaluation of the social rules that govern artistic practices and judgements. When debating artistry and artistic values, people make normative judgements in relation to whether particular artistic decisions are good or bad, apt or inapt. But, says the pessimist, good and bad artistic decisions will engage the same shared mental systems. This idea again refers to the premise of the shared systems in the objection from art's specificity. From this the pessimist concludes that the biological and cognitive sciences describing these shared systems will not be of any use in understanding or justifying our normative artistic judgements. These sciences, consequently, fail to locate art (or good art) because such sciences do not offer us resources to understand the normative dimension of artistic creation and appreciation.

The Thesis of Critical Naturalism in Art Theory

In my research, I defend an approach to the science of the arts guided by constructive criticism and critical rationalism. The background of this approach is a thesis that we could call *critical naturalism* applied to art theory. The thesis of this critical naturalism holds that scientific enquiries can significantly contribute to our understanding of the arts and the ways in which humans respond to particular works of art. Specifically, to adequately address questions about artistic topics, we need to examine mental mechanisms and social systems that are studied empirically in the biological and cognitive sciences.

I use the qualifier *critical* in 'critical naturalism' to indicate that I am referring to a philosophical form of naturalism and 'natural philosophy' (Thagard 2019), which demands from the enquirer a philosophical and historical evaluation of the key claims made by scientists and scientific theories. This critical attitude is exemplified by the works that have developed and assessed the objection from art's specificity. This includes Hyman's (2010) evaluation of the first wave of neuroaesthetics, Seeley's (2011, 2013) research on the cognitive science of art, and Bullot and Reber's (2013a) critique of empirical aesthetics. The reflective analysis that is distinctive of critical naturalism demarcates this approach from the positivistic and reductionistic views holding that cogent sources of knowledge about the arts only come from biological models.

To develop one's research as a critical naturalist and natural philosopher, one needs to be at least moderately optimistic about the prospect of fruitful collaborations between the arts and the natural sciences. Of course, critical naturalists and natural philosophers can be entirely pessimistic about the prospect of success of a particular scientific model.

To take an example of a task invited by critical naturalism, empirical research from the cognitive sciences is needed to test conceptual and philosophical theories of art (Bullot et al. 2017; Chmiel and Schubert 2019; Martindale 1990). Experimental research can help evaluate whether or not our best theories of an artistic practice match to the mental and social characteristic of our interactions with works of art. Where the results of this kind of empirical research contribute to our understanding of individual works and associated artistic practices, we can embrace them and incorporate them into our general and philosophical understanding of the arts.

Critical Naturalism and the Objection from Art's Specificity

To the critical naturalist, objections presented by pessimists about a science of art should to be seriously considered and thoroughly examined. The most interesting of such arguments will invite theoretical refinements and methodological corrections (Bullot et al. 2017). But such objections have neither argumentative acumen nor social influence capable of ending scientific enquiry into the arts. The current scholarly context is that of a growing interest in enquiries into the arts by an increasing number of new scientific fields (for example, neuroaesthetics, neuroanthropology, the theory of cultural evolution, cognitive archaeology and cognitive narratology). In this context, constructive objections to the science of art—such as the objection from art's specificity—are best interpreted as genuine *parts* of the integrative science of the arts, and an integral part of our reflection about its foundation. This is in contrast to views of such objections as demonstrations of the *a priori* impossibility of a science of the arts.

This process of critical assessment and integration is exactly what could happen in the case of the objection from art's specificity. Properly interpreted, the objection is consistent with critical naturalism. The objection from art's specificity affects scientific theories of art that lack a credible ontology of art. Yet, this objection is not sufficient to demonstrate that there exists an unsurmountable obstacle to the advancement of a science of the arts. Rather than showing the demise of the science of art, it demonstrates the need for scientific models of artistic practices to incorporate a better understanding of the historical genealogy of the arts (Bullot and Reber 2013a, b; Danto 1964; Shiner 2001). This is because such a historical genealogy is what determines the specific ontological characteristics of each art genre. This historical understanding of the arts is needed to define the scope of any scientific model of art.

Critical Naturalism and the Problem of Essentialist Thinking

To the critical naturalist, a potential problem brought by the assumption of art's specificity is that it can lead to essentialism (Gelman 2003, 2013; Newman et al. 2011; Wilson et al. 2007). An *essentialist conception of art* posits that there are distinctive and typically hidden properties of art in general. However, such a conception is questionable (Davies 2015; Gaut 2000; Levinson 1979; Lopes 2014). A problematic version of this idea consists in positing that art has an immutable essence, which would justify treating works of art as an entirely homogenous kind.

Thinkers won by the idea of an essence of art might seek to discover a definition that would characterise the distinctive essence of art. To such essentialists, an adequate definition of art would describe art's hidden and permanent properties by specifying individually necessary and jointly sufficient conditions to art status. But a number of essentialist attempts to define art in terms of individually necessary and jointly sufficient conditions have failed (Gaut 2000). Typically, these definitions were falsified by historical changes in how humans have regarded art statuses. So, historical change and cultural innovations in the arts in particular can render essentialist definitions of arts obsolete. One of the lessons that we can learn from the history of the arts is therefore that essentialist scholars are unlikely to succeed in formulating an essentialist and universalist concept of art. Reciprocally, another of the lessons that can be learned from art history is that concepts of artistic works and genres need to be historically situated to be informative, and that such concepts can only be specified by genealogical and contextual enquiries (Shiner 2001).

A Psychohistorical Approach to the Problem of Art's Specificity

Let me end by suggesting that the reasons why we should resist essentialism in art theory may be linked to a solution to the problem of specifying art in the scientific theory of art. For there is a way to rebut the objection of art's specificity that offers a way to define the *explanandum* of a science of the arts. The solution I propose is what I have termed a 'psychohistorical' approach to the science of art. It brings us to my third thesis, the psychohistorical thesis.

A Psychohistorical Thesis

In response to concerns about the definition of art in a science of art, I propose a *psychohistorical thesis*, which states that the problem of art's specificity can be generated by an integration of the cognitive and psychological sciences of art with historical genealogies of the arts and their cultural diversity. That is to say, a method apt for explaining artistic practices and experiences—and thus rebut the objection from art specificity—consists in combining research on the mental and brain capacities engaged in the arts with enquiries into the historical and cultural contexts of such practices. The psychohistorical approach pertains to a family of approaches aimed at integrating psychological explanation and cultural factors in fields such as cultural psychology (Cole 1996/1998; Heyes 2018), cognitive anthropology (Henrich et al. 2010; Richerson and Boyd 2005), neuroanthropology (Lende and Downey 2012) and cognitive narratology (Hogan 2013; Kukkonen 2017).

If the view derived from the psychohistorical thesis is correct, then only a historical genealogy of art practices in their cultural diversity can appropriately address the problem of art's specificity. Consequently, enquiries into the history of art practices are necessary to discover empirical tools to identify specific arts. This is because each artistic practice needs to be understood as dependent on specific processes of cultural transmission and unique historical kinds. In addition, this thesis suggests that we should dismiss essentialist theories of art. But it also invites research on how essentialist thinking influences some of the ways humans respond to art (Gelman 2013; Newman and Bloom 2012). Let me illustrate the virtues of the approaches identified by the psychohistorical thesis.

Solutions to the Problem of the Explanandum of a Science of the Arts: Psychohistorical and Neuroanthropological Methods

A theory that is psychohistorical denies that there exists entirely ahistorical entities that should be called ‘art’ *tout court*. This is because the key concepts that make talks about the arts intelligible are historical concepts, the meaning of which is dependent on specific contexts. Primary among these historical notions are a family of concepts and norms codified in the eighteenth century to describe the *fine arts* (Shiner 2001). According to Shiner (2001), conceptions of arts and craft did not make the distinction between craft, technique and fine art. Analysis of the history of artistic practices and concepts make it possible to identify specific traditions in the arts in a manner that is both informative and amenable to multiple empirical methods of enquiry.

Contextualisation and Genealogies of the Arts and Artistic Concepts

In the day-to-day practice of the scientific enquiry about the arts, researchers adopt a psychohistorical and psychocultural methods when they clarify their research questions with respect to a specific social *context*. This attitude differs from the method based on asking ahistorical questions guided by an essentialist conception of art. This contextualisation offers ways to address the problem of art’s specificity. Once located in cultural and historical situation, a question about any work of art is tied to ‘thick’ conceptual categories that reflect the context in which the investigation is taking place.

Once contextualised, it becomes clear that any genuine understanding of that work is contingent on a grasp of the relevant historical and cultural categories. Thoughts about artistic specificity are grounded by the idea that each of the arts pertains to a cluster of historical categories, which forms a conceptual network associated with specific artistic kinds. Thus, historical analysis avoids the problem of circularity in the task of defining the arts. An appropriate psychohistorical method consists in combining an enquiry into the systems that cause the specificity of artistic things (and thus takes in account the historical specificity of the arts) with an analysis of the mental systems we use to identify and respond to such artistic things.

Art Appreciation

In my previous research about art,[12] I have applied the psychohistorical approach to the study of the way we respond to works of art. In this context of art appreciation, the psychohistorical approach offers a conceptual framework to address the problem of art's specificity. To explain how this solution works, let me illustrate the approach with an example.

Consider the varieties of responses that can be offered to a painting in a Museum of Contemporary Art. Imagine Clement,[13] a visitor of that museum. Clement believes that one can ascertain the value of a painting from the first visual encounter of its aesthetic properties. He even thinks that his duty as an influential art critic is to make a first evaluation of a work of art in a state of mind untainted by beliefs about the artist and the social context in which the work was painted. At some point in his visit, Clement visually encounters a painting that includes a large oblong and flat visual object shaped like a cucumber and filled with dots. Radiating from the oblong object, there are twig-like lines that operate like routes and lead to large circular peripheral objects made of concentric circles of dots and lines (each one looks like a target).

At the moment of this brief visual encounter, Clement is in a situation that Bullot and Reber (2013a) classify as *basic exposure*. This term refers to a situation where a person (i) is perceptually exposed to a work for the first time and (ii) has not made any deliberate and conscious enquiry into the history of the work and its cultural context of origin. In that situation, Clement's actions and judgements are guided by capacities that regulate his perceptual and emotional sensitivity to the work. These mechanisms may include processes of the brain systems that Chatterjee and Vartanian (2016) identify as the sensory-motor system and the emotion-valuation system. In responding to the work, Clement's mind can succeed in performing a wide range of tasks, which may include detecting statistical regularities, recognising bodily gestures (mirroring), or responding with primary emotions and sensory pleasures. Although Clement might enjoy the experience of basic exposure to the painting, he would not be able to reliably perform a number of key tasks in relation to cultural learning, work identification, and artistic evaluation and value. This is because, being under the condition of basic exposure, Clement does not have access to historical and cultural information needed to successfully complete these tasks.

Take for example the identification of artistic categories relevant to interpret the painting. Let's assume that Clement's is mostly knowledgeable in European and American modern art. Basic exposure to the painting might activate Clement's recollections of traits of abstract expressionism, which may lead Clement to posit that the structure depicted in the piece was painted by an artist whose work pertains to the tradition of abstract expressionism. On this occasion however, this classification would be an artistic misunderstanding (Bullot and Reber 2017). The painting

[12] I proposed the idea of a psycho-historical model in Bullot (2009) and expanded this idea in Bullot and Reber (2013a).

[13] In this narrative, the character of 'Clement' is loosely inspired by Greenberg's (1999) methods in art criticism, which emphasised intuition and immediate experience.

I was trying to describe, which is entitled *Euro story* and was part of the exhibition *Tjungunutja: From Having Come Together* (The Museum and Art Gallery of the Northern Territory, 2017-2018) was painted in 1972 by Australian Indigenous artist Uta Uta Tjangala. The term *euro* refers to a species of marsupials (*Macropus robustus robustus*, also known as 'wallaroo') of the family of macropods (which includes kangaroos and wallabies). Critical aspects of the cultural and environmental context of this painting need to be learned in order to identify the relevant categories necessary to understand the painting.

Tjangala was one of the artists of the Papunya Tula cooperative (Johnson 2010). Papunya Tula, or Papunya Tula Artists Pty Ltd, is an artist cooperative formed in 1972 that is owned and operated by Indigenous people from the Western Desert of Australia. The group is known for its work with the Western Desert Art Movement, popularly referred to as 'dot painting'. Credited with bringing Aboriginal art to world attention, the artists Papunya Tula inspired other Indigenous artists and styles.[14] The work was exhibited accompanied with this note, presumably a description of the painter's intention: 'This painting depicts a group of Euro ancestors who have sought refuge from a fire at a waterhole. The waterhole is depicted by the central circle. The adjacent concentric circles are the homes of the Euro. The diagonal lines represent the bushfire'.[15] Because the work does not pertain to Western modernism and includes pictographic and diagrammatic elements, one would comit a major artistic misunderstanding if one were to classify it as a contribution to abstract expressionism and Western modernism.

The only way for Clement to avoid the artistic misunderstanding and biased evaluation just described is to learn about the history and cultural context of the work. For this, one may investigate the work as a trace of artistic decisions. This may lead to an active enquiry about the human agents who made the work, preserved it over time and curated its exhibition. This approach succeeds because each and every work of art is a historically situated trace that carries causal information and is part of cultural categories. Learning about these historical traces is what provides audience members with resources to identify artworks and their social functions. Clement could, for example, aim at having these questions answered: What is the title of this painting? Who was the individual or collective person who created it? Are there remarkable features of its commercial, curatorial and cultural history? What are the conceptual categories[16] that are relevant to describe the intentions of the artist

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[14]The company operates today out of Alice Springs and is widely regarded as the premier purveyor of Aboriginal art in Central Australia.

[15]In addition to the work's connection with core concepts from Pitjantjatjara people in central Australia (like the Tjukurrpa [*Dreamtime*]), we can discover that the painted figures were intended to be pictograms and diagrams. The painting is symbolic, it includes exemplifications and representations, as explained by notes made by the curator who worked with the artist.

[16]The historical categories that we use to identify works of art include: (1) categories of genre of fine arts such as *painting*, *music*, and *photography*; (2) technical concepts associated with a particular field of artistic practice (e.g., *chiaroscuro*, *tonality*, *synthesizer*, *chance operation*); (3) concepts of artistic styles, such as the *baroque* style, the *minimalist* style, or the *hip hop* style; (4) categories of norms used to identity and value of works of art, such as the concept of *formalism* and *modernism*.

and the cultural significance of the work? What could be the future legacy of such a work? These cognitive activities include what Bullot and Reber (2013a) called, after Dennett (1990, 1971) and Kelemen and Carey (2007), the design stance along with other causal and historical stances. In the artistic design stance, one adopts a strategy aimed at becoming sensitive to *unobservable* facts regarding the work and its history of production and cultural transmission.

This example illustrates that contextualisation and historical cognition are necessary to a wide range of responses to a work of art, which range from authentication of authorship and provenance to in-depth cultural interpretation. Without historical contextualisation, determining whether or not a thing pertains to a specific genre of art is not possible. Without historical and cultural contextualisation, it is impossible to learn whether or not the work under examination pertains to one of the traditional fine arts or one another cultural tradition. Thus, contextualisation is a fundamental process that needs to be understood in order to adequately address the problem of art's specificity. This point is made in a number of psychohistorical and psychocultural accounts. For example, a core hypothesis Bullot and Reber's (2013a) psychohistorical model is that processes of causal and social reasoning (for example, an artistic design stance) are necessary to artistic expertise and understanding, art authentication, and feelings responding to history of the work and the flow of time (for example, nostalgia).

By adopting the design stance and other strategies of contextual and social learning, artists and audience members gather the historical and cultural knowledge that enables them to identify what distinguishes a work or genre of art from non-artistic objects. The capacity to identify, value, and understand works of art as distinct from non-artistic objects therefore rests on the capacity to learn to categorise the work under appropriate historical concepts and relevant cultural notions such as *acrylic painting*, *Papunya Tula*, *conceptual art*, *Tjukurrpa*, or *baroque music*.

Psychohistorical Methods in Empirical Aesthetics

In their review of neuroaesthetic research, Chatterjee and Vartanian (2016) state that 'neuroscientific approaches are not ideally suited for extracting the historical, social, and cultural context within which works are produced and appreciated' (2016: p. 189)—see, also Chatterjee and Vartanian (2014). This acknowledgement led Chatterjee and Vartanian to conclude that 'multi-modal and interdisciplinary approaches that incorporate neuroscientific approaches would appear to be particularly fruitful for advancing our understanding of aesthetic phenomena' (2016: p. 189). This interdisciplinary aspiration dovetails well with both critical naturalism and the psychohistorical thesis. Still in support of an interdisciplinary approach, several projects[17] of

[17]This research includes enquiries into the effects of *training and expertise* on art appreciation (Else et al. 2015; Hekkert and van Wieringen 1996b; Nodine et al. 1993), *framing effects* caused

experimental research have examined the roles of contextualisation and psychohistorical factors in the creation and appreciation of artworks.

To take the example of a contextualist idea that has received experimental support from empirical investigations, consider the hypothesis that artistic education and expert training in the arts modifies responses to works of art. The social transmission of cultural information and skills has been documented in diverse contexts by qualitative descriptions in anthropology, art history and sociology. In addition to this qualitative evidence, psychologists have measured the differences between experts and non-experts both in terms of subjective ratings (Hekkert and van Wieringen 1996a, b) and viewing patterns measured by eye tracking (Nodine et al. 1993). These studies suggest that, whereas nonexperts tend to favour representational paintings over abstract paintings, this preference is attenuated or absent among participants with expert training in the arts (Leder et al. 2012). This suggests that artistic instruction provides learners with skills to interpret and understand the significance of abstract art, which in turn may lead to rewarding experiences.

Coda

To recapitulate, the previous discussion was aimed at defending and illustrating three philosophical theses. Collectively, these theses sketch a conceptual framework for interpreting the relations between the arts and scientific research, and for contributing to an integrative science of the arts. The first thesis, the *co-dependence thesis*, holds that a history of dependence relations has bond the arts and the sciences, and continues to link them in the current historical context. These dependence relations take place in historically changing art-and-science nexuses, which are studied by a variety of methods of cultural and empirical enquiry. Second, I presented a view consistent with the thesis of *critical naturalism*, which holds that scientific investigation of artistic practices and aesthetic experience can make significant contributions to our understanding of the arts. A desirable science of the arts may use critical analysis and interdisciplinary models to build integrative explanations of artistic practices and experiences (i.e., multidisciplinary explanations that combines research on the arts from both empirical and conceptual disciplines like philosophy). To support critical naturalism, I have discussed one of the objections that has generated pessimism against the science of art, which is the objection from art's specificity. Third, I have advanced a thesis regarding the *psychohistorical approach*, which states that a method apt for developing integrative explanations of artistic practices and experiences consists in combining research on the mental capacities engaged in the arts with enquiries into the historical and cultural genealogy of such practices. These three theses are philosophical heuristics in the sense of general thoughts that can orient enquiry and suggest more specific research hypotheses.

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by artistic labels (Huang et al. 2011; Kirk et al. 2009; Silveira et al. 2015), and the importance of information regarding *artistic authenticity* (Newman and Bloom 2012).

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Lines and Boxes: The Geometry of Thought

Barbara Tversky

Like most living creatures, we move on the earth. Our feet create paths as we go from place to place. Our remote flying cousins create paths in the sky. Those paths form lines that lead from one place to another. You could say I'm obsessed by lines. Not just by lines, but also by boxes, places, scattered along those lines and connected by them. I'm also obsessed with perspectives, real and actual perspectives, but even more by perspectives in the imagination. We can imagine ourselves on a line, perhaps traveling from place to place, stopping to look forward or backward or all around. We can also imagine ourselves looking down from above. From above, our perspective is map-like. We can see many paths, not just our own. We lose the detail of the things around us but gain the larger structure. Or, to borrow an old phrase, we lose the trees and gain the forest. Those spatial words, line, path or link, box or container, and perspective are abstractions, and extraordinarily useful ones. Here, we stay with lines, points, and boxes. Zero, one, and three dimensions (Talmy 1983). Perspective is a longer story, and a fascinating one, but for another time, not for now.

One way to regard places, events, people, ideas is as points, way stations along the paths or lines that link them. We talk that way when we are only interested in their places in space relative to other places. Florence is between Milan and Rome. Christmas is between Thanksgiving and New Year's. Your supervisor is between you and your boss. But there are other ways to look at places, events, people, and ideas, namely, as boxes or containers. After all, they are rich stimuli, integrating the many senses and associations that experience the places or events or people or ideas. Rome, New Year's, your boss, and justice are bursting with meaning, containing nuanced, vivid, general, and specific visual, auditory, olfactory, proprioceptive, tactile, emotional, and abstract information. And add to that the memories of old experiences and knowledge that new encounters always evoke.

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As we walk the earth, we leave traces on the ground, traces that over time crush the grass underfoot and make visible paths for us to follow, for others to follow. Moving in space leaves traces in the brain, in the hippocampus. Individual cells, single neurons, fire when we are in a particular place, different cells for different places (e.g., O'Keefe and Nadel 1978). Exploring an area, taking many paths and visiting many places, arranges those places topographically as they are in space, creating maps in the brain, in entorhinal cortex, a synapse away from the hippocampus—there's a straight and direct path from one to the other. Place cells in hippocampus are like checkers, and the spatial array of entorhinal cortex like a checkerboard. Remarkably, in humans, the hippocampus seems to create checkers and array them in entorhinal cortex not only for places in spaces in the world, but also for events and episodes in a temporal space, past or future, people in a social space, and ideas in a conceptual space. The brain arrays events in time and people into social networks and ideas into conceptual networks just as it arrays places in space. The hippocampus records the lines, the paths, that we take from place to place, from thought to thought. The array in entorhinal cortex allows taking an overview of the entire space of places, events, or ideas. The checkers and the checkerboard, the place cells and the grid cells, can be used and reused for new places, events, and ideas, erased like a blackboard and then rewritten. The same neural structures underlie place, time, people, ideas, past and future (e.g., Collin et al. 2017; Constantinescu et al. 2016; Deuker et al. 2016; Eichenbaum and Cohen 2014; Epstein et al. 2017; Garvert et al. 2017; Hassabis and Maguire 2007; Moser et al. 2008; Milivojevic and Doller 2013; Mullally and Maguire 2014; O'Keefe and Nadel 1978; Poppenk et al. 2013; Schacter et al. 2017; Scoville and Milner 1957).

It's no wonder that we talk about events or people or ideas as close or distant, that's how the brain represents them. It's no wonder that we talk about mapping temporal relations and social relations and conceptual relations. It's no wonder that we create paths through life as we do on the ground. Lines, like places, come from the world and come from the brain. The brain perceives the lines in the world and then reuses that neural apparatus to line up other things, events, numbers, ideas. The eye and the brain are partial to the lines in the world, horizontal and vertical (e.g. Howard and Templeton 1966), even remembering lines that are not quite horizontal and vertical as horizontal and vertical (Tversky 1981).

Lines on a Page: Neat and Messy

Humans (even Neanderthals!) seem to have always and everywhere put thought in the world, carvings on stone or bone, arrangements of pebbles and strings and pieces of wood, paintings on walls of caves, sketches on paper. Speech and gesture too, but they are ephemeral. Depictions and graphics of all sorts pre-date written language by many millennia. Putting thought in the world gives the thought some permanence and allows it to be worked with, by whoever put it in the world, but also by others, sometimes separated by thousands of years. Ancient representations of thought expressed ideas that were important then and are important now, so important that for the most part the brain evolved areas dedicated to analyzing and representing them. Space, as in maps, time as in events and sequences of events, objects, people, and number in tallies. Note that each of these forms of representation bears quite direct correspondences to thought. Events, objects, and people resemble what they represent. Maps array icons or points or paths as they are arrayed in real space. Tallies array vertical lines along virtual horizontal lines in one-to-one correspondences.

Even in ancient times, if far less ancient, the repertoire of visual spatial representations expanded in an important way, to representing thought in symbolically, in writing. Most early writing systems had resemblance as a foundation, if opaque and rife with ambiguity. In modern times, the catalog of visual spatial representations has expanded. Beginning in the late eighteenth century, it grew to include graphs and tables and by now many other inventive ways to visualize information. So many interrelated bursts of innovation happened at once then, the Industrial Revolution and the global expansion of commerce, the explosion of science and mathematics, and the graphic inventions of ways to represent the new knowledge. Graphics are abstractions, simplifications, ways to organize information. As such they rely on the same mechanisms that the mind uses to abstract, simplify, and organize thought: lines and points and boxes. Lines show up as axes of graphs; lines and points show up as graph lines and the points along them, boxes show up in bar graphs and matrices. Their meanings are clear from their geometric and gestalt forms, in context (Tversky et al. 2000; Tversky 2011). Boxes are containers, categories, separating one set of things from another; lines connect points along a shared dimension. Or on sketch maps, lines are paths linking places that are dots. Gestures, another form of visual spatial communication, do the same (Tversky et al. 2009; Tversky 2011), simplify, abstract, and set up spatial schemas that are stages for thought.

In contrast to these neat and orderly lines for conveying neat and orderly ideas are messy sketches, the kind architects and designers and artist create as they are working through ideas (e.g., Kantrowitz 2018; Tversky and Suwa 2009). The messy scatter plots of new data ripe for exploration. Their very messiness enables arranging and rearranging, configuration and reconfiguration, considering and reconsidering, inspection and reinspection. Artists and designers embrace the messiness and the ambiguity it provides, a platform for the emergence of new ideas.

Lines in the World

Looking down on the world from above, as we do so often these days, we see lines, the lines of highways and streets, lined with buildings. So much of the world has been designed, by us. Those designs reveal the ways we have organized the world, and reflect the ways we have organized our minds. We form categories of stuff, chairs and tables, apples and oranges, cups and plates, pants and shirts and shoes. They are grouped on shelves and in drawers and bins and rooms in our homes and in our shops. We line books on shelves, buildings along streets, people and cars in queues. We create themes, groups of different stuff that are used together, couches and coffee tables and media in living rooms, towels and soap and tubs in bathrooms, rows of seats and a stage in theaters, swings and slides and picnic tables and grass and trees in parks. We design symmetries and repetitions and embeddings in the facades of buildings. We create one-to-one correspondences in table settings and apartments. Everybody gets a plate and a glass and a knife and a fork and a spoon and a napkin. Not all is so neat and orderly as it seems, there is chaos outside and in. These arrangements form patterns that are good Gestalts and attract the eye. Their order (or disorder) tells us that they are products of a sentient, human mind. They were created by human actions, intentional ones. They communicate, if implicitly. Those patterns then used as deliberate communications, in the form of tables and graphs and diagrams. They encourage a search for the meaning behind the order (or disorder). So much intelligence embedded in the design of the world, apparent to all, even babies, without words (Tversky 2019).

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Some Ecological Thoughts About Artworks and Perception

William P. Seeley

> The organism influences its own evolution, by being both the object of natural selection and the creator of the conditions of that selection (Levins and Lewontin 1985, p. 106).

Artworks are attentional engines. They are artifacts intentionally designed to draw attention to themselves in particular ways. They are, in this context, occasions for a communicative exchange. They are vehicles of communication that carry information about their intended content, their point, purpose, or meaning. Artists use artworks to express themselves in a myriad of ways. Artworks express ideas, emotions, art-theoretical perspectives, socio-cultural commentary, and a broad array of other things beyond and in-between. Art in this regard, like any other communicative system, has a history. The expressive vocabulary available to artists at a time within an artistic community depends upon its place (and its community's place) within that history. The history of art can be thought of as a history of the success and failure of those communicative practices that define artistic communities. Art is a complex social environment made up of at least artists, artworks, and the individuals that consume them. Of course we should add in galleries, museums, marketplaces, curators, critics, pundits, and skeptics. The core question at the center of discussions of the nature of art is how, within the context this rarified social environment, artworks are constructed to mediate the communicative exchange between makers and receivers, between artists and consumers.

The core questions about the nature of art are questions about *artistic salience*. The artistically salient features of a work are those aspects of their formal-compositional structure that carry information about what they express, about their point, purpose, or meaning. These aspects of a work reflect the range of compositional strategies and

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choices an artist has employed to produce their work. Critically, artists deploy exogenous and endogenous perceptual strategies tailored to direct attention and reveal what they mean to express. Painters, for instance, manipulate the perceptual salience of different areas of the canvas to directly engage perceptual systems, e.g. manipulating contrasts in the tonal properties, hue value, or scale of spatial frequency information in local regions of a painting. However, shared art critical knowledge can also be exploited to indirectly engage endogenous attentional processes, shape perception, and guide a consumer's understanding of what is expressed in a work. The range of exogenous and endogenous perceptual strategies an artist employs shape what an artifact *affords* a consumer as an artwork, the cognitive behaviors it supports. Access to these affordances depends upon the structure of the works, the structure of perceptual systems, and an understanding of the broad range of art critical and cultural practices that define the artworld for a community at a time. In this chapter I will employ a *diagnostic recognition framework*, a *biased competition theory of selective attention*, and *niche construction theory* to map the complex environment of an artwork and develop a model for understanding the way artists exploit exogenous and endogenous perceptual strategies in their works.

The Puzzle of Locating Art

There is a puzzle that plagues research in cognitive science and aesthetics. The puzzle is an artifact of something we value as a defining feature of art itself. Art expresses itself ambiguously. It is an imprecise mode of communication that invites reflection and creative problem solving. Artworks challenges us. The value of art lies in part in its mystery, a mystery that is compounded by the rich variance among the productive methods and stylistic choices available to artists. We value novelty and creativity in the productive practices associated with art. Herein lies the problem. Art defies definition by definition. The exercise of puzzling out the meaning of an artwork from amidst this caucophony is a praiseworthy cognitive achievement. What then are we to identify as the target of research in cognitive science and aesthetics. What should we identify as the target of our attention when we set out to explain art in the lab. We can call this pressing conundrum the *puzzle of locating art*. Interestingly, this puzzle is often as germane to our understanding of art in the wild as it is to artworks in the lab.

The puzzle of locating art plays out in a set of general skeptical arguments that raise questions about the relevance of psychology and neuroscience to our understanding of art. We can call these arguments the *common perceptual mechanisms argument* and the *normative dimension of appreciation argument*. Artworks are, as mentioned above, vehicles of communication. They are artifacts intentionally created to express some point, purpose, or meaning. Artworks are, in this regard, one aspect of a complex communicative exchange. Understanding art involves, at bare minimum, an understanding the structure of these communicative events. Artworks carry information germane to the recovery of their content. Given this fact we should expect that artists compositional strategies, the unique stylistic elements of the formal-compositional structure of their works, will resonate with the operations of affective, perceptual, and cognitive systems. The communicative nature of art therefore entails that artists methods for constructing artworks ought to have become fine-tuned over time to the operations of cognitive systems. There is nothing remarkable about this claim. It is simply an extension of the observation that cognitive systems have evolved to resonate with signal properties that carry information about the biologically salient features of a species' local environment. In order for artworks to work at all their design features, the pattern of elements constitutive of the formal-compositional structure of individual artworks, have to ride piggyback on these processes. If so, researchers might use the resonance between artworks and cognitive systems to explain art, to explain how art works as powerful means of communication.

