THE POETRY OF LOGICAL IDEAS:
TOWARDS A MATHEMATICAL GENEALOGY OF MEDIA ART

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Abstract

In this dissertation I chart a mathematical genealogy of media art, demonstrating that mathematical thought has had a significant influence on contemporary experimental moving image production. Rather than looking for direct cause and effect relationships between mathematics and the arts, I will instead examine how mathematical developments have acted as a cultural zeitgeist, an indirect, but significant, influence on the humanities and the arts. In particular, I will be narrowing the focus of this study to the influence mathematical thought has had on cinema (and by extension media art), given that mathematics lies comfortably between the humanities and sciences, and that cinema is the object *par excellence* of such a study, since cinema and media studies arrived at a time when the humanities and sciences were held by many to be mutually exclusive disciplines.

It is also shown that many media scholars have been implicitly engaging with mathematical concepts without necessarily recognizing them as such. To demonstrate this, I examine many concepts from media studies that demonstrate or derive from mathematical concepts. For instance, Claude Shannon's mathematical model of communication is used to expand on Stuart Hall's cultural model, and the mathematical concept of the fractal is used to expand on Rosalind Krauss' argument that video is a medium that lends itself to narcissism. Given that the influence of mathematics on the humanities and the arts often occurs through a misuse or misinterpretation of mathematics, I mobilize the concept of a *productive misinterpretation* and argue that this type of misreading has the potential to lead to novel innovations within the humanities and the arts.

In this dissertation, it is also established that there are many mathematical concepts that can be utilized by media scholars to better analyze experimental moving images. In particular, I

explore the mathematical concepts of symmetry, infinity, fractals, permutations, the Axiom of Choice, and the algorithmic to moving images works by Hollis Frampton, Barbara Lattanzi, Dana Plays, T. Marie, and Isiah Medina, among others. It is my desire that this study appeal to scientists with an interest in cinema and media art, and to media theorists with an interest in experimental cinema and other contemporary moving image practices.

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CHAPTER ONE: INTRODUCTION

Pure mathematics is, in its way, *the poetry of logical ideas*. One seeks the most general ideas of operation which will bring together in simple, logical and unified form the largest circle of formal relationships. In this effort toward logical beauty spiritual formulas are discovered necessary for the deeper penetration into the laws of nature.
– Albert Einstein, "Obituary for Emmy Noether," *New York Times* (May 5, 1935)

Cinephiles are often more peremptory about the films they *think* are of the highest importance than mathematicians concerning theorems that they *know* have been demonstrated.
– Quentin Meillassoux,
"Decision and Undecidability of the Event in *Being and Event* I and II,"
trans. Alyosha Edlebi, *Parrhesia Journal* 19 (2014)

In 1959, novelist Lord Charles Percy (C.P.) Snow delivered a Rede lecture titled "The Two Cultures (and the Scientific Revolution)." In it he suggests there is a growing divide between the humanities and the sciences, a gap he perceives as detrimental to cultural evolution. The lecture was published as a book and generated heated debate and opposition, perhaps the most important being the thoughtful criticism of biochemist Michael Yudkin, and the scathing, controversial response from literary critic Frank Raymond (F.R.) Leavis. The debate has transformed in recent years but it is still seen as one of the major scholarly quarrels of the twentieth century, with some considering Snow's book as one of "the hundred most influential books since [World War II]."[1]

In this chapter, I provide an overview of the "two cultures" debate and some of its contemporary incarnations. It is one of the main purposes of this dissertation to present an argument against the "two culture" dichotomy through demonstrating the influence of mathematics on both media studies and aesthetic developments relating to experimental moving image production. In particular, I intend to demonstrate that mathematics forms one of the bonds between the sciences, and the humanities and arts. This chapter will also provide an overview for this dissertation, laying out my intentions, interventions and methodology.

1 "The Hundred Most Influential Books since the War," *The Times Literary Supplement* (October 6, 1995).

1.1 Divided We Fall: The "Two Cultures" Debate

Snow wrote "The Two Cultures" after noticing a curious divide between his two social circles, namely, his scientific peers and his literary colleagues.[2] In the lecture, Snow proposes that this separation was cultural and describes, in great detail, the ways in which these two cultures have "a curious distorted image of each other."[3]

> The non-scientists have a rooted impression that the scientists are shallowly optimistic, unaware of man's condition. On the other hand, the scientists believe that the literary intellectuals are totally lacking in foresight, peculiarly unconcerned with their brother men, in a deep sense anti-intellectual, anxious to restrict both art and thought to the existential moment.[4]

In attempting to better understand the gap between the sciences and the humanities, Snow unintentionally caricatures both the literary intellectual and the scientist, often justifying his generalizations through personal anecdotes. For instance, Snow suggests that scientists naturally have "the future in their bones"[5] while "intellectuals, in particular literary intellectuals, are natural Luddites,"[6] a rather contentious claim that seemingly asserts the superiority of the scientist.

Despite his somewhat strange characterizations, Snow's concern is not, I would argue, entirely unfounded, and there remains a lack of real and integral dialogue between the sciences and the humanities. Moreover, the impetus for Snow's lecture, succinctly summarized in his follow-up article, "The Two Cultures: A Second Look," is a legitimate one:

> In our society (that is, advanced Western society) we have lost even the pretence of a common culture. Persons educated with the greatest intensity we know can no longer communicate with each other on the plane of their major intellectual concern. This is serious for our creative, intellectual and, above all, our normal life. It is leading us to interpret the past wrongly, to misjudge the present and to deny our hopes of the future. It is making it difficult or impossible for us to take good action.[7]

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2 Snow considered himself member of both communities since he was a well-known novelist who as a Ph.D. student researched infra-red spectroscopy in Lord Rutherford's world-famous Cavendish Laboratory. Although Snow had worked as a scientific researcher, at the time of the Rede lecture it had been almost twenty years since he had participated in any first-hand research. Stefan Collini, "Introduction," in *The Two Cultures*, ed. Stefan Collini (Cambridge: Cambridge University Press, 1998), xx.
3 C. P. Snow, *The Two Cultures* (Cambridge: Cambridge University Press, 1998), 4.
4 Ibid., 5.
5 Ibid., 10.
6 Ibid., 22.
7 Ibid., 60.

Snow's observation that a lack of common culture has led relatively educated people to make poor decisions has been re-articulated in several ways. For instance, mathematician John Allen Paulos argues that the concept of innumeracy, the mathematical equivalence of illiteracy, is an extremely serious problem that plagues many people who are otherwise considered well educated. Moreover, he explores the ways in which common misconceptions about numbers can lead to illogical decision-making processes.[8]

As observed by historian Stefan Collini in his introduction to Snow's book *The Two Cultures*, the anxiety about the gap between the two cultures began in the nineteenth century despite the fact that there has always been, at least since the dawn of Western thought, different categorizations of knowledge.[9] Collini argues that contemporary cultural anxieties arose primarily out of developments in the educational system – namely, the ways in which the education system categorizes knowledge into subjects, and the ways in which students are eventually forced to specialize in one or two subjects.[10] Collini and other scholars, including historian Charlotte Sleigh and literary critic Lionel Trilling, observe that the two cultures debate was anticipated almost a century earlier in a debate between Thomas Henry (T.H.) Huxley and Matthew Arnold. In the 1880 essay "Science and Culture," Huxley vigorously argues for the legitimacy of science education at a time when the physical sciences were discouraged by both the educational and industrial realms. Although Huxley acknowledges the importance of literary education, he challenges conventional educational methodologies that focus on literature as a primary source of knowledge.[11]

In his 1882 Rede lecture titled "Literature and Science," Arnold takes up Huxley's concerns and argues for the superiority of literature over science on the basis that scientific literature is also a

8 John Allen Paulos, *Innumeracy: Mathematical Illiteracy and Its Consequences* (New York: Hill and Wang, 1988).
9 Stefan Collini, "Introduction," in *The Two Cultures*, ed. Stefan Collini (Cambridge: Cambridge University Press, 1998), ix.
10 Ibid., xvi-xvii.
11 Thomas Henry Huxley, "Science and Culture," in *Science and Culture and Other Essays* (London: MacMillan and Co., 1888), 1–23.

form of literature. Challenging Huxley's claim that literature alone is not enough to provide all cultural knowledge, Arnold responds with the aphorism, “literature is a large word; it may mean everything written with letters or printed in a book.”[12] To Arnold, literature is not simply Huxley's conception of *les belles lettres*, but also includes scientific texts such as Euclid's *Elements*, Newton's *Principia*, and Darwin's *The Origin of Species*. Although both Arnold and Huxley agree that scientific knowledge is important, Arnold suggests that focusing on scientific education seems to “leave one important thing out,” namely, “the constitution of human nature.”[13] In other words, Arnold is arguing for the superiority of what we would call humanistic literature over scientific literature, suggesting that science was systematically removing the beautiful and mysterious from the universe and that literature alone provides us with knowledge about human nature and the transcendental. With rather eccentric grammar, he states:

> But still it [physical science] will be *knowledge* only which it gives is; knowledge not put for us into relation with our sense for conduct, our sense for beauty, and touched with emotion by being so put; not thus put for us, and therefore, to the majority of [hu]mankind, after a certain while, unsatisfying, wearying.[14]

For Arnold, our sense for conduct and our sense for beauty are parts of human nature, and lie beyond the scope of scientific knowledge.

More than half a century later, when Snow renewed the two cultures debate, there was an urgency to his writing due to one of the most devastating uses of science in human history – namely, the detonation of nuclear bombs by the United States in the Second World War. According to cultural critic Robert Whelan, Snow believed “there were 'three menaces' threatening the world: the H-bomb, overpopulation, and the gap between the rich and the poor.”[15] Through uniting the two cultures, Snow

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12 Matthew Arnold, “Literature and Science (1882),” in *Complete Prose Works of Matthew Arnold*, ed. Robert Henry Super, (Ann Arbor: University of Michigan Press, 1960), 58.
13 Ibid., 61.
14 Ibid., 65. [Emphasis in original.]
15 Robert Whelan, ed., “Introduction: Any Culture At All Would Be Nice,” in *From Two Cultures to No Culture: C. P. Snow's “Two Cultures” Lecture Fifty Years On* (London: Civitas, 2009), 4. In the “The Two Cultures,” Snow does not say anything specific about the H-bomb and overpopulation; however, in the last section of his essay, titled “The Rich and the Poor,” Snow discusses at length the growing gap between “first world” countries and “third world” countries (Snow, *The*

thought social change could occur due to scientific advancements that would come to fruition through the influence of literary intellectuals on both the general public and government officials. Like Huxley, Snow was attempting to reform educational principles: “changes in education will not, by themselves, solve our problems: but without those changes we shan't even realize what the problems are.”[16] In other words, the essay is an attempt to generate discourse around education reform and about the future of humankind. Snow believed that by uniting the two cultures, humanity could overcome many of its problems including the dramatic economic disparities between industrialized and developing countries.

Despite Snow's laudable effort to generate discourse about the future of the human race, many were skeptical of his actual arguments. For instance, both Leavis and Yudkin disagree with Snow's assumption that understanding the Second Law of Thermodynamics is the “scientific equivalent”[17] of reading Shakespeare – an assumption that seems to suggest that having scientific knowledge is the same as having an artistic experience. Without any ambivalence, Leavis responds, “there *is* no scientific equivalent [to reading Shakespeare].”[18] Yudkin's response is slightly more nuanced:

> This sort of comparison is frequently made; it is of doubtful use and often misleads, for implied in it is an equivalence between an artistic experience and a scientific finding. To read Dickens, or to hear Mozart, or to see a Titian can be in itself a rewarding activity; but to find out what is meant by acceleration is to gain a piece of factual information which in itself has no value. [...] What would be of value is an understanding of the process and manner of scientific thinking; for it is the nature of scientific judgment, the habit of a peculiar form of critical thought, which is characteristic of the scientific culture, which makes scientific work a worthwhile intellectual activity and, incidentally, which would give science some value as a disciplined study for the non-scientist.[19]

Although Yudkin argues that an artistic experience is not the same as scientific knowledge, he also believes that artistic experiences, logical thought, and scientific methodologies are all worthwhile intellectual activities to both scientists and non-scientists.

Despite understanding how artistic appreciation could improve a scientist's life, Yudkin did not

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Two Cultures, 41-51).

16 Snow, *The Two Cultures*, 99–100.

17 Ibid., 15.

18 F. R. Leavis, *Two Cultures?: The Significance of C.P. Snow*, ed. Stefan Collini (Cambridge: Cambridge University Press, 2013), 73. [Emphasis in original.]

19 Michael Yudkin, “Sir Charles Snow’s Rede Lecture,” in *Two Cultures?: The Significance of C.P. Snow* (London: Chatto & Windus, 1962), 35–6.

understand how scientific knowledge could help an artist. Yudkin critically inquires, “just how does Sir Charles believe that the assimilation of science as part of the mental experience of the artist can improve his work?” He continues, “does Sir Charles believe that a poet examining the effect of the threat of modern warfare on the behaviour of his contemporaries will create a finer poem if he is aware of the mechanism of the hydrogen bomb?”[20] It seems naïve to assume Snow is demanding universal knowledge from everyone; however, it is unclear what type of common knowledge Snow believes every educated person should have. Yudkin is correct in assuming that scientific knowledge is not necessary for the creation of some artistic works, but many artists do engage with scientific ideas in the creation of their work. As will be demonstrated throughout this dissertation, the sciences and the humanities often implicitly influence each other, with mathematics acting as one of the bridges between the perceived gap. Moreover, recognizing the points at which interdisciplinary crossover occurs allows for cultural insight.

The most ferocious attack on Snow's work came in a lecture titled “Two Cultures?” by Leavis. Unlike Yudkin's response, which was an amicable critique in the same spirit as the Huxley–Arnold debate, Leavis' critique was personal and mean-spirited. Literary critic Lionel Trilling described it as follows:

> There can be no two opinions about the tone in which Dr. Leavis deals with Sir Charles. It is a bad tone, an impermissible tone. It is bad in a personal sense because it is cruel – it manifestly intends to wound. [...] The doctrine of the “Two Cultures” is a momentous one, and Dr. Leavis obscures its significance by bringing into consideration such matters as Sir Charles' abilities as a novelist, his club membership, his opinion of his own talents, his worldly success, and his relation to worldly power.[21]

By contrast, it was precisely for these reasons Leavis thought it would become “a classic”[22] and he was not entirely incorrect in his prediction. As Whelan observes, “Leavis' lecture was so astonishingly

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20 Ibid., 41–2.
21 Lionel Trilling, “The Levis-Snow Controversy,” in *The Moral Obligation to Be Intelligent: Selected Essays*, ed. Leon Wieseltier (New York: Farrar, Straus, Giroux, 2000), 406.
22 Letter of May 1, 1962 to Cambridge University Press quoted in Ian MacKillop, *F.R. Leavis: A Life in Criticism* (New York: St. Martin’s Press, 1997), 323. Leavis states, “I've looked through the lecture again and am bound to say that I've done better than I should have thought possible. I can't help saying, modestly, that it will be a classic.”

vitriolic, seasoned with an almost toxic dose of the most vulgar *ad hominem* abuse, that, when I was an undergraduate in the English faculty ten years later, people were still talking about it in tones of shock and awe."[23]

Leavis' lecture was a discursive performance that attempted to discredit Snow's position as a cultural authority. By suggesting that Snow was neither a good novelist nor a good scientist, Leavis called into question Snow's privileged status as a representative of both cultures. Turning the tables on Snow – who had previously suggested that literary intellectuals had, "while no one was looking," self-appointed themselves as "intellectuals" as "though there were no others"[24] – Leavis accused Snow of being a self-appointed ambassador to both cultures. In spite of his personal attacks on Snow, Leavis was not attempting to demonstrate the failings of one man – rather, he was attempting to critique a system that allowed for unfounded and clichéd ideas to masquerade as fact due to the perceived authority of their author. It is worth observing, as Collini has pointed out, that the title of Leavis' response contains a question mark, a gesture that calls into question the authority of his own writing.

In his introduction to Leavis' essay, Collini suggests that "whenever a critic departs from the prevailing norms of public discussion – whether by being deliberately provocative, or by appearing to be hopelessly unrealistic or intransigent, or by using the weapons of satire or humour, or by any other way of disturbing the discursive equilibrium – they are likely to be reproved for sacrificing the possibilities of making a 'positive' and 'constructive' contribution to the debate to the satisfactions of self-expression or self-indulgent displays."[25] As Collini further suggests, Leavis had been "irked by the way in which the Rede lecture started to crop up in essays written for Cambridge entrance scholarships"[26] and, through his provocative polemical argument, Leavis was not only attempting to

23 Whelan, "Introduction," 7.
24 Snow, *The Two Cultures*, 4.
25 Stefan Collini, "Introduction," in *Two Cultures?: The Significance of C.P. Snow*, ed. Stefan Collini (Cambridge: Cambridge University Press, 2013), 45.
26 Ibid., 7.

challenge Snow’s text, but, more importantly, the institutional weight it carried.

Leavis was not anti-science nor anti-science education, but upset by the cultural currency afforded to Snow, and by the ways in which Snow simply reinforced the dominant view that quality of life could not be reduced to “matters of merely material standard of living, with the advantages of technology and scientific hygiene.”[27] As the historian Guy Ortolano suggests,

> Snow believed that contemporary English society was the best of all possible worlds, in which social fluidity and material prosperity promised opportunity for the able and abundance for all. Leavis, by contrast, deplored the state of contemporary England, the steady descent of which since the seventh century was only being accelerated by the mass civilization of the present.[28]

In other words, the two cultures debate was a catalyst for the main point of contention between these two figures, an ideological difference concerning the future of humankind and Britain's role in determining it. Despite Snow's best intentions in suggesting that Britain's economic prosperity could be brought to the rest of the world through scientific and technological progress, it is possible to further understand Leavis’ pessimistic attitude simply by considering the consequences of Britain's past colonial endeavours. Snow literally imagined engineers from Europe and North America volunteering “at least ten years out of their lives” to aid in “a foreign country's industrialization.”[29] Whelan criticizes the simplicity of Snow's plan by cynically summarizing it as follows: “All poor people had to do was adopt Western science and technology, industrialize and make lots of money.”[30]

Finally, Leavis observed that Snow, as a man of both cultures, was simply presenting a problem without demonstrating how his solution – transcending the cultural divide – would transform into real-world solutions. Leavis states, “what I *am* saying is that such a concern is not enough – disastrously not enough.”[31] While perhaps slightly overzealous in his conviction that merging the two cultures would transform the world, it is difficult to seriously critique Snow's desire for the bridging of the cultural gap

27 Leavis, *Two Cultures?*, 70.
28 Guy Ortolano, “The Literature and the Science of ‘Two Cultures’ Historiography,” *Studies in History and Philosophy of Science Part A* 39, no. 1 (March 2008), 144.
29 Snow, *The Two Cultures*, 47.
30 Whelan, “Introduction,” 4.
31 Leavis, *Two Cultures?*, 71. [Emphasis in original.]

between the sciences and the humanities. Ever optimistic, Snow predicted that a new culture would emerge, a “third culture”[32] composed of literary intellectuals that would engage with scientists. There have been attempts at realizing Snow's vision. In 1972, Harry H. Krane and Gilbert H. Wright, two lecturers at the Prahran College of Technology in Australia, published *The Third Culture*, in which they proposed an outline for “a new educational complex” which would be “introduced between junior secondary schools and tertiary institutions.”[33] This complex was to be modelled after the methodology of the Bauhaus and intended to integrate art and technology.

At the respective times when Huxley and Snow delivered their lectures, science education was not considered as prestigious as it is today. As Whelan observes, “the low status of science in the education system that Huxley complained of in 1880 and that Snow complained of in 1959 was real enough.”[34] In recent years, the status of scientific education has changed significantly, and some scholars believe that a new “third culture” has emerged. For instance, John Brockman – founder of the Edge Foundation, an association of science and technology intellectuals dedicated to the integration of literary and scientific thinking – suggests that there is a third culture consisting of scientists who are in direct communication with the general public, a group he considers to be the “new public intellectuals.”[35] Brockman suggests that what was once hidden behind laboratory doors has now made its way into the public sphere, giving rise to scientific figures who attempt to make scientific knowledge accessible to the general public while maintaining the rigour and integrity of the original ideas. For example, consider Stephen Hawking and Neil deGrasse Tyson, two astrophysicists who are well known to the general public, and who have been very successful at engaging in discourse with the general public about ideas and concepts related to theoretical physics.

32 Snow, *The Two Cultures*, 70.
33 Harry H. Krane and Gilbert H. Wright, *The Third Culture: A New Education; an Integration of Technology with Art* (Melbourne: Published for International Co-operation for the Integration of Technology with Art by the Melbourne Group, I.C.I.T.A., 1972), 27.
34 Whelan, “Introduction,” 18.
35 Ibid.