The recent literature in neuroaesthetics is replete with examples of this strategy. Margaret Livingstone has, for instance, argued that the use of sfumato contours to depict Mona Lisa's dynamic expression resonates with the distribution and differential structure of peripheral and foveal photoreceptors in the retina. Livingstone has also argued that the compositional structure of Monet's depictions of moving water and windblown grass resonate with the basic neurophysiological processes responsible for McKay and Enigma illusions (Livingstone 2002). In each case the artist has manipulated the relative scale of local spatial frequency information to direct attention into the work, to shape what is perceived there, and to modulate how it is perceived.

The power of this explanatory strategy lies in its appeal to common neurophysiological mechanisms involved in everyday perception. If sound this strategy entails that there is nothing magic or ambiguous in the explanation of art. The shortcoming of the strategy is that it fails to explain art. The kinds of causal-psychological explanations deployed in these contexts apply equally to artworks and everyday non-art perceptual stimuli. They fail to locate the artistically salient features of those artifacts we recognize as artworks, the features that mark them off as exemplars of the category 'art'. So whereas they may help explain how a consumer can recover the content of a work of art they fail to explain what makes that content *artistic* in the first place. They take the artistic qualities of target artworks for granted and leave them unexplained. Said another way, they take the identities of artifacts as artworks as a given and discharge the business of explaining art to other, more qualified experts. This is the common perceptual mechanisms argument.

Skeptics argue that it is no surprise that psychologists and neuroscientists have failed to bring art into focus in the lab (Dickie 1962; Noë 2015; Wittgenstein 1966). They aren't looking for it. What they are looking for is how works of fine art function generally as exemplars of broader common categories of affective and perceptual stimuli. I'm not sure this is quite right. But let's take the argument at face value for now. It raises a valid challenge. What is owed in an explanation of art is an explanation of those categorially salient elements of artworks that enable ordinary consumers to disambiguate them from other kinds of objects, events, and actions. This is what's missing. This is what research in cognitive science has failed to bring into focus in the lab.

Alva Noë has argued that artworks are tools embedded in a network of normative appreciative conventions that guide behavior by calling attention to themselves in a particular way. Artworks are, in this regard, artifacts that *organize us*. Noë offers two examples by way of illustration. Back in the old days. Before the explosion of broadband wireless and handheld digital devices. Folks used to keep score at baseball games. I suppose they still do. But it's a dying skill. Fans could purchase a program as they entered the ballpark for a nominal fee. It came with a scorecard and a small, eraserless pencil—like the ones you used to find with the scratch paper at the tables at the card catalog at your university library. The scorecard was organized in columns and rows that formed a grid. Each box in the grid contained a small diagram of the infield diamond of a baseball field. Spectators at the park used a conventional set of marks to keep track of the outcomes of each at bat in the game. The columns and rows, the formal composition of the grid, were an efficient technology that enabled fans to track at bats by player, team, and inning. All one had to do to keep score successfully was watch the game with the rules for recording hits, outs, stolen bases, and etc. in mind. The conventions of keeping score were therefore a recipe for how to pay attention to the game, how to track those aspects of the action on the field that were salient to understanding baseball in general and that baseball game in particular. Dedicated fans might have had their own ringed notebook of scorecards to track the ebb and flow of the season. Or they might have kept the scorecard they collected in a shoebox organized by date like canceled checks. They might even have asked friends to clip the box scores of games missed while away from the local paper to help fill out missing scorecards. However they did it, the practice of keeping score was, and still is, a technology that organized individuals into community of baseball fans.

Noë notes that jokes are, in a way, like baseball. They are acts of communication that are embedded in a broad social network of normative conventions and other background information. For instance, the misadventures of folks living on the craggy north coast of the mouth of the St. Lawrence River are apparently hilarious if you live in Upper Canada. I never quite get it. Still, I get the underlying intentions of the class of jokes they belong to. The banal story about the adventures of two Irishmen Noë tells is easier for me. It is more familiar to my old fashioned New York City wiles. However, I prefer a different variety. We bought a t-shirt for my son a couple years ago that features the symbols for pi and imaginary numbers. A speech bubble on the shirt indicates that *i* says to pi, "Be rational." Pi retorts, "Get real!" Taken at face value, this set of sentences isn't particularly funny. And this is the point. They are only funny in the context of the conventions for telling a particular kind of joke. What you need to understand the joke is a capacity to appreciate why it ought to be funny for pi and *i* to talk that way (or to talk at all I suppose). This requires some knowledge of algebra, some knowledge of geometry, an understanding of what an equivocation is, and an understanding of a range of social conventions for a particular class of jokes. What's funny about the joke calls attention to itself if you understand the requisite set of normative conventions. Noë argues that artworks are like this too.

We are now in a position to circle back to the common perceptual mechanisms argument. Perceptual explanations of artworks are analogous to linguistic explanations of jokes. Any explanation of the way listeners or readers parse the literal meaning of the sentences involved is, strictly speaking, irrelevant to understanding a joke. What matters is an understanding of the normative conventions for constructing and appreciating that category of jokes. Psychology and neuroscience might, of course, help us understand how those normative conventions are deployed in the mental processes associated with understanding and appreciating those jokes. But they won't explain the meaning of a joke. They can't provide any leverage in understanding why it was funny. That requires a different kind of explanation directed at the social practices that bind groups of individuals together into a particular linguistic community. The same is true of the artistic salience of artworks.

Philosophers call this the normative dimensions of appreciation argument. The thought is that the identity of that range of artifacts we categorize as artworks emerges from their use as communicative tools. Their use as communicative tools is tied to the role they play in the web of normative conventions that bind us together into artistic communities. What needs explaining if we are to resolve the puzzle of locating art is the way some particular range of normative conventions shape the particular communicative functions of individual artworks. Causal psychological explanations of our engagement with artworks cannot be used to disambiguate the way artworks and other non-art communicative vehicles work in this regard. Maybe more to the point, even if we restrict the class of artifacts under investigation to artworks, psychology and neuroscience can't help us disambiguate works that are made well from art that is made poorly, those that are fit to the appropriate normative conventions than those that are not. The cognitive processes involved in apt and inapt evaluative judgements about art are the same. Psychology and neuroscience therefore fail to track and disambiguate the normative dimension of appreciation. The argument is that they are not, as a result, of much use in locating art.

Categories, Conventions, and the Ecology of Art

We might shift the story a little bit her. The puzzle of locating art can be recast as a puzzle about the behavioral ecology of art. Behavioral ecology is a branch of biology dedicated to studying behavioral relations among organisms and their environment. We can make a distinction in this sense between a world and an environment. An environment can be defined as that subclass of the total range of signal properties and features that are biologically salient to, or salient to the apical goals and instrumental behaviors of, an organism. Organisms are ordinarily adapted to be sensitive to just this subset of the total range of signal properties and features in their world (Levins and Lewontin 1985). An environment (E) can therefore be defined as a relation between an organism (O) and a world (W). Bees see ultraviolet light. They use it as a signal for the location of food. Mammals (with the exception of reindeer) are not visually sensitive to ultraviolet light. We rather feel it and recognize it as an indication of a potentially noxious stimulus. Magnetotactic bacteria, migratory turtles and birds, honey bees, and perhaps some species of large mammals are sensitive to the earth's magnetic field. Humans are not. There is a sense in both kinds of cases that humans live in a different environment from these other species.

The puzzle of locating art is a puzzle about the environment of art. The question is, what drives the communicative interactions between consumers and artworks, what are the stimulus properties constitutive of the environment of an artistic community. The puzzle arises because these stimulus properties only emerge in the context of a complex set of social relationships underwritten by the normative productive and evaluative conventions constitutive of categories of art. They are hard to see. They are hard to see because they aren't stand-alone, first-order properties of the environment. They are rather born of the behavioral relations among organisms that shape their perceptual interactions with their environment. We can use two theoretical apparatus to articulate this sense of the ecology of art: a *diagnostic recognition framework for perceptual recognition* and *niche construction theory*. The former is the subject of this section. We will discuss the latter in the next.

The environment is replete with information. Perceptual systems are, in contrast, limited capacity cognitive systems. Perceptual systems must therefore be fine-tuned to their environment in a way that enables them to select just what's needed to accomplish an organism's goals and react and respond to environmental contingencies. The question is, how? Some features of the environment are simply *perceptually salient*. They stand out in contrast to their surround. They are brighter, louder, smellier, hotter, colder, or move differently than their neighbors. Perceptually salient features naturally call attention to themselves. Unfortunately, task and biologically salient features of the environment are not always the most perceptually salient. The crooked stick you need to reach the honey in a hollow tree may look a lot like the others on the forest floor. Perceptual systems therefore need a strategy to enhance the perceptual salience of those features needed to accomplish an organism's cognitive and behavioral goals.

A biased competition model for selective attention suggests a solution. Perceptual systems need not construct full scale model of the shapes of object to recognize them. Minimal sets of *diagnostic features* will do. Diagnostic features are perceptible features that suffice to categorize the identities of objects, events and actions and generate expectations about their shapes, locations, and movements. The detection of diagnostic features enables an organism to make predictions about the identities and locations of further task salient aspects of scenes, events, actions, objects, and other agents. This called a diagnostic recognition framework for perceptual recognition (Schyns 1998). Biased competition theories of selective attention provide an implementation model for a diagnostic recognition framework. Biased competition models suggest that a fast-forward sweep through the visual system suffices to identify critical diagnostic features and recognize task salient elements of the environment. Top-down feedback from prefrontal areas, in turn, selectively enhances populations of sensory neurons that encode for further, expected, task salient objects and their parts, and inhibit the encoding of irrelevant and distracting local noise as early as the thalamus (Kastner 2004). The net result is a cognitive mechanism to enhance the relative perceptual salience of task relevant features and objects in the local environment.

What's the rub in all of this for the puzzle of locating art? Artists' productive strategies, their unique stylistic devices, the formal and compositional strategies they employ to render the subjects of their works, can be thought of as perceptual strategies for directing attention to those aspects of a work that carry its content. Artworks are, in this regard, attentional engines. They are artifacts intentionally designed to direct attention to their artistically salient features, or to those features that suffice to enable a consumer to recover their point, purpose, or meaning. What's the driver in this communicative exchange? The normative conventions constitutive of different categories of art. Artist's develop stylistic productive conventions through a back and forth communicative exchange with consumers. Evaluative conventions emerge over time relative to the success and failure of these communicative perceptual and attentional strategies. These evaluative conventions serve as normative constraints on artistic production that guide and shape the communicative exchange within an artistic community. They serve as cognitive recipes that guide how to produce and interact with artworks in various media and styles. Artworks thereby organize us into artistic communities.

Consider, for instance, Vito Acconci's *Following Piece* (1969) or Judy Pfaff's Deep Water (1980), *Either War* (1982), and *3D* (1983). Acconci's work is a performance piece of sorts. He randomly selected passerbys and followed them until they entered a private space. The work sometimes took him far afield on subway and bus rides across multiple boroughs in New York City. The work appears voyeuristic to a naïve eye. We might, with a little art critical background, turn this impression into a bit of cultural criticism, commentary on the putatively detached consumer's gaze in portraiture and landscape painting. But this isn't the right way to attend to the work. It is rather an example of contemporary nihilism in late twentieth century conceptual art. The point of the work was for Acconci to give over control of his body to external forces. It is a reflection on the structure and quality of everyday life in a modern urban economic landscape. Adopting the right art critical recipe alters the way we interpret the intentionality of Acconci's actions, conceptualize the emotional and spatial relationships between his body and his interlocutors', and attend to the physical structure of the work. Likewise, categorizing Pfaff's installations as drawings (or paintings) in space changes the way we perceive and interact with them. We cease to see them as interwoven sets of discrete sculptural vignettes and learn instead to see the gestural dynamics of a wholistic physical environment, a sensuous visual manifold blown out into an embodied three dimensional space that encompasses our physical perspective on the work wherever we might stand in the gallery (Sandler 2003).[1]

The key in all of this is that categorizing a work correctly reveals formal-compositional features and relations that might otherwise have been invisible to us. Consider a third example. *Missoula Ranch Locators: Vision Encompassed* (1972) is a work by the Land Art artist Nancy Holt. Holt installed a series of eight hollow,

[1] See retrieved February 12, 2019: https://www.judypfaffstudio.com/#/either-war-1982/.

one-and-a-half to two-inch black pipes in a field on a ranch in Missoula, Montana. The pipes were approximately eight inches long and suspended on black pipe posts at eye-level, level and horizontal, so that they functioned as viewfinders. Their arrangement and orientation marked the cardinal points on a compass that was aligned with the North Star, i.e., with the broader environment of the cosmos rather than the earth's magnetic north. The size of the compass itself was scaled in contrast to the local behaviors of the human body. The view finders were, as mentioned, placed at eye height. Their placement was determined by the visual angle subtended by a person within the viewfinder. The distance across the compass between viewfinders at opposite poles was scaled to just reveal the full height of a person standing behind the viewfinder across from it.

It is hard at first to ascertain the compositional structure of the work. The viewfinders are arbitrarily focused on whatever unremarkable aspect of the forested landscape in the distance that happened to fall within their purview. However, the documentary photographic evidence of the work provides a hint to how to disambiguate its content. The people shown standing by the viewfinders are looking into, or across the center of, the compass. Their focus is on the human scale of the local activity around the compass, not the geological scale of the distant landscape surrounding them. The work thereby focuses attention on the embodied spatio-temporal scale of this local human activity, perhaps in contrast to the invisibility of the geological and cosmological time/change the work references from the human perspective. Critically, the intimacy of the embodied human relationships depicted in the documentation is invisible to the casual eye focused outwards into the larger environment by the locators. It is only in recognizing how to categorize the work, as a land art exploration of the contrast between human activity and geological/cosmological time, that the artistically salient formal-compositional elements of the work snap into focus.

Attention can be directed exogenously or endogenously. Exogenously cued attention is directed by the environment, by the natural perceptual salience of objects, events, agents, their actions and their parts. Endogenously cued attention is driven internally, by cognitive mechanisms that focus attention on task salient aspects of the environment. Recognizing (categorizing) an artwork and recovering its content are cognitive behavioral tasks. A diagnostic recognition framework suggests that artists deploy exogenous and endogenous perceptual strategies to direct attention into their works. Exogenous stylistic cues support the fast categorization of artworks as belonging to a particular era, school, or movement, or the work of a particular artist. The fast categorization of a work unlocks a recipe of normative conventions that can be used to direct attention into the work to recover the information needed to ascertain its point, purpose, or meaning. The locators in Holt's work are, for instance, an exogenous cue to recognize the work as a variant of Nancy Holt's particular style of land art. Knowledge of her previous works, and of the fact that she was an early video artist (see her 16 mm films *Swamp*, 1971 and *Pine Barrens*, 1975), are endogenous cues that indicate that we should place ourselves at the perspective of the viewfinders. The locations of the interlocutors in the documentary photographs of the work are an exogenous cue to the atypical orientation of the compass—a compass ordinarily orients us to the surrounding landscape, not one another. This exogenous cue, in conjunction with categorical knowledge of the conceptual underpinnings of land art (and in particular the writings of Nancy Holt's partner, Robert Smithson, on human versus geological time in Earthworks), disambiguates how we are to orient to the work and leads to an interpretation of its communicative content, its point, purpose, and meaning. I can imagine others—interpretation is a matter of puzzling out the communicative intent of the artist within the historical context of their behaviors.

Painters, likewise, use spatial frequency information embedded in the texture of their brushstrokes to reveal different aspects of their subject and drive analogous processes. Bonnar et al. (2002) have shown how Salvador Dali used differential sets of high and low spatial frequency information to construct a bistable ambiguous image that selectively reveals two nuns at a slave market or a bust of Voltaire in his *Slave Market with a Disappearing Bust of Voltaire*. The way these images flip back and forth in our experience of the work is driven by exogenous compositional cues in the painting (Seeley, in press). The juxtaposition of the two images is a cue to categorize the work as a *Surrealist* painting. It is also a cue that is constitutive of the meaning of the work—perhaps something about the hypocrisy of cultural institutions that serve both the grounds for and constraints on human freedom.

An Ecology of Art

The solution to the puzzle of locating art lies in tracking the constructive role played by categories of art in our perceptual interactions with works of fine art. Philosophical skeptics might object that the current strategy merely sidesteps the problem. What matters is an explanation of the structure of categories of art, not the causal-psychological processes employed to implement them in the service of artistic practices. A diagnostic recognition framework provides a model for the latter. The former is left unresolved. This is a valid concern. My intuition, however, is that it relies on a false dichotomy between the structure of perception and the behaviors it supports. Cognitive and perceptual systems evolved in lock step with bodies, the behaviors they support, and the environments they must navigate (Levins and Lewontin 1985). Richards (2017) discussion of niche construction theory and the arts can be used to articulate how this observation might help resolve the puzzle of locating art.

The *ecological niche* of a species defines its environment.[2] The term refers to the habitat of the species. The habitat of a species includes the behavioral adaptations it has developed to achieve its apical and instrumental goals. An *evolutionary niche* is described by the concatenation of natural selection pressures a population is exposed to. *Niche construction* is a process by which organisms actively modify the local evolutionary niches that they share with conspecifics and others. An evolutionary niche is a developmental environment that can be shared and passed on to future generations in a process called *ecological inheritance*. The classic example is a beaver's dam which alters the local environment in a way that effects the behaviors

[2]See Laland et al. (2016) for a short introductory discussion of these issues.

and evolutionary niches of not only beavers, but a range of species from fish to birds to large mammals like deer and moose (Levins and Lewontin 1985). The reintroduction of wolves into Yellowstone Park provides another. The consequent reduction in the population of large grazing mammals allowed for the recovery of grasslands along river banks, the return of small mammals, the reduction of silt in river systems, and the recovery of fish populations…in short the recovery of a whole complex ecosystem composed of a range of overlapping evolutionary niches (Monbiot 2014).

Behavioral ecology is the study of how evolutionary niches shape the behavior and evolution of organisms. The *ecology of art* can be defined analogously. Niche construction theory suggests that evolutionary niches are, more often than not, *engineered niches*, constructed environments that enable a species to influence their own evolution. The artworld is an engineered niche, a habitat replete with associated adaptive behaviors. There are two central tenets within niche construction theory, already mentioned above, that drive this analogy. First, organisms often adapt their environment to their physiology, behaviors, and apical needs. Organisms do not passively adapt to their environment. They actively construct and modify the environments that shape them, e.g. a beaver's pod and dam (Lewontin 1983). We live in highly engineered environments replete with artifactual technologies that differ from the beaver's dam or the bees hive only in scale, e.g. stools, chairs, tables, and doorknobs (which are all tools that are scaled to the human body), city streets and buildings, river-bank levees, and administrative political structures. Second, these engineered environments are, again like the beaver's dam and pond, shared and passed onto others. What this entails is that engineered environments are cooperatively constructed. A corollary to this last thought is the observation that individuals do not interact in all of their associated niches equally. There is often a division of labor within and across species. Humans exemplify this fact. We are expert niche engineers. We construct complex, overlapping, and hierarchically ordered sets of engineered niches that support a division of ecological labor. This is no less true of the ecology of art where museum curatorial staff and artists might be thought to inhabit overlapping but distinct niches just as do visual artists, dancers, and musicians.

Niches are constructed from a range of *ecological technologies*. Richards divides these technologies into several classes. *Architectural technologies* are the structures that individuals within a species build to support their behaviors, e.g. a beaver's dam, a bear's den, and the mounds that define macrotermes nests. These also include the specialized buildings and spaces within which we make art. *Artifactual technologies* are the tools that individuals within a species construct to facilitate their behaviors. Human behavior is replete with artifactual technologies, a handful of which were mentioned above. Artists borrow and construct a range of analogous artifactual technologies to facilitate their productive practices, e.g. the painter's brush and aluminum paint tubes, the dancer's marley, the sculptor's welder and stone chisels, or the shared stylistic conventions governing artistic practices within a medium, school, or artistic movement. Notice that access to these architectural and artifactual technologies shape artistic behaviors in the same ways that access to laboratories and equipment shape scientific behaviors. Frank Stella was poorly resourced when he first moved to New York City. He worked as a house painter to make ends meet. The material surface and compositional structure of his early Minimalist paintings were derived in part from the broad industrial brushes and lots of commercial house paint he used and had easy access to at work. Knowledge of the roles that these artifactual technologies play in the productive practices of artists within different stylistic schools and movements, in turn, directs attention into artworks and shapes how they perceive them.

The concepts developed to guide behaviors are a form of *cognitive technology*. Categories of art emerge around sets of shared expressive behaviors and practices. The normative conventions and art critical concepts that define an era, school, or artistic movement are the constitutive elements of categories of art. They are the tools that artists use to directs attention into artworks to their diagnostic features. Note that, here again, access to architectural and artifactual technologies, to the means for making certain types of artifacts within an engineered niche, shapes artistic behaviors. The restriction of access to architectural and artifactual technologies restricts access to associated cognitive technologies, just as it does in scientific practice and academic practice more generally.

There is a sense in which Richard's discussion of cognitive technologies recapitulates Weitz's (1956) discussion of evaluative uses of the term 'art'. Weitz argued that artistic communities often artificially close their concept of art, reifying a narrow set of normative conventions as evaluative criteria that define their preferred categories art. What this means is that the recognition of concepts and other cognitive technologies within an artistic community serves a regulative role. As consumers learn to recognize these cognitive structures, they learn to accept the normalizing role they play in behavior within their community. Artists and consumers subsequently reify these cognitive technologies as conventions governing collective artistic practice within that community. What this amounts to is a cooperative convention governing artistic production and appreciation.

Richards identifies the behaviors associated with cognitive technologies as a form of *collective recognition*. He argues that collective recognition supports a *collective intentionality* within a community. The recognition of this collective intentionality, in turn, facilitates cooperative behaviors across a vast array of social behaviors, e.g. the artistic practices and overlapping artistic niches that make up an artistic community. We might interpret the collective recognition of collective intentionality as the grounds for a Gricean communicative framework (Grice 1957). Philosophers have argued that artworks are communicative events grounded in a paired set of reflexive conventions (Carroll 1992; Fodor 2012). Artists construct their artworks as communicative vehicles under an explicit assumption that the consumers that interact with them will recognize that they intended the consumer to recognize what they meant in making the work that way. What this amounts to is a claim that artistic practices unfold under the regulative guidance of the shared sets of normative conventions that define common categories of art. We might therefore argue that (a) categories of art are cognitive technologies that (b) regulate cooperative behaviors that are (c) guided by the transparency of a collective intentionality that is (d) the glue that holds artistic communities together. In other words, artists and consumers recognize the normative force of the different cognitive technologies governing artistic practice under the belief that others do as well.

We can close out our discussion of Richards' framework for an ecology of art with a quick discussion of *epistemic*, *pedagogical*, and *institutional technologies*. Cognitive technologies are paired with epistemic technologies associated with their development, application, and distribution. These technologies include interpretive art historical, art critical, and art theoretical practices. The establishment of epistemic technologies for the codification and distribution of cognitive technologies lead to the development of *pedagogical technologies* for their propagation across the community. These technologies facilitate the sharing the cognitive technologies associated with engineered niches, e.g. art reviews, formalized art critical discussions, exhibitions, apprenticeships, and art schools. Epistemic and pedagogical technologies together shape broader *institutional technologies* that codify, perpetuate, and facilitate the inheritance of concrete engineered niches like artistic niches, e.g. museums, journals, and publishing houses.

Conclusions

We can now once again circle back to the puzzle of locating art. I don't want to commit to any evolutionary claims about art. The ecology of art nonetheless provides a metaphorical framework against which we can understand the development, application and propagation of those normative conventions constitutive of categories of art. Artworks are communicative events. Categories of art are cognitive technologies that emerge from a negotiated social exchange between artists and consumers. They may be shaped by architectural, artifactual, epistemic, institutional, and other social technologies that govern artistic practice. But their structure is strongly constrained by the psychological and neurophysiological capacities and processes that enable communication in the first place. Perceptual theories of art provide the resources to explore how artworks carry information and how consumers recover that information and use it to recognize and understand their content. Perceptual theories of art thereby provide access to the environment of art, to the actual habitat that shapes the development of cognitive technologies and associated artistic behaviors. They provide the resources to locate art by identifying the details of the communicative exchange out of which normative conventions emerge as cognitive technologies for regulating artistic practice.

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Popular Art, Bad Art, and the Data of Philosophical Aesthetics

Jonathan Robson

In recent years, philosophy of art has been undergoing what is sometimes referred to as an ‘empirical turn’. Many philosophers interested in the arts have been paying increased attention to work in various experimental science and others have even begun to conduct experiments of their own.[1] Yet, calling this an empirical turn is—as others have already noted—apt to mislead since philosophers of art have a long history of paying detailed attention to various empirical phenomena. So much so that, as Lopes (2018: 1) notes, it seems to be unanimously agreed that ‘not a single one of [the key problems within aesthetics] has the faintest hope of finding a solution except by taking into account some richly and rightly informative empirical background.’ This is not, of course, to suggest that there is unanimous support for, say, using results from empirical psychology to support particular theories in aesthetics (far from it). Rather, the suggestion is that there are (virtually) no philosophers of art who would suggest that their subject can fruitfully be pursued in an entirely a priori manner. It would, for example, be difficult to take seriously the claims of a philosopher of film who had never watched a movie or a philosopher of music who had never experienced music for themselves.

This restriction naturally suggests a picture where experience of art works plays—or is amongst those things which play—a role for the philosopher of art somewhat similar to that which various experimental results play within certain empirical sciences.[2] Of course, the question of what role experimental data plays—and still more that of what role it *should* play—within various scientific disciplines is hardly a straightforward one and I wouldn’t presume to offer anything approaching a com-

[1]For some examples of this work see the essays in Schellekens and Goldie (2011), Currie et al. (2014), and Cova and Réhault (2018).

[2]For a discussion of different views of the data of aesthetics see Hepburn (1996).

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plete answer to it here. Still, it seems clear that it would, for example, be grossly inappropriate for scientists, or for aestheticians, to be cavalier about ignoring some large subset of the relevant date.[3] In this paper, I will suggest that philosophers of art have frequently been remis in this respect and have failed to pay sufficient attention to some important classes of artworks. In particular, I will suggest that insufficient attention has been made to works of bad (and merely mediocre) art.

In order to support this claim, I will focus on the relative neglect by aestheticians of so called ‘low’ or ‘popular’ art. I will argue that even if, as I by no means take to be the case, these works are uniformly lacking in value then this would provide no justification for their neglect. In “Popular Art and Neglect” I briefly consider this tradition of neglect of popular art and survey some possible explanations for it. I then focus in on a particular explanation centred around a putative lack of value. In “Popular Art as Bad Art” I consider the claim that popular works are genuine, albeit inferior, artworks and argue that this would provide no justification for their neglect. On the contrary, I suggest that there are a number of pressing reasons for philosophers of art to pay attention to various kinds of inferior work. In “Popular Art as Non-art” I examine an alternative dismissal of popular art according to which it is art in name only. That is, according to which popular artworks—owing to their lack of value—fail to even qualify as genuine artworks. I argue, again, though, that if this were the case it would actually provide additional reasons for philosophers of art to engage with such works. “Where to Now?” offers some concluding remarks.

Popular Art and Neglect

For the past several decades various attempts have been made to draw our attention to the long tradition of philosophical neglect towards popular art. Richard Shusterman (1991: 203), for example, noted that ‘Popular art has not been popular with aestheticians […] at least not in their professional moments. When not altogether ignored as beneath contempt, it is typically vilified as mindless, tasteless trash’. And Richard Anderson (1990: 33) opined that while ‘our fine arts have been the subject of prolonged and extensive speculative thought’ it was unclear whether there was ‘such a thing as an aesthetic of popular art’. The pages of aesthetics journals and monographs—it is often noted—have long been filled to bursting with discussions of Western classical music and conceptual art but rarely so much as mention rap music, videogames, or televised sitcoms. Their efforts have, to some extent, borne fruit and the neglect of popular art has lessened somewhat in recent years [especially since the publication of Carroll (1998)]. Yet, despite such advances, discussion of high, rather than popular, artworks remains very much the norm.[4]

[3] This is not, of course, to deny that there can be some cases in which there is good reason to regard some (indeed, much) of the relevant data as misleading.

[4] For recent discussions of some popular art forms see, e.g., Meskin (2009), Robson and Tavinor (forthcoming), Smuts (2013) and Bacharach (2015).

There are many possible explanations for this continued neglect. Some of these are merely sociological; perhaps philosophers of art just happen, as a matter of contingent fact, to be more interested in the traditional 'high' or 'fine' arts, or perhaps they believe that a focus on such works will give their work more scholarly credibility.[5] Others are equally pragmatic but less self-focused. It seems plausible, for example, that references to Shakespeare's plays are less likely to become dated and inaccessible to later audiences than references to the latest Hollywood blockbuster. There have, however, also been some proposed explanations which attempt to justify this neglect by appeal to the inferior quality of popular artworks themselves. It is explanations of this kind which will be the focus of this paper.

Before discussing such explanations, though, it is worth briefly commenting on the nature of the high art/popular art distinction itself. The question of how best to draw this distinction—and indeed whether to draw it at all—has been the subject of much debate within aesthetics. There are those, such as Novitz (1989), who take the distinction to be in large part a socio-historical one whereas others, such as Cohen (1993), take it to reflect something important about the nature of the works themselves. For the purposes of this paper I take no stance either on how best to delineate this distinction or on whether such a distinction serves any useful purpose in the first place.[6] Rather, I will merely assume in what follows that the distinction, whatever form it takes, is a genuine one—since this assumption is a key element of the view I intend to criticize—and aim to focus my discussion around relatively uncontroversial examples of fine and popular art.

Claims that popular art—either in general or of a particular kind—is lacking in aesthetic (or other) value abound in the history of aesthetics. Collingwood's (1938: 78) dismissal of so called 'amusement art' as being—in contrast to art proper—'not useful but only enjoyable', and Adorno's rejection of popular music as the worthless consumer product of a bourgeois society comprised of 'the obsolete and degenerated material of art music', being two of the most prominent examples.[7] Explicit defences of such an extreme position are, of course, becoming somewhat harder to locate in print in recent years but there are still those, such as Lamarque (2008: 255–296) and Scruton (2002), who defend, rather less trenchant versions of the same general position. Further, as attendees at various workshop and conferences in aesthetic will doubtless attest, there are many other philosophers of art who continue to express sympathy for the claim that there is some kind of difference in value between fine and popular art.[8]

[5] I will use 'high art' and 'fine art' interchangeably in this paper as a stipulative terms for whatever artworks (or artforms) the views I will discuss are contrasting with popular art.

[6] For more on these debates see, e.g., Cohen (1993), Gracyk (2007) and Smuts (2012).

[7] The Adorno quote is from p. 373 of his 'Zur gesellschaftlichen Lage der Musik' quoted in (and translated by) Paddison (1982: 202).