In spite of the emergence of a third culture, Brockman asserts that the "literary intellectuals are [still] not communicating with the scientists."[36] Despite this apparent lack of communication, cultural theorists, artists, and art critics have been both appropriating and engaging with scientific and mathematical concepts and language, evinced by the proliferation of terms like topology, entropy and rhizome within contemporary discourses in the humanities and the arts. As interdisciplinary scholar Andrew Yang observes, "the appropriation of scientific concepts by the humanities and the visual arts exemplifies what many feel are both the pitfalls and possibilities of interdisciplinary engagement."[37] On the one hand, as Yang demonstrates in "Second Laws, Two Cultures, and the Emergence of an Ecosystem Aesthetics," artists have been experimenting with concepts like the Second Law of Thermodynamics in innovative ways that would have quite easily satisfied what Yang refers to as Snow's "cultural litmus test"[38] – namely, the ability to accurately describe the Second Law of Thermodynamics. On the other hand, many cultural theorists use scientific and mathematical vocabularies and concepts without fully understanding them or respecting their original contexts, and many scientific and mathematical concepts have been exploited by those practicing what has been called "International Art English."[39]

One attempt to expose the lack of academic rigour in contemporary scholarship regarding the use of scientific and mathematical concepts by cultural theorists was physicist Alan Sokal's famous prank paper, "Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity," published in a 1996 issue of *Social Text*. The paper argues the clearly absurd claim that the laws of physics are merely social and linguistic constructs by using horribly misinformed quotes by

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36 John Brockman, "Introduction," in *The Third Culture*, ed. John Brockman (New York: Simon & Schuster, 1995), 18.
37 Andrew Yang, "Second Laws, Two Cultures, and the Emergence of an Ecosystem Aesthetics," *Interdisciplinary Science Reviews* 40, no. 2 (June 1, 2015), 168.
38 Ibid., 169. Snow explains, "once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative" (Snow, *The Two Cultures*, 14-5).
39 For a speculative history of IAE, see Alex Rule and David Levine, "International Art English," *Triple Canopy* 16 (July 30, 2012), <https://www.canopycanopycanopy.com/contents/international_art_english>.

postmodern scholars who use science in their scholarship. Sokal was not arguing against cultural theorists appropriating these concepts, he was simply concerned with their detrimental misuses. As Sokal's book *Fashionable Nonsense*, co-written with physicist Jean Bricmont, explains:

> Famous intellectuals such as Lacan, Kristeva, Irigaray, Baudrillard and Deleuze have repeatedly abused scientific concepts and terminology: either using scientific ideas totally out of context, without giving the slightest justification – note that we are not against extrapolating concepts from one field from another, but only the extrapolations made without argument – or throwing around scientific jargon in front of their non-scientist readers without any regard for its relevance or even its meaning.[40]

In other words, Sokal and Bricmont did not have a problem with authors honestly engaging with scientific ideas, but felt that many postmodern theorists were simply misappropriating scientific language and concepts as a form of academic pretension.

The debate generated by the Sokal hoax can be seen as a contemporary extension of the broader two cultures debate. In contrast, Yang does not see Sokal's hoax as symptomatic of "a two-culture dichotomy," but as asserting "that there is really just one authentic culture – the culture of science."[41] This observation seems unsympathetic to Sokal and Bricmont's legitimate concern that postmodern theorists were, in fact, misusing scientific ideas and concepts in support of their own arguments. As Sokal and Bricmont state,

> It could be argued that we are splitting hairs, criticizing authors who admittedly have no scientific training and who have perhaps made a mistake in venturing onto unfamiliar terrain, but whose contribution to philosophy and/or the social sciences is nevertheless important and is in no way invalidated by the 'small errors' we have uncovered. We would respond, first of all, that these texts contain much more than mere 'errors': they display a profound indifference, if not a disdain, for facts and logic. Our goal is not, therefore, to poke fun at literary critics who make mistakes when citing relativity or Gödel's theorem, but to defend the canons of rationality and intellectual honesty that are (or should be) common to all scholarly disciplines.[42]

In other words, Sokal and Bricmont were not attempting to discourage cultural appropriation, but were attempting to combat the perceived disregard for scientific research though superficial quotation and engagement. Moreover, Sokal and Bricmont were attempting to respond to much larger developments

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40 Alan Sokal and Jean Bricmont, *Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science* (New York: Picador, 1998), ix-x.
41 Yang, "Second Laws, Two Cultures, and the Emergence of an Ecosystem Aesthetics," 172.
42 Sokal and Bricmont, *Fashionable Nonsense*, 6.

within postmodern theory: radical relativism and the notion that scientific theories are mere "narratives" or social constructions.

There have been several responses to Sokal and Bricmont's argument, the most compelling being that there is cultural value to be found in *imperfect* cultural appropriation, especially in regards to artistic production. As Yang argues,

> We see that engaging with another culture of inquiry is not just a matter of understanding its principles on existing terms, but also a creative act of reinterpretation such that scientific theories might become a source of 'productive misreading,' with cultural variation acting as a generative wellspring for open-ended translation, not simply transcription. [...] Interpretive excess and the complications of an 'inauthentic' understanding of a scientific idea operate in this case as potent, imaginative resources for artists.[43]

The "productive misreadings" of scientific theories has been fertile grounds for artistic and cultural inspiration; however, there are still many artists and cultural theorists who have borrowed from the sciences without any consideration towards the original scientific research, and this practice is not entirely without its problems.

The two cultures debate continues, and while some scholars have pursued Snow's idea of creating a third culture and others have argued that such a third culture has emerged, this dissertation is suggesting something radically different. By demonstrating solid conceptual links between science, and the humanities and arts through mathematics, I contest Snow's assumption that "very little of twentieth-century science has been assimilated into twentieth-century art"[44] and, beyond that, cultural theory. Although it can be argued there is still very little direct dialogue between the humanities and the sciences (with some notable exceptions), this dissertation will use developments in mathematics to demonstrate there has indeed been significant cultural influence from twentieth-century science on twentieth- and now twenty-first-century art and cultural theory. I argue that cultural and theoretical developments in mathematics and the sciences have significantly, albeit somewhat implicitly, influenced artistic movements and the humanities, and that there are many artists who actively engage

43 Yang, "Second Laws, Two Cultures, and the Emergence of an Ecosystem Aesthetics," 172-73.
44 Snow, *The Two Cultures*, 16.

with scientific and mathematical concepts in the production of their works, whether they are conscious of it or not.

1.2 Managing Expectations: Reflections on this Present Study

I begin this dissertation with a discussion of the two cultures debate in order to provide at least one historical explanation as to why some feel there is a gap between the humanities and the sciences. I am not attempting to suggest that this gap is universal; however, it is a divide that has many contemporary iterations including the Sokal affair and discussions around International Art English. While there have been many collaborations between the arts and sciences in the last century, there remain many remnants of the two cultures divide. By examining the two cultures debate in detail, it is possible to see some of the ways in which the perception of the two cultures has emerged and some of the ways in which both artists and theorists can be seen as responding to it.

Experimental media is one of the places in which there exists the freedom to experiment with concepts related to content and form. As such, some media artists have been exploring mathematical concepts. In this way, these experimental media artists are challenging the perceived two cultures divide. But not many media scholars have the mathematical background to engage with the mathematical content found within this type of work. As such, this is one of the ways in which the perceived two cultures has infiltrated media studies; that is, media scholars, even those studying difficult works, are often intimidated by media works that engage with mathematical content. In fact, this observation can account for why there exists very little scholarship regarding experimental media that engages with mathematical content. In spite of this, I contend that even with a lack of direct dialogue between the two cultures, advancements within mathematics have had a significant impact on aesthetic and cultural developments, demonstrating that the dichotomy proposed by Snow is ultimately a false one.

To this end, I intend to extend the arguments developed in the recent works of art historian

Lynn Gamwell, media theorist Laura Marks, and filmmaker and cinema scholar R. Bruce Elder, in order to construct an alternative, mathematical genealogy of cinema and media art. Key texts will include Gamwell's *Mathematics + Art*, a book released in 2016 that attempts to demonstrate some of the ways in which cultural developments in the arts are intimately connected with those in mathematics and the sciences. Another crucial text will be media theorist Laura Marks' *Enfoldment and Infinity*, a book that uses the Deleuzian concept of the fold to argue for an Islamic genealogy of media art. In this book, Marks explores the traces of Islamic mathematics, philosophy and culture that remain latent in contemporary media art practices – in particular, those involving algorithmic procedures and the pixel. Finally, I will extend Elder's arguments about the influence of mathematics on cinema and avant-garde art movements in the early twentieth century, as explored in Elder's books *Dada, Surrealism, and the Cinematic Effect* and *Cubism and Futurism: Spiritual Machines and the Cinematic Effect.*

Beyond these texts, there has been a growing amount of scholarly interest in the connection between mathematics and the arts. Most notable are the edited anthologies compiled by Michele Emmers including *The Visual Mind: Mathematics and Culture I and II*, and *Mathematics, Art, Technology, and Cinema* (co-edited with Mirella Manaresi); the recent *Journal of Mathematics and the Arts* founded in 2007; the special issue of *Leonardo* dedicated to visual mathematics; mathematician Dan Pedoe's canonical book *Geometry and the Visual Arts*; and mathematician Michael Holt's book *Mathematics in Art*. Nevertheless, the subject still remains relatively niche, making it possible to conduct a fairly rigorous survey of the literature on this field. In this dissertation, I will provide a brief survey of the existing discourse surrounding mathematics and art in order to tease out some of the connections between contemporary and historical art practices that have incorporated mathematical ideas. In particular, I will explore some of the relationships between mathematics and aesthetics at historical periods where art and mathematics were intimately connected. By studying the historical connections between mathematics and art, it is possible to observe traces that remain visible within a contemporary context.

Given the rather broad nature of this multidisciplinary subject, I have limited myself to a few places where mathematics and media studies have impacted each other. Rather than attempting to develop a traditional chronological history, I will instead examine a few of the ways in which science has crept into the humanities through mathematics. As such, I am not looking for direct cause and effect relationships between sciences and the humanities, but instead will be examining how mathematical developments have acted as a form of cultural zeitgeist, an indirect, but significant, influence on the humanities and arts. In other words, I am attempting to explore a methodology that moves beyond crude determination.

In order to further narrow the focus of this study, I explore only a few of the influences mathematical thought has had on cinema and media art, since cinema, and by extension media art, is the object *par excellence* of such a study given that its birth came at a time when the arts and sciences were no longer intimately connected. In other words, cinema and media studies were born at a time when the humanities and sciences were considered by many to be mutually exclusive disciplines, implying that it should be an art form relatively untainted by the sciences, if those who propagate the two cultures divide are correct. Moreover, mathematics was undergoing monumental changes at the end of the nineteenth century and, as it will be argued, these changes had an incredible cultural impact. As observed by historians Carl Boyer and Uta Merzbach, "it was clear that not only the content of mathematics but also its institutional and interpersonal framework had changed radically since the early 1800s"[45] and these changes extended beyond the realm of mathematics. In this dissertation, I am suggesting abandoning the two cultures hypothesis in order to entertain more sophisticated questions: What are some of the ways in which these two cultures have influenced each other, and what can be learned by critically examining such connections?

45 Carl B. Boyer and Uta C. Merzbach, *A History of Mathematics* (Hoboken: John Wiley & Sons, Inc., 2011), 548.

The objects I will be analyzing in this dissertation are experimental moving image artworks, one form of media art. At this point in time, the term media art is contested, with many differences of opinion about its precise definition. It could be argued that media art consists of all art objects given that media is used to communicate a message; however, I will be using a slightly more restricted version of the term. In this dissertation, the term media art will be used to describe a certain class of artworks, namely time-based artworks involving sound and/or moving images, in contrast to static works, like painting, photography, and sculpture. Given this definition, media art consists of many different subcategories including new media, experimental cinema (film, video and other hybrid forms), sound art, expanded cinema and video art. I have chosen to work with media art and not narrative cinema because it is within the vanguard that artists have the freedom to pursue unconventional forms and interdisciplinary approaches.

The individual media art objects in this dissertation were chosen because they either visually or conceptually incorporate a mathematical concept, or the object itself has generated mathematical readings. The artists I chose for my dissertation are those who I felt were engaging with the mathematical ideas in good faith and that were not simply using them as a form of artistic or academic pretense. For all of the works, I perform a textual analysis of the work analyzing the work in relation to its preserved mathematical content. Some of the works in this dissertation are considered canonical, while others were selected precisely because they have generated very little scholarship, in part due to the fact they incorporate mathematical concepts. This dissertation isn't intended to act as a survey of all of the media artworks that incorporate mathematical ideas, but merely to provide a selection of works that demonstrate various mathematical concepts that are often associated with mathematics in art, including concepts of symmetry, infinity, fractals, permutations, the Axiom of Choice, and the algorithmic.

At this point in time, there have been very few attempts to analyze the actual mathematical content of media artworks, with a vast majority of the existing literature focused on narrative cinema. Much has been written about the mathematical content of movies like *Moebius* (1996), *Cube* (1997), and *π* (1998), while many experimental moving image works that explore mathematical concepts have quickly been written off as having little mathematical interest. For instance, one of the only books dedicated to mathematics in the cinema, *Math Goes to the Movies,* lists Hollis Frampton's experimental film *Zorns Lemma* (1970) as a film with a "math title but no math."[46]

In the same spirit, *Films in the Mathematics Classroom* reviews over two hundred 16mm films with mathematical content; however, most of the experimental films on the list – that is, films that engage with mathematical content but were not made explicitly to teach mathematics, including John Whitney's *Arabesque* (1975) and *Permutations* (1968), René Jodoin's *Danced Squared* (1961) and *Notes on a Triangle* (1966), and Norman McLaren and Evelyn Lambart's *Rythmetic* (1957) – were written off as having "questionable" or "irrelevant" mathematical content, as "more appropriate as an art film," "more aesthetic value than mathematical," and as having "uncertain," "limited" or "little" instructional value.[47] These experimental films may not have been explicitly engaging with the mathematical concepts depicted in their titles; it still is productive to analyze the films for their mathematical content since, in many cases, this content acts as an influential force in the work's production. In other words, even though these films may have limited instructional value in the traditional sense, these works demonstrate some of the ways in which mathematics has been utilized by experimental filmmakers in the construction of their films.

The research in this dissertation has evolved from a discourse analysis of the literature surrounding the connection between mathematics and art. Using the aforementioned texts, I provide a

46 Burkard Polster and Marty Ross, *Math Goes to the Movies* (Baltimore: Johns Hopkins University Press, 2012), 252. The book is dedicated to discussing the mathematics presented in narrative movies ranging from the superfluous (i.e. mathematics found on chalkboards in the background of scenes) to the beautiful adaptation of mathematical thought.
47 Barbara J. Bestgen and Robert E. Reys, *Films in the Mathematics Classroom* (Reston: National Council of Teachers of Mathematics, 1982), 18, 28, 60-2 and 67. Many of these films are described as entertaining which, as noted by one reviewer, "is a strong endorsement for a mathematics film!" (28).

brief history of the connections between mathematics and art and expand the literature to include media art. In addition, I perform my own close readings of several experimental moving image artworks, analyzing the mathematical content of the work. In order to do this, I use both primary and secondary sources that discuss the artworks themselves, and compare these ideas with literature surrounding the mathematical concepts related to the work. It is my desire that the mathematics be presented in formal but accessible terms, without shying away from difficult mathematical content or formalities. As such, I have attempted to introduce mathematical concepts that can be used in the future to analyze media artworks and have attempted to provide explanations that any media theorist could work through with some patience. Moreover, I have attempted to make the mathematical content more accessible through the use of simple examples, analogies and layperson's explanations whenever possible. It is my desire that this study appeal to scientists with an interest in media art, and to media theorists with an interest in experimental cinema and other contemporary moving image practices.

This dissertation begins by actively engaging with and expanding upon the previous scholarship that explores the relationship between mathematics and art in order to *trace* a mathematical genealogy of media art. By trace, I am suggesting the barely detectable mathematical marks that form the basis of many aesthetic movements within media art. Given that many Western ideas about beauty and harmony stem from mathematical concepts, I provide some of the historical connections between mathematics and art from periods when they were not considered mutually exclusive disciplines. Carrying many of these concepts and ideas forward, I argue that mathematics has been one of the cultural influences on aesthetic movements in media art, effectively challenging the two culture dichotomy and favouring a model in which ideas flow between disciplines. In this way, mathematics can be see as one of the bridges between the sciences and the humanities, implying that the two culture divide proposed by Snow is a false dichotomy.

Roughly speaking, this dissertation can be grouped as follows. In Chapters Two through Four, I examine a few of the ways in which mathematical thought has influenced media studies. In Chapters Five through Nine, I conduct a number of case studies in which various media art objects are analyzed in terms of their mathematical content. The following is a summary of the chapters themselves. In the next chapter, Chapter Two, an alternative, mathematical genealogy of media art is sketched. This cross-disciplinary flow of ideas does not always occur through an identifiable force, but through circumstances that often involve some element of chance. For instance, consider the ways in which seeds are dispersed by the wind. Ideas do not flow through direct conversation, but are more often than not gradually disseminated through multiple cultural channels affected by the individual interests of cultural producers and cultural trends. Despite not always having a clearly identifiable source of contact, it will be argued that mathematical developments have had a considerable cultural impact on the humanities, arts, and cinema and media studies.

One of the major impacts of mathematics on media studies was the development of Stuart Hall's Encoding/Decoding model. Chapter Three will argue that Claude Shannon's mathematical model of communication is closely related to Hall's model, demonstrating that Hall's model can be read as a cultural interpretation of Shannon's mathematical model. In this chapter, the mathematical model of communication will be explained in a way that should be accessible to media theorists. Given that Hall's model is quite limited in its scope – namely, that it can only be applied to producers working within a dominant ideology – there have been many attempts to extend his model to include producers working outside of the dominant ideology. The most successful expansion of Hall's model is by Sven Ross; however, it is still too limited and does not include producers working with experimental modes of communication. Using Shannon's model as a basis, I expand Ross' formulation to include the work of media artists who attempt to challenge conventional forms of communication. The influence of Shannon's model on cultural theorists demonstrates one of the ways in which mathematics has had a major impact on media studies.

The influence of mathematics on humanities often occurs through a misuse or misinterpretation of mathematics. In Chapter Four, I mobilize the concept of a *productive misinterpretation* and argue that this type of misreading has the potential to lead to new and innovative ideas. One of the more interesting misuses of mathematics in the humanities occurs in Alain Badiou's book *L'Être et l'Événement* [*Being and Event*]. Although Badiou is not specifically dealing with media art in *Being and Event*, his work has recently experienced a resurgence within media studies due to the 2005 English translation of *L'Être et l'Événement* by Oliver Feltham, the 2013 release of his book *Cinema*, and the use of his texts in Isiah Medina's critically acclaimed experimental feature *88:88* (2015). In this chapter, I argue against Badiou's controversial claim that *ontology is mathematics*, denying mathematics as a form of universality; however, I also argue that his misuse of *mathematics as ontology* is a productive misinterpretation that offers novel ways of approaching ontological questions. This chapter will conclude with some examples of works by experimental cinema and media artists that have used productive misinterpretations of mathematics and mathematics as metaphor.

In the remaining chapters, I mathematically analyze a selection of experimental moving image artworks that explore, contain or demonstrate mathematical concepts that are often discussed in relation to mathematics in art. The mathematical concepts chosen were influenced by Sasho Kalajdzievski's *Math and Art: An Introduction to Visual Mathematics*, a textbook published in 2008 with the intent to teach students how to recognize and understand mathematical ideas in visual art, and to provide students with some mathematical tools and techniques in order to experiment with and to create their own works. The textbook is accessible, but does not shy away from difficult mathematical concepts, hopefully, similar to my dissertation. In order to mathematically analyze a selection of experimental moving images, I begin with a comprehensive description of the mathematical concept being explored: symmetry in Chapter Five; fractals in Chapter Six; permutations in Chapter Seven; the Axiom of Choice in Chapter Eight; and algorithms in Chapter Nine. The description includes a brief history of the concept, an accessible formal description of the mathematics, and some of the ways in which it is related to art. The goal of this formal introduction to mathematical concepts is to provide media theorists with a working understanding of them, and to provide tools to perform similar analyses of other artworks. Explicating the mathematical concepts in the work will hopefully provide inspiration for further mathematical research. Moreover, demonstrating that experimental moving image artworks can exhibit mathematical concepts will hopefully generate further interest for individuals stimulated by mathematics, thereby creating further dialogue between the sciences and the humanities.

In the final chapter, Chapter Ten, I examine the influence of the computer on mathematical thought and use this analysis to discuss contemporary trends in media studies. By examining the parallels between mathematical developments and developments within media studies, I provide one final contemporary example that demonstrates the false dichotomy proposed by Snow. Finally, I present some of the limitations of this study and provide suggestions for future scholarship.

CHAPTER TWO: TOWARDS AN ALTERNATIVE GENEALOGY OF MEDIA ART

I'm a spectator of mathematics like others are spectators of soccer or pornography.
– Hollis Frampton

Mathematics is not for spectators; to gain in understanding, confidence, and enthusiasm one has to participate.
– M.A. Armstrong, *Groups and Symmetry*

Mathematics is the art of giving the same name to different things.
– Henri Poincaré, *The Future of Mathematics*

In this chapter, in order to trace a mathematical genealogy of art, I will first consider one of the ways in which mathematics became aestheticized, namely, through φ, commonly referred to as *the golden ratio*. The golden ratio will be defined mathematically and some of its properties will be explored. Moreover, some of the common myths and misconceptions about the golden ratio will be revealed. An additional observation will be provided as to why, at least for some, there might have been a perceived separation between science and the humanities in the nineteenth century, namely, the concept of *art for art's sake*. Finally, a speculative mathematical genealogy of media art will be traced.

In order to trace a mathematical genealogy of media art, I will first expand upon media scholar Laura Marks' genealogy of the algorithm and the pixel. In particular, I will trace an older genealogy than Marks develops in *Enfoldment and Infinity*, and will suggest that embedded within Marks' genealogy is a deeper mathematical fold which allows us to expand her ideas beyond Islamic culture. Next, connections will be made between the foundational crisis in mathematics in the late nineteenth century and the birth of various artistic movements that have had significant impacts on media art and media studies, in particular, formalism, cubism and dadaism. Finally, I will examine some of the cultural responses to Snow's paper, since it too seemed to have an impact within the arts and the humanities.