[8] Some versions of these claims are intended to reflect something essential about the nature of the artforms themselves. Other (more modest) claims are merely intended to be generalisations concerning extant works within these forms.

The common thought underlying such views is that popular works are seriously lacking in aesthetic value when compared with works of fine art.[9] They are formulaic, they are commercialised, they appeal to the lowest common denominator and so forth. Yet, explanations of this kind have, unsurprisingly, proven to be extremely controversial. Shusterman (1991: 203), for example, maintains that

> popular art provides us (even us intellectuals) with too much aesthetic satisfaction to accept its wholesale denunciation as aesthetically illegitimate. To condemn it as fit only for the barbaric taste and dull wit of the unenlightened, manipulated masses is to divide us not only against the rest of our community but just as painfully against ourselves. We are made to disdain the things which give us pleasure and to feel ashamed of the pleasure they give.

Further, as Lopes (2009: 120) highlights, the kind of rhetoric now directed against popular art has previously been employed to criticise certain works which are now widely accepted as instances of high art.[10] I am certainly sympathetic with these lines of response and do not believe that there is any convincing reason to regard works of popular art as uniformly (or even typically) aesthetically inferior to works of high art. However, in this paper I will assume that such responses are mistaken, and that popular art really is, in some sense I will not attempt to specify, aesthetically inferior to fine art. I will then ask whether this difference could justify the relative neglect of popular art and argue that it could not.

The strategy outlined above will, doubtless, strike many readers as an exceedingly curious one. Why, if I believe that the standard lines of defence offered on behalf of popular art are successful, should I feel the need to offer any further vindication of their study? There are two reasons for doing so. First, it is (at the risk of comical understatement) something of a rarity for any argument in philosophy to be met with universal assent. Given this, it cannot hurt for those of us keen to justify the philosophical study of popular art to have an extra arrow in our quiver. Second, I believe that the considerations I will highlight below have a wider import beyond the debate concerning popular art. Key to my argument is the claim that, surprising as it may seem, popular art's being less good than fine art—even its being downright bad—would provide no justification for neglect of popular art by philosophers of art. Indeed, I will suggest that a sustained philosophical study of the arts which focuses exclusively (or even primarily) on works of high aesthetic value is likely to be impoverished in a number of important respects. This claim has significant implications for the practice of philosophers of art regardless of the position we take concerning the status of popular art. It is, after all, common practice among aestheticians—including many of those who work on the aesthetics of popular artforms—to focus on those

[9]For ease of exposition I will, in what follows, focus on aesthetic value, but most of what follows could be applied *mutatis mutandis* to any other species of value which popular artworks putatively lack.

[10]Additional defences of (some) popular art can be found in Novitz (1989), Carroll (1998), and Smuts (2012).

works which have (or which they take to have) great aesthetic value.[11] A practice which, if my arguments below are cogent, stands in need of revision.

Popular Art as Bad Art

Massachusetts' Museum of Bad Art is something of an anomaly. While we might think that—as evidenced by the popularity of Thomas Kinkade's paintings and the *Twilight* novels—an interest in bad art is rather widespread, people are rarely drawn to works which are explicitly labelled as such. Further, it is relatively easy to see why this is the case. Whatever we take the value (or values) of engaging with art to be—affective, hedonic, cognitive, etc.—it is, presumably, something which, *ceteris paribus*, we find more of by engaging with good art than with bad art. We might reasonably think, then, that something similar applies with respect to the philosophy of art. That is, that the purposes of philosophical investigation into the arts—whatever these may be—are better served by an (almost) exclusive focus on works of high quality than by giving much time to the consideration of works of lower value. Perhaps, then, the reason why philosophers of art have neglected bad art, including popular art, is just that it is *bad* art.

Yet, things are rather more complicated than this line of thought suggests. It is unsurprising that audiences are primarily interested in engaging with works which they take to have a high level of aesthetic value. (And similar things can be said with respect to other activities such as purchasing the relevant works, placing them in galleries, preserving them for posterity, and so forth.) However, when it comes to the philosopher of art, the motivation for neglecting bad art becomes much less clear. A consideration of the various issues of interest to philosophers of art reveals no obvious benefit to focusing on works of great aesthetic value. A kitsch mass-produced landscape painting will serve as an instance of depiction, and representation more generally, just as well as a Rembrandt. Similarly, many of the ontological issues concerning musical works in the Western classical canon will also arise for the works of Muzak piped into your nearest elevator. The debate over aesthetic testimony could focus just as easily on testimony concerning the badness of bad art as the beauty of great art, and so forth. I do not, of course, mean to suggest that there is *no* legitimate issue in the philosophy of art which requires the discussion of high value works (the question of what it is to be a masterpiece stands as an obvious counterexample) but merely that such cases strike me as the exception rather than the rule.

It might be argued, though, that this claim of indifference could itself be used to support the focus on fine art. If one art work (or class of art works) will serve our purposes, *qua* philosophers of art, just as well as another then why not focus on those which we find it most rewarding, *qua* ordinary consumers of art works, to

[11] For example, in his discussion of the cognitive value of art Young (2001: ix) explicitly states that 'Of course, I have tended to refer to works that I most admire'. The 'of course' here is, I take it, testament to how commonplace such a practice is taken to be.

engage with? I will argue, however, that this is not the case and that there is reason to think that an exclusive (or virtually exclusive) focus on works of significant aesthetic value will actually be harmful to the work of philosophers of art. To see why this is so, consider a parallel with moral philosophy. Urmson (1958: 98) was surely right when he remarked that any moral theory which neglects consideration of the morally exceptional, of saints and heroes, will be 'totally inadequate to the facts of morality'. Yet, philosophers of art are in danger of making the opposite mistake. That is, the mistake of giving a disproportionate level of focus to works which are, in their view at least, exceptionally valuable; the aesthetic equivalent of a counterfactual tradition in moral philosophy which focused almost exclusively on Urmson's saints and heroes.

To see how such a focus can be problematic, let's consider one area where a greater focus on bad—as well as mediocre—works would clearly be desirable; the various debates concerning the nature of aesthetic value itself.[12] As Kieran (1997: 383) points out, there is a tendency in the history of these debates to focus on beauty and 'to generalize from our analysis of the nature and value of beauty, a particular aesthetic value, to an account of aesthetic value generally'. Kieran's own contention is that the focus on beauty has led philosophers of art to unduly neglect other more surprising ways in which a work could be aesthetically valuable. Discussing, for example, ways in which many of the best pieces by Goya and Bosch are actually made more valuable by their ugliness or incoherence (Ibid. 384–6). While I am sympathetic to Kieran's claim here, I don't believe that it goes far enough. In order to fully understand the nature of aesthetic value, we surely need insight not only into the manifold ways in which a work can be great, but also into the (likely even more varied) ways in which it can be bad or mediocre. Consider, for example, the relationship between aesthetic value and Sibleyian aesthetic concepts. It is important to note that Sibley's (1959: 428; 1965: 135) classic enumerations of paradigm aesthetic concepts included not only positive aesthetic concepts such as 'graceful' and 'balanced', but a range of more negative valanced features such as a work's being 'garish', 'gaudy' or 'chaotic'. It is doubtful, though, that we will gain much insight into the latter group of concepts by focusing only on artworks of the highest calibre.

Nor is this the only area where it seems that a sole focus on works of high value would be problematic. Those engaged in definitional debates concerning the scope of art, for example, would also do well to pay attention to a greater range of popular artworks, irrespective of the value of these works. If popular artworks are genuinely artworks, then we need to be careful that our definitions of art do not exclude them—or other bad or mediocre artworks—lest such definitions fail the test of extensional adequacy. Similarly, an exclusion of bad or mediocre works can cause difficulties for those investigating the ontology of art. As Lamarque (2010: 1) notes, giving 'primary focus to the great iconic works of art—from any tradition—can lead to distortion in an ontological enquiry as such works often turn out to have properties of a peculiar and uncharacteristic kind.' And, of course, the list goes on. Again, I certainly don't mean to suggest that *all* topics within the philosophy of art could benefit from a discussion of bad art (popular or otherwise). However, there is clearly a wide range

[12] For a discussion of the philosophical significance of 'medium-grade' art see Ridley (1996).

of topics where paying attention to such works is extremely important. As such, even if popular artworks were uniformly bad artworks then this would still provide no justification for their philosophical neglect.

Popular Art as Non-art

In the previous section I considered the position of someone who takes popular artworks to be bad artworks. According to others, though, popular art is no more art than rubber ducks are ducks. As Gracyk (2007: 381) points out, the 'prevailing assumption' amongst many philosophers of art 'has been that popular art lacks features that are fundamental to the value of art' to such an extent that popular art 'is only art in an honorific sense'.[13] If this claim were correct—as neither Gracyk nor I take it to be—then it may seem to provide an obvious motivation for the neglect popular art. The, perhaps merely hypothetical, philosophers of whatever (non-art) kind popular artworks fall into may well find these objects to be of interest but they will be outside the purview of the philosopher of *art*.

This conclusion would, however, be premature. It is, of course, true that philosophers of art are, as the name suggests, interested in artworks. Yet, this interest is very often not in artworks *qua* artworks. Many philosophers of art are—especially following Peter Kivy's influential (1997) work—interested in the philosophies of the individual arts, rather than art in general.[14] That is, they are interested in the philosophy of music, the philosophy of film, the philosophy of the novel, and so forth. Given this it is no longer clear that they are justified in neglecting various popular works. Even if it plausible to allow that (most) top forty singles, Hollywood blockbusters, and 'trashy' romance novels aren't artworks, it is clearly implausible to deny that they are musical works, films, and novels respectively. It is, of course, controversial precisely how far we should take this line of thought and whether it will, ultimately apply to all instances of popular art. Levinson (1990) and Hamilton (2007), for example, claim (incorrectly in my view) that instances of muzak don't even qualify as genuine works of music, a claim which some trenchant critics may be willing to extend to certain popular works. Regardless, though, I don't know of any philosopher of art who would seriously propose that no work of popular music is a genuine musical work (or that no popular film is genuinely a film…).

Given the above, it seems that someone who is interested in, say, the philosophy of film, should still care about works such as *Mary Poppins Returns* and *Wonder Woman* irrespective of whether they take these to be artworks. Even if films of this kind aren't genuine artworks, they can still be fruitfully compared to, and contrasted with, those films which *are* artworks. As such, a philosophy of film which neglected

[13]Gracyk (2007) goes on to provide a number of powerful arguments against this claim, but I will not discuss these here.

[14]See Lopes (2014) for an excellent recent discussion of the philosophies of arts.

these non-art films (not making space for them in its definition of *film*, its account of cinematic representation and so forth) would be problematically incomplete.

Some might object that this is rather too quick. After all, there appear to be many uncontroversial instances of films—such as instructional videos, inflight safety films and home movies—which are justifiably neglected by philosophers of film. Further, we might suggest, the reason why it is unproblematic to neglect such films is precisely because they are not artworks. Couldn't we, then, legitimately neglect popular films for the same reason? In short, no. First, I am not convinced that the almost complete neglect of instructional videos and the like *is* entirely legitimate. At the very least, I don't think we should merely take it for granted—in the absence of any cogent argument for this claim—that such films ought to be excluded from serious philosophical consideration. Second, even leaving such concerns aside, there are clearly important disanalogies between these other species of neglected film and the popular movies showing at your local multiplex. Disanalogies, which make it much more natural to compare the latter to certain (relatively) uncontroversial instances of artistic films than the former.[15] Popular films standardly feature many elements—character development, sustained story arcs, an intention (even if, as the critics of popular art would have it, an unfulfilled one) to instantiate various positive aesthetic properties and so forth—which are also key to our evaluation and understanding of many high art films.

Of course, this comparison doesn't hold in all cases. There is, for example, very little in common between *Wonder Woman* and an experimental film such as Brakhage's *Mothlight*. However, it is also true that certain comparisons between high art films appear rather strained. Indeed, it often seems more natural to compare particular instances of high art films to popular films than to other uncontroversially artistic films. It would, for example, be much more natural for someone studying the films of Ingmar Bergman to draw comparisons with the popular films of Wes Craven (especially given the clear influence that the former's work had on the latter) than it would for them to draw comparisons with *Mothlight* or Warhol's *Empire*. A claim which holds irrespective of any judgements we may make about the relative merits, or art status, of these films.

We can see, then, that popular artworks—even if artworks in name only—should still be of interest to those studying the philosophies of individual artforms. Yet, the usefulness of investigating popular artworks is hardly limited to those interested in the philosophies of arts in Kivy's sense. Even those philosophers of art who are not focused on particular artforms will often be interested in artworks not *qua* artworks, but *qua* exemplars of particular properties; aesthetic, expressive, representational, and so on. Properties which will, once again, clearly be instantiated by many popular works. Further, there is good reason to believe that a detailed investigation of popular artworks will help with our understanding of these properties. Consider, for example,

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[15] I say 'relatively' here since there may be those inclined to doubt [for reasons discussed in, e.g., Scruton (1981)] that film is an (independent) artform. Such a view is, of course, very much a minority view amongst philosophers of film but those who hold it can easily substitute the film examples I have used in these paragraphs with cases from, e.g., music or literature.

the way in which those interested in the nature of the aesthetic value have recently moved past a narrow focus on the aesthetics of artworks (alongside occasional forays into natural beauty) to fruitfully investigate the aesthetics of fashion, of food, of 'unscenic' nature, and even of bodily sensations such as itches.[16] Given this trend, I see no reason why studying the aesthetic value (or lack thereof) of another kind of putative non-art kind, popular artworks, wouldn't prove equally beneficial.

Finally, even those philosophers of art whose interest is primarily in artworks *qua* artworks will still have reason to pay attention to popular art. Consider, for example, the consequences of denying that popular artworks are genuine artworks for the debate surrounding the definition of art. If we accept that popular artworks are not genuine artworks—despite the fact that these often possess many of the same intrinsic and relational features as high (and so genuine) artworks—then this raises the important issue of what, precisely, marks the relevant difference. The obvious solution of highlighting their mere lack of value quickly becomes problematic here since as Lamarque (2010: 1) highlights, 'it would be wrong to suppose that the difference between those works that are art and those that are not rest only on their relative location on a scale of value'. That is, that even those who accept (as Lamarque does and I do not) that 'a run-of-the-mill whodunit' is not an artwork while *Middlemarch* is cannot explain this merely by claiming that 'the former tries and fails to do what the latter does well'. Of course, there may be *some* popular works which fail to class as genuine artworks by virtue of failing to do what certain high artworks do well, but many popular works are clearly attempting something very different. The question then becomes why such works doing what they are attempting, and even doing it very well, fails—for reasons of value or otherwise—to allow them to qualify as genuine *art*works.

Of course, there is no shortage of candidate answers here; that popular artworks—in contrast to artworks proper—are mere entertainment, that they are formulaic, that they reflect rather than challenge a bourgeois ideology, and so forth (though, as defenders of popular art are keen to highlight, these answers are not as easily defended as they might appear).[17] Yet, whatever difference critics of popular art ultimately propose it will surely be worthy of attention from the philosopher of art. Meskin (2011: 855) argues in his discussion of that art status of comics that 'if there really is something in the nature of comics that makes them less valuable than poems or symphonies or films or novels (that is, inherently or intrinsically less valuable) this is certainly of philosophical interest'. And, what hold for comics here holds for popular art more generally. In particular, whatever feature we highlight will be relevant to the project of defining art, since identifying this difference seems to require our highlighting either some disqualifying feature which all popular artworks possess, or else some necessary condition for arthood which they uniformly fail to meet. It is clear, though, that whatever this feature might turn out to be, philosophers of art are unlikely to discover it without undertaking a detailed study of a range of popular artworks.

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16 See, e.g., Freeland (2011), Korsmeyer (2002), Irvin (2008), and Saito (1998).

17 See, e.g., Novitz (1989) and Shusterman (1991).

Where to Now?

I have argued that the putative lack of value exhibited by popular artworks provides no justification for the relative neglect of popular art by philosophers of art. Of course, to reiterate a point I have already stressed above, I do not believe that popular artworks are uniformly (or even typically) lacking in value. Rather, I am in sympathy with those who have argued that there is no systematic difference in value between works of popular art and works of high art. I have aimed to show, though, that even if I am mistaken on this point—indeed, even if they are uniformly lacking in redeeming features (aesthetic or otherwise)—popular artworks would still be worthy objects of study for philosophers of art. Further, as I have suggested above, these arguments apply not only to popular artworks but to any work which is (putatively) lacking in aesthetic value. As such, philosophical neglect of such works remains unjustified. Given this, it looks as if anyone who takes seriously the comparison between observations of artworks and experimental data should—regardless of their overall attitude towards the empirical turn in aesthetics—take it to be a good thing to pay greater attention to bad art.

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Figurines and the Origin of Art

Nancy E. Aiken

Figurines and the Origin of Art

Figurines are small, portable objects that resemble humans or animals or objects and are made of cloth, clay (fired or unfired), stone, antler, bone, etc. They persist in virtually every culture and time. They can be sticks wrapped in palm leaves used by little girls pretending to be mothers to beautifully carved and ornamented idols worshiped by adults. They can be carvings of women hung from necklaces or tucked into pockets. They can be museum pieces or just bundles of rags. They can be cherished and used for special occasions or discarded or destroyed. They can be made by children and by adults. The question addressed here is why people all over the world have made them for thousands of years.

To answer this question the ethnographic and archaeological literature was searched in articles, books and the Human Relations Area Files (HRAF) using the key word "doll." A data collection form was developed so that information as to size, method of manufacture, what the figure is made of, what is depicted, its context of use (if known), the archaeological context of its find, and if it had been purposely broken (if that could be determined) because that issue was found to be significant.

While figurines have captured the interest of a number of researchers, as Rice points out most "students of prehistoric art" thought figurines were made to glorify fertility. Other suggestions for their manufacture have been uses in witchcraft and magic, images of goddesses of motherhood and childbirth, and objects of sexual and/or aesthetic appreciation (Rice 1981, p. 401). We believe that our cross-cultural approach to the manufacture and uses of figurines among extant peoples, especially pre-literate peoples, worldwide would provide insight into the manufacture and uses of prehistoric figurines. This paper presents a comparison between some figurines that were made in Africa during the early 20th century and so-called prehistoric "Venus" figurines. We are concerned only with why they were made, unlike most

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figurine authorities who, as Leasure (2011, p. 207) points out, base their discussions on stylistic similarities.

One thing we found pertinent to our study of figurines is that across cultures people believe in the supernatural. In the cultures we studied spirits of ancestors are believed to intervene into the lives of the living when called upon or when the situation demands it. Usually the spirits require a vessel to inhabit when they are called upon, and a figurine seems to be a natural vessel for a spirit. Often, the figurine is broken to release the spirit when the problem is solved. We also found that in pre-literate societies one of the most effective ways of socializing and educating children was through the use of story, song, and figurines which served as mnemonic devices to aid retention of the information to be learned. Initiation ceremonies for both boys and girls in Africa made use of stories, songs, and figurines. The children were exposed to the information in their ceremonies and in subsequent ceremonies for other children so that learning by association and repetition continued well into their adulthood. See Cory (1956) and Richards (1956).

Any child can turn a lump of clay into a recognizable form. While the only figurines that have survived from the Paleolithic are carved of bone or ivory, except for the relief sculpture of clay bison in Tucd'Audoubert cave (see Whitley, pp. 175–176). The bison indicate that clay figurines likely were made during this period even though they have not survived. Whitley discusses a chamber near the bison from where the clay was taken to make the high relief sculpture and finding there long clay "strings" made by rolling the clay back and forth between the hands (p. 177), which is a common method of preparing to build a clay pot or figure. While fired clay figurines appear many years in the future, traditional African cultures demonstrate how unfired, clay figurines could have been used in the Paleolithic. The Africans used clay figurines made by family members or others in ceremonies and destroyed them after use. Clay is more or less readily available and easily handled by nearly everyone, so it makes sense that it is the predominant material for making figurines. Also, the small scale of figurines allows ease of manufacture since internal support structures are seldom needed. The greatly elaborated figurines that are carved of bone, ivory, or stone such as the Hohle Fels and Willendorf Venuses, or modeled in clay with great detail, or mass produced from molds indicate the makers could spend the time and energy producing these and, thus, were craft specialists to some degree. This would indicate that the production of these figurines were more or less underwritten by the group and, thereby, were considered to have importance for the group.

The earliest such object so far discovered is the 40,000 year-old lion carved from mammoth ivory found in Vogelherd Cave in the Swabian Jura Mountains of present day Germany (Lobell 2014, p. 12). The 38,000 year old ivory carving of a lion-headed man standing 11 in. tall was found in a cave in Hohlenstein Mountain in southwest Germany (www.visual-arts-cork.com/prehistoric/lion-man-hohlenstein-stadel.htm). The HolenFels Venus, which is a 2.4 in. tall depiction of a, possibly pregnant, female caved from mammoth ivory, was also found in a cave in southwestern Germany. The figure's "head" is actually a carved ring suggesting that the figure was worn as a pendant (no author, *Archaeology*, 2009).

The ring indicates that the HohleFels figurine was most likely a charm. Modern studies of the uses of such figurines with holes for hanging on a string indicate that these were used as charms to bring good luck. Hechter-Schulz found that charms were important in the life of Bantu girls in Africa in the early 20th century A.D. He found that a Bantu woman did not become socially accepted until she married and had children; therefore charms were often used to try to control destiny by acquiring a husband. Ndebele girls carried charms, which they made of beadwork. These were hung on necklaces or carried secretly in their clothing (Hechter-Schulz 1966, pp. 518–519). The HohleFels figurine may have been used as a charm 37,000 years ago for similar reasons. The figurine with its robust breasts and belly does suggest fertility.

At a little over 4 in., the 25,000-year-old Venus of Willendorf also appears to depict a pregnant female. Although it has no ring for hanging, it could have been tucked into clothing and used as a charm. According to Marshack the Willendorf figurine had been painted with red ochre which probably increased its potency as a charm.

Two other examples of female figurines that were likely used as charms due to their small size are the Venus of Engen-Petersfels dating from about 13,000 years ago and the Venus of Monruz-Neuchatel (ca. 10,000 BCE) found in the area of modern Baden-Wurttemberg in Germany and across the border in Switzerland. The Venus of Engen-Petersfels is only 1.5 in. long or 38.1 mm and the Venus of Monruz-Neuchatel is 0.63 in. or 16 mm long. Both represent a kneeling, headless and breast-less female. Both are carved from jet which is a very hard coal, and both are quite abstract. Several more such carvings were found in the area, and these are even smaller (http://www.visual-arts-cork.com).

Perhaps the Berekhat Ram (200,000–300,000 years old) and the Tan-Tan (400,000 years old) modified pebbles were also charms for human predecessors. While these modified pebbles could be the result of a kind of curious play with the already human-like shape of the pebbles, the probable coating of red pigment on the Berekhat Ram implies something more than curious play. The use of red pigment applied to the body or to artifacts is generally suggestive of some special meaning and dates back at least 200–250,000 years ago with Neanderthal use of the pigment in Europe (Roébroeks et al. 2012). The Berekhat Ram, at least, may have had some special meaning as a charm.

Spirits

A stick can be a make-believe baby, and humans can make believe an unidentified sound in the night is the spirit of a dead ancestor, or a pixie, or a devil. A charm can bring good luck by appealing to the spirits to supply aid. Spirits can help in a number of other ways and figurines, being relatively easy to make, have been used in these cases. However, before the figurine can be useful, it must be infused with the power of an ancestral spirit. For example, the Mwona people of Nigeria used figurines, which were designed to hold liquid, in divination ceremonies: curing diseases of people and livestock; providing protection of the fetus during gestation and protection of children until puberty; and to counteract misfortune. The "diviner" or medicine man invested the figurine/vessel with the power of the spirit by pouring liquid into it (Slye, p. 23).

The Ainu of Sakhalin Island, Japan in the 1970s used small figurines depicting humans, which they carved from the badly smelling wood of the elder tree. These figurines were used as personal charms to ward off evil spirits (Ohnuki-Tierney 1981, p. 65).

The Nzema people of southwest Ghana made mud shrines with figurines which were interspersed in the bush as isolated shrines or in groups of threes and fours in a thick growth of trees. Each shrine consisted of a raised platform with a roof and a blind which could be lowered to cover the front of the shrine. On the platform were placed statuettes and bowls with food offerings. The 4–5 in. figurines were made of clay that turned brick red upon firing. After firing, the figurines were coated with a thick layer of white clay which had a symbolic purpose (Grottanelli 1961, pp. 48–49). These figurines were believed to be the home and, maybe, the image, of supernatural beings connected with children's sickness and death. Being objects of individual worship, each person could have only one of them (Grottanelli 1961, pp. 55, 56). Deliberate ritual action of the worshipper could stimulate the figurine's protection of a person, or, if malicious intent is aroused, the figurine would cause damage—usually sickness. However, if the worshipper did not keep his or her figurine satisfied with offerings, it could avenge itself by causing illness or the death of the worshipper or his or her relatives—especially children (Grottanelli 1961, p. 57).

If and when the figurine has accomplished its mission, it may be broken in order to release the spirit. This ensures the spirit will do no harm. The figurines used in early 20th century initiation rites in Africa were made of mud and either were destroyed by throwing them into the nearest pool of water or hidden for future use after the rites were completed. They were very secret (Corey 1956, p. 34). One figurine was an exception. This was a large figure that was ordinarily used in rites of ancestor worship, but it was also used in a rite that followed a boy's initiation. After a boy had completed initiation school, his mentor was called to participate in this ceremony. The figurine was placed on the floor and the boy and his tutor laid down beside it. The boy's father took some beer into his mouth and, then, spat it over the figurine asking the ancestress to protect the boy and to appeal to the tutor to help the boy as he, the mentor, has an unbreakable alliance with the boy's ancestor. Then the figurine is set upon the hearth and beer is poured over it. This figurine was kept by the head of the clan and was borrowed for ceremonies as needed. Usually this figurine was made by a craftsman and was sometimes over three feet high (Cory 1956, pp. 143–144, 146).

In general, the ethnographic evidence is replete with examples of figurines being said to hold spirits or have supernatural powers. In such cases, people reported that they were afraid that once used in a ritual, the figurines could be used to bewitch someone. Consequently, it is likely their secrecy was to protect the initiates from supernatural forces that potentially could cause them harm. Destroying the figurines would ensure they could not be used to cause harm. However, in some cases the spirit was removed from the figurine so that the figurine could be used in another way such as a toy, but initiation figurines were usually destroyed or hidden for future use in another initiation ceremony (Cory 1956, p. 54).

Soffer, et al. describe the ceramic figurines found at the Moravian sites of Dolni Vestonice, Pavlov, and Predmosti in today's Czechoslovakia. These figurines were made about 26,000 years BCE. The authors note that "…we know that a good deal of what we term 'art' in primitive societies was fashioned for brief, one-time use in sacred performance and broken in the process" (Soffer et al. 1993, p. 39). Figurines found at the Vela Spila site in modern Croatia were made about 17,500–15,000 BCE and were also ceramic. These ceramics depicting animals are the earliest ceramic figurative art in southeastern Europe (Farbstein et al. 2012, p. 2). Interestingly, another 8,000 years passed before ceramic *pottery* was made at Vela Spila (Farbstein et al. 2012, p. 13). Although the authors note that some scholars have suggested that ceramic figurines may have been intentionally exploded during firing (Farbstein et al. 2012, p. 12), they do not explore this avenue of thought. However, if the unfired ceramic figurines were infused with spirits and used in some ceremony, they could then be exploded during firing to set the spirits free.

Another example of the breaking of figurines was found on the Greek island of Keros in the Aegean Sea. Bronze Age (2800–2300 BC) marble figurines were broken elsewhere and brought to Keros for deposit. Colin Renfrew found that only a single piece of each were brought to Keros, He speculates that the figurines were used over and over—probably being painted and repainted year after year until they reached the end of their use. They would have to be de-sanctified. Thus, it appears that the figurines were broken with one piece being brought to Keros and the remaining pieces (since they have not been found) possibly tossed into the sea (http://www.physorg.com) (note: see also Woodard 2011; Betts 2012). Waraksa (2008) reports that many female figurines from ancient Egypt show a clean break across the torso-hip region, and this breakage indicates the break was likely deliberate at the end of a rite and before the figurine was discarded (Waraksa 2008, p. 2).

Figurines for Teaching

Humans, like some other animals, prepare their offspring for survival and success as adults. Little children are encouraged in their play to pretend adult roles. Little girls play with their dolls as though they were their babies and help their mothers with housework. Little boys pretend to hunt and work like their fathers. This play helps prepare children for their adult roles.

African girls, as studied in the early to mid-20th century, learned at an early age how to properly treat an infant. Small girls cared for their younger siblings. When little girls played with dolls their parents watched to see how the dolls were treated. A girl's behavior was considered to be an indicator of her future fertility and skill with babies. The Nguni-speaking people say that if a girl plays constantly with her dolls, she will have many children. If she mistreats her dolls she is reprimanded for not being a good future wife and mother. Many African customs revolved around dolls given to girls as symbols of their future children. Most African cultures only considered the marriage sealed when the first child was born. Sometimes a doll was a surrogate until the first baby arrived (Cameron 1997, pp. 30–31).

In pre-literate societies in Africa researchers found that figurines were used as teaching aids along with story and song in both male and female initiations. Figurines were especially essential in female initiation rites to teach girls about sex, pregnancy, and motherhood. Puberty rites were somewhat comparable to medical school anatomy lectures. Sex education was explicit and sex was considered a normal topic of discussion (Cory 1956, p. 29). Figurines were often used to teach about sex and pregnancy (Cory 1956, p. 21). The figurine makers were often the girls' mothers, but the maker could also be the instructor or, even, casual visitors (Cory 1956, p. 32). As noted above, the figurines were often destroyed after their use (Cory 1956, p. 54). Richards notes that the women in charge of the rites were "convinced…they were causing supernatural changes to take place in the girls under their care, as well as marking these changes. They were changing an alarming condition" (terror of menstrual blood) "to a safe one, and securing the transition from a calm but unproductive girlhood to a potentially dangerous but fertile womanhood" (Richards 1956, p. 125). The Bemba believed that supernatural events led to the release of menstrual blood and the puberty ceremony helped a girl safely transition to womanhood. Figurines were used to teach girls the skills needed to be a good wife, mother, and homemaker (Richards 1956, p. 163). Besides figurines, songs and stories (which were all strong mnemonic devices) were used to teach important information. Generally, the rites for females proceeded in stages over several years, with "preliminary and main rites," performed during early puberty, followed by rites to prepare girls for marriage, and, later, rites to prepare the young woman for pregnancy and childbirth (Cory 1956, p. 26).

Part of the rites for Zigua girls included staying in a hut, where no man could enter, after the first menstruation with a burnt clay figurine representing the labia majora tied on the head of the girl (Cory 1956, p. 84). (Perhaps, as the labia majora figurine was used as a teaching aid, the abundant depictions of vulvas in prehistoric art may also have been teaching aids.)