2.1 Irrational Mathematics: Rationalizing Beauty

Mathematically speaking, the golden ratio (also known as φ, *the golden mean*, *the golden proportion*, or *the divine proportion*) is defined as follows: Two non-negative numbers a and b are in golden ratio, denoted φ, if the ratio of $a+b$ to a is the same as a to b. In other words, φ is defined as follows:[48]

$$\frac{a+b}{a}=\frac{a}{b}\equiv\varphi$$

Through relatively simple algebraic manipulation it can be shown that:

$$\varphi=\frac{1+\sqrt{5}}{2}\approx 1.61803$$

The golden ratio is an irrational number, meaning it is a number that cannot be written as a fraction involving integers.[49] Other famous irrational numbers include the ratio of a circle's circumference to its diameter, namely π, and the square root of 2. In physicist Mario Livio's accessible and thorough book dedicated to φ, he writes:

> Some of the greatest mathematical minds of all ages, from Pythagoras and Euclid in ancient Greece, through the medieval Italian mathematician Leonardo of Pisa and the Renaissance astronomer Johannes Kepler, to present-day scientific figures such as Oxford physicist Roger Penrose, have spent endless hours over this simple ratio and its properties. But the fascination with the golden ratio is not confined just to mathematicians. Biologists, artists, musicians, historians, architects, psychologists, and even mystics have pondered and debated the basis of its ubiquity and appeal. In fact, it is probably fair to say that the golden ratio has inspired thinkers of all disciplines like no other number in the history of mathematics.[50]

In addition to being pondered by many great minds, this ratio is often considered the most aesthetically pleasing proportion and some considered it to be a mathematical standard for visual beauty.

The golden ratio was first introduced in Euclid's *Elements* around 300 BC. He defines it as follows:

> A straight-line is said to have been *cut in extreme and mean ratio* when as the whole is to the greater segment so the greater (segment is) to the lesser.[51]

Euclid defined this proportion in order to construct a pentagram and a regular pentagon, two objects that will be discussed later in detail. As Livio observes, "who could have guessed that this innocent-

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48 In the following equations, $\equiv$ means "if and only if" and $\approx$ means "is approximately equal to."
49 The integers, Z = {..., -2, -1, 0, 1, 2, ...}.
50 Mario Livio, *The Golden Ratio: The Story of Phi, the World's Most Astonishing Number* (New York: Broadway Books, 2002), 6.
51 Euclid, *Elements of Geometry*, ed. and trans. Richard Fitzpatrick (published by the author, 2007), 156. [Emphasis added.]

looking line division, which Euclid defined for some purely geometrical purposes, would have consequences in topics ranging from leaf arrangements in botany to the structure of galaxies containing billions of stars, and from mathematics to the arts?"[52] By simply introducing it as a line division and using it strictly for geometric purposes, Euclid does not provide it with the aesthetic value that is later attributed to it. Despite this, the golden ratio continues to be seen as an expression of mathematical beauty since it is a relatively easy concept to understand, yet often appears as a solution to relatively complex problems. For instance, it is a solution to two very different types of never-ending equations:

$$\varphi=\sqrt{1+\sqrt{1+\sqrt{1+\sqrt{1+\cdots}}}}$$

and

$$\varphi=1+\cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1+\cdots}}}}$$

Recalling that φ is defined in terms of a cut in a line segment, these results are relatively surprising and demonstrate a few of the ways in which the golden ratio seemingly appears out of nowhere, thereby reinforcing many mathematicians' fascination with the number.

Geometrically speaking, the golden ratio is found in the regular pentagon, a five-sided figure whose sides all have the same length and whose interior angles are 108°. It is possible to find the golden ratio within the regular pentagon by forming a pentagram within it [Fig. 1]. The acute, isosceles triangles that form the pentagram have a side length ratio which is the golden ratio. In other words, when the long side of the triangle is divided by the short side, it can be demonstrated that the result is the golden ratio.[53] This type

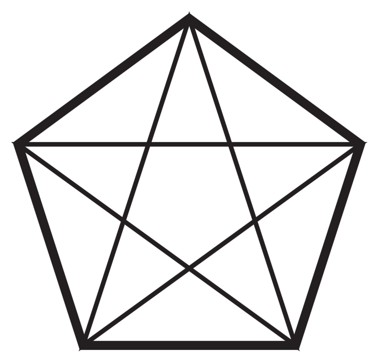

Fig. 1 – Pentagram inside a regular pentagon.

52 Livio, *The Golden Ratio*, 4. The name *golden ratio* only gained popularity around the 1830s (7).
53 An acute triangle is one where all three of its interior angles are less than 90°. An isosceles triangle is one where two of the sides are equal.

of triangle is referred to as a *golden acute triangle* and can be shown to have interior angles 72°, 72° and 36°.[54] Moreover, it is possible to create other fascinating geometric objects, like the *golden rectangle* and the *golden obtuse triangle,* simply by constructing them in such a manner that their side length ratios are the golden ratio.[55] A golden obtuse triangle can be shown to have interior angles 108°, 36° and 36°.[56] The golden rectangle can easily be subdivided into smaller golden rectangles simply by forming a square within it since it can be shown that the new rectangle created will have a side ratio which is golden. This process can be done indefinitely and if done in the correct order, it is possible to form a *golden spiral* [Fig. 2].

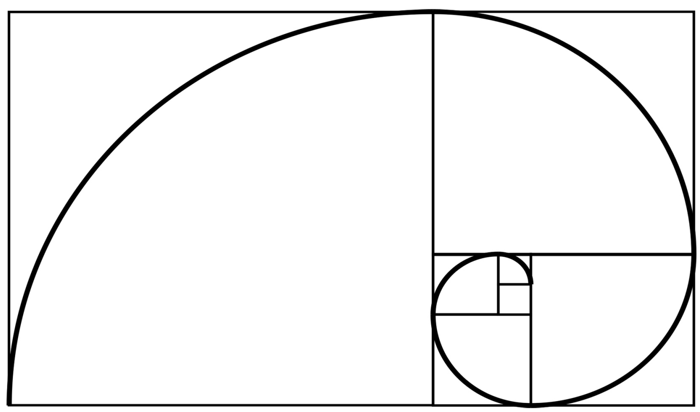

Fig. 2 – Golden rectangle containing a golden spiral.

The regular pentagon also forms the faces of a dodecahedron [see Fig. 3], a Platonic solid with twelve sides.[57] As argued, the golden ratio can be found in regular pentagrams, regular pentagons and dodecahedrons, all of which had considerable aesthetic value for many Greek philosophers. For instance, Plato describes the dodecahedron in the *Timaeus* as the one “which God used in the delineation of the universe.”[58] Plato saw the dodecahedron as the basis of the universe; this is perhaps why, as Livio argues, Salvador Dalí included a dodecahedron floating beyond the table in *The*

54 Any isosceles triangle with these interior angles can be shown to be a golden acute triangle.
55 An obtuse triangle is one where one of its interior angles is greater than 90°.
56 Any isosceles triangle with these interior angles can be shown to be a golden obtuse triangle.
57 Platonic solids will be discussed further in Chapter Five.
58 Plato, *Timaeus*, Sec. 55c.

Sacrament of the Last Supper (1955), which was painted on a canvas that formed a golden rectangle [Fig. 3].[59] It is also likely that Plato's speculation influenced the Renaissance astronomer Johannes Kepler, who created a model of the solar system based on the Platonic solids, as I will discuss later in this section. Kepler was particularly interested in the golden ratio and is believed to have independently discovered its relationship to the sequence generally attributed to the medieval Italian mathematician Leonardo of Pisa, better known as Fibonacci.[60]

Fig. 3 – Dalí's Sacrament of the Last Supper painted on a canvas that forms a golden rectangle and containing a portion of a dodecahedron.

The Fibonacci sequence was introduced by Leonardo of Pisa in the 1202 book *Liber Abaci* through the form of a problem:

> A certain man put a pair of rabbits in a place surrounded on all sides by a wall. How many pairs of rabbits can be produced from that pair in a year if it is supposed that every month each pair begets a new pair which from the second month on becomes productive?[61]

Working through this problem, the number of adult pairs forms the sequence:

1, 1, 2, 3, 5, 8, 13, 21, 34 ...

From this sequence it is possible to observe each term is the sum of the preceding two terms. In modern

59 Livio, *The Golden Ratio*, 68.
60 Ibid., 101.
61 Ibid., 96. The Fibonacci sequence was attributed to Fibonacci in the nineteenth century by the French mathematician Édouard Lucas; however, it was early explored by Indian mathematicians, in particular, Virahanka who attributes it to Pingala who worked circa 200 BC. See Susantha Goonatilake, *Toward a Global Science* (Bloomington: Indiana University Press, 1998), 126.

mathematics, the Fibonacci sequence can be written as a recursive expression as follows:

$$F_n = F_{n-1} + F_{n-2} \text{ for } n > 2 \text{ where } F_1 = 1 \text{ and } F_2 = 1.$$

It can be shown that the ratio of two successive Fibonacci numbers approaches the golden ratio. In terms of contemporary mathematics this means,

$$\lim_{n \to \infty} \frac{F_n}{F_{n-1}} = \varphi$$

Once again, it is surprising that a number defined by a line division is related to this sequence, and understanding this connection has captivated generations of mathematicians. The simplicity of the concept combined with its appearance in many seemingly unrelated branches of mathematics, is one of the reasons mathematicians find this number aesthetically beautiful or awe-inspiring.

As observed by historian Lynn Gamwell, the philosophical connection between the golden ratio and art came in the thirteenth century through the Italian mathematician and astronomer Johannes Campanus, who produced a commentary on a twelfth-century Latin translation from an Arabic version of Euclid's *Elements*.[62] According to Campanus:

> *Admirable* therefore is the power of a line divided according to the ratio with a mean and two extremes [the golden ratio]; since very many things worthy of admiration of philosophers are in *harmony* with it, this principle or maxim proceeds from the invariable nature of superior principles, so that it can rationally unite solids that are so diverse, first in magnitude, then in the number of bases, then too in shape, in a certain *irrational* symphony.[63]

The golden ratio was further reinforced in the three-volume treatise *Divina Proportione* (*The Divine Proportion*) by mathematician Luca Pacioli, published in 1509 and illustrated by Leonardo da Vinci. The first volume contains a summary of the properties of the golden ratio (or, more specifically, the divine proportion), a study of Platonic solids and other polyhedra, and reasons why the golden ratio should be considered divine. The second volume is a treatise on proportion and its application to architecture and the human body, largely based on Roman author Marcus Vitruvius Pollio's writing

62 Lynn Gamwell, *Mathematics + Art: A Cultural History* (Princeton: Princeton University Press, 2016), 88.
63 Albert van der Schoot, "The Divine Proportion," in *Mathematics and the Divine: A Historical Study*, ed. Teun Koetsier and Luc Bergmans (Amsterdam: Elsevier, 2005), 662. [Emphasis added.]

which is also a reference for da Vinci's well-known *Vitruvian Man*. Finally, the third volume is primarily an Italian translation of the fifteenth-century painter Piero della Francesca's Latin text, *Libellus de Quinque Corporibus Regularibus* (*A Study of the Five Regular Bodies*), included without citation, leading to much controversy among future scholars.[64] The book was quite influential, as were da Vinci's drawings.

As described by Livio, “Pacioli raves ceaselessly about the properties of the golden ratio;”[65] however, Pacioli's praise was not aesthetic. As Gamwell observes, “Pacioli's lengthy praise for the sublime properties of the divine [golden] ratio all centred on its theological symbolism.”[66] Although many scholars have argued against the fairly tenuous connections between Renaissance art and the golden ratio, they may have actually employed if, not for aesthetic reasons, but for its preceived theological symbolism described by Pacioli.[67] Nevertheless, it seems through the powerful influence of Pacioli's book, the golden ratio became mythologized as an ideal form of beauty, or as a way of measuring beauty, with many arguing that the golden rectangle is the most aesthetically pleasing or satisfying of all the rectangles. Officially, it was in the mid-nineteenth century when mathematician Matin Ohm first called Euclid's extreme mean the *goldener schnitt* (*golden section*)[68] and it was psychologist Adolf Zeising who adopted the term in his 1854 book *Neue Lehre von den Proportionen des menschlischen Körpers, aus einem bisher unerkannt geblienenen, die ganze Natur durchdringenden morphologischen Grundgesetze entwickelt und mit einer vollständigen historischen Übersicht der bisherigen Systeme begleitet* (*A New Theory of the proportions of the human body, developed from a basic morphological law which stayed hitherto unknown, and which permeates the whole nature and art, accompanied by a complete summary of the prevailing systems*) declaring,

64 Livio, *The Golden Ratio*, 135.
65 Ibid., 132.
66 Gamwell, *Mathematics + Art,* 91.
67 For examples, see Livio's *The Golden Ratio* or George Markowsky, “Misconceptions about the Golden Ratio,” *The College Mathematics Journal* 23, no. 1 (January 1, 1992) or Gamwell's *Mathematics + Art*.
68 Roger Herz-Fischler, *A Mathematical History of Division and Mean Ratio* (Waterloo: Wilfrid Laurier University Press, 1987), 164–70.

> [The golden section] underlies the formation of all beauty and wholeness in nature and in the pictorial arts, and from the beginning it provided the model for all representations and formal relations, whether cosmic or individual, organic or inorganic, acoustic or optical, which found most perfect realization, however, in the human figure.[69]

From this time forward, the myth of the golden ratio became a fixture of art history.

Since Zeising's proclamation, there have been many psychological experiments conducted to determine the validity of the claim that the golden ratio is the most aesthetically pleasing ratio. However, as convincingly argued in the paper “Misconceptions about the Golden Ratio” by mathematician George Markowsky, “if people do prefer certain rectangles, the only reasonable claim would be that people prefer ratios in a certain range.” He continues: “the various claims made about the aesthetic importance of the golden ratio seem to be without foundation.”[70] To demonstrate this, he sets up an informal experiment in which he places “48 randomly arranged rectangles all having the same height but with their widths ranging from 0.4 times the height to 2.5 times the height.”[71] He then asks people to select the “most pleasing rectangle.” His informal study demonstrates “people cannot find the golden rectangle” among these 48 randomly arranged rectangles.[72] In fact, I would be hard-pressed to find the golden rectangle among these choices even as someone who has studied the golden rectangle extensively and who can construct it without difficulty using only a compass and a straight edge, in addition to being able to demonstrate why this construction makes the rectangle golden.

The connection between a line division and artistic beauty seems to stem from conflating two conceptions of beauty, namely, visual beauty and mathematical beauty. The golden ratio may not be the most visually pleasing line division, but it has been a source of inspiration for artists due to its mathematical beauty and the mythology surrounding its visual beauty. In other words, due to this slippage, the ratio has been used by artists as a source of inspiration to generate works with artistic

69 Translated in Gamwell, *Mathematics + Art*, 92.
70 George Markowsky, “Misconceptions about the Golden Ratio,” *The College Mathematics Journal* 23, no. 1 (January 1, 1992), 14.
71 Ibid., 13.
72 Ibid.

merit. Although the golden ratio was written about as an object of beauty, it wasn't really employed in the construction of artworks until the late nineteenth and early twentieth century, through the works of Paul Serusier, Juan Gris, Jacques (Chaim Jacob) Lipchitz, Gino Severini, and the later work of Le Corbusier, who designed a system titled "Modulor" based on the harmonious proportions of the golden ratio.[73]

It is worth re-emphasizing that the golden ratio's use in artworks has been mythologized and many texts make unfounded claims that it forms the underlying structure of works such as Leonardo da Vinci's *Mona Lisa* (c. 1503–06) or Giotto di Bondone's *Ognissanti Madonna* (1306).[74] As Livio observes, the literature "is bursting with false claims and misconceptions about the appearance of the golden ratio in the arts (e.g., in the works of Giotto, Seurat, Mondrian)."[75] In fact, many scholars claim da Vinci often used the golden ratio in his work, seemingly due to the fact that he illustrated *Divina Proportione*, but there is little evidence to support this claim.[76] As observed by Livio when discussing the visual appeal of the golden ratio in relationship to physical beauty,

> I will certainly not attempt to make the ultimate sense of sex appeal in an article on the golden ratio. I would like to point out, however, that the human face provides us with hundreds of lengths to choose from. If you have the patience to juggle and manipulate the numbers in various ways, you are bound to come up with some ratios that are equal to the golden ratio.[77]

Given the complexity of the artworks analyzed, it is precisely through this form of number juggling that one obtains the golden ratio. To quote from Darren Aronofsky's film π (1998), "if you want the number, you can find it everywhere." Or perhaps, this is the same type of confirmation bias that leads people to believe Pink Floyd intentionally synced *The Dark Side of the Moon* (1973) to the *The Wizard of Oz* (1939).

73 For more, see Livio's *The Golden Ratio.*
74 Livio, *The Golden Ratio*, 161–62.
75 Mario Livio, "The Golden Ratio and Aesthetics," *Plus Magazine*, (November 1, 2002), <https://plus.maths.org/content/golden-ratio-and-aesthetics>. This claim is further justified in his book *The Golden Ratio*.
76 Markowsky, "Misconceptions about the Golden Ratio," 10–12.
77 Livio, *The Golden Ratio*, 132.

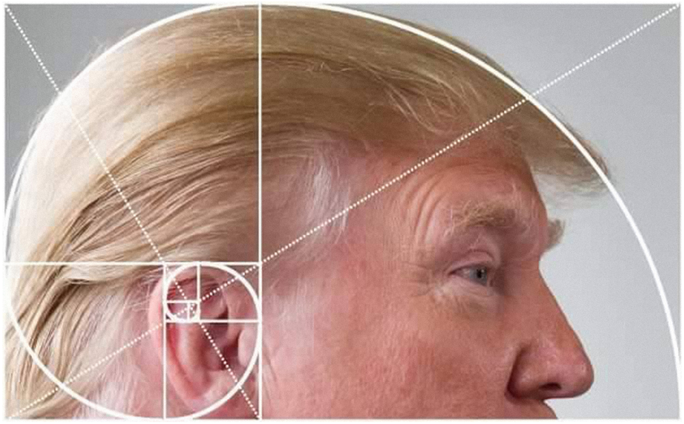

Fig. 4 – Trump Golden Spiral Meme.

In spite of this, the golden ratio has obtained its status as an object of beauty through mathematics and it has become a source of inspiration for artists, even if purely philosophically. Nevertheless, Livio warns against the ratio as an aesthetic standard, suggesting that “in spite of the golden ratio's amazing mathematical properties, and its propensity to pop up where least expected in natural phenomena, I believe that we should abandon its application as some sort of universal standard for 'beauty,' either in the human face or in the arts.”[78] Why are mathematicians always such killjoys? I am in agreement with Livio that the golden ratio is not “some sort of universal standard for ‘beauty’”; however, one of the ways in which mathematics has been useful to artists, scientists and theorists is precisely through this type of mathematical misinterpretation.

Consider Kepler's first major astronomical work, often referred to as *Mysterium Cosmographicum* (*Cosmic Mystery*) rather than its cumbersome full title *Prodromus dissertationum cosmographicarum, continens mysterium cosmographicum, de admirabili proportione orbium coelestium, de que causis coelorum numeri, magnitudinis, motuumque periodicorum genuinis & proprijs, demonstratum, per quinque regularia corpora geometrica* (*Forerunner of the Cosmological Essays, Which Contains the Secret of the Universe; on the Marvelous Proportion of the Celestial Spheres, and on the True and Particular Causes of the Number, Magnitude, and Periodic Motions of*

78 Livio, “Golden Ratio and Aesthetics.”

the Heavens; Established by Means of the Five Regular Geometric Solids). First published in 1596, the book is a defence of the Copernican system, a heliocentric view of the solar system, based on theological convictions. Kepler argues that the movement of planets within the solar system must be dictated by the geometry of the five Pythagorean regular polyhedra, in order to reflect the beauty of God's universal plan. In other words, Kepler, as a profoundly religious person, believed that God created the universe based on mathematical principles. At the time, there were only six known planets, and for each Platonic solid, Kepler created an inner and an outer sphere, with the inner sphere representing the planet and the outer sphere containing the next planet. Kepler calculated the arrangement according to empirical evidence, determining that the six planets from Mercury out to Saturn were separated by the octahedron, icosahedron, dodecahedron, tetrahedron and cube. Finally, the Sun was at the centre of the six concentric spheres [Fig. 5].

Kepler's model failed to capture the distance between the planets; however, it was still a major stepping stone for many scientific advancements. As Owen Gingerich states in a short biography of Kepler, "seldom in history has so wrong a book been so seminal in directing the future course of science."[79] Although theology and mathematical beauty were important inspirations on Kepler's model, so were the artistic illustrations of the era, as physicist Kenneth Brecher speculates. Brecher argues that Kepler was likely influenced by artists who were experimenting with nested solids:

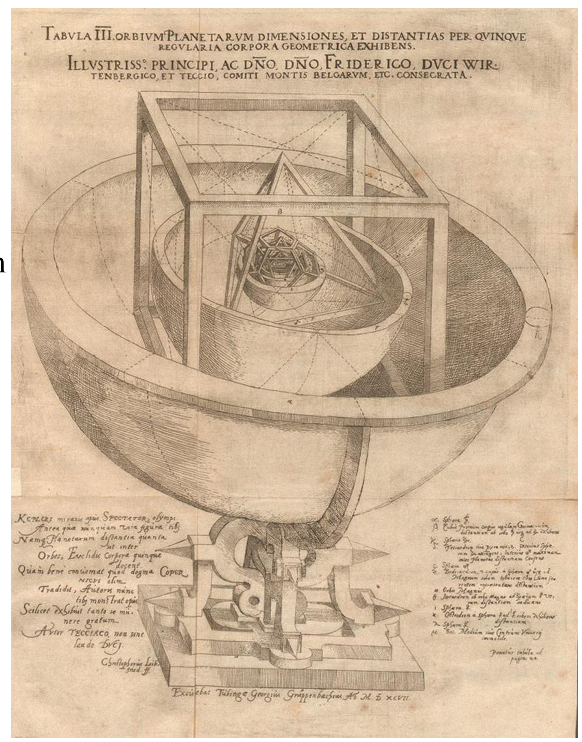

Fig. 5 – Kepler's Model of the Solar System.

> Kepler's model using five nested Platonic solids was a direct outgrowth of 16th century studies of

79 Owen Gingerich, "Johannes Kepler," in *Planetary Astronomy from the Renaissance to the Rise of Astrophysics Part A: Tycho Brahe to Newton.*, ed. René Taton and Curtis Wilson (Cambridge: Cambridge University Press, 1989), 58.

> perspective and of the art and craft of that time. Specifically, it seems possible – even likely – that Kepler was inspired (either consciously or unconsciously) by then well-known paintings, engravings, books and – perhaps most directly – magnificent and memorable three-dimensional sculptures of nested regular polyhedra made on "ornamental turning" engines. These elaborate wood and ivory sculptures could be found in "Wunderkammers," the forerunners of today's art and science museums.[80]

Using mainly visual evidence, Brecher connects Kepler's model to the artworks produced by artists of the era including da Vinci, Lorenz Stoer, Wenzel Jamnitzer, and Lorenzo Sirigatti. Brecher's arguments seem quite plausible, and further demonstrate the strong influence that works of art can have on the sciences. It is worth further observing that many of these artworks arose out of new developments in perspective, showing that the relationship between the arts and sciences was mutually beneficial.

2.2 A New Science: Art for Art's Sake

In order to discuss the relationship between mathematics and art after the cultural divide observed by C.P. Snow (and a century earlier by T.H. Huxley), it is important to note that the status of the humanities and science have both changed since the nineteenth century. In examining the genealogy of the term "science," historian Stefan Collini observes its uses became more restrictive in the nineteenth century, referring only to the natural or physical sciences and excluding both theology and metaphysics.[81] For instance, the 1816 *Encyclopaedia Perthensis* defines science as "any art or species of knowledge," suggesting that every branch of knowledge can be regarded as science.[82] Mathematician Michael Holt reinforces this idea, suggesting "before Newton's day science did not exist as a separate subject as it can now be learned at school and college. For this reason the mathematical and scientific ideas [...] overlap."[83]

Ideas around science, beauty and art are constantly changing over time as well; however, the birth of "*l'art pour l'art,*" or "art for art's sake" can be seen as demonstrating the complicated

80 Kenneth Brecher, "Kepler's Mysterium Cosmographicum: A Bridge Between Art and Astronomy?," in *Bridges 2011* (Coimbra, Portugal, July 27-31, 2011, n.d.), 381.
81 Collini, "Introduction [to *The Two Cultures*]," xi.
82 *Encyclopaedia Perthensis; or, Universal Dictionary of the Arts, Science, & Literature* (Vol. XX, 2nd Edition) (Edinburgh, John Brown, Anchor Close: 1816), 46. Before the development of modern science, "natural philosophy" was considered the study of nature and the physical universe.
83 Michael Holt, *Mathematics in Art* (London: Littlehampton Book Services Ltd, 1971), 18.

relationship between art and other disciplines. The term is often credited to Théophile Gautier, since it appeared in his 1835 book *Mademoiselle de Maupin.* The term was an attempt to recognize alternative forms of beauty and to separate art from moral or didactic purposes; however, for some, it also separated the relationship between art and nature. Moreover, some of the more extreme views of "art for art's sake" seem to illustrate a gap between art and science.

Many believed that "art for art's sake" was an empty phrase, arguing that it was impossible to separate art from truth and beauty. For instance, in 1897 Leo Tolstoy wrote *What is Art?*, in which he argues that art is inherently connected to morality, beauty and truth, and must convey emotion. In contrast, Edgar Allan Poe, in his 1850 essay "Poetic Principles," writes,

> The simple fact is that would we but permit ourselves to look into our own souls we should immediately there discover that under the sun there neither exists nor *can* exist any work more thoroughly dignified – more supremely noble, than this very poem – this poem *per se* – this poem which is a poem and nothing more, this poem written solely for the poem's sake.[84]

In addition to separating art from morality, truth and beauty, "art for art's sake," for some, complicated the relationship between art from nature. For instance, with "art for art's sake" some artists began working against concepts of the sublime. In 1889, Oscar Wilde wrote,

> My own experience is that the more we study Art, the less we care for Nature. What Art really reveals to us is Nature's lack of design, her curious crudities, her extraordinary monotony, her absolutely unfinished condition. Nature has good intentions, of course, but, as Aristotle once said, she cannot carry them out. When I look at a landscape I cannot help seeing all its defects.[85]

Wilde is articulating the disdain for nature that was felt by some artists of his era. As opposed to seeing nature as beautiful, they viewed it as flawed and disordered. In other words, to these artists, nature didn't have the ability to produce the beauty that art could.

By contrast, consider mathematician Henri Poincaré's description of nature written around the same era. In *Science et Méthode* (*Science and Method*) Poincaré writes,

> The scientist does not study nature because it is useful to do so. He studies it because he takes pleasure

84 Edgar Allan Poe, "Poetic Principles," in *The Works of Edgar Allan Poe*, Vol. 2 (New York: W. J.Widdleton, 1863), xi. [Emphasis in original.]
85 Oscar Wilde, "The Decay of Lying," *Nineteenth Century* 25 (January 1889), 35.

> in it, and he takes pleasure in it because it is beautiful. If nature were not beautiful it would not be worth knowing, and life would not be worth living. I am not speaking, of course, of the beauty which strikes the senses, of the beauty of qualities and appearances. I am far from despising this, but it has nothing to do with science. What I mean is that more intimate beauty which comes from the harmonious order of its parts, and which a pure intelligence can grasp.[86]

While not all scientists held Poincaré's perspective and not all artists held Wilde's position, the extreme contrast between these two opinions demonstrates how the concept of "art for art's sake" and some of its more popular conceptions may have contributed to the perception that there was a gap between the arts and the sciences.

Prior to nineteenth century, some of the greatest mathematical innovations had been developed by printmakers, painters and architects. For instance, consider the development of linear perspective through Italian Renaissance painters and architects, who both wrote treatises on it and incorporated it into their artworks. Influenced by architect Filippo Brunelleschi, who experimented with linear perspective, philosopher and artist Leon Battista Alberti published a treatise in 1435, titled *De pictura* (*On Painting*), demonstrating techniques for capturing the illusion of three-dimensional distance on a picture plane. In his treatise, Alberti related the idea of a "vanishing point," which he referred to as the "centric point."[87] Painter Piero della Francesca further elaborated on Alberti's ideas in his 1470 text, *De Prospectiva Pingendi* (*On the Perspective of Painting*). A century later, these ideas would be formalized into a mathematical theory called projective geometry by the French mathematician Girard Désargues, although Kepler was also formalizing the idea of vanishing points at around the same time.

During the development of linear perspective, artists were quick to adapt creative misuses for it. For instance, consider Erhard Schön's 1535 engraving *Anamorphosis*, which presents both a strange landscape when viewed straight-on *and* the faces of Emperors Charles V, Ferdinand I, Francis I, and Pope Paul III, and the letters of their titles when viewed side-on from the left [Fig. 6]. Similarly, consider William Hogarth's engraving *False Perspective* from 1754, which ignores one of the basic

86 Henri Poincaré, *Science and Hypothesis*, trans. William John Greenstreet (London: The Walter Scott Publishing Co. Ltd, 1905), 22.
87 Leon Battista Alberti, *On Painting,* trans. Cecil Grayson (London: Phaidon Press, 1972), 54.

rules of perspective to create what is now mathematically referred to as an impossible object [Fig. 7].[88] A decade after Hogarth's engraving, mathematicians would challenge their own conceptions of geometric space, an idea that will be explored in detail in the next section.

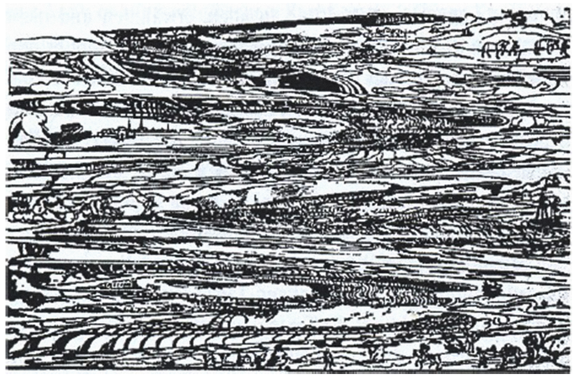

Fig. 6 – Schön's Anamorphosis.

Fig. 7 – Hogarth's False Perspective.

88 Namely, objects appear larger the closer they are to the picture plane and decrease in size proportionally the further away they are.

2.3 The Roots of Media Art: Early Traces of Mathematics in the Pixel and the Algorithm

Media scholar Laura U. Marks' book *Enfoldment and Infinity* uses a methodology inspired by Deleuze's interpretation of Leibniz – where "the smallest unit of matter is the fold, not the point"[89] – to unfold the Islamic genealogy hidden in media art. As Marks argues, "new media art, considered Western, has an important genealogy in the aesthetics, philosophy, and science of classical Islam."[90] She continues: "the historical properties of Islamic art [...] reemerge in new media art independent of the new media artist's intentions. They express a sort of Islamic *Kunstwollen* immanent to computer-based media."[91] Inspired by Deleuze and Guattari's concept of the *plane of immanence*, an infinite immense surface composed of an infinite number of folds containing "all that has existed, will exist, has never existed, will never exist, in a virtual state" – basically everything – she argues that hidden within one of these folds is an Islamic heritage of Western thought and culture waiting to be unfolded.[92] Marks also attempts to build an ontological argument by using the Arabic distinction between *zahir* (external and manifest) and *batin* (internal, esoteric and hidden), suggesting that Islamic art and philosophy can be used to reveal the *plane of immanence* enfolded in the world around us.

The main argument of *Enfoldment and Infinity* is that there are many theoretical, philosophical, and spiritual parallels between Islamic culture and aesthetics, and media art. The book covers much territory; media theorist Stijnie Thuijs succinctly summarizes some of the book's main connections: "the similarities of unity (God and code), infinity (spiritual and virtual), the vector (Mecca and telepresence), aniconism (figurative images and virals), abstract line and haptic space (abstract decorating figures and computer art) and embodied perception (subjective experiences in time and space)."[93] Marks is also attempting to develop her own ontological claims, an aesthetics of

89 Laura U. Marks, *Enfoldment and Infinity: An Islamic Genealogy of New Media Art* (Cambridge: MIT Press, 2010), 5.
90 Ibid., 149.
91 Ibid. Austrian art historian Alois Riegl's invented the term *Kunstwollen* (which translates to "that which wills art") to describe the historically contingent characteristics and boundaries of an epoch's aesthetics which exerts its "will" on the artist, like an aesthetic Zeitgeist.
92 Marks, *Enfoldment and Infinity,* 5.
93 Stijnie Thuijs, "Book Review: Enfoldment and Infinity by Laura U. Marks," Masters of Media (September 21, 2011),

enfolding/unfolding with three levels, "image, information and the infinite,"[94] which describe the relationship between Islamic art and philosophy, and media art [Fig. 8]. Media theorist Kathleen Scott describes one such relationship explored by Marks:

> Programming codes underlie computer images, art and networks and seem to have infinite depth in their ability to connect with each other and create new sources of information, just as the Qur'an mediates between the art through which its words are conveyed to the public and the infinite God whose authority it represents.[95]

Given the immense scope of Marks' scholarship, I am only going to focus on one of the more significant connections Marks makes between Islamic culture and media art – namely, the birth of the algorithmic and the pixel.

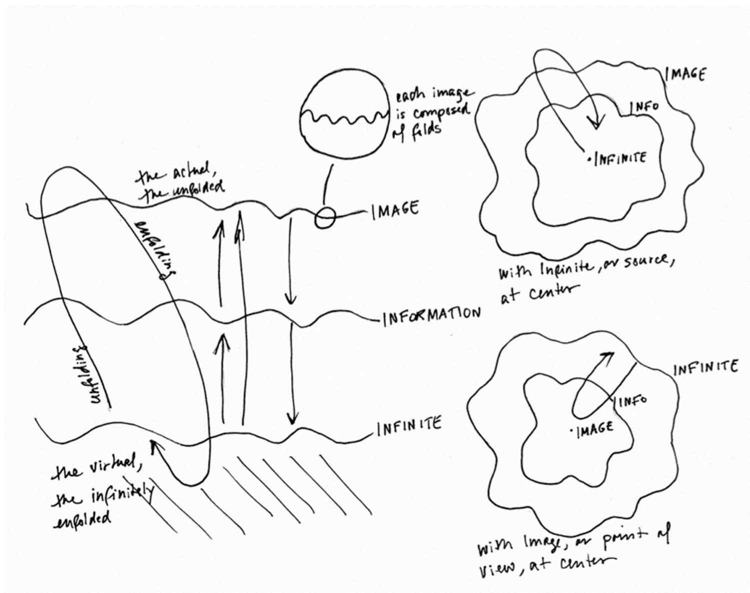

Fig. 8 – Marks' Enfolding/Unfolding Aesthetics

Marks observes that the birth of the algorithm can be found within the writing of mathematician Muḥammad ibn Mūsā al-Khwārizmī, whose surname was the basis for the Latin term *algorithmi*. This mangled mistranslation forms the basis of the term algorithm, which suggest, as Marks argues, that al-Khwārizmī "is enfolded in the instructions (algorithms) that propel all computer programs today."[96]

<https://mastersofmedia.hum.uva.nl/blog/2011/09/21/book-review-enfoldment-and-infinity-by-laura-u-marks/>.

94 Marks, *Enfoldment and Infinity*, 5. This is an aesthetic re-working of Delueze's concept of the virtual, code, the actual as seen in Fig. 8.

95 Kathleen Scott, "Enfoldment and Infinity: An Islamic Genealogy of New Media Art," *Screen* 52, no. 4 (December 1, 2011), 554–5.

96 Marks, *Enfoldment and Infinity*, 28. Al-Khwārizmī's 820 book *On the Calculation with Hindu Numerals* was translated

Best known for his introduction of the Hindu numeral system (now commonly referred to as the Arabic numeral system, or as the Hindu–Arabic numeral system) and, hence, the decimal system to the Western world, he also introduced procedures or algorithms for performing basic arithmetic within the decimal system. Expanding on Marks' observations, it is possible to speculate that the modern-day use of the term algorithm – that is, a set of rules that perform a sequence of operations – and al-Khwārizmī's writing on the basic procedures for performing arithmetic are linked through the calculator, one of the first mechanical devices to perform arithmetic by following simple procedures.

A direct predecessor of the calculator was the *abacus* or counting frame, a non-mechanical tool used for calculation whose exact origin is unknown but was used in many regions centuries before the adoption of the Hindu–Arabic numeral system.[97] Abaci were often constructed using a frame with beads on wires; however, they were originally simply stones placed in grooves in sand (or dust) or on tablets. As historians Carl Boyer and Uta Merzbach observe, "the word *abacus* is derived from the Semitic word 'abq,' or 'dust,' indicating that in other lands, as well as in China, it grew out of a sand tray used as a counting board."[98] Most cultures have used some of form of abacus; this can be accounted for by the fact that they visually perform basic operations like addition and multiplication, and are natural extensions of our fingers. They are also quite versatile, as observed by Boyer and Merzbach:

> The abacus can be readily adapted to any system of numeration or to any combination of systems; it is likely that the widespread use of the abacus accounts at least in part for the amazingly late development of a consistent positional system of notation for integers and fractions.[99]

into Latin as *Algoritmi de numero Indorum*. where Al-Khwārizmī was translated as Algoritmi eventually leading to the English term "algorithm."

97 Boyer and Merzbach, *A History of Mathematics*, 178-179. "The first clear descriptions of the modern forms [of the abaci], known in China as the *suan phan* and in Japan as the *soroban*, are of the sixteenth century, but anticipations would appear to have been in use perhaps a thousand years earlier" (178). Boyer and Merbach continue: "it is possible, but by no means certain, that the use of the counting board in China antedates the European, but clear-cut and reliable dates are not available. We have noted that in the National Museum in Athens, there is a marble slab, dating probably from the fourth century BCE, that appears to be a counting board. And when a century earlier Herodotus wrote, 'the Egyptians move their hand from right to left in calculation, while the Greeks move it from left to right,' he was probably referring to the use of some sort of counting board. Just when such devices gave way to the abacus proper is difficult to determine, nor can we tell whether the appearances of the abacus in China, Arabia, and Europe were independent inventions" (179).

98 Boyer and Merzbach, *A History of Mathematics*, 179.

99 Ibid., 56.

In other words, the transition from the Roman numeral system to the superior Hindu–Arabic numeral system was slow due to fact that computation with the abacus was common. Moreover, the users of the abacus did not necessarily have to understand how or why they worked, they just had to apply a set of memorized rules. From this standpoint, it is possible to see the *trace* of the abacus in the modern calculator and the modern computer.

Many artists who work with algorithms consider themselves *algorists*, another term that stems from a corruption of al-Khwārizmī, which in Latin was mistranslated into *algorismus* referring to the "decimal number system," a system that was first described by al-Khwārizmī in *On the Calculation with Hindu Numerals*. Algorithmic artist Roman Verostko writes,

> Often I am asked "Who are the algorists?" Simply put an algorist is anyone who works with algorithms. Historically we have viewed algorists as mathematicians. But it also applies to artists who create art using algorithmic procedures that include their own algorithms.[100]

Algorists were once mathematicians who attempted to develop new arithmetic methods and rules by writing numbers in place value form. In contrast, abacists were human calculators who could perform arithmetic quickly through the use of the abacus. Boyer and Merzbach observe that "for several centuries, there was keen competition between the 'abacists' and the 'algorists,' and the latter triumphed definitively only in the sixteenth century."[101] Most computer users are akin to abacists as they are able to perform operations without necessarily understanding them; algorists are those who attempt to understand the underlying mechanics. In this way, it is possible to position new media artists as contemporary algorists, re-affirming Marks' genealogy and further extending it towards a mathematical genealogy.

Another genealogy traced by Marks is that of the computer pixel, which she suggests can be found in the *kalām* concept of the atom.[102] Marks observes,

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100 Roman Verostko, "The Algorists," (2014) <http://www.verostko.com/algorist.html>.
101 Boyer and Merzbach, *A History of Mathematics*, *228.*
102 The *kalām*, literally translating as the science of discourse, is an Islamic form of scholastic theology which studies the Islamic doctrine.

> The point-based politics of standardization translates well to the world created by computers. Like the bodies described by the *kalām* atomists, digital objects are composed of minimal parts, including the on and off signals, the bit and byte of information, the pixel, and our modern term for the three-dimensional minimal part, the voxel. They are necessarily discrete, for the logic works only with minimal parts. We could consider what is "inside" these minimal parts, such as electric signals or subatomic particles. But unless these contents are uniform, they would no longer function as operable units: an electronic signal needs to be carried by enough electrons to make it signify "on."[103]

This passage unfolds atomist ideas that have been enfolded within the concept of the pixel. Moreover, Marks observes further similarities between point-based calligraphy and raster (or pixel-based) graphics. Marks argues, "the art associated with the Sunni revival adopted literally a WYSIWYG [What You See Is What You Get] aesthetics: viable forms of geometry and calligraphy corresponded exactly to religious meaning."[104] In other words, Marks relates user-friendly GUIs [Graphical User Interfaces] to religion-friendly geometry and calligraphy. However, this perceived relation seemingly ignores the importance of matrices in the production of computer-generated images.