Evidence suggests that prehistoric female figurines were very likely used in the same manner as the African figurines to educate girls about sex, pregnancy, and birth. Rice studied all of the 188 Upper Paleolithic female figurines that had been found at that time (1981) and separated them into depictions of four stages of womanhood: (1) pre-reproductive (2) reproductive (pregnant), (3) reproductive but not pregnant, and (4) post-reproductive). Using independent raters she found that 23% fell into category 1; 17% in category 2; 41% in category 3; and 19% in category 4. She reasoned that the figurines were tools to teach girls about their changing roles in life (Rice 1981, pp. 402–414). The Venus of Monpazier, dated to about 25,000 years ago and found in a field in France in 1970, for example, depicts a greatly exaggerated vulva (www.visual-arts-cork.com/prehistoric/venus-of-monpazier.htm). Its large breasts and belly suggest pregnancy. Its small size (2 in. in height) suggest that, rather than a teaching aid, it may have been a charm. Possibly, it served both purposes. According to Marshack the Petersfels figurine found in Southwest Germany along with 11 other small figurines (1.75 in. and smaller) have holes. He examined the largest one (Petersfels) under the microscope and found that it appeared to have been handled a lot. The wear on the hole indicated that it had been worn on a string for a long time. Likely, it had been worn around the neck as a charm.

Marshack noted that from the beginning of the Aurignacian to the end of the Magdalenian and from France east to the Ukraine and to Lake Baikal in Siberia, female figurines have been found in the same Upper Paleolithic layers as the tools and engraved bones and stones containing animal figures, signs, and symbols. The engraved bones and stones noted by Marshack for this long time period appeared to relate to phases of the moon and the seasons. He suggests that a "baton" has a composition engraved sequentially to tell a story. He thinks a "calendar" on a baton from the Upper Magdalenian seems to have "the integrated beginnings of arithmetic, astronomy, writing, abstracted symbolism, and notation". Intriguingly, he notes that the "art, symbols, and notations of the caves are related to the work on the bones". He is referring to the decorated caves of Europe, but he also notes that while the notations on portable bones and stones appear to represent phases of the moon and the seasons, the cave notations may be related to rituals. Some of the portable bones and stones had depictions of animals being killed with darts. The story of the "killing" was apparently repeated by overpainting or over-engraving, by adding a sign or a symbol. The depicted animals were renewed by engraving over the whole or a portion of the earlier engraving. Perhaps images of animals with darts in them were virtual sacrifices. Figurines of animals were sacrificed instead of actual animals. Marshack discussed an ivory figurine of a horse from the Vogelherd site in Germany dating to about 30,000 BC which had been carved with details such as its ears, nose, etc., but handling had worn the details away. In the shoulder of the horse was a more freshly engraved V signifying a point or a "killing." Horses and other animals such as cave lion and cave bear were not regularly eaten; the people who left these figurines were migratory reindeer hunters. Perhaps, figurines of these animals were used in ceremonies and "killing" would remove the spirit until the depiction was needed for another ceremony?

Among the broken figurines found at Brassempouy in southwest France (dated 28,000–22,000 years ago is a figure of a male (White 2006, p. 269) which is unusual but if figurines were used to teach girls about sex, only one male figurine would be useful while many female figurines would be needed to portray the various phases of conception, pregnancy, and birth. Many, mostly, female, figurines dating from the Paleolithic have been found throughout eastern and western Europe. The Paleolithic Kostenki and Avdeevo cites near Kursk in modern Russia are similar in that both have oval living areas surrounded with pits and sub-terrarium "pit-houses," the function of which is uncertain. The two complexes may have formed one settlement or, perhaps, were used at different times (Gvozdover 1995, pp. 1–3). While many images of animals were found at these sites, the focus here is on the figurines depicting humans. Of the 25 plus fragmentary and whole female figurines found at Avdeevo and carved from mammoth ivory, marl or chalk, 14 attracted the researchers' attention (Gvozdover 1995, pp. 19–21). These were numbered 1 through 14 by the researchers.

Figurines 1–3 appeared to be unfinished. Number 4 is suggestive of a depiction of a male. Number 5 was found in fragments in the wall of a pit. It appears to represent a tall, slender, mature woman who is *not* pregnant (Gvozdover 1995, p. 23). Figurines 6–8 were found together in a pit with two shovels, a large ivory wand, an ivory carving of a wolf metapodial or long bone of the foot, and a large flint blade suggestive of ritual operations. Figurine 6 depicts a “probably” pregnant female. Number 7 has the hair and face depicted. Figurines 6 and 8 have what appears to be intentionally made “dents” (Gvozdover 1995, p. 25). A fragment from a female figurine which may have been 8–9 in. tall appears to have been split by a “strong vertical blow” rather than naturally damaged (Gvozdover 1995, p. 25). Figurine number 14 found at Avdeevo has legs wide apart at hips and sharply bent at the knees. The shins turn backward and press against the bottom of the buttocks. Genitalia is realistically depicted at the perineum which may have been turned upward in a depiction of the moment of conception (Gvozdover 1995, pp. 26, 27, 44). One of the Kostenki figurines (number 13) is similar to number 14 and other researchers interpreted it as a depiction of a woman on her knees giving birth similar to the crouching position of monkeys giving birth (Rogachev et al. 1982).

One of the figurines found at the Kostenki site appears to be a male and the female figurines at Kostenki are similar to those at Aveedvo in that they represent women either not pregnant or in different states of pregnancy (Gvozdover 1995, p. 35). The figurines found at Aveedvo align with the findings of Rice (1981) that demonstrate that Paleolithic female figurines depict women in various stages from not pregnant to very pregnant. Pre-literate African societies in the early 20th century illustrate why these figurines were likely made and how they were used. Rice (1981) was no doubt correct when she assumed they were used to teach girls about pregnancy and childbirth.

The prehistoric figurines were likely also considered dangerous and had to be hidden when not in use just as the African figurines were as reported by Cory (1956), Richards (1956). Belief in the supernatural would have been no less strong among the people at Aveedvo than it was among the 20th century Africans judging from the wand and other such items.

A find at the Chalcolithic Cyprus site of Kissonerga (ca. 3,000 BC) provides parallels to the Paleolithic sites and the African ethnographies while demonstrating the teaching methods of pre-literate people. Figurines play a central role. In 1987 during an archaeological dig at Kissonerga, Cyprus, a cache of artifacts was found near one wall of a building in an oblong, flat-bottomed pit. The cache appeared to be deliberately deposited. At the bottom of the pit was a painted vessel which replicated a standard Chalcolithic building. Eighteen figurines depicting females were in and around the building model. Eight were made of fired clay and painted. Ten were made of stone. The largest pottery figurine depicts a woman in the act of giving birth. The infant, painted red, emerges between her legs as she sits on a birthing stool. The pottery figurines, painted with elaborate designs, portray a variety of stances corresponding to various stages of pregnancy and parturition (Bolger 1996, p. 368). As Goring suggested, these figurines were very probably used to teach girls about pregnancy and childbirth (Goring 1991, p. 158). All of the figurines show evidence of handling. The pottery figurines were likely handled as teaching aids. The holes of the pendants indicate a great deal of wear—probably, they were used as charms. The stone figurines, also exhibit wear as they were likely clutched as fetishes (Bolger 1996, p. 368).

The Kissonerga figurines, like the Avdeevo figurines were found hidden in a living area just as the 20th century Africans hid the figurines that they chose to keep for future ceremonies. It might be safe to say that due to the importance of the information to be imparted and the lack of the written word, teaching girls about sex, pregnancy, and giving birth was best done for thousands of years by using figurines as teaching aids.

Another Chalcolithic figurine was found in situ in a building in the Lemba-Lakkous settlement south of Kissonerga, Cyprus. At nearly 15 in. tall, it is considerably taller than the figurines found at Kissonerga. It was found on its back on top of a long groove in the plaster floor of the building. The groove was filled with loose soil, pebbles, and sherds which may have served as bedding for a light reed screen or it may have served as a channel for pouring liquids (Bolger 1996, p. 368). Comparing this figurine to the large figure described by Cory that was used after a boy's initiation, it may represent the ancestress of the boy (or girl) and it may have been used in a similar way to bond the initiate to the tutor.

These figurines are usually called art. Are they art? Kant, who is usually referenced as the expert on what is art, argued that art has no utility (Kant 1951), but if we are correct that they served a valuable utilitarian purpose and they are commonly called art, was Kant wrong? Kant could not have known about these figurines and their uses, and much of the art of his era that he was aware of did not *appear* to have a utilitarian purpose. The Paleolithic figurines had a utilitarian function, but some also had decorations: hair styles and suggestions of adornment of the body which were not essential to their function as far as we know. The Kissonerga figurines were painted to suggest clothing and other decorations. While the decorations may have had special meanings to their makers, adding the decorations is not so different from little girls "dressing" their stick babies in banana leaves or rags. The decorations are an addition to the basic figure being depicted. These figurines exhibit the increasing complexity of hominid thought from the Tan-Tan and the Berekhat Ram that were modified by ancestors of modern humans.

Burials

As our ancestors progressed making clothing, shelters, and weapons, the belief in the supernatural was maintained. Burials for the dead required grave goods and figurines often were placed in graves. The ancient Egyptians, for example, made figurines which would serve the deceased in the afterlife. As time and customs came and went so did the styles of figurines. Beginning with the 21st Dynasty these figurines or ushabtis, meant to serve the deceased in the afterlife, became common and numerous in Egyptian tombs. Sometimes hundreds of these figurines would be put into a tomb

(Longennecker 1998, p. 28). During the XVIII Dynasty the ushabtis changed from being depicted as mummies to depictions of servants performing chores (no author, 1916, pp. 213–214).

Figurines were often included in graves throughout the ancient world. For example pendants in a cruciform shape such as the one on the figure of the woman giving birth in the Kissonerga cache are found only in graves of women and children at that time in Kissonerga, Lemba, and one other site of the period on Cyprus (Bolger 1996, p. 368). While figurines are not uncommon in graves, during the 3rd century B.C. Chinese emperor Qin Shi Huangdi, who was the self-proclaimed first emperor of China in 221 BC, had thousands of *life size* terra cotta warriors and horses buried to guard his tomb, which may have been a facsimile of his real-life court (Lubow 2009, pp. 34–41).

An early 7th century A. D. burial in the city of Waka, Guatemala depicts a royal funeral and a ritual of resurrection. The dead man is the Mayan king. The 23 figurines range from 4 to 9 in. in size. The figure of the dead king is in a pose typical of a shaman's patient in modern Maya cultures. He kneels next to a deer spirit that is praying over him. The king's headdress is that of the Maize God who resurrects people from death, and this may mean that the deer is preparing to cure him of death (Freidel et al. 2010, p. 42). Mayan rulers had spirit companions who were attached to lineages and the spirit deer may be the companion to the royal couple who appear to be presiding over the ritual. The spirit deer is being "conjured" by a singer whose figurine was filled with red paint, which is the color of life (Freidel et al. 2010, p. 43). Besides those figurines already mentioned, the scene also includes a dwarf helper, a toad, which is a symbol of birth, dwarf boxers, who would have performed as part of the ceremony, and a presiding king and queen. The figurines are beautifully crafted and retain original colors.

When technology made it feasible, figurines became statues. The full-sized Chinese soldiers protecting the emperor's tomb in the 3rd century B.C., the Greek discus thrower, and Michelangelo's *David* are figurines on a grand scale. Figures of the Christ and the Virgin Mary became the focus of increasingly elaborate cathedrals. Today, statues of the Christ and Buddha and Shiva and other icons of religion are treated with the reverence reserved for gods. For many, the spirit continues to be in the figure.

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Mathematics and Art Connections Expressed in Artworks by South African Students

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Introduction

Since 2012, the *Bridges Organization* (www.bridgesmathart.org), the world's largest mathematics and art community, has hosted exhibitions which present children and youth artworks as well. The artworks are inspired by the children and youth artists' own understanding, experimentation and research on connections between mathematics and the arts. The *Bridges Children and Youth Math-Art Exhibits* were originally initiated by John A. Hiigli (1943–2017), a painter and educator, and the founder of the *Jardin Children's Art Galerie* in New York (http://jardingalerie.org/). The growing collection is also facilitated and maintained by Kristóf Fenyvesi, together

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with several of his colleagues from the *Experience Workshop International STEAM Movement* (www.experienceworkshop.org).

Research has shown that motivation and engagement can be effectively boosted by emotional involvement and creative activities, which can also lead to new discoveries about the complex relationship between learning, emotions and creativity (Ainley and Ainley 2011; Immordino-Yang and Damasio 2007; Immordino-Yang 2015; Ryan and Deci 2009). Since their beginnings, the main goals of the *Bridges Children and Youth Math-Art Exhibits* were to support both the participants and the audience to actively explore new sources of mathematical learning through creative and artistic experiences and to gain new tools and inspiration for artistic expression through implementing mathematical knowledge.

In this chapter, we do not have the capacity to analyze or even introduce the more than 500 pieces currently in the *Bridges Children and Youth Math-Art Collection*, but we have focused special attention to one of the latest additions: drawings and paintings from South African learners. These artworks were collected in a *Math Art Competition*, organized by *Nelson Mandela University's Govan Mbeki Mathematics Development Centre,* as part of their STEAM education development program launched in collaboration with Experience Workshop, and were on show in 2018 July in the *Swedish National Museum of Science and Technology* at the *Bridges Stockholm Conference* (www.bridgesmathart.org/bridges-2018).

Basing our analysis of the South African children and youth artworks, our research team seeks to provide insights into some pragmatic implications of the epistemological and ontological dimensions of mathematics and art connections. With an emphasis on the relationship to the concept of "aesthetics of interdisciplinarity" in the context of creative education (Fenyvesi and Lähdesmäki 2017: 7–9). "Aesthetics of Interdisciplinarity" is a conceptual framework for research, that combines the different perspectives of science, mathematics, and art. Its goal is to open a new discourse on the aesthetic aspects of scientific objects and the scientific aspects of aesthetic artefacts. With this approach, it became possible to surpass the discursive duality of the mathematical-logical and cultural-emblematic epistemes in grasping the world. It does so by exploring the characteristics of communicating aesthetic experiences through mathematical representations. It has proved to be a useful tool to describe the process of implementation and the role of mathematical concepts and objects in the creation of artworks and it turned out to be helpful in recognizing the playful and creative potentials of mathematical objects and concepts in artistic, self-reflective contexts.

Aesthetics of interdisciplinarity as a mathematics and arts education framework may be productive in: (1) providing motivation and engagement for students and their teachers; (2) enriching mathematics and arts learning on a meaningful way; (3) enhancing pluridisciplinary STEAM learning approaches with strong cultural embeddedness and social impact. Assuming art as an integrative and transformative element of the STEAM concept, not just a vehicle for STEM learning.

Among the objectives of this project was a furthering of the aesthetics of interdisciplinarity to a discursive method for analyzing learner produced works seeking connections between mathematics and the arts. In order to accomplish this we created a "MathArt Methodology" based in our collective and emergent understandings, which came about during our analytic process. Emerging from these discussions was the neologism "MathArtWork" as a moniker for learner-produced, culturally situated, problem-inspired responses to mathematics and ways of knowing in art (Wright 2012). In so doing, we adapted the commonly used colloquialism from the *Bridges Mathematics and Art Community* of "mathart", to fashion 'MathArtWorks.'

We anticipate that this chapter is a starting point for further studies and projects in pluridisciplinary learning opportunities that implement the MathArt Method. The expectation is that we are laying a foundation for later research to build upon and encourage teachers, parents, and educators to create similar opportunities for learners to incorporate the emotional and cognitive relationships to their knowledges and skills.

Contextualizing Mathematics Educational Policy and Practice in South Africa

The education system in South Africa has emerged from a political system of official apartheid two decades ago. Inequalities are still prevalent in the basic school education system. The socio-economic disparities, language differences and the impact of former department of education policies are largely contributing to the current challenges of public education. There is a divide in South Africa with regard to historically "white" and "black" schools. The historically "white" public education sectors have involved more affluent schools presenting fewer challenges, more focused teachers and a good drive to motivate learners (Wolhuter 2014). The historically "black" schools tend to be more socio-economically challenged schools; wherein teachers who may have low expectations, poor motivation and a resistance to change, display diminished efficacy (Geldenhuys and Oosthuizen 2015; Keble 2012; Spaull 2019). Although progress has been made, the majority of public schools suffer from a lack of appropriate classroom infrastructure as well as a shortage of qualified and motivated educators (Spaull 2019). Van der Berg et al. (2016) identified the following challenges that hinder the progress in providing quality education especially in the poorer sections of society: (1) poor provincial administration, (2) inappropriate teacher union influence, (3) weak teacher content knowledge and pedagogical skill, (4) loss of teaching and learning time due to improper time management. This is also reflected in the perennially low position of South Africa in international studies, which compare Maths and Science performance of learners across countries, such as TIMSS Study Report (Spaull 2019).

Mathematics teaching in South Africa is characterized as using rigid, traditional pedagogies (Khembo 2011; Webb and Webb 2011; Wolhuter 2014), which focus only at the lower cognitive levels (Lombard and Grosser 2008). Researchers (Kereluik et al. 2013) have argued for a more learner-centered and creative approach to teaching mathematics. Furthermore, the *South African Department of Basic Education* endeavors to promote STEM (Department of Basic Education 2014). In spite of these efforts, mathematics is still perceived as a stand-alone subject and little inter-, multi- or transdisciplinary learning takes place in the classroom.

The low mathematics performance of South African learners in national and international studies is a matter of great concern. However, a great number of schools have become high performing schools despite the challenges (Tsanwani et al. 2014). Tsanwani et al. (2014) found that a positive perception of themselves, mathematics and their teachers appear to influence disadvantaged learners' decisions to persist and achieve in mathematics. In contrast, in low performing schools the teachers often have the perception that mathematics is too difficult for the learners implying that their expectations are, that the learners are not up to the challenge (Tsanwani et al. 2014). This resonates with the comments made in the statements related to their artworks by the learners who have entered the *Math Art Competition* in 2018. Learners' MathArtWorks statements also indicate the perception that creativity in a mathematical context is something that was inspiring to them and out of the ordinary practice within their mathematics classes.

Creativity and critical thinking are seen as some of the most important skills required for success in the 21st century (Kereluik et al. 2013). According to the *Future of Jobs Report of the World Economic Forum* (WEF Report 2016), the need for creativity in the workplace is on the rise (see Table 1). Thus teachers will have to become creative and innovative when applying their knowledge and skills to prepare learners. From this it can be concluded that the extension of STEM education efforts to include the arts is becoming a general and global imperative, bringing into focus the efforts of STEAM researchers (Colucci-Gray et al. 2017).

The *Math Art Competition* in South Africa

The *Math Art Competition* was launched as the result of efforts at the *Nelson Mandela University* in Port Elizabeth, South Africa to enhance blended teaching and learning solutions, which have been developed by the *Govan Mbeki Mathematics Development Centre* (GMMDC). The GMMDC is an engagement centre of the *Nelson Mandela University* and has been involved in developing offline programmes that aim to improve student outcomes in mathematics and science especially in rural areas of the country. Recently, the centre has initiated collaboration with the *Experience Workshop STEAM Movement* and integrated the development of creative STEAM educational activities. The *Math Art Competition* was introduced as part of this STEAM development programme, designed to encourage learners to make connections between the mathematics and arts for creative problem solving and in design.

For this chapter we consider only school level differences in socioeconomic terms, no efforts to gather individual learner data were undertaken. The competition was suc-

Table 1 Ranking of skills in the job market. Notice that Creativity has risen from 10th to 3rd position in these years

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

Top 10 skills

	in 2020		in 2015
1.	Complex Problem Solving	1.	Complex Problem Solving
2.	Critical Thinking	2.	Coordinating with Others
3.	Creativity	3.	People Management
4.	People Management	4.	Critical Thinking
5.	Coordinating with Others	5.	Negotiation
6.	Emotional Intelligence	6.	Quality Control
7.	Judgment and Decision Making	7.	Service Orientation
8.	Service Orientation	8.	Judgment and Decision Making
9.	Negotiation	9.	Active Listening
10.	Cognitive Flexibility	10.	Creativity

Source: Future of Jobs Report, World Economic Forum

cessfully piloted in the Eastern Cape Province (ECP), which is the poorest province of the nine provinces in South Africa.

The competition was completely free and open to all the secondary school learners in the ECP region from grade 8–12. 18 (49%) out of the 37 schools, that participated in the *Math Art Competition* are historically "black" non-fee paying or low socioeconomic status schools. These are located in township areas. Only four of the schools that entered were private schools. Two of these private schools have excellent facilities and motivated staff, but the socioeconomic background of the learners is poor.

The *Math Art Competition* was advertised through local media and emails to their schools. Flyers and entry forms were handed out at learner programmes held after school hours and hosted by the GMMDC. The call for submissions included the following:

- The focus of the competition was to stimulate learners and teachers to look at mathematics differently. By including art, the organizers wanted to promote mathematics, but also develop creative thinking and innovation.

- The submission could make use of any visual medium, including photography, drawing, painting, collage, and mixed media.
- There were two categories: "Curriculum aligned (CAPS) category", where the organizers were looking for direct links between the maths curriculum in participants' grade and their artwork. "Open Category", where artworks could explore the relationship between art and maths, but did not need to be linked to the curriculum. Here the learner could interpret the theme of art and maths in many ways, and look at mathematics that exists in everyday objects, buildings and nature etc.
- The submission had to be two dimensional and no smaller than a standard A4 size and no larger than standard A2 size.
- A paragraph of 100–200 words had to be secured on the back of the artworks in which the learner described the link between their artwork and math used.

Because English is not necessarily the mother tongue of the learner in South Africa, it should be acknowledged, that all communication was done in English and the learners' written submissions were as well.

The *Math Art Competition* ran for two months. After the first month very, few entries had been received. The project leader interviewed a few learners in various regions for possible reasons for their presumed lack of interest. The most common response was that they did not know where to start to link mathematics and art. In response to this, GMMDC has developed a presentation on various internationally known approaches to link mathematics and art in education and hosted STEAM workshops with learners in three local provincial regions in an attempt to stimulate their interest. The workshops seemed to have had the desired effect, resulting in a sizable number of entries which were received from schools in those regions. Finally, the organizers collected 113 "MathArtWorks" through the competition.

The participants in the 2018 *Math Art Competition*, both learners and teachers, responded with overwhelming enthusiasm. The positive outcomes of this innovative project emphasize the need for the STEAM approach to release creativity especially in under-resourced schools.

While viewing the "MathArtWorks" in conjunction with reading the connected paragraphs submitted to the competition, the organizers realised the richness of the data and recognized the *Math Art Competition* as an unusual, but effective data collection method. The "MathArtWorks" and the connected paragraphs demonstrated the need of many learners to express their emotions and frustrations (with life, school and mathematics), but also their enjoyment of mathematics, art and nature. The submissions of the learners demonstrated an unexpected level of awareness of connections between mathematics and art and the organizers decided that the collected material warranted further study.

A total of 87 of the 113 submissions were selected by the organizers to be studied by this chapter's authors, who then formed an international transdisciplinary research group. These authors met periodically online, to create their own criteria and research methodology to analyze the 87 selected submissions.

In the next section we will describe our process for analysis of these submissions. Our process of analysis did not follow the criteria for the competition but as we focused on other aspects of the interplay between math and art we developed our own methodology.

Developing an Analysis Framework and a Shared Discourse on "MathArtWorks"

Our team included seven mathematics and art experts with an education focus, who all contribute to STEM, STEAM, Mathematics, and Study of Arts and Creativities research. With extensive experience both in the practice of and research surrounding STEAM Education, our team's newly developed research method exemplifies several practice-based characteristics (Heikkinen et al. 2016). Each of the seven brought a different focus and lens to the study. The first step in this project was to develop pluridisciplinary criteria for selecting those pieces, which would become the centerpieces of our study.

We decided to implement a constant comparative approach focusing on the images and 'connected paragraphs,' to develop a framework for analysis of learner perspectives in dialogue with each other. This is an often used tool in art classes and professional artists in the process of constructing a portfolio. This way, both the 'MathArtWorks' and connected paragraphs provided datasets, could be approached thematically and interpretively, focusing on identifying and understanding the mathematical-artistic knowledge nexus along with learners' emotions related to mathematics. We adopted an Axial coding approach (Strauss and Corbin 1990) until a final coding template emerged.

With this research we had three interrelated goals: (1) To gain insight into the connections learners' can create with mathematics and art, (2) To gain insight into learners' perceptions of mathematics in their broader experience, (3) To gain insight into the potentials of our "Mathart method" as a part of a STEAM approach to learn and express complex understandings and emotions simultaneously. Breaking these aspirations down we came to these objectives:

- To acquire a deeper understanding of South African learners implicit, tacit and explicit knowledges and practices that underpin the fundamental processes that are induced by their MathArtWorks and the connected paragraphs.
- To identify mathematical understandings of the learners as expressed in less mathematically formal language/symbolization/expressions. How do learners view mathematics as a system and a way of making sense of the world (Gutstein 2006)?
- To identify what is distinctive and embodied in the learners' personal and cultural expressions, which constitute a form of self-exposure, enjoyment, inspiration, creativity, vulnerability, confrontation. Creating these MathArtWorks require a degree of courage to be vulnerable. We inquired, whether this vulnerability takes

the learners somewhere they would not otherwise go by activities offered in more traditional pedagogies.
- To explore the significance and potential role of creating MathArtWorks in developing new forms of STEAM/pluridisciplinary education.

The framework for the MathArtWorks analysis involved a multi-layered and pluridisciplinary understanding of artistic modes of authorship and knowledges working together to create complex and meaningful pieces. From the viewpoint of the mathematics education research, we have drawn upon studies that investigate the affective, attitudinal and emotional aspects of mathematics learning. Emphasis upon the social, cognitive, and psychological aspects of mathematics education were also included in the framework of analysis. Specific focus was placed upon the benefits of approaching mathematical understandings through artistic endeavors.

From the epistemological and aesthetic point of view, we draw upon the following concepts as we established the framework of our analysis: Deleuze and Guattari (1987) introduced "rhizomatic inquiry" through concepts of 'assemblages' and 'plateaus'. These ideas inspired us to study of how these learners presented the multiplicities of their being and their pathways in the form of their MathArtWorks. Within this framework the studied pieces became mappings of ideas and contexts, reflections on ruptures of hierarchies, structures and arboreal histories and lines of flight or deterritorializations, that move beyond binaries and concrete foundations. Through the Deleuzean concepts of 'antigenealogy' and 'antimemory' (Ibid., 21) we were able to recognize unending beginnings and transversal movements of overlapping contexts, thoughts and actions, of multiplicity that 'becomes' and 'becomings' (Ibid., 21, 27), given in the South African learners' MathArtWorks.

The rhizomatic complexity of our analytic approach and perspectives are illustrated in Fig. 1.

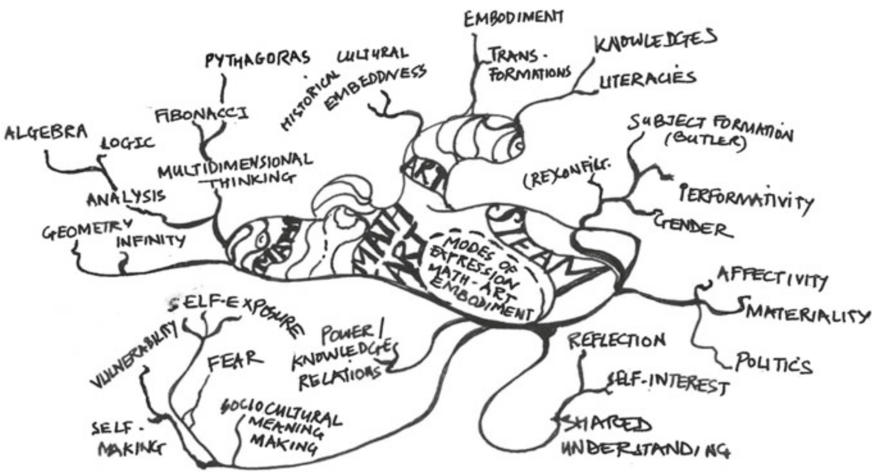

Fig. 1 An emerging MathArtWorks rhizome by Pallawi Sinha

A Process for MathArtWork Analysis

Our first task was to code all 87 MathArtWorks according to the mathematical and art concepts recognized in the pieces. Attention was also given to learners' perceptions and communication of cultural, social, historical, personal and emotional dimensions. As this chapter would not provide space enough to communicate all that was discovered, we developed a selection criteria to narrow the body of MathArtWorks for this study.

First, out of the total of 87 MathArtWorks, we selected 20 according to the criteria delineated below. Those that were selected most frequently formed the basis of our study.

- MathArtWorks and their connected paragraphs that demonstrate deeper conceptual understanding of mathematical and art knowledge. To develop our perspectives on art knowledge we built upon Herbert Read's schematic summary including Scribble, Line, Symbolism, Realism, Artistic (Read 1943: 118–120); Ellen Dissanayake's criteria for 'aesthetic quality' (Dissanayake 2000: 209); and Claire Bishop's 'participatory art' (Bishop 2012: 104).
- MathArtWorks and connected paragraphs that demonstrate greater creativity in the representation of mathematical knowledge. We focused intentionally upon the learners communication of abstraction of knowledge; or what/how are the structural, relational and cognitive connections, abstractions, embeddedness of mathart knowledges applied in the MathArtWorks and connected paragraphs?
- MathArtWorks and connected paragraphs offering mathematical concepts or knowledge that go beyond the curriculum.
- Embodiment of the mathematical concept and richer expression of emotional, affective, imaginative, socio-cultural and historical connections to mathematical and art and mathart knowledges.
- MathArtWorks and connected paragraphs that demonstrate greater creativity in representing the complexity of personal relationship to mathematics.

The selection of the 20 MathArtWorks and the connected paragraphs were analyzed for frequency of mathematical and artistic conceptual understandings. The wide variety of both mathematical and artistic concepts and their frequencies are summarized in Table 2.

As is shown in Table 2, both mathematics and art concepts have wide frequency distributions. There are seven mathematical concepts which have scores over 10 points, meaning that many MathArtWorks incorporated that concept (e.g. 12 learners referenced "planar geometric objects" in their piece or paragraph). Within the art concepts there are three whose frequencies are greater than 10 points, meaning that many MathArtWorks incorporated that concept (e.g. 12 learners employed "figurative art" in their piece).

We considered that 20 pieces were still too great a number to include in the research for this chapter. We discovered that all seven of us had independently and separately chosen the 4 pieces which we have included in the next section.