Matrices were first used to solve a system of linear equations. For instance, matrix manipulation is the easiest way to solve the following system of equations:

$$\begin{gathered} 3x + 2y + z = 39 \\ 2x + 3y + z = 34 \\ x + 2y + 3z = 26 \end{gathered}$$

with the above equation represented by a matrix as follows:

$$\begin{vmatrix} 3 & 2 & 1 & : & 39 \\ 2 & 3 & 1 & : & 34 \\ 1 & 2 & 3 & : & 26 \end{vmatrix}$$

Rules for solving these forms of system of equations were first introduced in *The Nine Chapters on the Mathematical Art,* a Chinese book of mathematics that was composed by several generations of scholars between the tenth and second centuries BCE; however, It wasn't until the late nineteenth century that systems of matrices were formalized by mathematician Arthur Cayley. They now comprise a branch of mathematics referred to as linear algebra.[105] Matrices are the underlying structure of both

103 Marks, *Enfoldment and Infinity*, 203.
104 Ibid., 206.
105 Boyer and Merzbach, *A History of Mathematics*, 176-7.

vector graphics and raster graphics.[106] With raster graphics, the image itself is represented as a matrix [Fig. 9] and manipulating the image involves different types of matrix manipulation.[107] With vector graphics, the images are represented using mathematical descriptions of geometric objects. If points of these geometric objects are represented in specific ways by matrices, then many types of motions and deformations can be performed through matrix multiplication.[108]

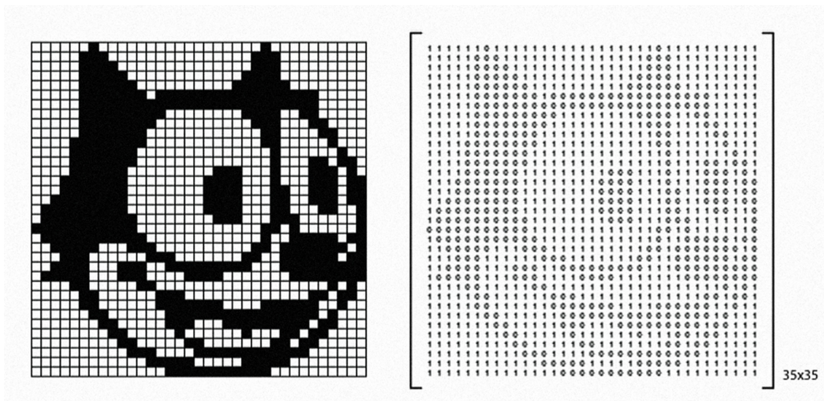

Fig. 9 – Felix the Cat as a binary (two colour) digital image and as 35 x 35 matrix.

In Chapter Eight ("Fang Cheng" [Rectangular Arrays]) of the *Nine Chapters*, matrices are introduced to solve real-life problems such as calculating yields of grain, numbers of domestic animals, and prices of different products.[109] For instance, the first problem states,

> There are three grades of grain: top, medium and low. Three sheaves of top-grade, two sheaves of medium-grade and one sheaf of low-grade are 39 Dous.[110] Two sheaves of top-grade, three sheaves of medium-grade and one sheaf of low-grade are 34 Dous. One sheaf of top-grade, two sheaves of medium-

106 Vector graphics were used in some of the earliest computer graphic systems, but they have now been largely surpassed by raster graphics, for better or worse. Marks, following the Deleuzian film scholar Sean Cubitt, suggests it is "a shame that the transparency of the vector-based screen, which allows us to see how it builds its image, gives way to the opacity of the pixel-based screen. In the vector were movement and performative, real-time connection; in the pixel, connections are hidden, movement stops, and the resulting image cannot be considered a living act" (Marks, *Enfoldment and Infinity*, 68). Whether either is to be considered "a living act" is debatable; nonetheless, there are both advantages and disadvantages in a practical comparison between vector and raster graphics, and many contemporary computer games use a combination of both.

107 For an interactive demonstration of how binary digital images are represented by matrices and how images change through matrix manipulations see: <http://www.cdme.im-uff.mat.br/matrix/matrix-html/matrix_boolean/matrix_boolean_en.html>.

108 This is a tiny more complicated than raster graphics. For a beautiful introduction see: <http://web.csulb.edu/~jchang9/m247/m247_sp12_Daniel_Kris_James_Walter.pdf>.

109 Ya-xiang Yuan, "Jiu Zhang Suan Shu and the Gauss Algorithm for Linear Equations," *Documenta Mathemathics* Optimization Stories (2012), 10.

110 Dou, a unit of dry measurement for grain in ancient China, is one deciliter.

> grade and three sheaves of low-grade are 26 Dous. How many Dous does one sheaf of top-grade, medium-grade and low-grade grain yield respectively?[111]

The technique given for solving this problem is an elimination similar to what is now referred to as Gaussian elimination. Moreover, as mathematician Ya-xiang Yuan observes, a tool similar to the abacus was used in the calculation:

> Calculations in ancient China were done by moving small wood or bamboo sticks (actually, the Chinese translation of operational research is Yun Chou which means *moving sticks*), namely addition is done by adding sticks, and subtraction is done by taking away sticks.[112]

In other words, given that moving sticks can be seen as a predecessor of the abacus, and that the instructions used to solve this problem are literally an algorithm, this traces an alternative and much older genealogy than that proposed by Marks in relation to both algorithms and computer graphics. Moreover, enfolded within the algorithm are both traces of its commercial roots, given that the initial problems dealt with yields and prices of different products, and the seeds of collaboration and knowledge sharing, given that the *Nine Chapters* was a collaborative text designed to share mathematical ideas.

The connection between the abacus and the matrix, as shown in the *Nine Chapters*, allows us to trace an alternative genealogy for the WYSIWYG methodology. The birth of the contemporary GUI system began in 1962. Working out of MIT's Lincoln Lab, Ivan Sutherland used his access to the TX-2 ("the Tixo"), the computer which originally ran the U.S. Defence Department's Project Whirlwind, to create a drawing program called Sketchpad, which Sutherland describes as "a man-machine graphical communication system," and which others have called "one of the most influential programs ever made."[113] Animation scholar Tom Sito explains:

> There was no need for any written language [with Sketchpad], no points to enter. All you did was draw and articulate some buttons marked "erase" and "move." [Sutherland] developed something called "rubber banding" where you created one point and by moving the pen you stretched a line to another

111 Yuan, "Jiu Zhang Suan Shu and the Gauss Algorithm for Linear Equations," 11. The system of equations which were stated earlier correspond to this problem.
112 Ibid., 12. [Emphasis in original.]
113 Description from Sutherland's 1988 Turing Award nomination.

> part of the screen, anchoring it as your second point. Also, you could turn objects and the entire wireframe, not just a particular line, would move as one unit.[114]

Sketchpad was the first interactive real-time graphic system that allowed the user to "draw" on the computer without typing commands.

In the same period that Sutherland was developing Sketchpad, Ken Knowlton and Michael Noll were working at Bell Labs (Bell Telephone Laboratories) developing similar software, with the goal of making computer graphics accessible to artists and filmmakers. In 1963, Knowlton developed BEFLIX (Bell Flicks), a computer program that, once loaded on the IBM 7094 through a stack of punch cards, allowed artists to directly manipulate images on a CRT monitor with a light pen. In 1966, Bell Labs paired Knowlton with experimental filmmakers Lillian Schwartz, Stan VanDerBeek, and Frank Sinden, collaborations that would produce some of the earliest computer animations, such as *Mutations* (Schwartz, 1973) and the *Poem Field* series (VanDerBeek and Knowlton, 1964–67). Knowlton explains:

> Bell Telephone Laboratories, as my colleagues and I experienced it during the 1960s and 1970s, was a beehive of scientific and technological scurrying. Practitioners within, tethered on long leashes if at all, were earnestly seeking enigmatic solutions to arcane puzzles. What happened there would have baffled millions of telephone subscribers who, knowing or not, supported the quiet circus.[115]

While a hub for artistic production in the 1960s and 1970s, Bell Labs had in fact started working with artists in the 1950s, when they sponsored visual music pioneer Mary Ellen Bute's experiments with moving image production involving an oscilloscope, an early GUI that allowed an electrical signal to be measured by analyzing the waveform generated against a graph built into the screen of the instrument.[116]

December 9, 1968, marked a major turning point in the popular understanding of GUIs. At the Joint Computer Conference in San Francisco, Dr. Douglas Engelbart and the Stanford Research

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114 Tom Sito, *Moving Innovation: A History of Computer Animation* (Cambridge: MIT Press, 2013), 42.
115 Ken Knowlton, "Portrait of the Artist as a Young Scientist," Digital Art Guild (October 2004), <http://www.digitalartguild.com/content/view/26/26/>.
116 Although it is possible to view the oscilloscope as an early GUI, there are many other examples of mechanical GUIs. For instance, consider the Arithmométre, a mass-produced mechanical calculator.

Institute (SRI) presented the "The Mother of All Demos" to over 1,000 computer enthusiasts.[117] The demo was part performance video and part computer demonstration, and was projected into the auditorium using a Eidophor video projector onto a 22' × 18' screen that used picture-in-picture and superimposition to simultaneously display a screen capture of the computer's output and live video feeds of Engelbart and his research team, some of whom were at the Stanford lab thirty miles away. Computer engineer Bill English (who helped invent the mouse) used a video switcher to control what was presented on the screen while Stewart Brand, editor of the *Whole Earth Catalog,* ran the camera.[118] In this demo, many elements that were to become fundamental to contemporary home computers were introduced to the general public for the first time: windows, hypertext, graphics, video conferencing, word processing, dynamic file linking, revision control, and navigation using a wooden mouse and keyboard. Suddenly, computer files could be managed and manipulated using a mouse and cursor instead of typed code. The demo was extremely well received, prompting a standing ovation from the crowd. Moreover, this demo was the inspiration for the WYSIWYG methodology inherent in most contemporary GUIs.

The development of GUIs established the home computer as a comprehensible, user-friendly device by making the computer "people literate" as opposed to making people "computer literate."[119] As such, the underlying code and mathematics is often hidden from the end users, creating two types of users: the abacists and the algorists. The contemporary black box nature of the computer shouldn't be

117 "The Mother of All Demos" was presented under the official title "A research centre for augmenting human intellect." In recent years, computer demos have been defined as programs "whose purpose is to present the technical and artistic skills of its makers and produce audiovisual pleasure to the viewer." Demos also "usually include various kinds of real-time computer produced graphics effects." The demo-scene distinguishes between computer demos and demonstrations of commercial products. Given this distinction, Engelbart's presentation can be seen as an early demo despite the fact that many of his innovations became incorporated in commercial products. Petri Kuittinen, "Computer Demos – The Story So Far," (April 28, 2001), <http://mlab.uiah.fi/~eye/demos/#begin>.

118 It is also worth noting that Stewart Brand helped to design the demo's presentation. Brand is a counter-culture legend who edited the *Whole Earth Catalog*, an early example of desktop publishing issued between 1969 and 1972, which promoted both hippie ideologies and the idea that computers were for everyone. The *Whole Earth Catalog* was extremely influential among early computer programmers. As observed by Sito, "dog-eared copies of the *Whole Earth Catalog* sat on workstation shelves from Hewlett-Packard (HP) to Xerox PARC." Sito, *Moving Innovation*, 93.

119 This methodology is attributed to Commodore founder Jack Tramiel envisioned building computers for "the masses, not the classes." Roberto Dillon, *Ready: A Commodore 64 Retrospective* (Singapore: Springer, 2015), 5.

surprising given that it, as previously argued, contains traces of the abacus, a tool that allows its users to perform mathematical operations without necessarily having to understand them. Moreover, the *Nine Chapters* was a collaboratively written text designed to help others understand the underlying mathematics, a trace that is found in the open-source methodology embraced by many algorists.

In this section, I am not simply trying to reveal an older genealogy than the one presented in *Enfoldment and Infinity*; I am suggesting that embedded within Marks' Islamic genealogy of media art is a mathematical fold. As previously demonstrated, the two main aspects of new media art explored by Marks, namely, the pixel and the algorithm, can also be explored in terms of their mathematical traces. Using this idea, it is possible to extend Marks' genealogy of media art beyond Islamic culture.

2.4 Under the Influence of Mathematics: The Trace of Mathematics in Twentieth-Century Media Art

Continuing the quest to discover mathematical traces within media art, in this section I look towards a few significant developments in mathematical thought that occurred at the end of nineteenth century and the beginning of the twentieth century, and compare them to aesthetic movements that developed in relative tandem. I will focus on two major mathematical developments: the discovery of non-Euclidean geometries and the formalization of mathematics. I will first examine how in the middle of the nineteenth century Euclid's fifth axiom, the parallel line postulate, was called into question, a monumental event that led to the invention of hyperbolic and elliptic geometry (i.e. non-Euclidean geometry), higher dimensional geometries, and, ultimately, to the desire to formalize mathematics. I will then describe how the desire to formalize mathematics caused a foundational crisis in mathematics prompting an epistemological crisis that gave rise to several different philosophical frameworks, all of which correspond to the different artistic movements of the era.

The root of non-Euclidean geometries lies in Euclid's fifth postulate presented in the *Elements*. The fifth postulate formally states:

> If a straight line crossing two (other) straight lines makes the interior angles on the same side less than two right angles, then, the two (other) straight lines, if extended to infinity, meet on that side on which are the angles less than the two right angles.[120]

Informally, this simply states that if two unique lines are not parallel, they will eventually cross. The most well-known equivalent statement of Euclid's fifth postulate was formulated by Scottish mathematician John Playfair, generally known as Playfair's Axiom. It states:

> For any given line *R* and point *A*, which is not on *R*, there is only one line through *A* that does not intersect *R*.

In other words, this axiom states that for every line, there is *exactly one* parallel line through any point not on the original line – a key insight into the development of non-Euclidean geometries. Many mathematicians before the mid-nineteenth century were bothered by the fifth postulate due to its complexity compared with the other postulates, and they unsuccessfully attempted to prove this axiom from the other four, often through proof by contradiction.[121] While independently attempting to prove the parallel line postulate, mathematicians Nikolai Ivanovich Lobachevsky (sometimes referred to as the "Copernicus of Geometry") and Farkas Bolyai noticed that there did not seem to be any logical contradictions when negating it, and thereby independently discovered hyperbolic geometry, or Bolyai-Lobachevskian geometry, in the early nineteenth century.[122] Hyperbolic geometry is obtained when the parallel line postulate is replaced with the following:

> For any given line *R* and point *A*, which is not on *R*, there are infinitely many lines through *A* that do not intersect *R*.

In other words, this axiom states that for every line there are *infinitely many* parallel lines through any

120 Euclid*, Elements of Geometry*, 7. [Revised slightly for clarity.]
121 One of the more elaborate attempts was by Girolamo Saccher. Boyer and Merzbach, *A History of Mathematics*, 403–404.
The axioms of Euclidean geometry are as follows:
"**Postulates**
1. Let it have been postulated to draw a straight-line from any point to any point. [It is possible to draw a straight-line through any two points.]
2. And to produce a finite straight-line continuously in a straight-line. [It is possible to extend any line.]
3. And to draw a circle with any centre and radius. [It is possible to draw a circle of any radius around any point.]
4. And that all right-angles are equal to one another. [A *right-angle* is an angle of 90° and occurs at the meeting point of two perpendicular lines.]" (Euclid*, Elements of Geometry*, 7).
122 E.T. Bell, *Men of Mathematics: The Lives and Achievements of the Great Mathematicians from Zeno to Poincaré* (New York: Simon and Schuster, 2014), 294.

point not on the original line. Hyperbolic geometry can be thought of as the geometry of a convex surface, and is an example of a non-Euclidean geometry. The first model for it was provided by Eugenio Beltrami in 1868.[123]

Another non-Euclidean geometry, discovered by mathematician G.F. Bernard Riemann, was elliptical geometry or Riemann geometry. In this geometry, the parallel line postulate is replaced with the following:

> For any given line *R* and point *P*, which is not on *R*, all lines through *A* will intersect *R*.

In other words, this axiom states that for every line there are *no* parallel lines through any point not on the original line. Elliptical geometry can be thought of as the geometry of a concave surface. Riemann went further than the other two mathematicians by generalizing their results. Boyer and Merzbach explain:

> His geometries are non-Euclidean in a far more general sense than is [Bolyai-Lobachevskian] geometry, where the question is simply *how many parallels are possible through a point*. Riemann saw that geometry should not even necessarily deal with points or lines or space in the ordinary sense, but with sets of ordered *n*-tuples that are combined according to certain rules.[124]

Riemann's generalization not only allowed us to talk about non-Euclidean geometry, but it formally introduced the concept of higher-dimensional spaces.[125]

The discovery of non-Euclidean geometry and higher-dimensional space can be seen as relating to the Cubist movement, an idea that was explored in depth by filmmaker and cinema scholar R. Bruce Elder in his 2018 book *Cubism and Futurism*. As Elder argues, in 1902 mathematician Henri Poincaré published *La Science et l'hypothèse* (*Science and Hypothesis*), a book which summarized many of the recent developments in geometry, arguing that the axioms of Euclidean geometry were only one of many possible systems and that it was possible to construct consistent geometric systems beyond three-

123 In 1871, mathematician Felix Klein coined the terms "hyperbolic" and "elliptical" geometry. Boyer and Merzbach, *A History of Mathematics,* 500.
124 Boyer and Merzbach, *A History of Mathematics*, 496.
125 For an interesting history of four-dimensional space see Florian Cajori, "Origins of Fourth Dimension Concepts," *The American Mathematical Monthly* 33, no. 8 (1926). "Inquiries into the possibility of fourth dimensional space go as far back as Greek philosophy. Nevertheless, for 2000 years no-one dared to proclaim the existence of such a space" (397).

dimensional space. Poincaré's ideas were introduced to the Cubists through mathematician Maurice Princet, “le mathématicien du cubisme” (“the mathematician of Cubism”).[126] Princet delivered informal lectures on mathematics to “la bande à Picasso” and introduced Picasso to *Traité élémentaire de géométrie à quatre dimensions* (*Elementary Treatise on the Geometry of Four Dimensions*), a 1903 book by Esprit Jouffret which made many of Poincaré's arguments in *Science and Hypothesis* accessible, as well as demonstrated how fourth-dimensional hypercubes and other complex polyhedra can be projected onto a two-dimensional page, a result which had a formative influence on Picasso.[127] Moreover, artist Jean Metzinger observed that Princet “conceived of mathematics like an artist and evoked continua of *n* dimensions as an aesthetician. He liked to interest painters in the new views of space [...] and he succeeded in doing this.”[128] By opening up space beyond illusionary optics in which a person can only perceive one perspective in a three-dimensional space at any given time, Poincaré (through Princet) opened up the possibility of perceiving the world from a purely geometric perspective, something explored by the Cubists.

In the following passage, Poincaré envisions how it is possible to “picture a world of four dimensions”:

> The images of external objects are painted on the retina, which is a plane of two dimensions; these are *perspectives*. But as eye and objects are movable, we see in succession different perspectives of the same body taken from different points of view. [...] Well, in the same way that we draw the perspective of a three-dimensional figure on a plane, so we can draw that of a four-dimensional figure on a canvas of three (or two) dimensions. To a geometer this is but child's play. We can even draw several perspectives of the same figure from several different points of view. We can easily represent to ourselves these perspectives, since they are of only three dimensions.[129]

In the same way three dimensions can be represented within a two-dimensional form, four dimensions can also be represented in two dimensions. While Poincaré saw our vision as a succession of different perspectives, Picasso drew them simultaneously, introducing a sense of spatial simultaneity. In this

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126 Arthur I Miller, *Einstein, Picasso: Space, Time, and the Beauty That Causes Havoc* (New York: Basic Books, 2001), 100.
127 Ibid., 101.
128 Quoted in Ibid.
129 Poincaré, *Science and Hypothesis*, 68-9.

way, it is possible to observe a direct influence of mathematical thought on the Cubist movement.

Although the discovery of non-Euclidean geometries allowed us to think differently about space, it also created a foundational crisis for mathematics by suggesting that some of the axioms that had been taken for granted since Euclid's *Elements* could be called into question. Furthermore, the birth of non-Euclidean geometry fundamentally challenged our preconceived notions of space, truth and even God. As Ivan argues in Dostoevsky's influential 1880 novel *The Brothers Karamazov*,

> My task is to explain to you as quickly as possible my essence, that is, what sort of man I am, what I believe in, and what I hope for, is that right? And therefore I declare that I accept God pure and simple. But this, however, needs to be noted: if God exists and if he indeed created the earth, then, as we know perfectly well, he created it in accordance with Euclidean geometry, and he created human reason with a conception of only three dimensions of space. At the same time there were and are even now geometers and philosophers, even some of the most outstanding among them, who doubt that the whole universe, or, even more broadly, the whole of being, was created purely in accordance with Euclidean geometry; they even dare to dream that two parallel lines, which according to Euclid cannot possibly meet on earth, may perhaps meet somewhere in infinity. I, my dear, have come to the conclusion that if I cannot understand even that, then it is not for me to understand about God. I humbly confess that I do not have any ability to resolve such questions, I have a Euclidean mind, an earthly mind, and therefore it is not for us to resolve things that are not of this world.[130]

If this axiom could challenge our fundamental conceptions of space and geometry, what is the basis for any truth in mathematics? As mathematician Morris Kline writes, "this new geometry drove home the idea that mathematics, for all its usefulness in organizing thought and advancing the works of man, does not offer truths but is a man-made fable having the semblance of fact."[131] More directly, the new geometry raised much more urgent questions: what other axioms do mathematicians simply take for granted, and is the underlying logic of our mathematical system even consistent?[132]

This foundational crisis of mathematics in the early twentieth century led to the search for a potential solution, formally proposed by mathematician David Hilbert in 1921, and known as the

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130 Fyodor Dostoevsky, *The Brothers Karamazov: A Novel in Four Parts with Epilogue,* Trans. Ricard Pevear and Larissa Volokhonsky (New York: Farrar, Straus and Giroux, 1990), 235.

131 Morris Kline, "Geometry," *Scientific American* 211, no. 3 (September 1964), 67.

132 A formal system is consistent if no contradictions exist, that is, there is no statement that can be formulated in the language of the system which is both true and false. Kant sees knowledge of arithmetic and geometry as *a priori* knowledge: "Geometry, however, proceeds with security in knowledge that it is completely *a priori*, and has no need to beseech philosophy for any certificate of pure and legitimate descent of its fundamental concept of space." Immanuel Kant, *Critique of Pure Reason,* trans. Norman Kemp Smith (London: Macmillan, 1929), 122.