Table 2 Frequencies of mathematics and arts concepts, knowledges and practices

Math concepts	Frequency	Math concepts	Frequency	Art concepts	Frequency
Accuracy, precision	14	Fibonacci	3	Technical skills demonstrated	15
2-dimensional geometric relationships	14	Graphs	3	Composition	14
Patterns	13	Linearity	2	Figurative art	12
Measurement	13	Problem solving	2	Metaphoric content	9
Planar geometrical objects	12	Graphic equations	2	Symbolism	9
3-dimensional geometric relationships	11	Proof	2	Non-figurative	9
Symmetry	11	Theorems	2	Applied art/design	8
Calculation	8	Golden ratio	2	Poetic interpretation	7
Mathematical thinking	8	Fractals	2	Embodlement	7
Proportions	8	Reference to history of math	2	Portrait	6
Curves	7	Congruency	2	Op art	6
Numbers	6	Infinity	1	Strong affects expressed	5
Applied mathematics	6	singularity	1	Cultural heritage	5
Tessellation	6	Antisymmetry	1	Ubiquitus math	5
Sequences	5	Vector calculus	1	Perspective	4
Counting	5	Pythagorean theorem	1	Historical references to art	3
Reflection on mathematics education	5			Gender awareness	3
Formulae, mathematical symbols	4			Humour	2
Reflection on math anxiety	4			Playfulness	2

(continued)

Table 2 (continued)

Math concepts	Frequency	Math concepts	Frequency	Art concepts	Frequency
Equations	4			Manga art	1
Mathematics in nature	4			Poetry	1
Ethnomathematics	4			Impressionism	1
Coordinate system	3			Expressionism	1
Asymmetry	3			Pointillism	1
Analytic geometry	3			Music	1

Detailed Analysis of the Selected Works

Below you will find the four selected MathArtWorks with the connected paragraph (Artist Statement) by the learner. Each of the pieces are followed by a synopsis of both artistic and mathematical analyses. They are placed in no particular order.

Artist statement: *"This drawing shows us the relation between engineering and geometry and how they are related to engineers and designers. Cars are not only built and sold. They are carefully thought through and designed machines which comes in all shapes and sizes. During the period of designing a car, everything must be measured and shaped precisely. If one part is not measured or shaped to specifications, one of the major components which is aerodynamics will be negatively affected. This then influences the fuel consumption/economy, due to drag and air friction. Geometry and EGD are subjects which prepare learners that to pursue a career in this field. At my school we do not have the opportunity to nurture our skill in the arts, design or mechanics/engineering. A lack of resources and interest shown by our government deprives learners, like myself an opportunity to get a head start to get the necessary foundation that would prepare one for such a career." [SIC]*

This MathArtWork uses design, colour, structural form, balance, symmetry and studious attentiveness to detail in its composition (Fig. 2). The math-art relationship, knowledges and skills are explicit. It is a dialogic expression encapsulating structure and unstructure, realism and imagination; symbolic and calculative specifications. There are overlaps and intersections in the process of embodiment and affect—attending to self-reference, self-identity, self-interest demonstrated through Deleuze and Guattari's (1987) concept of 'inward' and 'outward' performance of MathArtWork. Compositionally, the placement of the car in relation to the mathematical expressions, which are set in the background of the piece, makes the embodiment of math-art appear explicit. We see this in multiple voicings such as: (a) the title 'mechanism' which references (b) the 'mechanics' of making a MathArtWork (c) the social 'mechanisms' of reproducing social inequities and (d) the 'machinations' of connecting actions and ideas. The multiplicities of those connections, between artful and mathematical concepts, calculations, symbolisms, metaphors and art literacies,

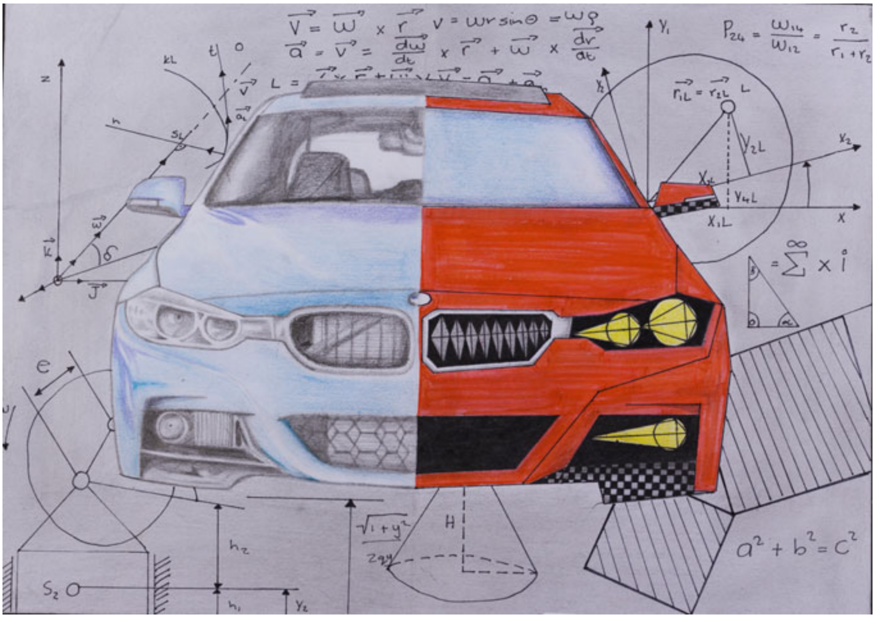

Fig. 2 ‘Mechanism’ by a male learner, age 17 years in grade 12. Learner is in a non-fee-paying public school (quintile 3) and thus the school community has a low socio-economic background

are reflective of Dissanayake’s (2000) ‘evocative resonance’. The artist appears to be intending to get both the design and construction “right”.

The mathematical concepts visible within the MathArtWork itself include the use of precision and accuracy in constructing, an awareness of a variety of higher level mathematics including vector analysis in both 2- and 3-dimensions, calculus of the real numbers, the Pythagorean relationship, analytic and synthetic geometry. The use of an apparent mathematical aesthetic informs the drawing (much of which appears to have been drafted using Euclidean tools). Within the Artist Statement it is apparent this student understands the interrelationship between mathematics and the physical sciences employed in engineering and designing vehicles. He turns his analytic eye to what he sees as a decision by the government to “deprive(s) learners, like myself an opportunity to get a head start…that would prepare one for such a career.” This learner is viewing his world through mathematics (Gutstein 2006).

Artist statement: “*In my drawing I have chosen to use numberlines as numbers can go on till infinity and our hair grows continuously, non-stop, this is a comparison between the two. The numberlines as hair is representing the roots of our lives as we cannot go one day without counting or using numbers to represent or solve anything. I have drawn a little demonic girl and as you can see the numbers close to her head are small numbers, but as they go on, the numbers increase continuously and there is no end. This represents the knowledge we obtain in our everyday lives, subjects and Maths. I’ve used black and white because those colours are drab and my interest in*

Maths before was boring. The little bit of red shows my slow interest in Maths. To me Maths is like a demon slowly stealing my soul, like I'm becoming addicted to it and starting to enjoy it." [SIC]

This MathArtWork communicates number sequencing and the sophisticated math concept of infinity in an imaginative manner (Fig. 3). The number-lines create textural qualities and nuanced compositional definitions while the considered monotone shading, and use of black and white spaces to transform the MathArtWork into an 'emotionally meaningful', rhythmic and cognitively interesting representation. In contrast, the featured use of the red eye and sewn lips introduce a dramatic expressive embodied affect with symbolic self-reference to repressed anxieties or suppressed anger, transferred to this expression through math-art abstraction creates an 'evocative dissonance'. Reflecting her own affective responses to mathematics, this expression is a highly charged, emotive self-critique (i.e. the demonic child) that allows for the multiplicities to 'becomings' (Deleuze and Guattari 1987) reducible neither to One or the multiple.

The mathematical concepts visible within the MathArtWork are primarily related to number with a hint towards infinity. This is seen in the artist's employing of sequences embedded in the hair of the figure. Within the Artist Statement we get a clearer glimpse into what this girl is thinking regarding the nature of mathematics and her interaction with it. She tells us that mathematics has a ubiquitous quality to

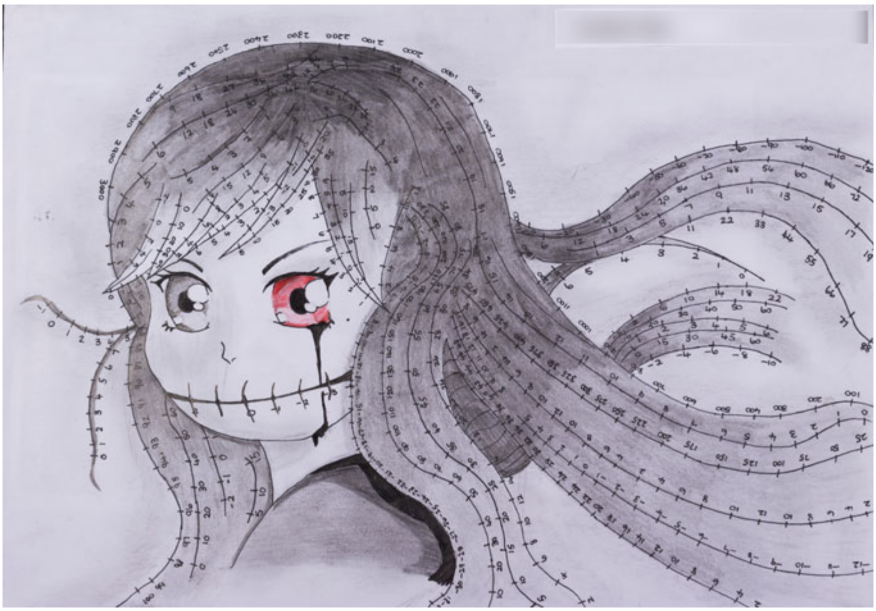

Fig. 3 'Soul Number' by a female learner, aged 15 years in grade 10. Learner is in a fee-paying public school (Quintile 4) and the school community is from a low to average socio-economic background

it, how we cannot “go one day without counting…representing…solving anything,” She further extends her thoughts to the nature of infinity and infinite increase in particular. Her characterization of mathematics appears at first to be sinister, but she indicates the reason for the coloring of the eye is to signify her slowly growing interest, possibly to the point of addiction to it. She embodies what Byers would describe as paradox, one of the core necessities for creating new mathematics (Byers 2007).

Artist’s Statement: *“In this artwork I used the Golden Ratio as my base. We live about ten minutes from the sea and that is what inspired me to use the whale, dolphin, seaweed and compass. I also went online and saw many famous artworks including the Mona Lisa that uses the golden ratio. My tutor gave me other options of math mediums to work with for example, fractals. I never knew it was part of Math and to think I thought it was an art term. This has truly been a challenging and fun competition and I am thankful that I got a chance to take part.” [SIC]*

The learner’s fine, pencil-line drawing indicates a multiplicity of connections, meanings, and associations expressed through specific elements of self-interest (compass, references to sea, self-reference) (Fig. 4). Its simplicity is poignant as is the offer of a kind of re-assembling and use/application of maths ‘in this artwork’ illustrating how art engages with the cultural significance of the kinds of learning that occurs in and through art i.e. subjectivity through affect (see post-critical theory of Hickey-Moody 2012 Youth, Arts and Education: Reassembling Subjectivity through Affect. UK: Routledge). This piece offers a crucial insight into significance of the kinds of learning/material thinking that occurs when art and mathematics are combined. The learner’s reference to the ‘place’ (where she lives) and the cultural significance in her contextual self-references as that of the affect (i.e. the vehicle) through which the mathart production can work and opportunities of transcultural/transdisciplinary work on identity as seen/exaggerated in the ‘evocative resonance’ (Dissanayake 2000: 216). It is also shown through the crafting and connectedness of the whale to the compass, seaweed expressed through complex mathematical concepts. The composition of this MathArtWork is precise, delicate and rhythmic, presenting a balanced image with the advancing movement of the forms of reference (compass, whale, seaweed). It demonstrates strong perceptual awareness and conceptual knowledge with its realism transforming complex mathematical concepts (such as logarithmic spiral, Fibonacci sequence and Cartesian plane) into an aesthetically expressive (Hickey-Moody 2012, would say creating a kind of ‘aesthetic citizenship’) and intrinsically meaningful/kind of learning that occurs in and through MathArtWork.

The mathematical concepts visible within the MathArtWork include the use of a grid paper as a background to ensure the artist makes accurate approximations to ratios she is interested in representing, therefore the idea of ratio and proportion is also among her subjects. She employs a commonly taught mode of constructing what some call a Fibonacci Spiral as the backbone or contour for three ocean-based characters. This spiral has been connected to both the art and natural world in literature both popular and academic. Within the Artist Statement she admits that the Golden Ratio (often used synonymously with the Fibonacci Spiral), which is generated through the construction of the spiral, is the base of her artwork.

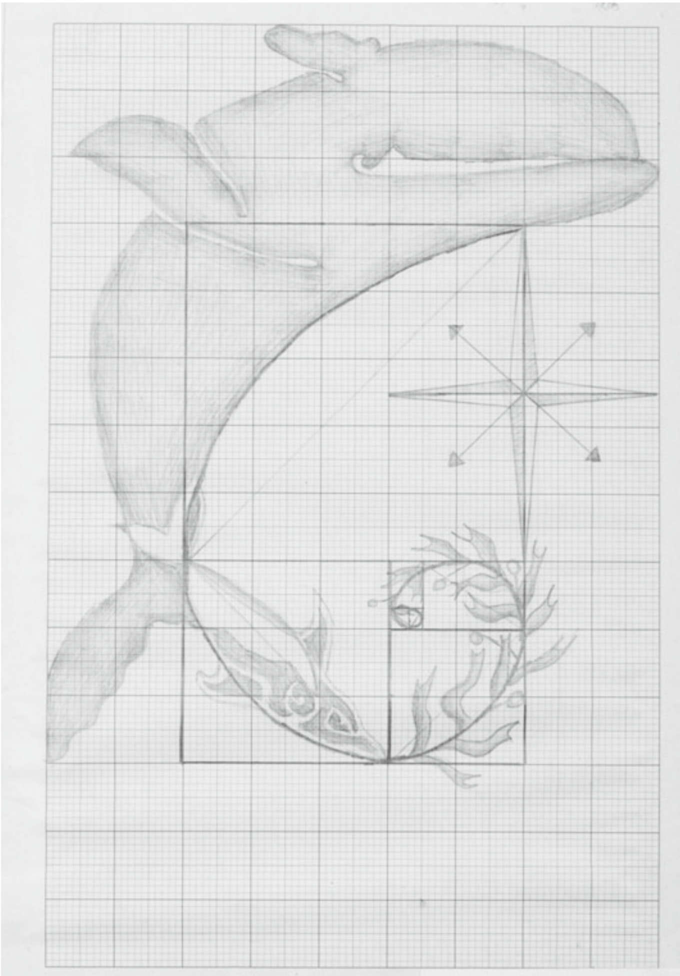

Fig. 4 The Ocean's Ratio by Female learner, grade 9, age 14 years. Learner is home-schooled in a rural area

Artist Statement: *"This artwork implies how Mathematics is involved in our daily lives. It gives the impression of how intact Maths is and effective Maths is. Upon the decision of choosing this specific image, I made it clear that Mathematics could have a positive or negative impacts. A few examples of how we experience Math daily are measurements of our clothing; which is why in my artwork you will see the right side has measurements that is in centimetres which is used to measure clothes. Clothes require accurate calculations together with the fact that our bodies are asymmetrical; which you see the left side does not look like the right side. We need our measurements to make sure we get the right fittings. My artwork illustrates the simplicity which is how the effect of maths has been ignored and neglected. My* *illustration also shows the reality of Mathematics, that even though it is interesting and effective, Mathematics could prove to be stressing especially for teenagers who have other interests. The artwork has the main figure who is stressed. I've indicated that his head is slightly bowed to show the negative impact. The hands which cover the face are an indication of frustration. This has brought about the reality which I didn't intend to hide. The answers to the equations represent that there is always a solution. This is a form of encouragement to the mathematical society. I placed the equations on different places to show that there are different ways to get the answer. On the same note, I've shown that if done frequently Math could cause a negative toil inside every part of the brain. The two sides have different shading as indication to the positive (simple art, no shading) and negative (complicated side with shading) influence of the subject on a person.*

I call it "The Stressed Vitruvian Man"; would be the modern version of Da Vinci's artwork. I admire the artist a lot and I feel we might have the same ideals on art. The lines on the background are from the Vitruvian Man with his arms open and legs spread out. [SIC]

The learner makes explicit use of realism to convey affective and embodied expressions of 'evocative dissonance' (Dissanayake 2000: 216) (Fig. 5). The MathArtWork's complex mapping pathways reveal the learner's relationship to mathematics and his views about mathematics' role in society. From personal interaction with the learner, it is known, that the image is a self-portrait, which is intrinsically emotionally captivating. This is significant in its expression of the 'inevitability of the stage of repression' (Read 1943: 120). The subjective juxtaposition of self, maths and art, monotonality reflects different shades of black. There is however, a metaphorical representation of self-other and a strong cultural reference. One of these design elements seem to predominate with an implication that the schema is not arbitrary but rather offering binaries. The representation of bi-tonal hands manifest culturally and historically elements and cultural associations; embodies an inward pull and contest, the perception of unknowing; the qualities of associated with struggle and challenge, confrontation, and emphasis and intensification through elaboration and exaggeration. The high quality of the artistic skills demonstrated in the piece indicate competence, and communicate solemnness and care which imply the seriousness of the maker's intent.

The mathematical concepts visible in this MathArtWork include algebraic expressions of solutions to equations, the ideas of analytic geometry and its reliance upon an origin point at the intersection of orthogonal axes. Some evidence appears that this learner is aware of the methods of solving systems of equations in 2-dimensional space. The mastery of representing on a 2-dimensional surface and object projected from a 3-dimensional space makes this work visually stunning and mathematically complex. Within the Artist Statement he brings us into his understanding of mathematics, which to him is a complex mix of positives and negatives, both empowering "accurate calculations that are required" and the idea of asymmetry. Here too in this artist we see someone employing the ideas of paradox and contradiction to create (Byers 2007). Clearly, this learner approaches mathematics with some trepidation and feels that this causes him some stress, which then yields a very beautiful work.

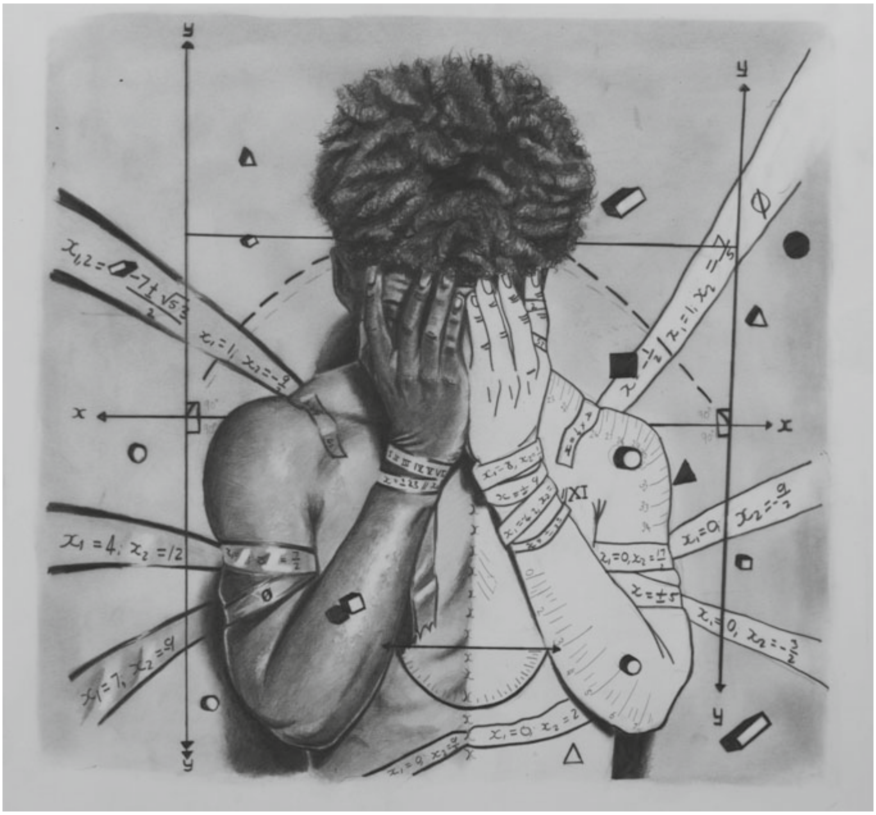

Fig. 5 The Stressed Vitruvian Man by a male, aged 16 years, in grade 11. Learner from a private school that supports learners from less privileged backgrounds. Thus, the learners come from various socioeconomic backgrounds

Concluding Thoughts and Implications

Above we have shown what insights can be garnered through the use of our MathArt method of inquiry. In this section, we will expand upon the theoretical underpinnings of this methodology. In considering which theoretical lens to make sense of the complexity of the pluridisciplinary and cultural embeddedness of this project, what follows are some possibilities for reimagining what constitutes MathArtWorks.

It became clear from the MathArtWorks and connected paragraphs that these pieces have so much more to offer than could be captured within this space. We can find several other ideas to investigate by employing sociocultural theory, diverse creativities theory, and postcolonial or other critical theories. Conceptions of youth culture and self-making or meaning-making alone could have been more deeply analyzed to elucidate the core characteristics emerging as forms of authorship, along with the technological and temporal modalities. One could combine these with a focus on bringing about the social change needed to reduce barriers created through formal, often patriarchal institutional practices to discover learner perspectives on these matters.

A more complete understanding of the "rhizomatic" approach (see Fig. 1) can offer further rich analytic perspectives; therefore, we summarize some of the aspects of what underpinned our discussions as an analytic team. In *A Thousand Plateaus* (1987), Deleuze and Guattari employ the biological concept of a rhizome (or a tuber) that bourgeons in unstructured and unpredictable directions. They expound, "There are no points or positions in a rhizome, such as those found in a structure, tree, or root. There are only lines" which "connect(s) any point to any other point" (Deleuze and Guattari 1987: 9, 21). We found similar structures while examining and analyzing the MathArtWorks with regard to making connections between differing ideas, emerging from different disciplines, ideas and concepts, contexts, and dialectic moments. These connections enabled a more fluid exploration of the multiplicities in thinking, seeing mathematics and art literacies as 'ways of being,' that have emerged from the varying ages, contexts and abilities of the learners, but also across disciplines and the different cultures engaged in the study. The construct of connections is relayed in the form of "assemblages" that form "plateaus", described as "any multiplicity connected to other multiplicities by superficial underground stems in such a way as to form or extend a rhizome (Deleuze and Guattari 1987: 24). For instance, while Mathart Method is an assemblage (of academics, research associates, learners and teachers) within broader context of research, offering "unexpected, disparate and productive connections that create new ways of thinking, seeing, doing, or being" (Colebrook 2009: 76).

Using the idea of 'assemblages', we continued to build the plateaus or lines of flight which informed our analysis. This means that in our analysis the MathArtWorks that the South African learners have produced, constitute plateaus which represent the multiplicities in their sociocultural or economic background connected to other multiplicities such as different cultural contexts, embodiment, and the affective response to the two subjects: mathematics and art. Such an understanding has enabled connections, interrelations and disruption of normative connections, crucial to the analysis of mathart literacies and knowledges. By underscoring conceptualisations of 'practice', the analysis shifted from investing in the '*who*' (student, researcher, teacher) or the '*what*' (artwork, math-art research or academia), to '*when*' a person takes on those roles and 'when' is an encounter or experience of mathart in education (see Kingwell 2005). Using the Rhizomatic approach[1] to mathart analysis allowed us to go beyond traditional ways of reading data as evidence via the "nonrepresentational, transgressive" (St. Pierre 1997: 174). In other words, it allowed us to 'read' factors such as culture, embodiment or transgressions of gendering, political histo-

[1] '**Rhizomatic approach**' refers to rhizomatic thought and practice applied to educational research and this particular 'mathart' analysis that locate dynamic "events" of becoming within complex intersections of sociocultural and material conditions and not the *perfection of being* or the outcome. It relies on mapping connections and disconnections between and across multiple pathways to avoid normative discourses and ideals.

ries, which may not necessarily be quantifiable but are highly relevant, valid and accountable for self/meaning-making.

As a part of our analysis we also employed aspects of a quantitative inquiry to identify the mathematics and artistic concepts contained in the MathArtWorks and connected paragraphs. See Table 2 where we have listed both Math and Art Concepts along with their frequencies. From this analysis we were able to create a "Concept Richness Score" derived from the analysis of each piece. This score is essentially the sum of the number of identifiable mathematical concepts + identifiable artistic concepts (as determined by the members of the team): CRS = MCF + ACF [where CRS is Concept Richness Score, MCF is Math Concept Frequency, and ACF is Artistic Concept Frequency]. See Table 3, where the column labeled "Sum" displays the CRS for the first 15 of the 20 pieces, which were more closely analyzed by the team.

Of interest to our research team is what we see in the Concept Richness Scores. Here, an apparent range for these scores for the bulk of the works is between 20 and 25. This seems to be achieved through a balancing (perhaps subconsciously) between math and art concepts by the learners. There are within these fifteen MathArtWorks, three apparent outliers. These works seem to incorporate a very great many concepts (e.g. "Stressed Vitruvian Man," "Mystery Math," and "Beautiful Gray"). Of further interest is that it is the Math Concept score that pulls the Concept Richness Score higher, these students appear to consciously incorporate a great many more mathematical concepts in their works.

In conclusion when we combine the rhizomatic and quantitative analyses we have discovered three significant and recurring features emerging:

- Mathart knowledge advances a theory concerning Mathematical and Art knowledges and re-presentations/assemblages through images-mark-making (lines, dots, textures); colours (hues, shades, tones); composition (use of space, size and place-

Table 3 Concept richness score of the MathArtWorks

Titles	Art Freq	Math Freq	Sum	Diff
Soul Number	11	13	24	2
The stressed Vitruvian Man	12	21	33	9
Mechanism	6	15	21	9
The Ocean's Ratio	7	14	21	7
The Reality of Our Thought	11	7	18	-4
Mathematics in Africa	11	14	25	3
Clash of Perception	6	12	18	6
African Youth	12	8	20	-4
Mystery of Mathematics	11	23	34	12
Abstract Duck	7	14	21	7
Shtam ni tra	6	18	24	12
Math-o-man	11	9	20	-2
Sacred Aloe	7	12	19	5
Beautiful grey	12	17	29	5

ment of art and design elements; structure and flexibility; shapes and patterns). Including these features of art offers space to bring in the socioeconomic, geographical, personal and intangible yet demonstrable contexts for the individual to deconstruct and reconstruct.

- Mathart embodiment advances the cultural significance of meaning-making characterised by self-reference, self-interest, cultural (including gender), political, historical, place (belonging) and "evocative resonances and dissonances" that characterise 'aesthetic citizenship' created by youth MathArtWork.
- Mathart modes of expression advancing several dimensions of mathart creativities by the ways in which applied, conceptual, subject, or procedural knowledges become the vehicle through which the mathart production of young people facilitates learning and co-production of mathart literacies. The affect is also the vehicle for expression of fear and struggle, disempowerment and empowerment; symbolism and expressive symbols, differentiation, elaboration and exaggeration, haptic over-exaggeration, self-reflection and reconfiguration of identity/ies as a mathematician, an artist, and the transculturality of being a South African; advancing a theory of aesthetic citizenship.

From these features we are drawing the following implications:

1. Challenging the canon in the name of MathArtWork understanding, cognitive growth and education practices would enable developing future modes of pluridisciplinary pedagogic practices through creative production. The challenge of STEAM education demands that we question normative discourse, and accepted modes of teaching and learning. It is also important to recognise that in much of children and adolescents' creative production (i.e. creation of artefacts and text), the modes are in fact integrated.
2. Research on mathart practices as forms of innovative STEAM pedagogy indicate that there are a great deal of diverse creativities, knowledges, and literacies in the lives of youth and in their everyday lives that draw heavily on (popular) culture as resource of authoring new forms and practices. Academics, researcher and practitioners thus need to consider the relationships between new technologies, culture, creativities and STEAM education.

The Future of the *Math Art Competitions* in South Africa and the MathArt Method

Due to the positive response that the GMMDC received from learners, teachers, parents and a wide range of stakeholders in education and the international attention from the global mathart community, an extension of the Math Art Competition to all the provinces in South Africa was undertaken in 2019. It is now the intention of the GMMDC to partner with key stakeholders in the educational sector in hosting the competition as an annual event on a national basis. It is suggested that this second iteration have a formal research study established to further investigate the mathart knowledges that are fostered by the experience. The goal of this study being the dissemination of the benefits of these activities and understandings.

The GMMDC will continue to host a series of bi-annual STEAM events as well as Math-Art Workshops with learners to stimulate interest in including the creative into learning mathematics. A STEAM short learning programme for in-service teachers is being developed and researched. The intentions of this short learning programme is aligned with the global goals of STEAM education and will also incorporate the special needs of learners in under-resourced schools in South Africa.

Coming out of this project work has begun already on the creation and dissemination of more STEAM related activities and events based on several MathArtWorks received from these learners. There are significant gender-related questions to pursue with this collection of MathArtWorks that would deserve a complete investigation. A further re-examination of this project under a new materialist, new feminist and posthumanist lens in relation to STEAM education is among our future plans.

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The Sinai Light Show: Using Science to Tune Fractal Aesthetics

B. Van Dusen, B. C. Scannell, M. E. Sereno, B. Spehar and R. P. Taylor

Introduction

Nature's beauty is profound. To better understand the source of this beauty, here we will focus on the aesthetic impact of fractals. Fractals are patterns that repeat at increasingly fine size scales and they are prevalent throughout nature's scenery (Mandelbrot 1982). Examples include lightning, clouds, trees, rivers and mountains. Furthermore, they have permeated cultures spanning across many centuries and continents, ranging from Hellinic friezes (300 B.C.E) to Jackson Pollock's poured paintings (1950s) (Taylor et al. 1999, 2007, 2018). We will discuss how science can be used to determine the origin of fractal aesthetics and also to generate patterns that maximize this aesthetic experience.

Fractals play a central role in our visual experiences because the human visual system has adapted to these prevalent natural patterns. We will review our experiments showing that this adaption influences many stages of the visual system. Based on these results, we will present a 'fractal fluency' model in which the visual system processes the visual properties of fractals with relative ease. This fluency optimizes the observer's skill at performing visual tasks (for example, leading to enhanced pattern recognition capabilities) and generates an aesthetic experience accompanied by a reduction in the observer's physiological stress-levels.

Having established the visual mechanism underlying fractal aesthetics, we will then refine the fractal characteristics to amplify their visual impact. Although

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computer-generated fractals are well-known within the art world, we will adopt a more natural process to achieve our goal. Many of nature's fractal objects are experienced through light effects—for example, the shadows of clouds, mountains and trees pervade our daily experiences. Inspired by this prevalence of light patterns, we will reflect rays of light between multiple mirrors to build light patterns at many scales (Fig. 1). Known as a Sinai billiard (Sinai 1963), the apparatus we will use consists of a cube of mirrors with a spherical mirror positioned at its center. Reflection off the curved surfaces induces chaos in the light rays and this leads to fractal light patterns.