Hilbert Program.[133] The Hilbert Program called for a consistent system based on a finite number of axioms that captured *all* of mathematics. The search for such a system began at the International Congress held in Paris in 1900, in which Hilbert delivered a much-celebrated talk. As explained by Boyer and Merzbach,

> Hilbert's talk was titled "Mathematical Problems." It consisted of an introduction that has become a classic of mathematical rhetoric, followed by a list of twenty-three problems designed to serve as examples of the kind of problem whose treatment should lead to a furthering of the discipline. In fact, on the advice of Hurwitz and Minkowski, Hilbert cut the spoken version of the talk so that it contained only ten of the twenty-three problems. Yet the complete version of the talk, as well as excerpts, were soon translated and published in several countries.[134]

The second mathematical problem proposed by Hilbert was the first step towards his generalized program, and asked "whether it can be proved that the axioms of arithmetic [Peano's axioms] are consistent – that a finite number of logical steps based on them can never lead to contradictory results."[135] This second problem was at the heart of the foundational crisis, revealing that mathematics didn't even know whether the rules for performing basic arithmetic – something that most people assumed was universal until that point – were consistent. As Elder observes in his 2013 book, *Dada, Surrealism, and the Cinematic Effect*,

> The fate of Hilbert's program only confirmed that anxiety. What Hilbert wanted to show was that no contradictions could be derived from the axioms of arithmetic, using the procedures (the methods of inference) that arithmetic judged valid. But how could one go about showing that no contradictions could be derived from the axioms of arithmetic? After all, we can imagine all the world's professional mathematicians spending many lifetimes deriving theorems that do not contradict one another, and then one day, some bright graduate student could strike on one that contradicts a known theorem. How exactly could one go about showing that it is not possible to derive a contradiction?[136]

The anxiety described by Elder resulted in mathematicians attempting to work towards creating a solid mathematical foundation; however, it also called into question the universality of mathematical truth.

Elder further argues that this foundational collapse in logical reason led to the critiques of

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133 Richard Zach, "Hilbert's Program," *The Stanford Encyclopedia of Philosophy* (Spring 2016), <https://plato.stanford.edu/archives/spr2016/entries/hilbert-program/>.
134 Boyer and Merzbach, *A History of Mathematics*, 559.
135 Ibid., 560. Peano's axioms are the axioms for the natural numbers, N* = {1, 2, 3 ...}, which allow for basic addition and multiplication and were first introduced by mathematician Giuseppe Peano in the nineteenth century.
136 R. Bruce Elder, *Dada, Surrealism, and the Cinematic Effect* (Waterloo: Wilfrid Laurier University Press, 2013), 49.

“reason's overreaching ambition”[137] found in the work of Surrealist and Dada artists. Elder argues:

> Reason's collapse, as Hilbert noted, was intolerable. Many artists concluded that reason had been exposed as an impostor and, worse, a dangerous seducer, and philosophical writings nothing more than seducers' diaries. These beliefs about reason were to play a crucial role in the artistic movements discussed in this book [*Dada, Surrealism, and the Cinematic Effect*]. Reactions to the discovery that symbol manipulation and string-rewriting processes – thought to be at the heart of all rational thinking – had severe limits reverberated through the intellectual life and culture of the twentieth century, including the arts. Logic and reason seemed feebler than they had been thought to be, and that allowed the province of other forms of thinking, including primitive modes, to expand. Philosophers and cultural theorists began to acknowledge that more savage forms of thinking were more fundamentally human than they had heretofore recognized – the proposition that “a human is a rational animal” seemed thin and weak. As a result, many thinkers (and especially vanguard artists) advocated that savage thought be granted broader scope.[138]

The Dada movement, with its embrace of the irrational and its rejection of reason and logic, can be seen as one response to these mathematical developments. Moreover, the return to the individual idea or intuition, as opposed to a formal system, was advocated by some mathematicians at the time, like L. E. J. Brouwer, who espoused a philosophy referred to as intuitionism that promoted the belief that all concepts in mathematics could be fundamentally understood using our sense of intuition. These mathematicians and artists were not incorrect in their mistrust of absolute reason, as would later be demonstrated by the discovery of Gödel's Incompleteness Theorems, discussed later in this section.

The foundational crisis at the 1900 International Congress revealed that our faith in mathematical reasoning might not be grounded; however, it also inspired mathematicians to work towards solving it.[139] To this end, the congress provoked many responses including Bertrand Russell's 1903 book *The Principles of Mathematics*, in which he argued that mathematics and logic are identical, and presented his famous paradox, now known as Russell's paradox, as a massive hurdle to overcome.[140] A decade later, Russell and Alfred North Whitehead would continue this line of reasoning

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137 Ibid., 7.
138 Ibid., 52.
139 For instance, Bertrand Russell states “it was at the International Congress of Philosophy in Paris in the year 1900 that I became aware of the importance of logical reform for the philosophy of mathematics” [Bertrand Russell, *My Philosophical Development* (New York: Simon and Schuster, 1959), 65].
140 Russell's Paradox: Let *S* be the set of all sets that are members of themselves. If *S* is a member of itself, it is not a member of itself; if *S* is not a member of itself, it is a member of itself. Informally, consider the sentence: This sentence is false. If it is true, it is false; if it is false, it is true. Formally, let S = { x : x ´ x} then S a S if and only if S ´ S.

in *Principia Mathematica*, a three-volume set in which they attempted to describe a set of axioms and rules in symbolic logic from which they believed all mathematical truths could be proven. The work avoided Russell's paradox, however, and it ultimately (and necessarily) failed to prove its own consistency. In 1908, mathematician Ernst Zermelo proposed the first axiomatic set theory which avoided Russell's paradox, and which would eventually form the basis for modern mathematics. However, once again, it also inevitably failed to demonstrate its own consistency.

Like the doubt produced by the foundational crisis, the work towards formalizing mathematics was paralleled within the humanities, as seen in various formalist movements. As Gamwell explains,

> Sensing a common purpose with formalist mathematicians (as well as linguists), Russian Constructivist artists and poets in Moscow, Saint Petersburg, and Kazan reduced their visual and verbal vocabularies to meaning-free signs and composed them as autonomous structures. [...] This research into signs and symbols came to be "formalism" in Germanic intellectual circles, "structuralism" in France, and "semiotics" in Anglo-American universities.[141]

In relation to cinema, this can be seen in both the birth of formalist film theory, and in the desire to better understand what cinema is, just as mathematicians were attempting to figure out what exactly mathematics was. Similar to the formalist approach in literature,[142] the formalization of cinema was taken on by early film theorists like Béla Balázs and Sergei Eisenstein. Both of these theorists were attempting to understand what cinema is and to figure out its basic elements. In his book *Visible Man* (1924), Balázs presented a theory of the silent film which attempted to formalize the language of physiognomy. The project is ambitious, given, in Balázs words, "the screens of the entire world are now starting to project the *first international language*, the language of gestures and facial expressions."[143] (Similarly, mathematics is often considered an international language.) He later continues, "when man finally becomes visible, he will always be able to recognize himself, despite the gulf between widely differing languages."[144] In his next book, *The Spirit of Film* (1930), he attempts to

141 Gamwell, *Mathematics + Art*, 153–54.
142 For a nice summary, see Gamwell, *Mathematics + Art*, 169–72.
143 Béla Balázs, *Béla Balázs: Early Film Theory*, ed. Erika Carter, trans. Rodney Livingstone (New York: Berghahn Books, 2010), 14.
144 Ibid., 14–5.

formalize and "outline a kind of grammar of this language [of cinema]."[145]

Eisenstein also attempted to formalize cinema in his essay "A Dialectic Approach to Film Theory," stating that he is "seeking a definition of the whole nature, the principal style and spirit of cinema from its technical (optical) basis."[146] To Eisenstein, "shot and montage are the basic elements of cinema," and through *conflict* these basic elements transform into art.[147] Moreover, Eisenstein suggests that "to determine the nature of montage is to *solve* the specific problem of cinema,"[148] a problem that he attempts to solve in a quasi-mathematical sense through formalizing the different montage forms in the essay "Methods of Montage." Eisenstein's formal approach was criticized in the widespread backlash to his film *October* (1927) for "obscurantism and self-indulgence."[149] In "Ideology as Mass Entertainment," film scholar Richard Taylor explains the perception of the film:

> The faults of Soviet cinema were thus laid at the door of an intelligentsia severed from the proletariat and an avant-garde portrayed as making films largely for its own benefit. Because the films that they produced were divorced from the masses and therefore from reality (or so the argument went), their achievement was an *empty* and a *purely formal* one. Thus the avant-garde intellectuals were tarred with the brushes of aestheticism and Formalism as well.[150]

Despite not having mass (or, more importantly, state) appeal, the film cannot simply be reduced to a formal experiment given its political and dramatic content. However, this argument can be seen as re-asserting the formal nature of the film, and one aspect of Eisenstein's project.

Another early filmmaker and theorist, Dziga Vertov, approached the same problem of formalizing cinema in a slightly different way. Vertov's writing was less systematic than that of Balázs and Eisenstein, perhaps due to the fact it was equally inspired by the form of the political manifesto. Similar to constructing axioms, one of the functions of manifestos is often to establish a new

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145 Ibid., 97.
146 Ibid., 49.
147 Ibid., 46–8.
148 Ibid., 48. [Emphasis added.]
149 Richard Taylor, "Ideology as Mass Entertainment: Boris Shumyatsky and 193 Soviet Cinema in the 1930s," in *The Film Factory : Russian and Soviet Cinema in Documents*, ed. Richard Taylor and Ian Christie, trans. Richard Taylor (Cambridge: Harvard University Press, 1988), 196.
150 Ibid.

foundational basis. One of the intentions of Vertov's essay "Kino-Eye to Radio-Eye" is to establish the foundations of cinema, and Vertov even uses a *formula* in order to describe his concept of the "kino-eye":

> Kino-eye = kino-seeing (I see through the camera) + kino-writing (I write on film with the camera) + kino-organization (I edit).[151]

In this essay, Vertov also formalizes his concept of the interval[152] and from this formalization he obtains a "*theory* of intervals."[153] His theory comes without formal proof; however, as Jay Leyda suggests, Vertov provides "practical *proofs* of his ideas."[154]

Another attempt to formalize cinema came from a slightly different angle in the writing of Germaine Dulac. Dulac was attempting to get to the essence of dramatic cinema through "pure cinema" – that is, a cinema that "did not reject sensitivity or drama, but that tried to attain them through purely visual elements."[155] Through this reduction of cinema to abstract form, Deluc even suggests that "*proofs* were to be given" for some of the properties she believed cinema had.[156] Moreover, she

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151 Dziga Vertov, "Kino-Eye to Radio-Eye," in *Kino-Eye: The Writings of Dziga Vertov*, ed. Annette Michelson, trans. Kevin O'Brien (Berkeley: University of California Press, 1984), 87.
152 Ibid, 90-1. Certove explains, "movement between shots, the visual "interval," the visual correlation of shots, is, according to kino-eye, a complex quantity. It consists of the sum of various correlations, of which the chief ones are:
1. the correlation of planes (close-up, long shot, etc.);
2. the correlation of fore shortenings;
3. the correlation of movements within the frame;
4. the correlation of light and shadow;
5. the correlation of recording speeds.
Proceeding from one or another combination of these correlations, the author determines: (1) the sequence of changes, the sequence of pieces one after another, (2) the length of each change (in feet, in frames), that is, the projection time, the viewing time of each individual image. Moreover, besides the movement between shots (the "interval"), one takes into account the visual relation between adjacent shots and of each individual shot to all others engaged in the "montage battle" that is beginning."
153 Ibid., 91. [Emphasis added.] Vertov states, "this theory known as the 'theory of intervals' was put forward by the kinoks in a variant of the manifesto "We" written in 1919."
154 Jay Leyda, *Kino: A History of the Russian and Soviet Film* (London: G. Allen & Unwin, 1960), 251. [Emphasis added.] It should be noted Leyda original states: "In this [providing a practical proof of his theory] he has failed." Leyda later changes his opinion. As Vertov suggests, "Kino-eye's position on intervals is most clearly illustrated in our work on *The Eleventh Year* (1928) and particularly, *The Man with a Movie Camera* (1929)" (Vertov, "Kino-Eye to Radio-Eye," 91).
155 Germaine Dulac, "The Avant-Garde Cinema," in *The Avant-Garde Film : A Reader of Theory and Criticism*, ed. P. Adams Sitney (New York: New York University Press, 1978), 47.
156 Ibid. [Emphasis added.] Deluc's properties are as follows:
"1. That the expression of a movement depends on its rhythm;
2. That the rhythm in itself and the development of a movement constitute the two perceptual and emotional elements which are the bases of the dramaturgy of the screen;
3. That the cinematic work must reject every aesthetic principle which does not properly belong to it and seek out its own

concludes,

> To sum it up, the avant-garde has been the abstract exploration and realization of pure thought and technique, later applied to more clearly human films. It has not only *established the foundations* of dramaturgy on the screen, but researched and cultivated all the possibilities of expression locked in the lens of the movie camera.[157]

In other words, Dulac believed that pure cinema can be seen as forming the foundations of drama in cinema. Similarly, many attempted to determine the foundations of pure mathematics; however, the introduction of Gödel's Incompleteness Theorems would radically challenge this initiative.

In 1931, Kurt Gödel released his famous paper, "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme" ("On Formally Undecidable Propositions of Principia Mathematica and Related Systems"), which contained his two famous Incompleteness Theorems. Formally, Gödel's First Incompleteness Theorem states:

> Any consistent formal system which contains Peano's axioms is incomplete.[158]

That is, in any consistent system in which you can perform basic arithmetic, there will always exist statements which are unprovable from within the system. Gödel's Second Incompleteness Theorem states:

> Any consistent system which contains Peano's axioms cannot prove its own consistency.[159]

In other words, any system that can prove its own consistency is inconsistent. These two statements dealt a death blow to Hilbert's program by demonstrating the impossibility of finding a consistent system based on a finite number of axioms that captured *all* of mathematics. Elder suggests that the

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aesthetic in the contributions of the visual;
4. That the cinematic action must be *life*.
5. That the cinematic action must not be limited to the human person, but must extend beyond it into the realm of nature and dream."

157 Ibid., 48. [Emphasis added.]

158 Panu Raatikainen, "Gödel's Incompleteness Theorems," *The Stanford Encyclopedia of Philosophy* (January 20, 2015), <https://plato.stanford.edu/archives/fall2018/entries/goedel-incompleteness/>. [Revised slightly for clarity.]
A formal system is *complete* if for every statement of the language of the system, either the statement or its negation can be proved in the system. A formal system is *consistent* if no contradictions exist, that is, there is no statement that can be formulated in the language of the system which is both true and false. Peano's axioms are the axioms for the natural numbers, N* = {1, 2, 3 ...}, which allow for basic addition and multiplication and were first introduced by mathematician Giuseppe Peano in the nineteenth century.

159 Ibid.

cultural consequences of Gödel's Incompleteness Theorems were of an equally considerable impact:

> In much the same way that many mathematicians abandoned their efforts to connect mathematics with reality and proclaimed that mathematics was simply a formal system (one that authorizes the task of rewriting one string of uninterpreted symbols into another form), many thinkers proclaimed that thought itself had been released from the duty of disclosing reality. Ideas, instead, should be judged for their ability to stimulate us, to intensify the throb and pulse of life.[160]

Here, Elder is arguing that the events that led to Gödel's Incompleteness Theorems (and ultimately the theorems themselves) led to new forms of Romanticism, and to the reduction of mathematics to simply a formal system. Moreover, this new celebration of ideas is reinforced by the birth of conceptual art, which some have argued occurred in the same era, as the artist Joseph Kosuth suggests in his essay “Art after Philosophy.” Kosuth asserts, “all art (after Duchamp) is conceptual (in nature) because art only exists conceptually.”[161]

Gödel's Incompleteness Theorems demonstrate the limitations of mathematical knowledge but were by no means the end of mathematics as we know it. As Boyer and Merzbach observe:

> In its implications, the discovery by Gödel of undecidable propositions is as disturbing as was the disclosure by Hippasus of incommensurable magnitudes, for it appears to foredoom hope of mathematical certitude through use of the obvious methods. Perhaps also doomed, as a result, is the ideal of science – to devise a set of axioms from which all phenomena of the natural world can be deduced. Nevertheless, mathematicians and scientists alike have taken the blow in stride and have continued to pile theorem on theorem at a rate greater than ever before.[162]

Starting in 1935, a non-existent mathematician of the name Nicolas Bourbaki (a pseudonym adopted by a group of French mathematicians) began to publish a series of books to formalize many areas of mathematics under the new foundation of Zermelo–Fraenkel set theory.[163] In particular Zermelo–Fraenkel set theory, combined with first-order logic, gave a satisfactory and generally accepted formalism for almost all current mathematics. Moreover, much can be said about the natural world using this mathematical system given that it captures both Peano's arithmetic and our intuitions about

160 Elder, *Dada, Surrealism, and the Cinematic Effect*, 568.
161 Joseph Kosuth, “Art After Philosophy,” in *Art After Philosophy and After* (Cambridge: MIT Press, 1993), 18.
162 Boyer and Merzbach, *A History of Mathematics*, 561.
163 In practice, most mathematicians do not work from axiomatic systems and the most preferred axiomatic system is ZFC, or Zermelo–Fraenkel set theory with the Axiom of Choice. Of course, the consistency of ZFC cannot be proved within ZFC itself (unless it is actually inconsistent), however, within ZFC it is possible to prove the consistency of Peano's axioms. It is also worth observing that even Gödel himself did not quit producing mathematics after his two incompleteness theorems.

the physical world, at least in the finite case.[164] Zermelo–Fraenkel set theory has resolved the mathematical crisis, at least for the time being; however, there continues to be a foundational crisis in other disciplines whenever an idea or concept is introduced that breaks from preconceived notions or intuitions.

Similar to the foundational crisis in mathematics (caused in part by the discovery of non-Euclidean geometry), the emergence of video in the late 1960s and early 1970s contributed to a foundational crisis for cinema. This new moving image format revealed that some of the properties that were previously thought to be necessary for the production of moving images were in fact contingent. Given this new development, both filmmakers and video artists began exploring and challenging the limits of their medium. In "A Pentagram for Conjuring the Narrative," Hollis Frampton asks,

> What are the irreducible axioms of that part of thought we call the art of film?[165]

Given the wording, the question conjures up Hilbert's program as applied to cinema, namely, a quest for an axiomatic system for cinema. P. Adams Sitney describes this quest, which I refer to as "Frampton's Program," as an attempt to define the "fundamental characteristics of cinema."[166] Frampton even explicitly references the foundational crisis in mathematics before introducing his question.

> Euclid is speaking: "Given a straight line, and a point exterior to that line, only one line may be drawn through the point that is parallel to the line." The West listens, nodding torpid assent: the proposition requires no proof. It is axiomatic, self-evident.
>
> It is not.
>
> The famous Postulate rests upon two unstated assumptions concerning the plane upon which the geometer draws: that it is infinite in extent; and that it is flat. Concerning the behaviour of those redoubtable fictions, the point and the line, in spaces that are curved, or bounded, Riemann and

164 For instance, philosopher and mathematician Feferman argues "*the actual infinite is not required for the mathematics of the physical world*" [Solomon Feferman, "Infinity in Mathematics: Is Cantor Necessary?" in *In the Light of Logic* (Oxford: Oxford University Press, 1998), 30]. [Emphasis in original.]
165 Hollis Frampton, "A Pentagram for Conjuring the Narrative," in *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, ed. Bruce Jenkins (Cambridge: MIT Press, 2009), 143.
166 P. Adams Sitney, *Visionary Film: The American Avant-Garde, 1943-2000* (Oxford: Oxford University Press, 2002), 382.

Lobachevsky have other tales to tell.[167]

Just as assumptions have been made about space, assumptions were made about moving images, which the introduction of video problematized. At this point, it shouldn't be surprising that a similar foundational crisis has emerged with the introduction of digital cinema, a crisis which will be further discussed in Chapter Ten.

Since C.P. Snow delivered his lecture on the two cultures, a surprising number of artists and theorists have developed an interest in the concept of entropy. In his paper, Snow argued that everyone in the humanities should be familiar with the Second Law of Thermodynamics. Explicitly, the Second Law of Thermodynamics states that the total entropy of an isolated system can never decrease over time. Either the system remains at equilibrium, is in a reversible process with no increase in entropy, or is increasing in entropy in an irreversible process. Aesthetically, the term has been used to describe artworks or systems that are in a state of inevitable and steady deterioration. As if attempting to prove Snow wrong, a 1966 paper titled "Entropy and the New Monuments" by artist Robert Smithson argues that the Second Law of Thermodynamics has been used by many artists:

> In a rather round-about way, many of the artists have provided a visible analog for the Second Law of Thermodynamics, which extrapolates the range of entropy by telling us energy is more easily lost than obtained, and that in the ultimate future the whole universe will burn out and be transformed into an all-encompassing sameness.[168]

The concept was further expanded upon in Rudolf Arnheim's 1971 book, *Art and Entropy*. Directly responding to Smithson's essay, Arnheim was critical of its use in explaining minimalist artworks:

> Occasional explicit references to entropy can be found in critical writing. Richard Kostelanetz, in an article on "Inferential Arts," quotes Robert Smithson's "Entropy and the New Monuments" as saying of recent towering sculptures of basic shapes that they are "not built for the ages but rather against the ages" and "have provided a visible analogue for the Second Law of Thermodynamics." Surely the popular use of the notion of entropy has changed. If during the last century it served to diagnose, explain, and deplore the degradation of culture, it now provides a positive rationale for "minimal" art and the pleasures of chaos.[169]

167 Ibid., 142.
168 Robert Smithson, "Entropy and the New Monuments," in *Robert Smithson: The Collected Writings*, ed. Jack Flam (Berkeley: University of California Press, 1996), 11.
169 Rudolf Arnheim, *Entropy and Art: An Essay on Disorder and Order* (Berkeley: University of California Press, 1971), 11.