By adjusting the mirrors, the fractal characteristics of the observed pattern can be evolved. In particular, the relative amounts of coarse and fine structure in the fractal can be changed. Significantly, the resulting evolution in the pattern's visual complexity is central to its fractal aesthetics. Consequently, we can use this system to increase the aesthetic quality of the pattern. Crucially, we will show that, although there are universal preferences shared by all observers, there are also factors that cause subtle differences between observers. Hence, our system is ideal for tuning the aesthetics to the needs of the individual observer.

The Visual Impact of Fractals

In Fig. 2, we use trees to demonstrate the intrinsic visual properties of fractals. Fractals fit into 2 categories—'exact' (left image) and 'statistical' (right image). Whereas exact fractals are built by repeating a pattern at increasingly fine magnifications, 'statistical' fractals introduce randomness into their construction. This disrupts the precise repetition so that only the pattern's statistical qualities (e.g. density, roughness, and complexity) repeat. Consequently, statistical fractals simply look similar at different size scales. Whereas exact fractals exhibit the cleanliness of artificial shapes, statistical fractals reveal the organic signature of nature's scenery.

Statistical fractals feature strongly in studies of bio-inspiration, in which scientists investigate the remarkable functions of natural systems and incorporate them into their artificial systems. The growing role of fractals in art suggests that the repeating patterns serve a bio-inspired function beyond the scientific realm—an aesthetic quality. Previous studies demonstrated that exposure to natural scenery can have dramatic, positive consequences for the observer (Ulrich and Simons 1986; Ulrich 1981, 1993). For example, patients recover more rapidly from surgery in hospital rooms with windows overlooking nature. Although pioneering, these demonstrations of 'biophilic' (nature-loving) responses employed vague descriptions for nature's visual properties. Our research builds on these studies by testing a specific hypothesis—that the statistical fractals inherent in natural objects are inducing these striking effects (Taylor et al. 2011; Taylor and Spehar 2016).

To quantify the visual intricacy of the statistical fractals, we adopt a parameter employed by mathematicians—the pattern's fractal dimension D (Mandelbrot 1982; Fairbanks and Taylor 2011). This describes how the patterns occurring at different

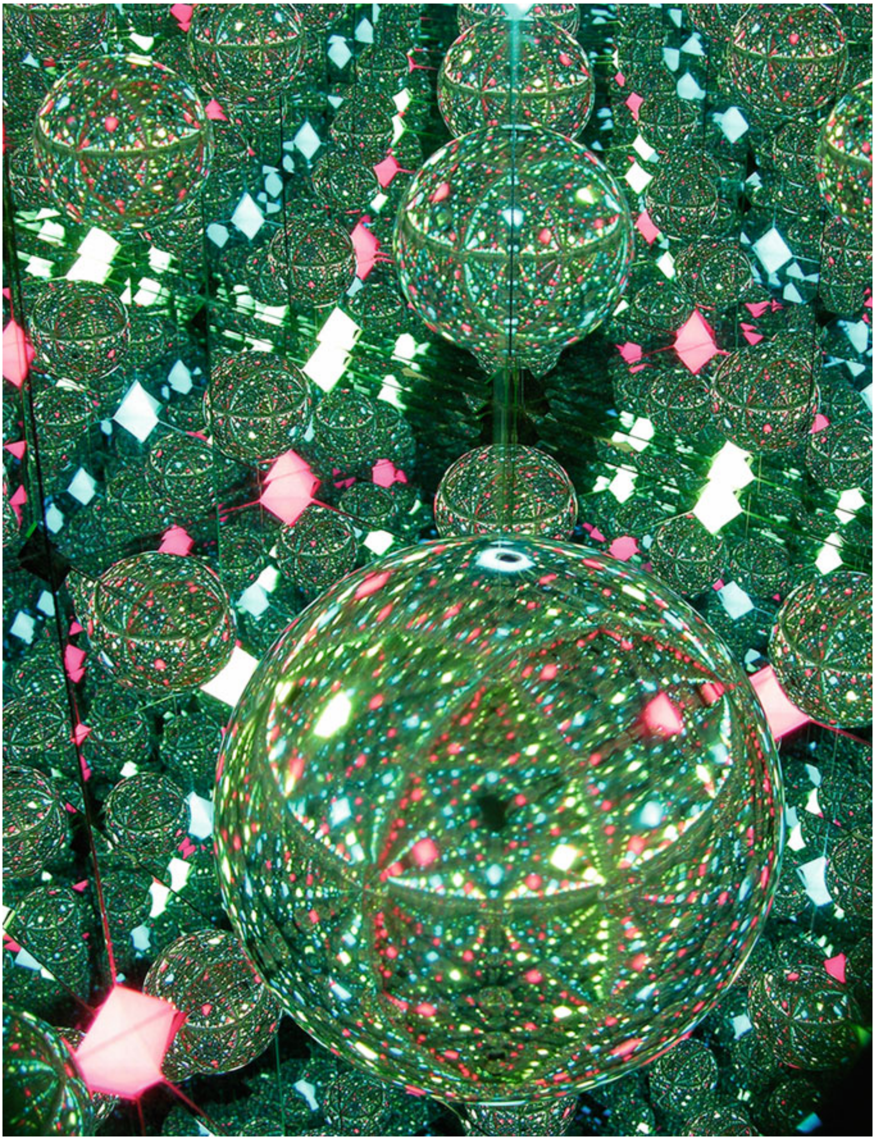


Fig. 1 Red, green and blue light rays reflect off multiple mirrors in the Sinai billiard, building light patterns at many size scales

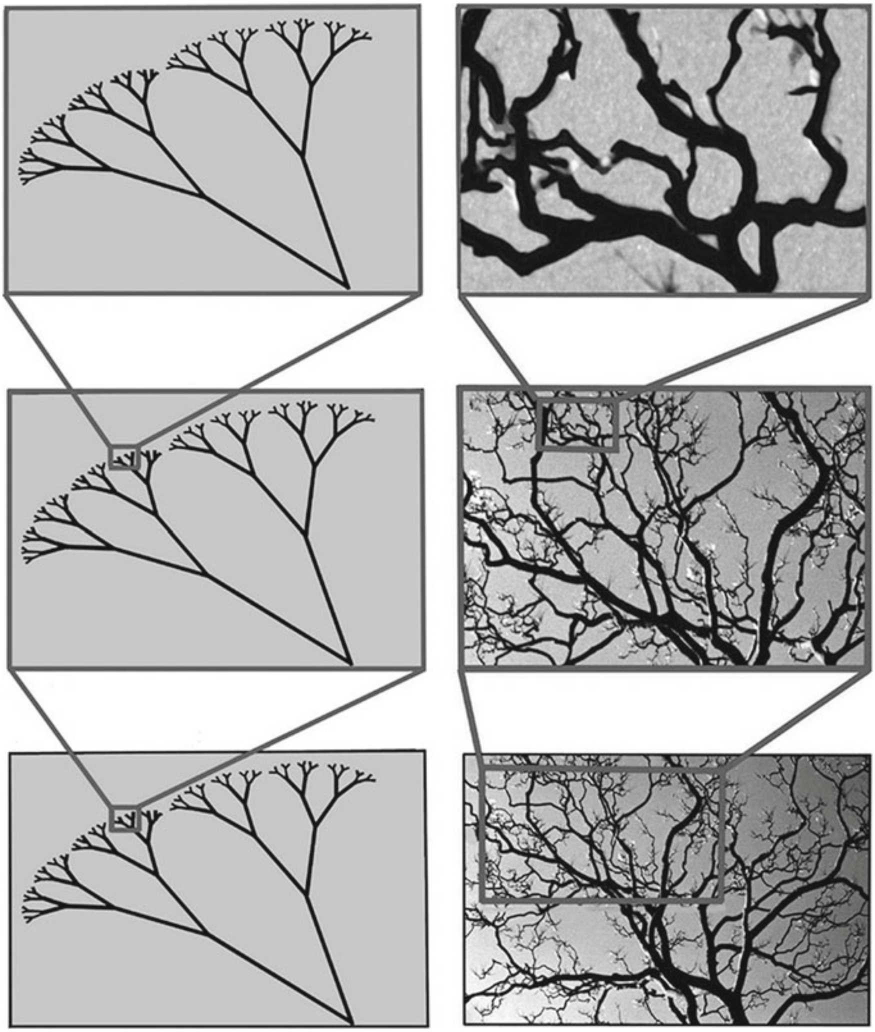


Fig. 2 The branch patterns of an artificial tree repeat exactly at different magnifications (left column). In contrast, only the statistical qualities repeat for a real tree (right column)

magnifications combine to build the resulting fractal shape. For a smooth line (containing no fractal structure) *D* has a value of 1, while for a completely filled area (again containing no fractal structure) its value is 2. However, the repeating patterns of the fractal line cause the line to begin to occupy space. As a consequence, its *D* value lies between 1 and 2. By increasing the amount of fine structure in the fractal mix of repeating patterns, the line spreads even further across the two-dimensional plane and its *D* value therefore moves closer to 2.

Figure 3 demonstrates how a fractal's *D* value has a powerful effect on its visual appearance. This figure summarizes the variety of fractals we have used in our studies, including images from nature, art and mathematics (Taylor et al. 2011; Spehar et al. 2003; Spehar and Taylor 2013; Bies et al. 2016a; Hagerhall et al. 2004). For each of the rows, the image in the left column has a lower *D* value than that in the right column. Clearly, for the low *D* fractals, the small content of fine structure builds a very smooth sparse, shape. However, for fractals with *D* values closer to 2, the larger amount of fine structure builds a shape full of intricate, detailed structure. More specifically, because the *D* value charts the ratio of fine to coarse structure, it is expected that *D* will serve as a measure of the visual complexity generated by the repeating patterns. Behavioral research by our group (Spehar et al. 2016) and others (Cutting and Garvin 1987) confirms that the complexity perceived by observers does indeed increase with the image's *D* value (Fig. 4).

Returning to Fig. 3, the top-row images are photographs of natural scenes (clouds and forests). The second-row images are examples of Jackson Pollock's poured paintings created at different stages in his career (Taylor 2002; Taylor et al. 2002). The remaining rows feature different types of computer-generated fractals as follows. The third row shows geographical terrains (in this case viewed from above) and these serve as the source to generate the images below them. To obtain the fourth-row images, a horizontal slice is taken through the terrain at a selected height. Then all of the terrain below this height is colored black and all of the terrain above is colored white. Referred to as the coastline pattern (black being the water), this image is used to generate the fifth-row images by highlighting the coastline edges in white. In the sixth row, grayscale images are generated by assigning grayscale values to the heights of the terrain. Despite their superficial differences in appearance, these 6 families of statistical fractals all possess identical scaling properties and they induce similar effects in the observer. These examples of biophilic fractals differ from the exact fractals shown in the bottom row. Later, we will discuss why these more artificial-looking fractals have a different impact than the biophilic fractals shown above them.

Fractal Fluency

The physical processes that form nature's fractals determine their *D* values. For example, wave erosion generates the low complexity of the Australian coastline while ice erosion results in the high complexity of the Norwegian fiords. Significantly, although natural objects are quantified by *D* values across the full range from 1.1 to 1.9, the most prevalent fractals lie in the narrower range of 1.3–1.5. For example, many examples of clouds, trees and mountains lie in this range. This forms the basis of our fluency model, which proposes that the visual system has adapted to efficiently process the mid-complexity patterns of these prevalent fractals (Taylor et al. 2011; Spehar et al. 2003). We expect this adaption to be evident at many levels of the visual system, ranging from data acquisition by the eye through to the processing of this data in the higher visual areas of the brain.

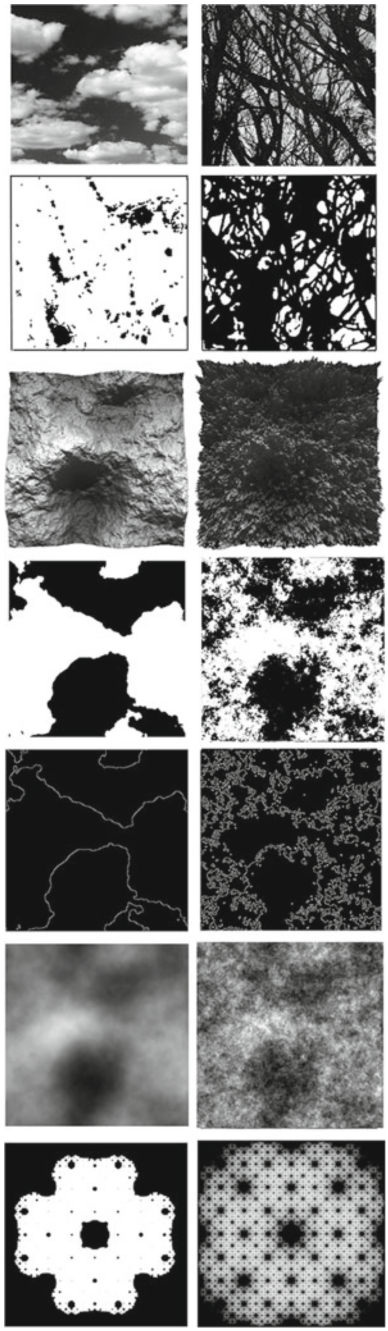


Fig. 3 Fractal complexity in nature, art and mathematics. The different rows summarize the variety of fractal images employed in our studies (see text for details). In each case, the left column shows examples of low *D* fractals and the right column show the equivalent high *D* fractals

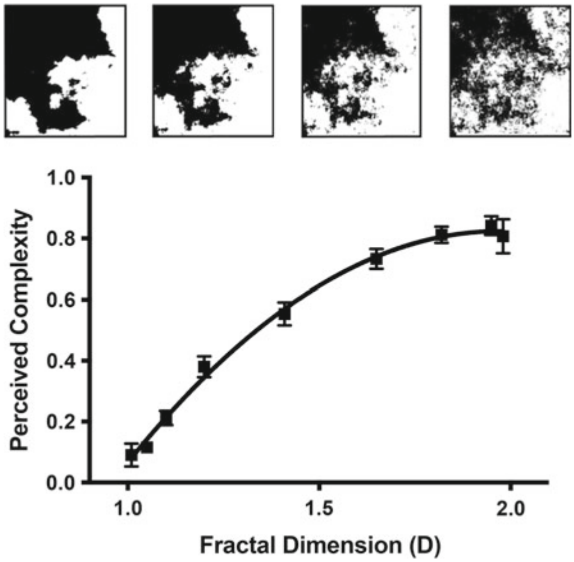


Fig. 4 Perceived complexity increases with the fractal's *D* value. Examples of computer-generated fractals quantified by $D = 1.2$, 1.4, 1.6 and 1.8 are shown above the graph

Based on the phenomenon of synesthesia, in which sensations are transferred between the senses, it is possible that mid-complexity fractals might also hold special significance for tactile and audial experiences in addition to visual ones. This is being tested using three-D printers to generate physical versions of the terrains shown in Fig. 3 and using computers to convert visual stimuli into the sonic equivalents. We also plan to convert the fractals in Pollock's paintings into music and compare people's responses to these equivalent visual and sonic fractals (Boon et al. 2011).

Our studies of fractal fluency commenced with the eye-motion studies shown in Fig. 5 (Taylor et al. 2011; Fairbanks and Taylor 2011; Moon et al. 2014). The eye-tracking system integrates infra-red and visual camera techniques to determine the eye's gaze when looking at fractal images displayed on a monitor. As expected, the eye motion is composed of long 'saccade' trajectories as the eye jumps between the locations of interest and smaller 'micro-saccades' that occur during the dwell periods. Our results show that the saccade trajectories trace out fractal patterns with *D* values that are insensitive to the *D* value of the fractal image being observed. More specifically, the saccade pattern is quantified by $D = 1.4$ even though the viewed image varied over a large range from 1.1 to 1.9. Furthermore, participants with neurological conditions such as Alzheimer's disease exhibited the same fractal gaze dynamics as healthy participants, indicating that the fractal motion is fundamental to eye-movement behavior and is not modified by processing in the higher levels of the visual system (Marlow et al. 2015).

We propose that the purpose of the eye's search through fractal scenery is to confirm its fractal character. If the gaze is directed at just one location, the peripheral vision only has sufficient resolution to detect coarse patterns. Therefore, the gaze shifts position to allow the eye's fovea to detect the fine scale patterns at multiple

Fig. 5 Photographs of some of our behavioral and physiological experiments. Top-left: the eye-tracking apparatus, top-right: skin conductance measurements, bottom-left: fractal scenery displayed on a computer monitor during the navigation experiment, bottom-right: a behavioral preference experiment

locations. This allows the eye to experience the coarse and fine scale patterns necessary for confirmation of fractal character. Why, though, does the eye adopt a fractal trajectory when performing this task? We found the answer in studies of animals foraging for food in their natural terrains (Viswanathan et al. 1996). Their foraging motions are also fractal. The short trajectories allow the animal to look for food in a small region and then to travel to neighboring regions and then onto regions even further away, allowing searches across multiple size scales. Mathematics shows these fractal searches to be very efficient (Fairbanks and Taylor 2011). This provides the likely explanation for why they are used by animals searching for food and also the eye in its search for visual information (Fairbanks and Taylor 2011). The mid-*D* saccade is optimal for this fractal search because it matches the *D* values found in prevalent fractal scenery. The saccades then have the same amounts of coarse and fine structure as the scenery, allowing the eye to sift through the visual information efficiently.

Effective strategies for processing mid-*D* fractals are also thought be apparent at later stages in the visual system. The brain's visual cortex has been modelled as a set of virtual 'pathways' used to process scenic information (Field and Brady 1997; Knill et al. 1990). Some pathways are dedicated to analyzing large objects in nature's environment, others to small objects. These pathways have evolved to accommodate fractal scenery as follows. The number of pathways dedicated to each object size is proportional to the number of objects of that size appearing in the scene. In other words, the distribution of processing pathways matches the *D* values that dominate the environment. It has also been proposed that fractal processing utilizes fractal images stored in our memories (Geake and Landini 1997).

Modern neurophysiological techniques such as quantitative EEG (qEEG) and functional MRI (fMRI) offer the potential to refine these preliminary models of how the brain processes fractal scenery. Employing EEG, we use electrodes to measure the time variations in brain activity. Specifically, peaks in 'alpha waves' indicate a wakefully relaxed state while peaks in 'beta waves' are associated with external focus, attention and an alert state (Kolb and Whishaw 2003). In our studies, $D = 1.3$ fractals are found to induce the largest changes in participants' alpha and beta responses (Hagerhall et al. 2008). These changes in alpha waves agree with our skin conductance measurements (Fig. 5), which similarly demonstrate that mid-*D* fractals are stress-reducing (Taylor 2006). Our preliminary studies using the fMRI technique further indicate that mid-*D* fractals induce distinct responses when compared to those of low or high *D* equivalent images (Taylor et al. 2011).

Enhanced Performance and Fractal Aesthetics

The fluency model proposes that our increased capability to process mid-*D* fractals results in enhanced performances of visual tasks when viewing them (Taylor and Spehar 2016). For example, our behavioural studies demonstrate participants' heightened sensitivity to mid-*D* fractals (Spehar et al. 2015). Using fractal images displayed on a monitor, the pattern contrast was gradually reduced until the monitor displayed uniform luminance. We found that participants were able to detect the mid-*D* fractals for much lower contrasts than the low and high *D* fractals (Fig. 6a) (Spehar et al. 2015). Similarly, participants displayed a superior ability to distinguish between fractals with different *D* values in the mid-*D* range (Fig. 6b) (Spehar et al. 2015). Furthermore, the increased beta response in our qEEG studies suggests a heightened ability to concentrate when viewing mid-*D* range fractals (Hagerhall et al. 2008).

There is also evidence to suggest that pattern recognition capabilities increase for mid-*D* fractals. For example, we are all familiar with imaginary objects induced by clouds. A possible explanation is that our pattern recognition processes are so enhanced by these fractal clouds that the visual system becomes 'trigger happy' and consequently we see patterns that aren't actually there (Taylor and Spehar 2016). Our research reveals that mid-*D* fractal images do indeed induce a large number of percepts (Bies et al. 2016b) and that they activate the object perception and recognition areas of the visual cortex (Bies et al. 2015). This agrees with our studies of

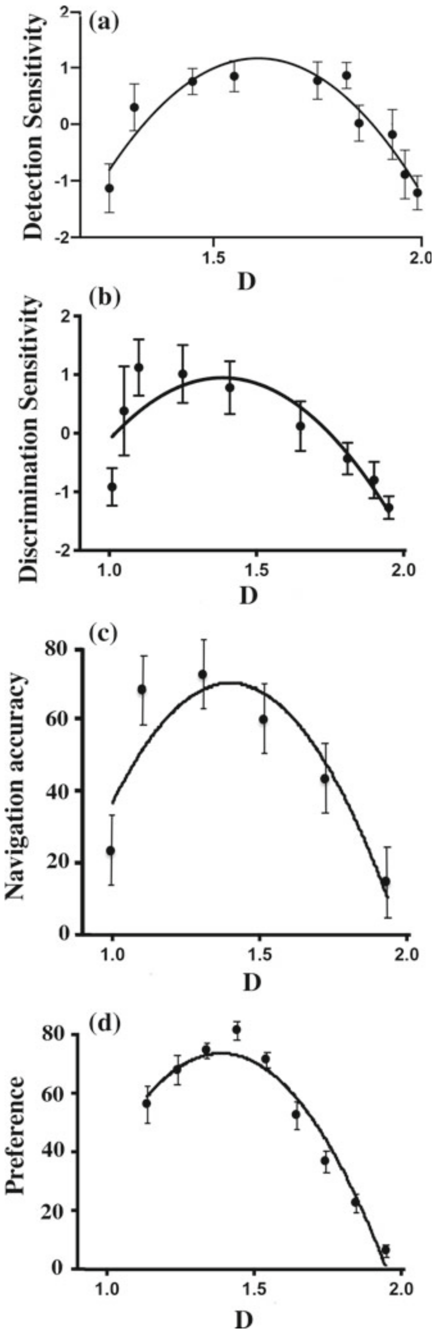


Fig. 6 Capability tasks and preference ratings plotted against the fractal's *D* value. Refer to the individual studies for details of the measurements and the relevant y-axis scale

Rorschach ink blots, in which the capacity to perceive shapes in the fractal blots peaks in the lower *D* range (Taylor et al. 2017).

Does fractal fluency also lead to an enhanced processing of visual spatial information and therefore to a superior ability to navigate through environments characterized by mid-*D* fractals? To answer this question, participants navigated an avatar through virtual fractal environments (Fig. 5) (Juliani et al. 2016). They were instructed to search as quickly as possible for a goal randomly placed within the landscape. In each case, completion speeds and accuracy (the ratio of finding the goal before or after arriving at the distractor) were measured and the overall performance was found to peak at the mid-*D* complexity predicted by the fluency model (Fig. 6c).

All of these enhanced performances raise a crucial question: does fractal fluency also create a unique aesthetic quality because we find mid-*D* fractals relatively easy to process and comprehend? If so, perhaps this 'aesthetic resonance' also induces the state of relaxation indicated by our alpha wave and skin conductance studies? Our behavioral experiments confirm the importance of fractal aesthetics, showing that ninety-five per cent of observers prefer complex fractal images over simple Euclidean ones (Taylor 1998).

Over the past 2 decades, fractal aesthetics experiments performed by ourselves and other groups have shown that preference for mid-*D* fractals is universal in the sense that it is robust to the specific details of how the fractals are generated (Spehar et al. 2003; Spehar et al. 2015; Aks and Sprott 1996). Figure 5 shows a participant rating the preference of 2 Pollock paintings with different *D* values displayed on a monitor (Spehar et al. 2003). Figure 6d shows example results exhibiting the peak in preference, in this case for computer-generated fractals. In addition to these laboratory-based behavioral experiments, a computer server has been used to send screen-savers to a large audience of 5000 people. New fractals were generated by an interactive process between the server and the audience, in which users voted electronically for the images they preferred (Taylor and Sprott 2008). In this way, the parameters generating the fractal screen-savers evolved with time, much like a genome, to create the most aesthetically preferred fractals. The results re-enforced the preference for mid-*D* fractals found in the laboratory-based experiments.

Our most recent experiments investigate subtle deviations from this apparent universal preference. Although the population as a whole prefers mid-*D* fractals, Fig. 7a highlights 3 sub-groups exhibiting distinct preferences. Whereas the majority's preference peaks at mid-*D*, just under one quarter of the participants are 'sharpies' who prefer high *D* and a similar number are 'smoothies' who prefer low *D* (Spehar et al. 2016). It will be intriguing to explore the personality traits characterizing these groups. For example, perhaps Autism might be more prevalent in the sharpies group (in which case, fractal stimuli might be useful as a novel predictor of this condition). Alternatively, the *D* value of Pollock's paintings increased as his career progressed, possibly suggesting that creative artists might be drawn to high *D* imagery? Or perhaps his exposure to fractal paintings over the years built up a tolerance for higher complexity so raising his preferred *D* values? Certainly, some of our studies show that urban versus rural living and also age influence fractal preference, indicating that exposure is a factor (Street et al. 2016).

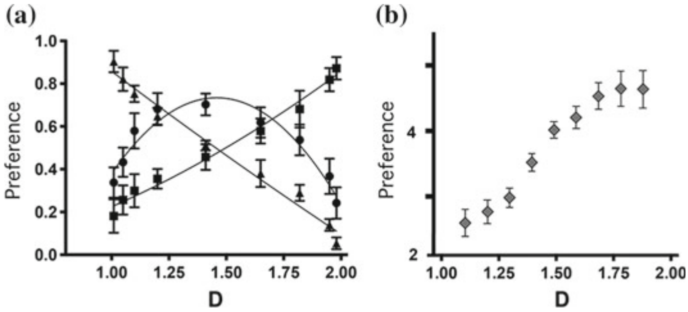


Fig. 7 Deviations away from 'universal' preference behavior. **a** Whereas the majority of participants report a preference peak between $D = 1.3$–1.5 (circular symbols), other subgroups reveal a preference for low D (triangles) and high D (squares) fractals. **b** Exact fractals induce preferences for higher D values than statistical fractals

Our experiments show that preference for mid-D values also breaks down when moving from statistical to exact fractals (Fig. 7b). Given that the fluency model is founded on people's adaption to nature's statistical fractals, it is not surprising that exact fractals induce a different aesthetic impact (indeed, EEG responses were found to dampen when the images were morphed from the statistical to exact versions, emphasizing the adaption of processing fluency to nature's biophilic fractals (Hagerhall et al. 2015)). Observers are found to prefer higher D values for exact fractals, with the peak D depending on the specifics of the fractal pattern (Bies et al. 2016a). For example, Fig. 7b shows that the exact fractals of Fig. 3 induce a peak preference in the D range from 1.8 to 1.9. This pattern has a high degree of symmetry and it is thought that the associated order increases the observer's tolerance for fractal complexity. For fractals featuring fewer symmetries, the reduced order decreases this tolerance and the preference falls to lower fractal complexities.

This concept of complexity tolerance is further supported by our experiments which project statistical fractal images on walls rather than exhibiting them on computer monitors as done in our previous experiments. The observer then witnesses the fractal pattern embedded within the simplicity of a blank wall. This integration of Euclidean simplicity again increases the tolerance for high fractal complexity and the peak preference rises to higher D values (Abboushi et al. 2018).

Tuning the Fractal Aesthetics: The Sinai Light Box

Our on-going studies of fractal aesthetics present an appealing basis for understanding the beauty of nature's scenery. Quantified by D, fractal complexity is a dominant influence on our preferences. Although D values lying between 1.3 and 1.5 represent a magic range for maximizing preference in general, it is also clear that preference can peak outside this range for specific subgroups of observers, and also for subgroups of fractals (e.g. exact fractals) and for situations in which the complexity of the surrounding environment differs from that of the fractal. Based on this diversity of conditions, fractal artists should consider creating art for which *D* can be adjusted to accommodate for these variations.

The *D* values of nature's fractal objects are set by the dynamical processes which shape them. For example, the turbulence creating clouds, fissures that shape cracks, and the erosion of coastlines all generate patterns with specific *D* values. Consequently, once formed, it is rare for natural objects to change their *D* values. Exceptions include trees, which increase their *D* values when, each Autumn, the falling leaves expose the higher *D* fractals of the underlying branches (Fig. 8). Another exception involves the foam bubbles shown in Fig. 9. Small bubbles combine to create bigger bubbles, adding larger structure into the fractal mix of the pattern, and this leads to a decrease in *D* value as a function of time (Taylor 2011).

We aim to outdo nature by building an object which can be used to tune the *D* value of the fractal pattern to match the observer's preferences. Our apparatus is based on the theoretical research of the Russian mathematician Yakov Sinai. In the 1960s and 1970s, Sinai studied the game of billiards (Sinai 1963). Figure 10a shows two trajectories of balls bouncing around a standard billiard table. Launching the ball from slightly different locations does do not alter the trajectories in a significant

Fig. 8 Photographs of trees with (low *D*) and without (high *D*) leaves

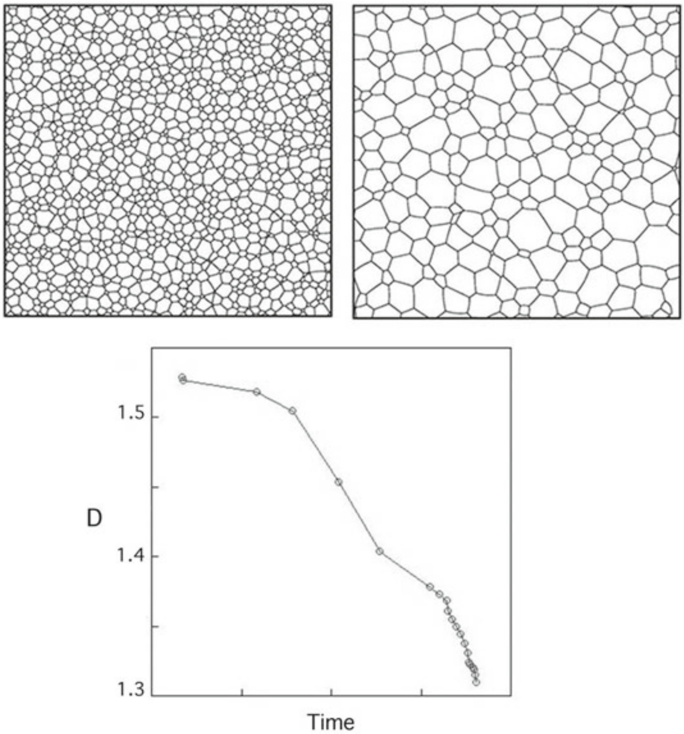


Fig. 9 Top: Computer simulations of bubbles evolving from high *D* (left) to low D (right) patterns. Bottom: A plot of *D* as a function of time

manner. However, the game changes substantially when a circular wall is inserted at the center of the table to create what is now known as a Sinai billiard (Fig. 10b). In his theoretical work, Sinai noticed that the two trajectories then diverge rapidly, ending at significantly different locations on the table. This signature—an extreme sensitivity to initial conditions—is known as chaos. Chaos is prevalent in nature and it is responsible for generating many of the fractals found in our daily scenery. In the case of the Sinai billiard, the outside walls of the table repeatedly reflect the balls onto the curved surface of the inner wall. This curvature causes the trajectories to diverge and induces the chaos. As the balls bounce around the table, their trajectories map out patterns at many scales, gradually building a fractal pattern.

Sinai's billiard is well-known in science as an artificial system in which nature's chaos can be studied (in 2014, Sinai became an Abel Laureate, the mathematical equivalent of a Nobel Laurette, for his work). It has also been used for technological applications. For example, fractal transistors are based on miniature Sinai billiards defined in electronic chips. The enhanced sensitivity of chaotic electricity allows the fractal transistors to out-perform traditional transistors (Taylor et al. 1997a, b; 2003; Taylor 1994; Marlow et al. 2006). Here, we will exploit Sinai billiards to cross into the

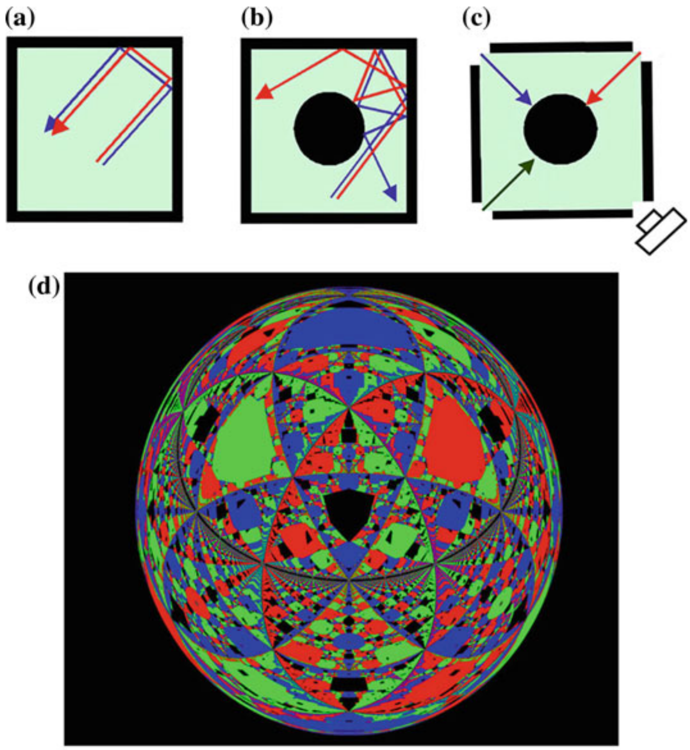


Fig. 10 **a**–**c** Schematic representations of billiard games. In contrast to the traditional game shown in (**a**), two balls launched from slightly different locations diverge rapidly for the chaotic game in (**b**). For the optical game in (**c**), red, green and blue rays shine in through the openings and a camera takes a photograph through the fourth opening. The simulation (**d**) reveals reflections on the spherical surface that repeat at multiple size scales

world of art and use the chaos to create tunable fractal patterns. To do this, we replace the billiard walls with mirrors and the balls with rays of light. Shown in Fig. 10c, red, green and blue rays of light are shone into three openings in the billiard's corners and the resulting patterns are viewed through the fourth corner either by eye or camera. Figure 10d shows a simulation of the fractal reflections from the spherical surface.

The photographs of Fig. 11 summarize the operation of the actual apparatus, which is comprised of a 30 cm wide cube of mirrors, a central spherical mirror and three lamps shining colored light into openings in the upper corners (Fig. 11a). Whereas Fig. 11b shows the resulting pattern from the multiple light rays generated by the three lights (and so matches the simulation shown in Fig. 10d), Figs. 11c,d show the trajectories of individual rays made visible using the fog from dry ice. In particular, Fig. 11c captures the chaos of two rays reflecting off the sphere and Fig. 11d shows the non-chaotic rays when the sphere is removed.

The next step is to investigate how the *D* values of the fractal light patterns can be tuned. Intriguingly, the impact on *D* of adjusting the geometric properties of the

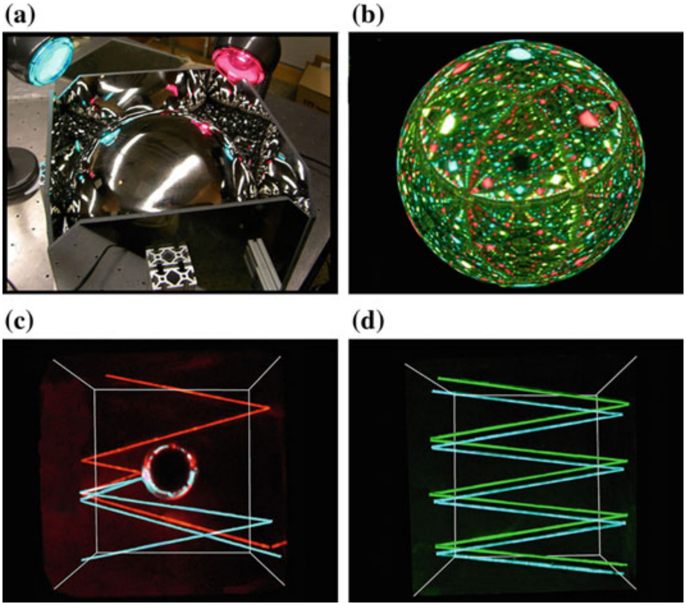


Fig. 11 Photographs of: **a** the optical Sinai billiard, **b** reflected patterns formed on the spherical mirror, **c** two chaotic rays created by reflections off the sphere, **d** two non-chaotic rays occurring when the sphere is removed

billiard has not been addressed in previous studies of Sinai billiards. Figure 12a shows simulations of the patterns generated when the sphere radius is 33% of the box's width and the openings make up 20% of the box's surface area. Increasing the sphere size can be seen to relocate the positions of reflections on the sphere surface (Fig. 12b). However, the reflections are relocated in the same fashion irrespective of their sizes. Consequently, the ratio of fine to coarse structure in the fractal pattern is unaltered and so D remains constant. Figure 12c shows the asymmetry introduced when the sphere is moved away from its central position. Again, because this asymmetry is introduced at all scales, the D value remains the same.

The remaining question of adjusting the sizes of the openings produces a much more subtle effect. Widening the openings increases the sizes of the reflections (Fig. 12d). However, the reflections evolve differently at increasingly fine scales. As can be seen in Fig. 13, increasing the openings results in a well-controlled, systematic rise and fall of D (methods for analyzing D values can be found elsewhere (Fairbanks and Taylor 2011; Pilgrim and Taylor 2018)). This novel effect is currently being modelled to provide a detailed picture of its origin. However, in essence, widening the openings increases the chance of light rays escaping rather than circulating around the billiard and undergoing multiple reflections. Clearly, mid-sized openings provide the optimal conditions for preserving the rays that generate the smaller reflection patterns, leading to an increase in the ratio of fine to coarse structure in the fractal reflection and a peak in its D value.

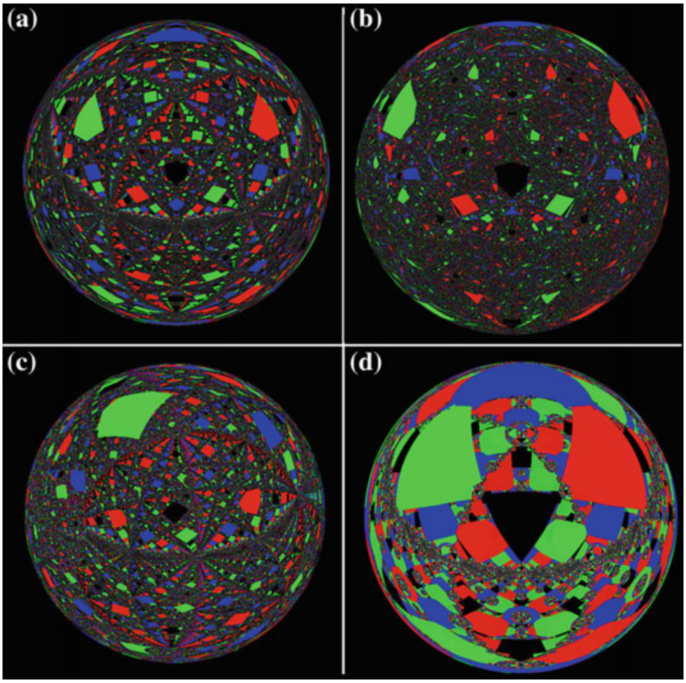
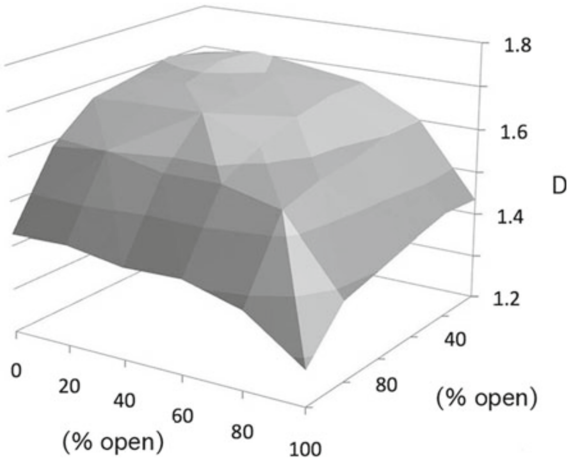


Fig. 12 Simulations of the fractal pattern before (**a**) and after enlarging the sphere (**b**), moving the sphere (**c**), and enlarging the openings (**d**)

Fig. 13 The fractal pattern's *D* value plotted as the size of two of the openings are independently increased. The openness is measured as the percentage area of the opening to the sidewall surface area



This remarkable effect results in our capacity to adjust the fractal patterns based on the observer's aesthetic needs. The current studies purposely considered high fidelity mirrors which minimize any distortions in the reflections. The resulting exact fractals allowed the evolution in D to be demonstrated with clarity. We note that the equivalent statistical fractals can be generated by introducing random bumps into the surface of the spheres.

Conclusion: Fractals as a Bridge Between Art and Science

Aesthetics is a rich field for art-science collaboration. In this chapter, we have demonstrated the value of science for understanding a central aspect of art—nature's beauty. In addition to exploring this fundamental question, our fractal studies have important practical consequences. Mid-D fractals have the potential to address stress-related illnesses, which currently cost countries such as the US over $300 billion annually.

Our model of fractal fluency also adds fuel to on-going and often controversial discussions within aesthetics studies: to what extent is appreciation driven by the automatic responses of human neurophysiology and biology versus the intellectual and emotional deliberations of the observer? (Taylor 2010) Our studies indicate that a range of automatic processes unfold within a quick time frame. Consequently, we are well on the way to appreciating the fractal object's beauty before we have had time to consciously deliberate on its visual qualities.

In addition to understanding fractal aesthetics, our chapter also considers the role of science in generating fractal aesthetics. Our Sinai billiard was first exhibited at Portland Art Museum in Oregon in 2009 where it was seen by over 60,000 visitors (Taylor 2009). It was then transferred to Oregon Museum of Science and Industry where it has been enjoyed by countless others. Given its success, it is interesting to consider the Sinai billiard within the spectrum of previous fractal artists. In particular, M.C. Escher and Jackson Pollock present contrasting approaches to their creation of fractals. Escher employed the precision of mathematics to carefully map out his repeating patterns (Van Dusen and Taylor 2013). Pollock, on the other hand, exploited his chaotic body motion to pour his fractals onto a canvas (Taylor et al. 2003; Abbott 2006). The Sinai system sits somewhere between the two. Like Pollock, it exploits chaos to effortlessly generate fractals. Certainly, it is impressive that such a simple system—a sphere placed within a cube—could generate such visual complexity. Like Escher, the mathematics of the system can be tuned with precision. By careful adjustment of the openings, the D value can be selected.

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Art as an Aid to Resolve Tension

Ghosh Raghunath

In present day society there are crises of many types: moral, economic, technological, environmental etc. If the main cause of such crises is seriously looked into, it would be observed that human values are eroded day by day due to an individual being's excessive greed and lust. In present day society most of the people are always self-centred due to the loss of human value and sensitivity towards our environment, trees and other social beings. In the *Dhammapada*, the sacred Buddhist text, it is said that mental pollution is the main cause of external or environmental or other types of pollution. The Sanskrit rendering of the term 'peace' is '*śānti*', which is derived from the root *'śaṁ'* meaning 'restrain of the sense-organs' (*vahirindriya-nigraha*). In fact, in Buddhism and Hindu tradition the root cause of the absence of peace from our mind is 'thirst' for enjoyment or '*tanha*', which causes cravings for getting more and more consumable objects. Such thirst can never be quenched with the fulfillment of the desire and hence it is an unending phenomenon. The more we get, the more we urge for it. In order to get rid of it we have to search for self-satisfaction, which ultimately leads us to the world of peace. In order to arrive at such stage it is essential to go through some rigorous meditative training so that we can control our sense-organs including the inner one (*antaḥ-karaṇa or mind*). The excessive greed and mental turmoil leads an individual to the performance of immoral works like killing trees, polluting environment and other types of crises in the society.

These sense-organs are always rushing towards the external objects to fulfill one's thirst, which is cause of painfulness or an unpleasant situation. Hence in order to have peace in our mind we should try to resist the rushing of the external sense-organs towards the objects and to bring them back towards an opposite direction i.e., self. Just as the flow of the river can be brought to the opposite direction through some method, the nature of the sense-organs which rush to the external objects can be changed through turning them towards the opposite direction, i.e., the internal side. An individual who is wise tries to withdraw his sense-organs from the external world

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and concentrates these to his own self,[1] which is called '*śama'* ('the restrain of the sense-organs') from which the word *'śānti'* meaning 'peace' is originated as told earlier.

If the sense-organs rush to the external objects without being controlled by us, our minds become polluted and troubled through the vitiation of thinking on the object of enjoyment. Such a polluted mind cannot give us peace or happiness. For this reason the sense-organs are called non-favourable (*duḥ*).[2] On the other hand, if an individual, after withdrawing it from the external object, puts the sense-organs towards his inner self, the mind becomes calm and non-polluted. Hence the sense-organs (*kha*) become '*su*' or favourable by virtue of their utilization for attaining one's calmness. Moreover, in order to keep our mind balanced, it is necessary to bring sense-organs within our control.[3] It is possible if their flow is turned towards our own self or inward direction. At this stage mind becomes calm and tranquillized producing 'peace' or '*śānti*'. It confirms the famous saying that one's own control over sense organs can generate peace to him while those sense organs that are not under one's control can provide only misery. How can this flow of sense-organs be brought towards the opposite direction or inner self? The Indian thinkers have prescribed various ways of achieving this. The first is the path of meditation prescribed by Patañjali and the Buddhists. These are called Eight-fold path or *aṣṭāngika-mārga* following which one can bring the sense-organs under one's control. To the Buddhists the Eight-fold path or the correct path of life and the correct knowledge of Reality is the only means to control the sense-organs. If it is known to us that each and every object is transitory or momentary or essenceless or *śūṇya* in nature, then such realization can make our sense-organs restricted due to not having the influence of thirst as told earlier, which ultimately can give us peace. That is why, Buddha himself is called an embodiment of peace and an embodiment of aesthetic pleasure called *śāntarasa* and by virtue of being worthy of it he is described as *śāntātmā* (one whose whole being becomes calm or peaceful) and *śāntamanas* (one whose mind becomes free from tranquility).

The last method of reducing our thirst is to encourage an individual to engage him in the enjoyment of fine arts like film, novel, drama, music, dance, paintings etc. It is a well-known fact that while enjoying aesthetic pleasure a human being can bracket his day to day problems and engross himself in some non-pathological enjoyment. It is non-pathological in the sense that this type of enjoyment has no connection with the fulfillment of this-worldly matter. Through the inculcation of such enjoyment one can easily reduce one's this-worldly interested pathological desire arising out of cravings.

Machine is essential no doubt but we do not want that a man should be a machine without having any feelings towards nature, environment etc. Hence Vivekananda told that we want machine but not mechanical heart.

In order to remove such mechanization of heart art may be taken as an aid. When we are in aesthetic enjoyment through drama, literature, music and dance, we can have

[1]*Katha-Upaniṣad*, 2/1.

[2]Ibid.

[3]Ibid.

real mental rest or relief or freedom (technically called *viśrānti*) for the time being due to its disinterested, impersonal and universal character after removing tension from human beings and making them mentally balanced which is not available in the phenomenal world. If art is practiced, one will have sensitivity of heart towards not only art objects but our environment, nature, forest and other human beings. Though art can give us a temporal relief yet it can help in nurturing delicate parts and feeling or sensitivity of heart. A crisis arising from exploitation of human beings, deforestation, destruction of natural resources etc. is due to the loss of sensitivity or feelings towards them. Such sensitivity is a matter of practice and nourishment. Bharata told that there are abiding emotions hidden in our mind in a seed forms (*sthāyibhāvas*) that are to be nourished regularly. Otherwise, they would have been nipped in the bud leading a human being to highest level of cruelty. As a result of this he is going to exploit nature and environment to fulfill his narrow desire. When our pathological needs and greed are controlled, a man will have mental relief which comes from aesthetic delight. Saving of our heart is primary for solution of some of crises mentioned above. For this reason music, dance etc. have been taken as therapies in modern science as they can remove mental pollution which is the precondition of external pollution. Art intensifies the feeling for others in case of enjoyable objects through transcendence towards daily hazards of practical life. Art has got some meditative or yogic value through which our feeling for non-art objects also like environment, nature and social beings can easily be extended through our rigorous involvement in art and due to the development or nourishment of tenderness of heart.

That the aesthetic pleasure has some power of transcendence can again be known from the fact that the aesthetic emotional mood of grief is found to give rise to the experience of joy. How is the joy realized in the depicted painful situations? In the dramatic situation our mind is absorbed in the performances of the actors and this absorption depends on the equilibrium of mind. When our mind is absorbed in an art object having pathos, the pain follows. If our mind remains in the state of aesthetic experience, there is something, which forcibly snatches our mind and keeps it in a state of complete rest, which is called *viśrānti*. When a human situation is artistically presented usually against the background of the nature, the critic does not get himself transported to the peak of *rasaviśrānti* or repose. It is in fact the last stage of his contemplation. Leading up to it are the diverse impressions he is receiving from different angles, almost simultaneously. His imaginative sensibility helps him in reception while his intellect is at work all along sorting them out. When the intellect and imagination slide into the margin, his heart is moved to an intense aesthetic state of repose, which is an end in itself. It is the aesthetic pleasure, which only can do this thing. This joy is endowed with such a type of unique power by which the audience can enjoy this bliss even out of painful situation, but in our practical life human nature is found averse to experience pain. Hence, Viśvanātha, the celebrated rhetorician, has said that poetry is a unique unworldly phenomenon, an extraordinary creation of a supernatural supernormal genius and hence it cannot be governed by the rules of ordinary human intellect. In ordinary life sorrow comes from sorrow, fear follows fear, but in the world of poetry we find pleasure deriving from the painful, horrible and terrible situations.[4]

It may be asked why this-worldly pleasure is not aesthetic. In reply, it can be said that the said pleasure is not aesthetic because aesthetic pleasure should be impersonal, disinterested and universal in character. When an individual feels happy at the happiness of the dramatic character, that pleasure is not exclusively his own (i.e. arising form his personal life) and it is impersonal. As this pleasure is not owing to the fulfillment of his self-interest, it is disinterested. Such a type of feeling does not occur in the case of only one individual. It happens so in the case of all individuals. That is why, it is universal.[5] It has been stated earlier that due to complete absorption in the aesthetic pleasure a man forgets his own loves and fears etc. At that time there remains a universal love, which is aesthetic pleasure. When a terrible scene is represented, there is an enjoyment of aesthetic pleasure from the sentiment of fearfulness called *bhayānaka*. In this case too we generally forget that this fear felt by us belongs to the dramatic character and enjoys the universal character of fear, which is free from privative barriers of individualistic elements. The generalization is the process of idealization through which an individual transcends and alights on his personal emotion to the serenity of contemplation of a poetic sentiment. The poet and the audience have to be endowed with the capacity of idealization. The poet can present personal emotion as an impersonal aesthetic pleasure, which is enjoyed by others, as if it were theirs.[6] As this pleasure transcends the limitations of personal interest and inclinations, it is disinterested universal pleasure. A pleasure which transcends this-worldly interest is surely transcendental. As this worldly pleasure arising out of these worldly affairs like the birth of a son, attainment of property etc. is hardly impersonal, disinterested and universal, it cannot be described as aesthetic.[7] Aesthetic pleasure is the emotional mood revealed in a blissful state of knowledge free of all barriers. When someone undergoes aesthetic experience, he becomes identified with the characters of the drama, and it is called identification of self (*ekātmatā*). Like identification there is also distancing from the characters. The pathos experienced as joyous in aesthetic sentiment is due to the impersonalization of the sorrow. Had this sorrow been my personal feeling, it would make us cripple, but actually we 'enjoys' sorrow under such a special and unique situation. The enjoyment of sorrow is possible through impersonalization, which is the product of distancing from the characters. It is a kind of identification with as well as distancing from the characters. Hence it is very difficult to say whether the experience belongs to the characters of drama or to me. As there are both the situations of distancing and identification, it is very difficult to describe it as belonging to me or belonging to other. This is Viśvanātha's account of the aesthetic communication (*Sāhityadarpaṇa*-3/12). When the emotion is shared by us, we are identified with the characters. As this identification is impersonal in

[4] *Sāhityadarpaṇa*, 3/6-7.

[5] Ibid.

[6] *Kāvyādarśa*, Commentary on verse no. 10, Ch. I, edited by K. roy, 3rd Edition, Calcutta, 1971.

[7] Ibid.

nature, there is also a sense of distancing. That is why, the sorrow depicted in the film in heroes' or heroine's life becomes enjoyable to us due to the impersonalization.

According to Abhinavagupta, an object becomes beautiful when our self gets involved in it. When someone realizes the misery of some character in a piece of literature, he thinks it as if it were his own due to the reflection of his own self there. This view is more firmly rooted in the Upaniṣadic view. The Bṛhadāraṇyakopaniṣad says that husband is loved by his wife not because she loves her husband but because she loves her own self etc. ("… *na vā are patyuḥ kāmāya patiḥ priyo bhavati, ātmanastu kāmāya patiḥ priyo bhavati*" etc.[8]) One can realize the nature of *Rasa* with the help of bliss arising from the realization of Brahman as accepted by the Advaitins. When an individual's personal desire is transformed into the impersonal aesthetic sentiment, the realization of aesthetic pleasure which is universal in character comes into being. Hence, Abhinavagupta has accepted the process of 'generalization' (*sādhāraṇīkaraṇa*) as one of the characteristic features of aesthetic pleasure. Though there is reflection of Brahman in an individual's mind, which is free due to the prominence of *sattvaguṇa*, this pleasure is quantitatively different (but qualitatively same) from the pleasure of Brahman (*Brahmāsvādasahodara*). Aesthetic pleasure is so enchanting that it is compared to the shorter image of spiritual bliss. It is quantitatively shorter in duration, but qualitatively same as the spiritual bliss due to its nature of disinterestedness or non-pathological.[9]

The theory of *Dhvani* (suggestive meaning) and *Rasa* (aesthetic sentiment), though invented in connection with the literary form of art, can be extended to other forms of art also. It has been stated by Ānandavardhana that an individual, though conversant in respect of word, meaning and their relation, cannot understand literature until and unless his heart is saturated with aesthetic sentiment. He explains this phenomenon with the help of an example taken from the world of music. He adds that an individual, though expert in the science of music, cannot understand melody and pleasure arising from it until and unless his heart is saturated with *rasa*.[10] The same theory can be applicable to the pictorial form of art also. In the phrase of Abhinavagupta, any type of the creative art presupposes the condition of *rasāveśa*[11] (involvement in aesthetic sentiment) in an individual. Various experiences of our daily life are represented in the art-objects like literature, painting etc. In order to represent the reality one should need deep concentration, which is supported in the Śrīmadbhagavadgītā—'*na cāyuktasya bhāvanā*'.[12] This abiding emotion or sentiment must exist in artist, dramatic character and spectators (in the case of literary art). In the case of pictorial art also, there must exist the same sentiment among artist, pictorial presentation, and the viewer. Hence, the property of being *sahṛdaya* (having the same heart) is not essential in the case of literature only, but is in other forms

[8] *Bṛhadāraṇyakopaniṣad,* 4/5/321/6.

[9] *Locana* on Dhvanyāloka, 2/4.

[10] Prose-portion of Kārikā no. 1/7 of *Dhvanyāloka.*

[11] Dr. K. Krishnamurthy: *Dhvanyāloka,* p. XL, Motilal, Delhi, 1982.

[12] *Śrīmadbhagavadgītā* 2/66.

of art also. A connoisseur is called *sahṛdaya* or having the same heart having same feeling in trio- the poet, the dramatic characters and spectators.

Such unique element can be traced in dance, music etc. also. A man is found to forget his own joys and sorrows at the time of the enjoying the performances of music or dance. That the spontaneity, as already noted, is one of the vital features of aesthetic experience of literature can be had in cases of music and dance. How far the performance of dance and music is artistic can be judged from their spontaneity along with other qualities. If the performance of dance or music is not spontaneous, they seem to be artificial. As the spontaneity comes from within, it belongs to the artist with his brimming with aesthetic relish. If a musician or dancer is absorbed in deep relish (which is usually called 'mood' in ordinary language), he cannot help dancing or singing. At this stage only spontaneity comes. Musical melody and dance forms are born and give rise to aesthetic pleasure. The dance, not unlike other arts, is also spiritually significant, independent of its theme or charm. As music and dance clearly express the aesthetic delight and enable the spectators to have a relish of them, they give them the foretaste of Brahman. This in its turn leads us to the domain of uniqueness.

In the domain or world of *kāvya* or literature the poet is called the Prajāpati or Creative Deity ('*apāre kāvyasamsāre kavireva prajāpatiḥ*'*-Agnipurāṇa-345/10*). Hence a poet is independent having only a goad in the form of his intellect. This goad is his strong sense of *aucitya.* When a poet is inclined in poetic creation, he first adheres to bring out an aesthetic pleasure in heart of the connoisseur. A poet has the privilege to deviate from the historical facts if it is conducive to the creation of aesthetic pleasure. People read history to get the facts while they resort to literature to have the taste of aesthetic pleasure. Poetic truth lies in the *vibhāvas,* which are created by the poet by slightly distorting historical facts if necessary. For it is not the function of the poet to relate history. In literature aesthetic sentiment is the main objective. If it is not manifested, historical facts are mere data and hence they cannot be transformed into art. There is a difference between a historical narrative and a poem. A narrative is a catalogue of detached facts, which may have no connection with time, place, circumstances, cause and effect: the other (i.e., poem) is the creation of action according to the unchangeable ways of human nature. Hence some thinkers have accepted the role of *aucitya.*

In any piece of literary art aesthetic enjoyment (*rasa*) is a corner stone. It is the aesthetic pleasure, which controls the story, characterization, style etc. According to some rhetoricians, the poetic beauty depends on the words and their meanings. The words associated with the rhetoric are able to create poetic beauty. The beauty in meaning is produced out of the rhetoric like *vakrokti* etc. All these formal elements may or could be necessary, but hardly sufficient. And this leads to another theoretical consideration.

The merit, rhetoric or figure etc. cannot be taken as vital factors of a literary art due to their inadequacy in the matter of poetic creation. When the poetic language is completely distinguished from the ordinary language, the beauty of the former can easily be realized. Though the merit, rhetoric etc. are of course found in the language in our day-to-day communications, it is not taken as evidence of literature. All persons are gifted to follow the ordinary language, but hardly the poetic one. In enquiring into its cause Ānandavardhana has proposed the theory of *Dhvani* or suggestion, which alone can offer the reasonable explanation of the creation of the poetic beauty. The nature of *Dhvani* is given in the following way—"*Arthaḥ sahṛdayaślāghyaḥ kāvyātmā yo vyavasthitaḥ*".[13] The aesthetic pleasure arising from literary art cannot be understood by all, but only by the appreciators (*sahṛdaya*). In other words, literature is always appreciated by the *sahṛdayas* alone. The portion which the appreciators specifically apprehend and which is taken as a vital factor in literature is called *Dhvani.* The aesthetic pleasure (*rasa*) arises if there is supremacy of *Dhvani*; otherwise it is *rasavadalamkāra* (i.e. rhetoric mixed with *rasa*).

The aesthetic experience arising out of literary form of art, as Abhinavagupta has observed, is different from the experience arising from other sources (i.e. non-art objects). Those who enjoy a literature (either in the form of poetry or drama) become happy or unhappy after sharing the happiness or misery of the hero or heroine. Behind this happiness or misery of the audience there is no reason by which a logical mind can be satisfied. As for example, Rāma, a character of a drama, might be happy or unhappy, but there is no reason of being involved emotionally with the dramatic character sharing their pleasure and misery. It is true of course that an audience or an appreciator is found to be emotionally involved. From this particular effect on the audience it is quite rational to look for a cause. As this cause is not found through ordinary sense organs and logical argumentation, it can be taken as something mysterious, non-logical in essence.

That the aesthetic pleasure is mystical can again be known from the fact that the aesthetic emotional mood of grief is found to give rise to the experience of joy. How is the joy realized in the depicted painful situations? In the dramatic situation our mind is absorbed in the performances of the actors and this absorption depends on the equilibrium of mind. When our mind is disturbed, the pain follows. If our mind remains in the state of aesthetic experience, there is something, which forcibly snatches our mind and keeps it in a state of complete rest, which is called *viśrānti.* When a human situation is artistically presented usually against the background of the nature, the critic does not get himself transported to the peak of *rasa-viśrānti* or repose. It is in fact the last stage of his contemplation. Leading up to it are the diverse impressions he is receiving from different angles, almost simultaneously. His imaginative sensibility helps him in reception while his intellect is at work all along sorting them out. When the intellect and imagination slide into the margin, his heart is moved to an intense aesthetic state of repose, which is an end in itself. It is the aesthetic pleasure, which only can do this thing. This joy is endowed with such a type of mystical power by which the audience can enjoy this bliss even out of painful situation, but in our practical life human nature is found averse to experience pain. In cases of aesthetic encounter there is some sort of identity between the audience and the object of experience. This notion of identity emerges from having self-involvement (*ekātmatā*) with it. As for example, when an individual perceives a scene in which Duṣyanta, for example, enjoys happiness in company of Śakuntalā, he is realizing

[13] *Dhvanyāloka*, Karika no. 2.

bliss just as Duṣyanta. For the time being he is identified himself with the character of the drama. On account of this identification (with the hero) the spectator loses his individuality and forgets his personal this-worldly matters. This shows the mystical power of the aesthetic pleasure.