The main argument of Arnheim's book is that "a high level of structural order is a *necessary* but not a sufficient prerequisite of art."[170] In other words, Arnheim is arguing for a form of equilibrium, one in which disorder is employed by the artist to create tension in otherwise ordered or structured works.

Both Arnheim and Smithson can be seen as providing a counter-response to Snow's Second Law of Thermodynamics challenge. This chapter demonstrates some of the other ways in which mathematical developments have implicitly influenced developments in the arts, further establishing the fallacy of Snow's two cultures dichotomy. Regardless of whether or not the two cultures are in direct dialogue, it is impossible to ignore the impact they have had on each other. Given that direct dialogue is often rare, the genealogy traced here is highly speculative in nature. Nevertheless, this genealogy provides us with new ways of thinking about the ways in which some art movements have developed and the ways in which traces of mathematics have become embedded within media art.

170 Ibid., 55. [Emphasis added.]

CHAPTER THREE: COMMUNICATING WITH MATHEMATICS

Nonsense is better than no sense at all.
– NoMeansNo, "*0+2=1*"

Stuart Hall's formative 1973 essay "Encoding/Decoding" develops a cultural framework to examine the ways in which media messages are produced, disseminated, and interpreted.[171] Hall's model can be understood as a response to the questions posed by the American scientist Warren Weaver in his explanation of mathematician Claude E. Shannon's 1948 article, "The Mathematical Theory of Communication." Shannon's was a historically important paper that established a branch of mathematics referred to as information theory.[172] Weaver's interpretation of Shannon's model was an attempt to make Shannon's discoveries accessible to a larger audience by providing a plain-language interpretation of the mathematics involved. In his article, Weaver argues that the mathematical framework provided by Shannon does not only impact the technical aspect of sending and receiving messages, but can also be applied to interpretation.

It is my contention that Hall's cultural model is a truncated cultural variation of Shannon's mathematical model; as such, it is possible to re-examine Hall's model within a mathematical context in order to re-evaluate it and to further develop potential cultural interpretations. In this section, I will provide a brief summary of Hall's article, Shannon's theory and Weaver's response. Moreover, I will present an extended version of Hall's cultural framework and suggest the ways in which it can be used to examine how experimental media makers disrupt and subvert dominant modes of media production and interpretation in an attempt to allow for more complex forms of communication.

171 "Encoding/Decoding" is an edited version of a paper originally published as "Encoding and Decoding in Television Discourse," *CCCS Stencilled Paper*, no. 7 (1973), 128-39.
172 Although Hall does not explicitly reference Shannon's model, they share an underlying structure, and Hall's essay can be read as response to the cultural questions posed by Weaver. During that period, there were other cultural theorists, such as Marshall McLuhan and Rudolf Arnheim, who were actively engaging with Shannon's model, so it is likely that Hall would have been aware of the model in one form or another.

3.1 Encoding/Decoding: From Math Culture to Mass Culture

Shannon's ground-breaking 1948 paper "The Mathematical Theory of Communication" was an attempt to provide the foundations for a general theory of communication. The paper is elegant and imaginative and, according to Weaver, "exceedingly general in its scope, fundamental in the problems it treats, and of classic simplicity and power in the results it reaches."[173] Given the importance of Shannon's results and the relative difficulty of the mathematics associated with the paper, Weaver attempted to make its results more accessible to a general audience, in a paper titled "Recent Contributions to the Mathematical Theory of Communication."[174] In non-technical terms, Weaver describes the types of problems that Shannon was attempting to solve:

> a. How does one measure *amount of information*?
> b. How does one measure the *capacity* of a communication channel?
> c. The action of the transmitter in changing the message into the signal often involves a coding process. What are the characters of an efficient coding process? And when the coding is as efficient as possible, at what rate can the channel convey information?
> d. What are the general characteristics of *noise*? How does noise affect the accuracy of the message finally received at the destination? How can one minimize the undesirable effects of noise, and to what extent can they be eliminated?
> e. If the signal being transmitted is *continuous* (as in oral speech or music) rather than being formed of discrete symbols (as in written speech, telegraphy, etc.), how does this affect the problem?[175]

In his paper, Weaver clearly and succinctly describes Shannon's results; perhaps more importantly, he suggests that the reach of Shannon's model extends far beyond the technical problems associated with the transmission of information.

Shannon's theory of communication consists of five parts: First, there is the *information source*, which selects a message out of a set of possible messages. For instance, the message could be a discrete set of symbols (e.g. written words), a continuous function dependent on time (e.g. sound), or several continuous functions dependent on time and other variables (e.g. colour television). Second, there is a *transmitter*, which codes the message into a signal that can be transmitted over a channel. A basic

173 Warren Weaver, "Recent Contributions to the Mathematical Theory of Communication," in *The Mathematical Theory of Communication* (Urbana: University of Illinois Press, 1998), 25.
174 A condensed version of this paper appeared in *Scientific American* in July 1949.
175 Weaver, "Recent Contributions to the Mathematical Theory of Communication," 8. [Emphasis in original.]

example would be telegraphy, which transforms words into a sequence of dots, dashes and spaces using Morse code, or the telephone, which changes sound vibrations into an electronic current. Third, there is the *communication channel*, the medium used to send the signal from the transmitter to the receiver. For instance, in telegraphy the channel is a wire and the signal is the varying electric current corresponding to the encoded message. Within the transmission there is often unwanted interference in the communication channel, leading to disruptions in the signal referred to as *noise* (e.g. radio static). Fourth, there is the *receiver*, which changes the signal back into the message. Of course, if there is too much noise the message may contain errors or be misinterpreted by the receiver. Finally, there is the *destination*, which is the person (or object) that receives the message.

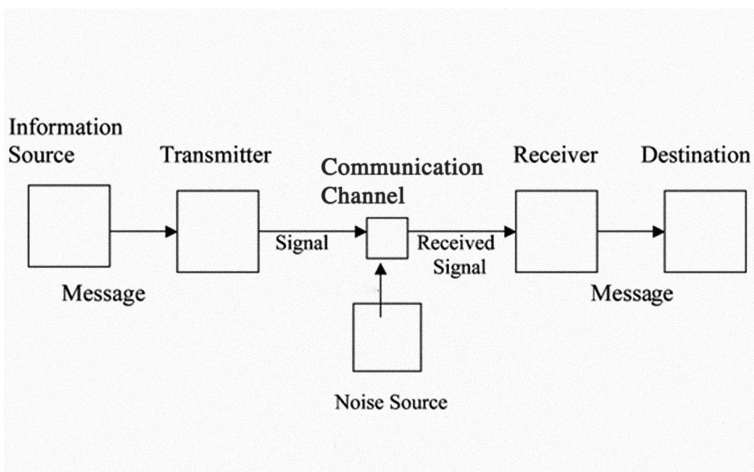

Fig. 10 – Shannon's Mathematical Model of Communication.

While describing his model, Shannon states that the “semantic aspects of communication are irrelevant to the engineering problem.”[176] While this is true, Weaver argues this does not imply that engineering problems are irrelevant to those interested in the semantic aspects of communication. For Weaver, Shannon's theory of communication can be applied to a much broader definition of communication, for example, “equally well to music of any sort, and to still or moving pictures as in television.”[177] Weaver observes that Shannon's model can be used to discuss the interpretation of the

176 Claude Shannon, *The Mathematical Theory of Communication* (Urbana: University of Illinois Press, 1998), 31.
177 Weaver, “Recent Contributions to the Mathematical Theory of Communication,” 3-4.

messages with "minor additions, and no real revision."[178] For instance, Weaver argues,

> One can imagine, as an addition to the diagram, another box labeled "Semantic Receiver" interposed between the engineering receiver (which changes signals to messages) and the destination. The semantic receiver subjects the message to a second decoding, the demand on this one being that it must match the statistical *semantic* characteristics of the message to the statistical semantic capacities of the totality of receivers, or of that subset of receivers which constitute the audience one wishes to affect.[179]

Of course, adopting an additional box labeled "Semantic Receiver" might be one way of transforming Shannon's model into one that is relevant to cultural theorists. However, Weaver's suggestion that the relevance of this model extends beyond its importance to engineers was more efficiently taken up a few decades later by cultural theorist Stuart Hall in "Encoding/Decoding."

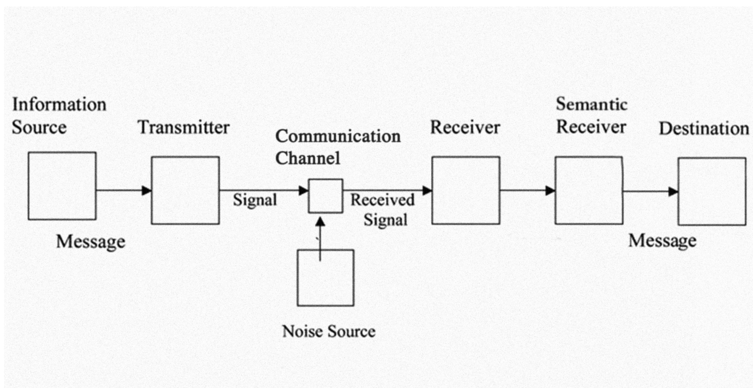

Fig. 11 – Shannon's Model with Weaver's suggested "Semantic Receiver."

In his paper, Hall creates a cultural model of communication that seemingly replicates Shannon's model in order to critique what he perceives as the dominant cultural model of mass communication, a "circulation circuit or loop" simply consisting of "sender/message/receiver."[180] In challenging the dominant model, Hall was attempting to re-evaluate how mass media messages are produced, distributed and received. By re-imagining Shannon's framework in a manner similar to the one Weaver suggested a few decades earlier, Hall's cultural model can be read as a semantic interpretation of Shannon's mathematical model. To Hall, mass media messages are encoded through

178 Ibid., 26.
179 Weaver, "Recent Contributions to the Mathematical Theory of Communication," 26. [Emphasis in original.]
180 Stuart Hall, "Encoding/Decoding," in *Language Culture, Media, Language Working Papers in Cultural Studies, 1972 – 79*, ed. Stuart Hall et al. (London: Hutchinson, 1980), 128.

the production of the message. In other words, the mass media producers act in a similar manner to the transmitter in Shannon's model: they transform a message using a system of coded meanings, determined by "the institutional-societal relations of production,"[181] into a programme which they expect their intended audience to be able to meaningfully interpret. Shannon's communication channel in Hall's model is the programme itself. Finally, the receiver in Hall's model is the viewer of the programme and is similar to Weaver's imagined "semantic receiver." In this way, Hall's model can be read as a cultural interpretation of Shannon's model.

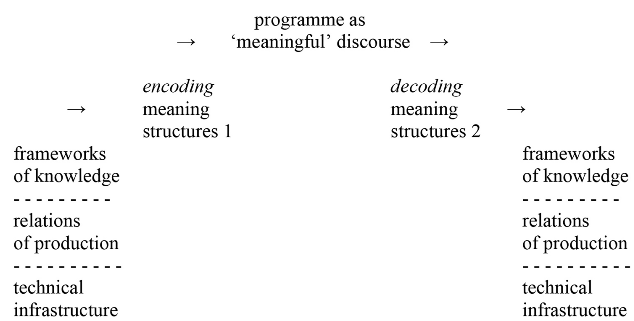

Fig. 12 – Hall's Cultural Model of Communication.

A considerable critique of Shannon's model came from Marshall McLuhan, who argued that it is simply a theory of transportation that "has nothing to do with the effects these forms have on you."[182] According to media theorist and McLuhan scholar Janine Marchessault, McLuhan saw Hall's model as having "limited use (at least for the humanistic scholars) because of its disconnected and closed approach to studying technology."[183] In response, McLuhan put forward a theory of transformation which studies "how people are changed by the instruments they employ."[184] In other words, for McLuhan, the embodied experience of communication ran counter to a linear model of communication

181 Ibid., 130.
182 Alexander Kuskis, "Claude Shannon's Transportation Theory of Communication Versus Marshall McLuhan's Transformation Theory," *McLuhan Galaxy* (June 27, 2017). <https://mcluhangalaxy.wordpress.com/2017/06/27/claude-shannons-transportation-theory-of-communication-versus-marshall-mcluhans-transformation-theory/>.
183 Janine Marchessault, *Marshall McLuhan: Cosmic Media* (London: SAGE, 2004), 85.
184 Kuskis, "Claude Shannon's Transportation Theory of Communication Versus Marshall McLuhan's Transformation Theory."

that was originally designed for machines. As described by communications scholar John Durham Peters, "McLuhan sought to create a vision of communication based not on transporting content but moving souls."[185]

Hall's model, like Shannon's, is about the effectiveness of communication, not about its phenomenological effects; however, by envisioning his model as a circulation loop, Hall avoids one aspect of McLuhan's critique by acknowledging that media has the ability to change us and vice versa. McLuhan saw communication "as transformation of source and target simultaneously."[186] While this may be true of communication between two people, the objects we are dealing with are moving images, that is, static sources.[187] Hall acknowledges the target as able to undergo transformation and as an active participant. To this end, Hall suggests that a viewer "*is operating inside the dominant code*"[188] if they simply respond to a message produced by mass media in the way that the broadcaster intended it to be received. Given that not all viewers operate within the dominant code, Hall attempts to understand viewers that actively misread the broadcaster's intended message.

When Hall uses the term "misunderstanding," he is not referring to a literal misunderstanding. He is referring to the ways in which an active audience fails to read the message in the way that broadcasters encode it:

> Television producers who find their message 'failing to get across' are frequently concerned to straighten out the kinks in the communication chain, thus facilitating the 'effectiveness' of their communication. Much research which claims the objectivity of 'policy-oriented analysis' reproduces this administrative goal by attempting to discover how much of a message the audience recalls and to improve the extent of understanding. No doubt misunderstandings of a literal kind do exist. The viewer does not know the terms employed, cannot follow the complex logic of argument or exposition, is unfamiliar with the language, find the concepts too alien or difficult or is foxed by the expository narrative. But more often broadcasters are concerned that the audience has failed to take the meaning as they – the broadcasters – intended.[189]

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185 John Durham Peters, "McLuhan's Grammatical Theology," *Canadian Journal of Communication* 36, no. 2 (August 4, 2011), 231.
186 Richard Cavell, *McLuhan in Space: A Cultural Geography* (Toronto: University of Toronto Press, 2002), 5.
187 To clarify, this is not to say that their readings aren't historically or socially contingent, just that the object itself remains the same.
188 Hall, "Encoding/Decoding," 136. [Emphasis in original.]
189 Ibid., 135.

In other words, Hall is not concerned with a “misunderstanding” of an encoded message due to incompetence from either the broadcaster or the audience, but with alternative positions from which a competent viewer can decode mass media messages. In his essay, Hall defines three positions from which messages can be decoded: the dominant-hegemonic position, the negotiated position and the oppositional position.

Despite Hall envisioning the viewer to be an active one, a major limitation of Hall's model is that the producer is always assumed to be working within the dominant ideology. Since Hall has restricted his model to broadcasters, this does not seem to pose a problem; however, as media theorist Sven Ross observes in his paper “The Encoding/Decoding Model Revisited,”

> If we assume other encoding possibilities, like a reception analysis of a text encoded within a radical framework, for example an independent film criticizing the prevailing social system, it becomes problematic. If the reader understands the text and agrees with it he or she is probably oppositional in relation to the dominant ideology of society but not oppositional to the message of the text. And the other way round, if you read it from a dominant-hegemonic ideological position you will be oppositional in relation to the text, but not in relation to the dominant ideology.[190]

The problems, Ross argues, arise within Hall's model if one assumes that the producer is not working from the dominant-hegemonic position. Moreover, as Ross and other scholars have observed, in Hall's model it is difficult to distinguish between the viewer's evaluation of the text itself and the viewer's evaluation of the text's ideology. In order to overcome these problems, Ross offers “two alternative typologies”[191] that extend Hall's model, creating the Ross-Hall model of communication. First, Ross' extension allows the message to be encoded from a dominant-hegemonic position (Hall's assumed position), the negotiated position (a partly critical text) and the oppositional position (a radical text). Second, Ross suggests that the model be split into two parts, with the first part dealing with readings of the text itself, and with the second part dealing with the ideological position of the text, allowing the viewer to agree or disagree with the meaning of a text independent of its ideological position. For

190 Sven Ross, “The Encoding/Decoding Model Revisited,” (presented at the Annual Meeting of the International Communication Association in Boston, Massachusetts on May 25, 2011), 4.
191 Ibid., 12.

instance, it is possible to agree with the ideology of a text without necessarily agreeing with the content of the text itself. Furthermore, it is possible to agree with the content of a text encoded within the dominant-ideology while still being opposed to the ideology in which the text was encoded.

		ENCODING POSITIONS		
		Dominant-hegemonic encoding (Hall's assumed mode)	**Negotiated encoding (partly critical text)**	**Oppositional encoding (a radical text)**
DECODING POSITIONS (ideological)	**Dominant-hegemonic position**	Dominant-hegemonic reading of dominant-hegemonic text	Dominant-hegemonic reading of negotiated text *=Neutralization*	Dominant-hegemonic reading of oppositional text *=Neutralization*
	Negotiated position	Negotiated reading of dominant-hegemonic text	Negotiated reading of negotiated text	Negotiated reading of oppositional text
	Oppositional position	Oppositional reading of dominant-hegemonic text	Oppositional reading of negotiated text *=Amplification of critique*	Oppositional reading of oppositional text *=Agreement with oppositional text*

		ENCODING POSITIONS		
		Dominant-hegemonic encoding (Hall' assumed mode)	**Negotiated encoding (partly critical text)**	**Oppositional encoding (radical text)**
DECODING POSITIONS (text-relative)	**Text-accepting position**	Text-acceptance of dominant-hegemonic text	Text-acceptance of negotiated text	Text-acceptance of oppositional text
	Text-negotiation position	Negotiation of dominant-hegemonic text	Negotiation of negotiated text	Negotiation of oppositional text
	Text-oppositional position	Text-oppositional reading of dominant-hegemonic text	Text-oppositional reading of negotiated text	Text-oppositional reading of oppositional text *=Neutralization*

Fig. 13 – Ross-Hall Model of Communication.

Given that the Ross-Hall cultural model of communication seems to replicate Shannon's mathematical model, it is possible to observe that both of their models are missing one essential element of Shannon's model: *noise*. I conjecture that these models do not deal with noise because they are only considering producers, both independent and mainstream, that are attempting to produce media that conform to established methods of communication. In the next section, I will introduce an expanded version of the Ross-Hall model of communication, arguing that some experimental media artists disrupt the Ross-Hall model of communication by intentionally introducing uncertainty into their work, either by breaking from established conventions or by literally introducing noise into the signal.

3.2 Introducing Uncertainty: Expanding the Ross-Hall Cultural Model of Communication

Given that the Ross-Hall model only seems to describe forms of communication that conform to established models, it is natural to extend their model to include producers that are experimenting or deviating from these conventions. By comparing the Ross-Hall model to Shannon's model of communication, it becomes apparent that there has been at least one significant oversight, namely, that the model neglects noisy signals. Allowing certain types of noise into the model allows us to discuss producers that literally experiment with noise and signal decay, or that employ strategies involving formal abstraction. Given that noise is beyond the functionality of message communication, some might argue that is where the art lies. In his discussion of Shannon's model, Weaver provides a list of *undesirable noise* or "certain things added to the signal which *were not intended* by the information source."[192] Weaver's list includes the various ways in which noise can disrupt the communication signal itself:

> The *unwanted* additions may be distortions of sound (in telephony, for example) or static (in radio), or distortions in shape or shading of picture (televisions), or errors in transmission (telegraphy or facsimile), etc. All of these changes in the transmitted signal are called *noise*.[193]

Although these types of disruptions can occur organically through signal interference, many artists experiment with signal disruptions and do not view them not as *unwanted* phenomenon, but as desirable. As McLuhan famously declared, "what they call 'NOISE,' I call the *medium* – that is, all the side-effects, all the unintended patterns and changes."[194]

Consider John Cage's 1937 article "The Future of Music: Credo" in which he suggests that "the sound of a truck at fifty miles per hour," the "static between the stations" and "rain" can be used "not as sound effects, but as musical instruments"[195]; or Nam June Paik's *Magnet TV* (1965), an early example of Paik's prepared televisions in which a magnetic field is introduced to distort a television

192 Weaver, "Recent Contributions to the Mathematical Theory of Communication," 7. [Emphasis added.]
193 Ibid. [Emphasis slightly changed from original.]
194 Cavell, *McLuhan in Space,* 5.
195 John Cage, "The Future of Music: Credo," in *Audio Culture: Readings in Modern Music* (New York: Continuum, 2004), 25–26.

image; or the “fax art” described in Karen O'Rourke's *New Observations* article, “Notes on 'Fax-Art'.”[196] Some of these forms of noise have even been incorporated into mainstream productions, suggesting that meaningful cultural conventions for encoding and decoding these forms of noise have already been established. This reinforces the idea that media conventions, like other cultural conventions, are historically contingent. In others words, it is possible to transform noise into a desired signal.