The real appreciator of a literature is a s*ahṛdaya.* The property of being a *sahṛdaya* lies in the fact of being identified with the feeling of the poet. The poet creates poetry, the appreciator realizes it and being a *sahṛdaya* he recreates the creative mood in his own self. Just as fire covers the dry wood, the aesthetic pleasure arising in one's heart engulfs experiencer's whole being. This aesthetic pleasure is generated if the work of art is appreciated by the heart (*hṛdayasamvādī*). ("*Yo 'rtho hṛdayasamvādī tasya bhāvo rasodbhavaḥ/śarīraṁ vyāpyate tena sūkṣaṁ kāṣṭhamivāgninā.*")[14] Generally artists are not content with a simple and direct representation of nature. They make the *bhāva* or representation more and more complex when they are gifted with imagination. The more refined critic welcomes it too, and the most complex pattern thus imposed on nature and human nature by the imagination of the artist wins the admiration of the most cultivated man of taste. He calls such a completely successful *bhāva*-complex itself by the name *rasa* since it means supreme delight.

The aesthetic pleasure leads a man to the world of creativity. After seeing the separation of the one of the curlew-couple V*ālmīki* became greatly moved, and out of his grief he created a *śloka.* He intensely felt the pathos in which he lost himself. Due to the complete loss of personality he had a sense of joy out of the grief. This joyous experience of pathos prompted him to composing a *śloka* spontaneously. V*ālmīki's* grief was not this-worldly. Had it been so, he would have felt sympathy with the bird. This could not have been sufficient for the creation of poetry. This worldly grief makes a man dumb. When a poet's vision deepens, he gets inspired from within. Then the crafts of writing of *Kāvya* (like characterization, plot etc.) follow just as water overflows a jar already filled with water. The poet's genius absorbed in the aesthetic state comes to be endowed with capacity of composing a *Kāvya* in a spontaneous manner. If a poet's heart is filled with emotion, it (emotion) finds a spontaneous outlet in the metrical form. This spontaneity arises when there are no barriers (like personal interest etc.) for the realization of aesthetic pleasure. The spontaneous outlet of poetry from a man who was idle before having aesthetic absorption proves again the mystical character of aesthetic pleasure. This spontaneous poetry is called *śloka* as it arises from the grief due to the separation of the curlew couple ('*krauñcadvandvaviyogotthaḥ śokaḥ ślokatvamāgataḥ*'-*Dhvanyāloka*[1/15]).

Let us look into the concept of aesthetic experience as adumbrated in the basic text of rhetoric—the *Nāṭyasāstra* of Bharata. Therein we find the first *Rasasūtra* in the Indian poetics. This *sūtra* runs as follows: *Tatra vibhāvānubhāva-vyabhicāri-samyogād rasaniṣpattiḥ.*[15] That is, the aesthetic pleasure (*rasa*) is manifested through the amalgamation of *vibhāva, anubhāva* and *vyabhicāribhāva.* Bharata mentions that there are eight innate abiding emotions (*sthāyibhāvas*). When these abiding emotions are aroused by some external factors, we enjoy the aesthetic delight. These abiding

[14]*Locana* on *Dhvanyāloka* (Ed. By Kappusv*āmi Sastri*) Madras, 1964, pp. 77–78.

[15]*Nāṭyaśāstra*, 6/34.

emotions are eros (*rati*), the factor that gives rise to laughter (*hāsa)*, grief (*śoka*), anger (*krodha*), enthusiasm (*utsāha*) fear (*bhaya*), hatred (*jugupsā*) and astonishment (*vismaya*),[16] which yields to eight types of aesthetic pleasure—*śṛṅgāra* (love sentiment) *hāsya* (laughter), *karuṇa* (pathos), *raudra* (terrifc) *vīra* (heroic), *bhayānaka* (fearful), *vibhatsa* (repulsive) and *adbhūta* (wonderful) respectively.[17]

The causal factors giving rise to the abiding emotions (*sthāyibhāvas*) are called *vibhāvas* e.g. the abiding the emotion in the *Abhijñānaśakuntalam* is romanticism (*rati*), the cause of which is the appearance of Duṣyanta and Śakuntalā, the bank of Mālinī, bower etc. Among these the appearance of Duṣyanta and Śakuntalā is called *ālambana-vibhāva* and natural background of the scene etc. is called *uddīpana-vibhāva.* Both being the causes of abiding emotion are called *vibhāvas.*[18]

In a similar fashion, the effects of abiding emotions are called *anubhāvas* viz., the romantic glance of a hero or arch glances of a heroine, expression of anger, astonishment etc. There are other abiding emotions that, according to the situations, keep appearing or/and disappearing. These changing emotions are called *sañcāribhāvas* or *vyabhicāribhāvas*.[19] Let us explain the situation with the help of an example. A heroine, for example, is given an appointment by a hero to meet her in a particular place and time but somehow the hero has failed to meet in time. Under this situation the heroine might have gone through various changing abiding emotions. After waiting for a long time she would bemuse that her lover might have met some accident on his way. This thought would give rise to some expression of anxiety in her face. After a few moments she might think that her lover might have fallen in love with some other woman, which results in arousing the expression of jealousy in her face. In the same way, she might think about his coaxing words, which he might say to her to account for his delay, thus giving rise to expressions of smile and pride in her face. In this case we find a series of abiding emotions appearing and disappearing, and hence these are called *vyabhicāribhāvas.* For the manifestation of the aesthetic pleasure the amalgamation of these *bhāvas* is a pre-requisite. It is already told that the aesthetic pleasure is the product of an intuitive cognition (*prātibhajñāna*). Let us see why such experience is called intuitive. It may be said that in the world of literary form of art a connoisseur transcends his own world of interest and enjoys the pathos or feelings of others without being indifferent to these. Hence, the pleasure arising through this self-involvement with the characters of the drama is called disinterested or non-pathological, which can be substantiated with the following argument. An individual being's attitude towards an object may be of three types: inclination (*pravṛtti*), refraining from (*nivṛtti*) and indifference (*upekṣā*). Human inclination presupposes the knowledge of the conduciveness of what is desired (*iṣṭasādhanatājñāna*); refrain-

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[16]Ratirhāsaśca śokaśca krodhotsāhau bhayaṁ tathā. Jugupsā vismayaśceti sthāyibhāvāḥ prakīrtitāḥ/*Nāṭyaśāstra* 6/18.

[17]Śṛṅgāra-hāsya-karuṇa-raudra-vīra-bhayānakāḥ/Vibhatsādbhutasamjñau cetyaṣṭau nāṭye rasāḥ smṛtāḥ—Ibid. 6/16.

[18]Yāni ca kāryatayā tāni anubhāvaśabdena. Anu paścādbhāvaḥ utpattiryeṣām. Anubhāvayati iti vā vyutpatteḥ".—*Rasagangādhara* 1/16.

[19]"Vi-abhi ityetau upasargau, car iti gatyartho dhātuḥ vividham ābhimukhyena raseṣu caranti iti vyabhicāriṇaḥ".—*Nāṭyaśāstra*, 7/43.

ing from some activity indicates the existence of the knowledge of the conduciveness to what is not desired (*aniṣṭasādhanatājñāna*). If there is an object which is not related to the conduciveness of what is desired or non-desired, there arises the attitude of indifference.[20] As the pleasure or grief of a dramatic character is not related to our direct interest, we should have shown indifferent attitude to them. But it is found that we are inclined to share their grief or pleasure and enjoy disinterested pleasure, which is called a non-pathological one. From this it follows that the world of aesthetic experience is completely different from our reactions in the mundane world. In the mundane world we generally get pathological (*laukika*) pleasure like 'your son is born' (*putraste jātaḥ*) 'your daughter has conceived' (*kanyā te garbhinī*) etc. Hence the non-pathological pleasures are called non-mundane (*lokottara)* in their essence and character.

The transcendental or *prātibha* character of such cognition may also be shown by the help of the following arguments.

If it were argued that the scenes, background music etc. (in the case of a dramatic performance) are the causes of the realization of aesthetic experience, it would be asked whether these causes are the producers (*kārakahetu*) or the revealers (*jñāpakahetu)* of the experience. The *kārakahetu* ceases to exist just after the effect comes into being. As for example, a table is made by a carpenter, though it may last for longer time, even when the carpenter is no more. So far as aesthetic experience is concerned, it ceases if the scene, background music etc. are withdrawn and hence, they are not producers. On the other hand, they cannot either be put under *jñāpakahetu* since aesthetic pleasure was not there previously (i.e. before scenes, background music etc. are set). When a cause reveals an object, it has got to be there. As for example, the opening of the door reveals the objects existing in the room and hence it is called revealer. It cannot be said that aesthetic experience existed before the causes mentioned above were set. Experientially there is nothing to reveal, nothing is revealed, and there is only the suggestion that the aesthetic pleasure enjoyed. The enjoyment as an object which is, neither caused (*kārya*) nor revealed (*jñāpya*) and nor found in this empirical world, is mystical or transcendental. From another standpoint too aesthetic experience may be considered mystical. An experience is either determinate (*savikalpaka*) or indeterminate (*nirvikalpaka*). An experience is not indeterminate because it gives rise to bliss (*ānanda*). In the indeterminate mental state one has the feeling of indifference. But aesthetic experience entails a feeling of positive bliss and hence cannot be indeterminate. It cannot be described as determinate either (that is, definite and related to name, quality etc.) since this experience, though blissful, is not capable of being expressed.[21] After having enjoyed reading a novel one may taste blissful experience that cannot be explained with the help of descriptions (like name, quality etc.) like ordinary pleasure and hence, it is not deter-

[20]*Bhāṣāpariccheda*, verse—140 and 147 *Siddhāntamuktāvalī* on *Ibid*.

[21]Raghunath Ghosh: *Is Aesthetic Experience Mystic? Review of Darshana*, Vol. IV, Nos. 3–4. University of Allahabad, pp.13–22, 1986.

minate. As this does not come under the purview of both the types of knowledge, it is considered as mystical.[22]

Further, each and every type of experience will be either wholly true or false. While aesthetic experience is not wholly true, because it stands negated by worldly knowledge when the absorption breaks up. When we come back to this practical world from the world of aesthetic experience, we do realize that the characters and the incidents that occurred (in the drama) were not real at all. Again, this experience cannot be described as wholly false, as it gives rise to a particular kind of pleasure by which we are drawn again and again and hence, it cannot be ignored by saying that it was unreal. On account of this it cannot be ignored as partially true and partially false, which is not possible at all, because aesthetic objects are not found in this phenomenal world. Hence it can only be concluded that it is mystical in character.

Now *Pratibhā* (intuition) is of two types: creative (*kārayitrī*) and sensitive *(bhāvayitrī*). When an individual shares the feelings of the hero or heroine, he becomes sensitive in having heart saturated with aesthetic pleasure generated within him through his self-involvement. The situation of being moved by *rasa* (*rasāveśa*) impels the individual with the power of creativity (*nirmāṇakṣamatva*). Sharing the pathos of others in a drama he gets aesthetic pleasure, which associates him with the power of creativity. If, on the other hand, he has the feeling of pathos from the incident occurred in his own life due to the death of a son etc., it (this pathos) renders him incapacitated instead of conjoining him with the power of creativity, which is called *kārayitrī pratibhā.* An individual can enjoy aesthetic pleasure after sharing his self with the character of the drama as he is also having same feeling subsisting in the dramatist and dramatic characters. This common experience is possible due to having the similar feelings, because they are *sahṛdayas* (literally having common heart). When the hearts of the people are expanded having clear mind due to a culture of fine arts and inculcate the capability of being identified with the characters of the drama as described (*varṇanīyatanmayībhavanayogyatā*), they are called *sahṛdayas* as they all possess the same feeling.[23]

If the above-mentioned view of *sahṛdayatva* were accepted, the aesthetic experience would be regarded as universal. The success of an art-object depends on its engendering universalisation (*sādhāraṇīkaraṇa*), which depends on the experience of *sahṛdayatva*. If each and every reader or audience has got the same sensitivity or feeling, there is transparency regarding the fact, which is going on in all the hearts of the spectators (*sakala-sahṛdaya-samvāda-śālitā*). This phenomenon is otherwise described as 'one-pointed concentration of all the audiences' (*sarvasāmājikānām ekaghanatā*).[24] Universality (*sādhāraṇīkaraṇa*) is the hallmark of aesthetic experience though it proceeds from the object highly individualized by the artist. The situation presented in art becomes aesthetic only when all the elements therein are

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[22]Ibid.

[23]"Yeṣāṁ kāvyānuśīlanābhyāsavaśād viśadībhūte manomukure varṇanīya-tanmayībhavanayogyatā, te hṛdayasamvādabhājaḥ sahṛdayāḥ." *Locana on Dhvanyāloka,* 1/1.

[24]*Kāvyaprakāśa*, Vṛtti, 4/28.

grasped by the critic in their universal aspects. Personal considerations fade away. Even impossible things in life do not engender disbelief in art.

This universalization is possible through the melting of the state of being a knower (*pramātṛbhāvavigalana*). It can be explained in the following manner. A knower or *pramātā* has got some elasticity through which he can expand himself. This may be called 'subjectification'. As a subject is no more confined within him and is extended to the objects after covering their essential characters, it is called subjectification of the object.[25]

It may be adduced in this context, and it has already been stated earlier, that one gets identified with object (*tanmayībhavana*). This state may be called 'objectified subject.' Again, when it is said that subject extends himself to the object (*pramātṛbhāvavigalana*), it may be called 'subjectified object.' I think there is no fundamental difference between 'subjectified object' and 'objectified subject' because this state allows a two-way traffic. If someone shares the grief of a character of drama, he obviously expands himself to the object. In other words, the same case can also be interpreted, as 'objectified subject' as the subject is really objectified in the sense that subject has no personal feeling at this stage. That is why, it is said that in such an experience a two way-traffic may be accepted, even though Abhinavagupta has emphasized on the subjectification of aesthetic experience. To Viśvanātha also the subject sees himself in the object being identified with it ("*pramātā tadabhedena svātmānaṁ pratipadyate*").[26] In fact, self exists everywhere and hence, following the Advaitin's line Abhinavagupta is of the opinion that the relishment itself is *rasa* (*rasanīyaḥ rasaḥ*). What is the object of relishment? In reply, it is said that relishment of the bliss arising out of self-knowledge (as reflected in the characters of the drama) is called *svasamvidānanda.* As if we have undertaken an activity of savouring (*carvaṇavyāpāra*) of the bliss arising from self-knowledge. It can be asserted that to Abhinavagupta the relishment in the form of chewing activity of the bliss rising from self-knowledge is called *rasa*.[27] As *rasa* is itself a kind of self-relishment, it is not proper to say—'relishment of *rasa*' with genitive case-ending, as we cannot say that he is cooking the boiled rice, (*odanaṁ pacati*).[28] Just as 'boiled rice' is itself a cooked object, relishment is itself *rasa*. If *rasa* is subjectified, it is not proper to say—'*rasa* of', which presupposes subject-object dichotomy, which is not accepted in Abhinavagupta's philosophy.

One could ask: what is the proof for the existence of bliss in pathos etc. (*karuṇādau rase*)? The reply can be given following Viśvanātha. The existence of bliss in pathos etc. is proved only through the feeling of a connoisseur (*Karuṇādāvapi rase jāyate yat paraṁ sukhaṁ sacetasāmanubhavaḥ pramāṇaṁ tatra kevalam*).[29] If in the pathetic sentiment (*karuṇarasa*) there is only feeling of grief, nobody would feel attraction

[25]Ibid.

[26]Pramāta tadabhedena svāmānaṁ pratipadyate" *Sāhityadarpaṇa*, 3/42.

[27]Śabdasamarpyamāṇa … svasamvidānanda-carvaṇavyāpāra-rasanīyarūpo rasaḥ".—*Locana on Dhvanyāloka*, ¼.

[28]Odanaṁ pacatītivadvyavahāraḥ pratīyamāna eva rasaḥ." *Locana on* 2/4.

[29]*Sāhityadarpaṇa*, 3/36–38.

for that. Eventually, the *Rāmāyaṇa* etc. would become the cause of our grief and sorrow. But in the practical world the reverse is noticed. This proves the existence of bliss in pathos etc.[30]

In fact, one's mind is dominated by the *sattvaguṇa* at the situation of aesthetic relish and hence it is uncontaminated by *Rajaḥ* and *Tamoguṇa.* Due to the prominence of *sattvaguṇa* a person can enjoy the self-knowledge identified with him and hence he is not moved or swayed away by knowledge of other objects *(vedyāntarasparśaśūṇya*). This bliss is the highest possible *ānanda* arising from self-revelation (*svaprakāśānanda*), and it is qualitatively equivalent to the taste of Brahman but not quantitatively. The former is transitory while the latter is ever abiding. That is why; such pleasure is described by Viśvanātha also as *Brahmasvādasahodara* (i.e. the subling manifest of the taste of Brahman).[31]

We have earlier remarked that though these theories are discussed in connection with the literary form of art, they can very well be extended to other forms of arts like music, pictorial form of art, dance etc. Hence Rabindranath stated that music does not belong to the singer alone, but to both singer and audience. The former sings it vocally while the audience sings it mentally, and hence there is a correspondence of aesthetic eventuality (*samvāda*) ('*Ekak gāyaker nahe to gan, milite habe dui jane/Ek jan gābe khuliyā galā, ār jan gābe mane//*' Ganbhanga in *Katha o Kahini*). William Radice translates it thus: 'The singer alone does not make a song, there has to be someone who hears/One man peons his throat to sing, the other sings in his mind.' Tagore: *Selected Poems*, Penguin Classics, 1985, London.

Moreover, the concepts of disinterested pleasure (*lokottarānanda*), universalisation (*sādhāraṇīkaraṇa*), subjectification etc. are not to be taken as closed concepts but open ones as they can be applied in a similar fashion to not-literary art objects like music, dance etc. The bliss arising from melody, dance etc. is disinterested, universal and subjectified in the same way as shown in the case of literature. In short, the aesthetic experience is essentially a state of bliss, a state of self-realization. This state of bliss is pervaded by a feeling of spiritual illumination and free from sensual elements. The physical emotions shake off their sordid attributes when they are converted into artistic emotions—they are free from the limitations of time and space and are universalized. As a result they do not become a part of the direct physical experience of the spectator; they raise him above the petty mundane experience of the self, refine his sensibility and sublimate his consciousness. But it is not a state of pure spiritual bliss, because it is neither a permanent state of joy nor is it completely unrelated with the material attainments.

Such unique aesthetic feeling can save us from the tyranny of cravings, greed etc. which actually lead us to involve in natural or environmental crises. There might be

[30]"Kiñca teṣu yadā duḥkhaṁ na ko'pi syāt tadunmukhaḥ/Tathā rāmāyaṇādināṁ bhavitā duḥkhahetutā//"—Ibid.

[31]"Sattvodrekād akhaṇḍa-svaprakāśānanda-cinmayaḥ//
vedyāntara – sparśaśūṇyo brahmā-svāda-sahodaraḥ//
Lokottara-comatkāra-prāṇaḥ kaiścit pramātṛbhiḥ//
Svākāravad abhinnatvenāyamāsvādyate rasaḥ//
Rajastamobhyāmaspṛṣṭaṁ manaḥ sattvamihocyate//". *Sāhiyadarpaṇa* 3/35.

so many means to reduce tension from the human beings just as counseling, moral teaching, practicing meditation etc. But aesthetic pleasure arising from art objects is a natural one and very much attractive to the human being and hence it has got some lasting impression in him. This situation does not allow him to think of evil of others including environment etc. Though the aesthetic experience is temporary in nature yet it is qualitatively of higher order and for this reason it can help an individual to change his personality resulting in the resolution of crises arising from environmental, natural and other types of pollution.

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Afterword

I'd like to venture a few comments on science and culture, from my perspective as a research scientist (an astronomer). In the last century there was much discussion of the so-called 'two cultures' and the lack of communication between science and the arts. Today it would be truer to say that 'culture' has many interweaving strands—including of course the social sciences. Nonetheless, intellectual narrowness and ignorance are still endemic—and there are worryingly many, especially in influential positions in politics and the media, to whom the sciences remain a closed book (This remains, incidentally, a special concern in my own country, England, where young people are forced towards a specialized school curriculum by the age of sixteen.).

Scientists don't have a special reason to moan about public ignorance or indifference to their work. Many are ignorant of the history and literature of even their own nation—and that's just as sad. I find it remarkable how many lay people are interested in subjects as blazingly irrelevant to practical life as dinosaurs, the Higgs boson, and cosmology. And the sales of popular books suggest that there is a widespread (and of course gratifying) interest in fundamental big questions—such as the origins of consciousness, of life, and of the cosmos itself. Of course the technicalities are not widely understood; but it's the concepts that are important and they can be widely shared.

Darwin's ideas have sustained their cultural and philosophical resonance ever since he first propounded them in 1859—indeed they have never provoked more vibrant debates than they do today. He was perhaps the last great scientist who could present his researches in a format accessible to general readers. Indeed 'On the Origin of Species' (which he described as 'one long argument' underpinning his theory) ranks highly as a work of literature. Darwin changed our perception of human beings by revealing that we were an outcome of a grand evolutionary process that can be traced back to the beginning of life on Earth.

Astronomy and cosmology now play a cultural role alongside Darwinism. Today, it's a real intellectual deprivation to be blind to the marvellous vision offered by Darwinism and by modern cosmology—the chain of emergent complexity leading from a 'big bang' to stars, planets, biospheres and human brains able to ponder the wonder and the mystery of it all.

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Concepts such as these should surely be part of general culture; so also should some conception of our natural environment and the principles that govern the biosphere and climate. Science is the one culture that all humans can share: protons, proteins and Pythagoras's theorem are the same the world over; they all look upat (and wonder at) the same night sky. So science should transcend all barriers of nationality. [And, by the way, it should straddle all faiths too. Modern cosmologists evince a variety of religious attitudes: there are traditional believers as well as hard-line atheists among them. My personal view—a boring one for those who wish to promote constructive dialogue (or even just unconstructive debate) between science and religion—is that, if we learn anything from the pursuit of science, it is that even something as basic as an atom is quite hard to understand. This should induce scepticism about any dogma, or any claim to have achieved more than a very incomplete and metaphorical insight into any profound aspect of our existence. Those who attack mainstream religion, rather than striving for peaceful coexistence with it, damage science, and also weaken the fight against fundamentalism—but that's a theme for another article.]

Among the sciences, astronomy and evolutionary biology are specially appealing not only because both subjects involve beautiful images and fascinating ideas, but because they have a positive and non-threatening public image. In contrast, genetics and nuclear physics may be equally interesting, but the public is ambivalent about them because they have downsides as well as benefits.

Indeed the glad optimism about science has faded: The impact of new breakthroughs is viewed with ambivalence rather than enthusiasm. Indeed the advances of science, though the basis of marvellous technologies, create new hazards and raise new ethical issues. Many are anxious that science is 'running away' so fast that neither politicians nor the lay public can assimilate or cope with it. The stakes are indeed getting higher: science offers huge opportunities, but future generations will be vulnerable to technologies powerful enough to jeopardise the very survival of our civilization. To cope with it we need well-directed science and technology—informed by values and ethics that science itself can't provide.

Today we live in a world more dependent on technology than ever before, and ever more vulnerable to its failures or misdirection. To be at ease in this fast-changing world, and to be effective citizens, everyone needs at least a basic grasp of science's concepts and discoveries. This is a second reason—over and above its sheer interest and cultural value—why scientific education and communication isn't just for scientists, and why it needs widening and improving.

Society already confronts difficult questions like: Who should access the 'readout' of our personal genetic code? How will lengthening life-spans affect society? Should we build nuclear power stations—or wind farms—to keep the lights on? Should we plant GM crops? Should the law allow 'designer babies' or cognition-enhancing drugs? These decisions should be made democratically by the wide public, not just by scientists. The choices involve not just science, but ethics, economics and politic as well. But if the discussion is to rise above mere sloganising, everyone needs enough 'feel' for science to prevent their being bamboozled by propaganda and bad statistics, or being over-deferential to experts.

And the need for proper debate will become more acute in future as the pressures on the environment and from misdirected technology get more diverse and threatening.

Science itself is a 'work in progress'. Some theories are supported by overwhelming evidence; others are provisional and tentative. But, however confident we may be in a theory, we should keep our minds open—or at least ajar—to the possibility that some intellectual revolution will offer a drastically different perspective.

A lot has been written about creativity in science and in the arts. There are parallels, but differences too. Any artist's work is individual and distinctive—but it is generally soon forgotten. In contrast, even the journeyman scientist adds a few durable bricks to the corpus of 'public knowledge'. But our contributions as scientists lose their identity. If A didn't discover something, in general B soon would—indeed there are many cases of near-simultaneous discovery. Not so, of course, in the arts. As the great biologist Peter Medawar, remarked, when Wagner diverted his energies for ten years, in the middle of the Ring cycle, to compose Meistersinger and Tristan, he wasn't worried that someone would scoop him on Gotterdammerung.

Even Einstein exemplifies this contrast. He made a greater imprint on 20th century science than any other individual; but had he never existed all his insights would by now have been revealed—though gradually, by several people, rather than by one great mind. Einstein's fame extends far wider than science—he was one of the few who really did achieve public celebrity. His image—the benign and unkempt sage—became as much an icon of creative genius as Beethoven. His impact on general culture though has been ambivalent. It's a pity, in retrospect, that he called his theory 'relativity'. Its essence is that the local laws are **just the same** in different frames of reference. 'Theory of invariance' might have been an apter choice, and would have staunched the misleading analogies with relativism in human contexts. But in terms of cultural fallout he's fared no worse than others. Heisenberg's uncertainty principle—a mathematically precise concept, the keystone of quantum mechanics—has been hijacked by adherents of oriental mysticism. And Darwin has likewise suffered tendentious distortions, especially in applications to human psychology.

Scientists don't fall into a single mould. Indeed even the greatest of all display a wide range of personalities and intellectual styles. For instance, Newton's mental powers seem to have been really 'off scale'. His concentration was as exceptional as his intellect: when asked how he cracked such deep problems, he said 'by thinking on them continually'. He was solitary and reclusive when young; vain and vindictive in his later years. In contrast, Darwin was an agreeable and sympathetic personality, and modest in his self-assessment: he wrote 'I have a fair share of invention, and of common sense or judgment, such as every fairly successful lawyer or doctor must have, but not, I believe, in any higher degree'.

Darwin's statement reminds us that the thought processes of most scientists are not intrinsically different from those of other professionals—nor indeed from those of a detective assessing the evidence at a crime scene. It is simplistic to refer to 'the scientific method': the methodology varies widely depending on the topic: there is a different mix between mathematical modelling, experiments and fieldwork; each of these demands different styles of thinking, and attracts different personality types. Some see themselves as intellectuals, others as technocrats.

A related (and indeed damaging) misperception is the mind-set that supposes that there is something especially 'elite' about the quality of their thought. 'Academic ability' is one facet of the far wider concept of intellectual ability—possessed in equal measure by the best journalists, lawyers, engineers, and politicians. The great ecologist E. O. Wilson avers that to be effective in some scientific fields it's actually best not to be too bright.[1] He's not disparaging the insights and eureka moments that punctuate (albeit rarely) scientists' working lives. But, as the world expert on tens of thousands of ant species, Wilson's research has involved decades of hard slog: armchair theorizing is not enough. So, there is a risk of boredom. And he is indeed right that those with short attention spans—with 'grasshopper minds'—may find happier (albeit less worthwhile) employment as 'millisecond traders' on Wall Street, or the like.

Those embarking on research should pick a topic to suit their personality, and also their skills and tastes (for fieldwork? For computer modelling? For high-precision experiments? For handling huge data sets? And so forth). Moreover, young researchers can expect to find it especially gratifying to enter a field where things are advancing fast—where you have access to novel techniques, more powerful computers, or bigger data sets—so that the experience of the older generation is at a deep discount.

What about those who switch to a new field of science in mid-career? The ability to bring in new insights, and a new perspective, is a 'plus'—indeed, the most vibrant scientific fields often cut across traditional disciplinary boundaries, On the other hand, it's conventional wisdom that scientists don't improve with age—that they 'burn out'. The physicist Wolfgang Pauli had a famous put-down for scientists past thirty: 'still so young, and already so unknown'. But I hope it's not just wishful thinking on the part of an aging scientist to be less fatalistic. There seem to be three destinies for us. First, and most common, is a diminishing focus on research—sometimes compensated by energetic efforts in other directions, sometimes just by a decline into torpor. A second pathway, followed by some of the greatest scientists, is an unwise and overconfident diversification into other fields. Those who follow this route are still, in their own eyes, 'doing science'—they want to understand the world and the cosmos—but they no longer get satisfaction from researching in the traditional piecemeal way: they overreach themselves, sometimes to the embarrassment of their admirers. This syndrome has been aggravated by the tendency for the eminent and elderly to be shielded from criticism—though one of the many benefits of a less hierarchical society is that this insulation is now rarer, at least in the West; moreover, the increasingly collaborative nature of science makes isolation less likely. But there is a third way—the most admirable. This is to continue to do what one is competent at, accepting that there may be some new techniques that the young can assimilate more easily than the old,

[1] E. O. Wilson, *Letters to a Young Scientist* (New York: Liveright, 2014).

and that one can probably at best aspire to be on a plateau rather than scaling new heights.

There are many composers whose last works are their greatest, but (despite a few late-flowering exceptions) there are few scientists for whom this is so. The reason, I think, is that composers, though influenced in their youth (like scientists) by the then-prevailing culture and style, can thereafter improve and deepen solely through ‘internal development’. Scientists, in contrast, need continually to absorb new concepts and new techniques if they want to stay at the frontier—and that’s what gets harder as we get older.

If you ask individual scientists what they are working on, they will rarely respond by saying ’trying to understand the universe’ or ‘curing cancer’. Their normal response is something very narrow and specific. They realise that the big questions are important, but that they must be tackled in a step-by-step way. Only cranks or geniuses try to solve the big questions in one go: the rest of us tackle a problem that is bite-size and hope to make incremental progress that way. But the occupational risk of scientists is that they forget that these narrow problems are only worthwhile insofar as they are steps towards answering some big question. And that is why it is good for scientists to engage with general audiences. I personally would derive less satisfaction from my own research if I could only talk about it to a few other specialists.. In fact, when one discusses the ‘great unknowns’, there is less of a gap between the specialist and the audience because, when even the experts haven’t a clue, they are in a sense in the same position as the public. The experts are perhaps confused at a deeper level, but that is all. Even if we explain ourselves badly, we benefit from exposure to general audiences who focus on the big questions and remind us of how much we still don’t know.

Indeed, now that the impact of researches can be so much greater, scientists have a genuine and deep responsibility to engage with society—though they should accept that on the economic, social and ethical aspects of any policy they speak as citizens and not as experts.

No scientists should be indifferent to the fruits of their ideas—their creations. They should try to foster benign spin-offs—commercial or otherwise. They should resist, so far as they can, dubious or threatening applications of their work, and alert the public and politicians to perceived dangers. A special responsibility lies on those in academia or self-employed entrepreneurs—they have more freedom to engage in public debate than those in government service or in industry. And those of us who are academics have a special privilege to influence successive generations of students. We should try to sensitise them to the issues that will confront them in their careers. Indeed, polls show, unsurprisingly, that younger people who expect to survive most of the century, are more engaged and anxious about long-term and global issues—and that is one of the grounds for hope in a world where the gap betweein how things could be and how they actually are is getting wider.

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