In mathematics, the encoding and decoding of information are implicitly connected and based upon a predetermined set of rules. By contrast, in communication studies the bond between encoding and decoding messages is slightly more complicated and is based upon cultural codes and conventions. As observed by Hall, “there is no intelligible discourse without the operation of a code.”[197] Hall describes the application of such codes as follows:

> Certain codes may, of course, be widely distributed in a specific language community or culture and be learned at so early an age, that they appear not to be constructed – the effect of an articulation between sign and referent – but to be 'naturally' given. Simple visual signs appear to have achieved a 'near universality' in this sense: though evidence remains that even apparently 'natural' visual codes are culture-specific. However, this does not mean that no codes have intervened; rather, that the codes have been profoundly *naturalized.* [...] Actually, what naturalized codes demonstrate is the degree of habituation produced when there is a fundamental alignment and reciprocity – an achieved equivalence – between the encoding and decoding sides of an exchange meaning.[198]

As Hall explains, cultural codes are *naturalized* by those involved in the communication system. That is, they are subconscious within the system while still being essential for meaningful exchanges. Despite the fact that codes have, for the most part, become naturalized (unlike the mathematical model in which they are formalized), the encoder and decoder still have agency, and it is possible for both to become conscious of the codes they have been implicitly employing and consequently to challenge their conventions – this activity is, in essence, what Hall refers to as the “politics of signification.”[199]

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196 Karen O'Rourke, “Notes on 'Fax-Art',” *New Observations* 76 (May-June 1990): 24–5.
197 Hall, “Encoding/Decoding,” 131.
198 Ibid., 132.
199 Ibid., 138. Media producers were also directly engaging with this form of politics of signification. Consider, *Television Delivers People* (1973) by Richard Serra and Carlota Fay Schoolman, a video that attempts to reveal the corporate structures inherent in the information industry, produced the same year as “Encoding/Decoding.”

To Hall, it is the viewer who engages with the politics of signification, and it is the viewer that recognizes and challenges the dominant-hegemonic codes inherent in the communication system. The Ross-Hall model of communication extends the Hall model by considering producers that make work outside of the dominant ideology, including producers that engage with the politics of signification. This model does not, however, include producers that deviate from the dominant modes of communication and experiment with abstraction and ambiguity. In order to expand the Ross-Hall model to include producers of experimental media, I will first examine some of the specific results of Shannon's theory of communication.

As a bit of an aside, it is worth commenting on the methodology employed by Abraham Moles in his book *Théorie de l'information et perception esthétique* (*Information Theory and Esthetic Perception*), given that he also sought to develop a psychological theory of perception based on Shannon's model. Moles describes the scope of his book as follows:

> Our purpose here will be to show the role information theory plays in the mechanisms of perception and more particularly of esthetic perception. The theory is recent, and this field of application seems to have been nearly ignored by the theory's authors, whose outlook has been rather technical. We shall try as we go along to note the simplest and most immediate philosophic consequences of the theory, but we shall limit our subject to the field of objective or experimental psychology. The extrapolation of a new theory is indeed particularly dangerous because its limits of validity are uncertain and the normal method of extrapolation, logical extension, possesses no assured value.[200]

In an attempt to examine the philosophical consequences of Shannon's theory on aesthetic perception, Moles often ends in naïve attempts to quantitatively measure aesthetic concepts by treating aesthetics in a mathematical manner. In order to avoid these pitfalls, I will not attempt to directly translate concepts from semantics and aesthetics into a mathematical theory, but will instead develop cultural interpretations by examining the mathematical results associated with Shannon's Model.

3.3 Expanded Media: Cultural Interpretations of Shannon's Model

One of the most remarkable elements of information theory is its connection to the thermodynamic concept of *entropy.* As observed by Weaver, “to those who have studied the physical sciences, it is

200 Abraham A. Moles, *Information Theory and Esthetic Perception* (Urbana: University of Illinois Press, 1966), 4.

most significant that an entropy-like expression appears in the theory as a measure of information."[201] Information in Shannon's mathematical model is defined in a way that is quite different from its natural language usage. Weaver clarifies, "the word information in communication theory relates not so much to what you *do* say, as to what you *could* say."[202] One of the significant aspects of Shannon's model is that the sender (or information source) selects a message out of a set of possible messages; as Weaver notes, "information is a measure of one's freedom of choice when one selects a message."[203] Again, as Shannon definitively (and correctly) declared, semantics is irrelevant to the mathematical model.

In Shannon's model, entropy (often referred to as "Shannon's entropy") is the measure of the unpredictability or uncertainty of the information being sent and can be determined by a formula that uses the probability that a given outcome might occur. For instance, a coin toss involving a fair coin has relatively high entropy since there is no way to predict the coin toss ahead of time. In contrast, a toss involving a double-sided coin has zero entropy since the outcome can be perfectly predicted. In other words, the higher the unpredictability, the higher the entropy measure. The English language has a relatively low entropy measure given its fairly rigid grammatical structure. The connection between entropy and information is natural. Weaver explains:

> That information be measured in entropy is, after all, natural when we remember that information, in communication theory, is associated with the amount of freedom of choice we have in constructing messages. Thus for a communication source one can say, just as he would also say it of a thermodynamic ensemble, "this situation is highly organized, it is not characterized by a large degree of randomness or of choice – that is to say, the information (or entropy) is low."[204]

In other words, entropy is the amount of choice that one has in choosing the message.

In the cultural model, the producer is the one selecting the message. The greater the freedom of choice in selecting a message, the greater the information, that is, the higher the entropy. From another perspective, those working within the dominant ideology have less freedom of choice in constructing

201 Weaver, "Recent Contributions to the Mathematical Theory of Communication," 12. [Emphasis in original.]
202 Ibid., 8.
203 Ibid., 9.
204 Ibid., 13.

their messages than those working within an experimental framework, suggesting that the former have less entropy than the latter. Similarly, those working within an experimental framework seem to have significantly more choice in their messages than those working within the mainstream, suggesting that messages produced by those working within an experimental framework have more entropy than those produced within more conventional frameworks.

By working outside of established cultural conventions and norms, experimental artists have more choice – that is, there is a higher degree of freedom in the production of their work. As observed by the American mathematician and philosopher Norbert Wiener in *The Human Use of Human Beings*:

> Messages are themselves a form of pattern and organization. Indeed, it is possible to treat sets of messages as having an entropy like sets of states of the external world. Just as entropy is a measure of disorganization, the information carried by a set of messages is a measure of organization. In fact, it is possible to interpret the information carried by a message as essentially the negative of its entropy, and the negative logarithm of its probability. That is, the more probable the message, the less information it gives. Clichés, for example, are less illuminating than great poems.[205]

Compare the freedom of word usage in poetry to that of conventional novels. Conventional novels follow a fairly rigid structure and grammar, whereas contemporary poetry often challenges these conventions. For instance, the phrase “He he he he and he” is extremely improbable in natural language; however, it is precisely this phrase that we encounter in Gertrude Stein's 1923 portrait of her friend Pablo Picasso titled “If I Told Him / A Completed Portrait of Picasso.” Although it has been argued that Stein's poem is more illuminating than a conventional biography of Picasso and, at the very least, is far more imaginative, there are still many readers that find Stein's prose unintelligible.[206]

Although higher entropy means more freedom to produce messages that are innovative, unconventional or subversive, it also means that there is more uncertainty for the viewer since there is more uncertainty about the message intended by the producer. These uncertainties disrupt a certain power dynamic between the artist and the viewer. By following established conventions, the mass

205 Norbert Wiener, *The Human Use of Human Beings* (Boston: Houghton Mifflin Company, 1950), 21.
206 See Linda Voris, “'Shutters Shut and Open': Making Sense of Gertrude Stein's Second Portrait of Picasso,” *Studies in American Fiction* 39, no. 2 (November 8, 2012): 175–205. On the other hand, my grandmother, an avid reader, finds Stein incomprehensible.

media producer simply invites the user to decode the intended message. By deviating from these conventions, experimental producers increase complexity and the potential for novelty while introducing uncertainty for the viewer, providing the viewer with more freedom to interpret the intended message of their work. This increase in entropy in the encoding phase leads to an increase in uncertainty in the decoding phase, generating greater complexity and the potential transmission of ideas that deviate from established norms, allowing for the possibility of novel forms of political, spiritual, emotional or aesthetic engagement.

As media theorist Gene Youngblood suggests in a section of *Expanded Cinema* titled “Art, Entertainment, Entropy,”

> Art is freedom from the conditions of memory; entertainment is conditional on a present that is conditioned on the past. Entertainment gives us what we want; art gives us what we don't know we want. To confront a work of art is to confront oneself – but aspects of oneself previously unrecognized.[207]

Youngblood is arguing for “an expanded cinematic language”[208] that offers a form of freedom to the viewer by not simply following preconceived formulas. To Youngblood, following established formulas appeals to memory and “encourages an unthinking response to daily life,”[209] while breaking from them promotes self-awareness, creativity and allows the audience to “appreciate and participate in the creative process.”[210] In arguing for an expanded cinematic language, Youngblood offers one of the first cultural interpretations of Shannon's model in terms of entropy:

> In communication theory and the laws of thermodynamics the quantity called entropy is the amount of energy reversibly exchanged from one system in the universe to another. Entropy also is the measure of disorder within those systems. It measures the lack of information about the structure of the system. For our purposes “structure of the system” should be taken to mean “the human condition,” the universal subject of aesthetic activity. Entropy should be understood as the degree of our ignorance about that condition. Ignorance always increases when a system's messages are redundant. Ignorance is not a state of limbo in which no information exists, but rather a state of increasing chaos due to *mis*information about the structure of the system.[211]

Youngblood is attempting to equate scientific and aesthetic concepts but it is unclear, at least to me,

207 Gene Youngblood, *Expanded Cinema* (New York: Dutton, 1970), 60.
208 Ibid., 59.
209 Ibid., 60.
210 Ibid., 59.
211 Ibid., 62.

why he would equate the "structure of the system" to "the human condition," since the model he is dealing with is communication. In other words, this seems superfluous since a model of communication can be both cultural and scientific.

Youngblood makes one other significant mistake while developing a cultural interpretation for Shannon's model by insisting "the noted authority on communication theory, J. R. Pierce, has demonstrated that an increase in entropy means a decrease in the ability to change."[212] He uses this appeal to authority to conclude that "we have found entertainment to be inherently entropic, opposed to change, and art to be inherently negentropic, a catalyst to change."[213] Yet, Youngblood – in his ever-optimistic desire for experimental cinema to be a force of revolutionary change – seems to have conflated two related ideas: the entropy associated with thermodynamics, and that of information theory. More precisely, J.R. Pierce states, "an increase in entropy means a decrease in our ability to change thermal energy, the energy of heat, into mechanical energy"[214]; however, in direct opposition to Youngblood's conclusion, Pierce also argues, "entropy increases as the number of messages among which the source may choose increases."[215] In other words, experimental forms of communication often have *higher entropy* than conventional forms of communication and, as Youngblood desires, thereby expand the cinematic language. Moreover, the higher the entropy the greater the disorder, suggesting that expanding the cinematic language increases disorder in the system. This is what potentially makes experimental communication more complex. Once again, the disorder introduced into the system is a double-edged sword, as it allows for the creation of novel forms of expression while simultaneously generating uncertainty in the viewer.

Youngblood's mistake is quite common. In fact, it is precisely this type of slippage that

212 Ibid., 65.
213 Ibid.
214 John Robinson Pierce, *Symbols, Signals, and Noise: The Nature and Process of Communication* (New York: Harper, 1961), 22.
215 Ibid., 81.

prompted cultural theorist Rudolf Arnheim to warn against aesthetic interpretations of information theory in *Entropy and Art,* a book that is perhaps the best response to C.P. Snow's controversial claim that literary intellectuals are ignorant of The Second Law of Thermodynamics. To Arnheim, "dealing with structure, as is constantly done in the arts, regularity of form is not redundancy. It does not diminish information and thereby diminish order." He continues: "the word 'information,' taken literally, means to give form; and form needs structure. This is why the tempting prospect of applying information theory to the arts and thereby reducing aesthetic form to quantitative measurement has remained largely unrewarding."[216] Arnheim provides a concrete example to illustrate his point:

> He [the information theorist] asks how likely is a particular melody written by Mozart to continue in a certain way, given the tone sequences Mozart is known to have written on previous occasions. The less predictable the sequence, the more information the sequence will be said to yield, and if information is identified with order, the paradox I mentioned will occur and the least structured sequence will be called the most orderly.[217]

Arnheim's observations seem valid, although all we can conclude is that Shannon's model provides counter-intuitive results if "information is identified with order."[218] However, as previously argued, increased information, namely, an increase in the freedom of message choice, leads to disorder which increases complexity. This suggests that the correlation between information and complexity does correspond to our intuition that information corresponds with order. In other words, in this model, information actually is related to disorder.

In his critique, Arnheim also seems to confuse *cultural redundancy* with the mathematical concept of redundancy. Redundancy, in information theory, is built into a transmitted signal in order for the receiver to be able to decode the intended message over a noisy channel. One of the most unsophisticated redundancy schemes is simply to repeat the message. Arnheim seems to view cultural redundancy in precisely these terms. He states "any predictable regularity is termed redundant by the

216 Arnheim, *Entropy and Art*, 18.
217 Ibid., 19.
218 The information theorist Arnheim is implicitly critiquing is none other than Moles who in *Information Theory and Esthetic Perception* claims it is possible to objectively define the originality of a program of symphonic works (28).

information theories because he is committed to economy. Every statement must be limited to what is needed."[219] This is true in regards to sending a signal, but let us return to the Stein example: "He he he he and he." This message is quite redundant in terms of its repetition, but the statement is anything but culturally redundant given its ingenuity and uniqueness. Cultural redundancy is directly related to the unpredictability or uncertainty of the information being sent, not to its literal redundancy. That is, clichés are a form of cultural redundancy since they express ideas that have lost originality, ingenuity and impact through overuse. Cultural redundancy is a form of cultural repetition. Hence, the more unpredictable a statement is, the more information and entropy it has. Again, as observed by Wiener (and cited by Arnheim), "clichés are less illuminating than great poems."

The set of messages from which we can choose is sometimes referred to as the repertoire. Ideas within the repertoire that are commonly used are more culturally redundant. In other words, the more probable a message, the more culturally redundant it is. Moreover, the repertoire is historically and socially contingent given that cultural conventions are dependent on the socio-cultural positions of the participants. For instance, a unique expression can transform into one that is commonly used. Techniques, concepts and ideas that were once considered experimental or avant-garde in nature can become mainstream, and standardized interpretations naturally develop the more it is repeated. Even within the genre of experimental cinema, original ideas often quickly become cliché.

In order to develop cultural interpretations of Shannon's mathematical results, let us examine Shannon's Fundamental Theory of Communication:

> Let a discrete channel have a capacity C and a discrete source the entropy per second H. If $H < C$ there exists a coding system such that the output of the source can be transmitted over the channel with an arbitrarily small frequency of errors (or an arbitrarily small equivocation). If $H > C$ it is possible to encode the source so that the equivocation is less than $H - C + \varepsilon$, where ε is arbitrarily small. There is no method of encoding which gives an equivocation less than $H - C$.[220]

Mathematically speaking, this relatively sophisticated result connects the rate of transmission to the

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219 Arnheim, *Entropy and Art*, 17.
220 Shannon, *The Mathematical Theory of Communication*, 71.

channel capacity and suggests that it is possible to encode any message with as few errors as specified. J.R. Pierce explains the result and some of its consequences in natural language:

> This is a precise statement of the result which so astonished engineers and mathematicians. As errors in transmission become more probable, that is, as they occur more frequently, the channel capacity as defined by Shannon gradually goes down. For instance, if our system transmits binary digits and if some are in error, the channel capacity *C*, that is, number of bits of information we can send per binary digit transmitted, decreases. But the channel capacity decreases gradually as the errors in transmission of digits become more frequent. To achieve transmission with as few errors as we may care to specify, we have to reduce our rate of transmission so that it is equal to or less than the channel capacity.[221]

In other words, the channel capacity is affected by the frequency of errors in transmission. Culturally speaking, experimental media producers work beyond the "channel capacity" by breaking from established conventions, increasing ambiguity and leading the audience to some uncertainty about the author's intended message. Weaver provides one cultural interpretation of this phenomenon:

> It seems highly suggestive for the problem at all levels that error and confusion arise and fidelity decreases, when, no matter how good the coding, one tries to crowd too much over a channel (i.e., $H > C$). Here again a general theory at all levels will surely have to take into account not only the capacity of the channel but also (even the words are right!) the capacity of the audience. If one tries to overcrowd the capacity of the audience, it is probably true, by direct analogy, that you do not, so to speak, fill the audience up and then waste only the remainder by spilling. More likely, and again by direct analogy, if you overcrowd the capacity of the audience you force a general and inescapable error and confusion.[222]

In fact, Weaver's explanation that "overcrowding the capacity of the audience" leads to confusion explains why many viewers encountering experimental cinema for the first time feel perplexed. In fact, it is experimental cinema's propensity for bewilderment that distinguishes it from other forms of cinema that abide by established conventions. In order for media to be understood in the way that the cultural producer intended, a certain amount of cultural redundancy is required. Conventional forms of communication attempt to work within the "channel capacity" or are encoded with enough cultural redundancy to allow for effective decoding.

The Ross-Hall model only deals with producers that are attempting to encode messages in such a way that they can be transmitted and interpreted with relatively small uncertainty about the content of the message. In order to reduce uncertainty, the producers encode their messages with a certain amount

221 Pierce, *Symbols, Signals, and Noise*, 156.
222 Weaver, "Recent Contributions to the Mathematical Theory of Communication," 27.

of cultural redundancy. The expanded Ross-Hall model includes media producers that introduce error by reducing their reliance on cultural redundancy. As both Hall and Ross recognized, it is possible to decode messages from positions that recognize and potentially challenge the ideology encoded in the work. Expanding on this, the producers of experimental forms of communication produce work that challenges the communication system itself. By rejecting the conventions employed of the mainstream media producers and by choosing messages outside of the traditional repertoire, uncertainty is created in the viewer. Due to this uncertainty, the viewer is invited, at least to some degree, to interpret the work for themselves. In other words, the viewer does not simply decode the intended content of the message by using previously established codes like a mathematical receiver, but, to some extent, is invited to interpret the work for themselves. This act goes beyond simply recognizing and challenging the ideology encoded in the work, it is a gesture that both challenges conventional media production and acknowledges the agency of the viewer.

3.4 Expanding the Repertoire: Originality, Uncertainty and Cultural Redundancy

Shannon's Fundamental Theorem of Communication is about encoding messages in order to reduce the frequency of errors. While conventional media producers attempt to reduce the "frequency of errors" through encoding their messages with a certain amount of cultural redundancy, this is not necessarily the focus of experimental media producers, allowing for some ambiguity and uncertainty in the viewer. Unfortunately, Shannon's Fundamental Theorem does not seem to provide any particular insight into decoding messages where the established conventions have been compromised.

In 1972, filmmaker Hollis Frampton proposed his own theorem of cultural communication, namely, Brakhage's Theorem, which states,

> For any finite series of shots ['film'] whatsoever there exists in real time a rational narrative, such that every term in the series, together with its position, duration, partition and reference, shall be perfectly and entirely accounted for.[223]

223 Frampton, "A Pentagram for Conjuring the Narrative," 144.

This tongue-in-cheek theorem proposed by Frampton and attributed to experimental filmmaker Stan Brakhage can be seen as one cultural interpretation of Shannon's Fundamental Theorem of Communication, and is worth analyzing despite its ironic tenor. Film scholar P. Adams Sitney, in *Eyes Upside Down*, describes the impetus and origins of this theorem:

> Frampton ironically called the postulation of the inevitability of narrative “Brakhage's Theorem,” claiming that Brakhage, acting as “advocatus diaboli” had proposed it to him, and that it had been tested against such difficult cases as Kubelka's *Arnulf Rainer* (1960) and Conrad's *The Flicker* (1965). The issues at stake in the essay were very much on the filmmaker's mind when he went to England in May 1972 to show what he had completed of *Hapax Legomena* and to film material for what would become *Ordinary Matter* (1972). That was three months before he submitted the text of “A Pentagram for Conjuring the Narrative” to the Vancouver Art Gallery for its initial publication. Frampton neglected to mention that his encounter with Peter Gidal, the British filmmaker and theoretician, was crucial to the elaboration of this thesis. Gidal challenged Frampton's apparent lapse into narrative in parts of *Hapax Legomena*, which he contrasted with *Zorns Lemma* (1970), claiming that Kubelka and Conrad retain narrative and “authoritarian” elements in their flicker films but that *Zorns Lemma*, as well as films by Sharits and Snow, avoided those pitfalls.[224]

In essence, as observed by Sitney, Frampton is providing an argument against Gidal, who insisted that “narrative is an illusionistic procedure, manipulatory, mystificatory, repressive.”[225] Unfortunately, claiming to test the theorem “against difficult cases” like Kubelka and Conrad's film, although humorous in context, does not constitute a proof. Given that there does not yet exist a proof of Brakhage's Theorem, it formally remains a conjecture.

One of the first examples Frampton gives of Brakhage's Theorem is the narrativization of the following expansion of the number 30:

$$30=\frac{30}{3}+\frac{30}{5}+\frac{30}{6}+\frac{30}{10}+6$$

Frampton provides one rational narrative that accounts for the expansion:

> “A necklace was broken during an amorous struggle. One-third of the pearls fell to the ground, one-fifth stayed on the couch, one-sixth was found by the girl, and one-tenth recovered by her lover: six pearls remained on the string. Say of how many pearls the necklace was composed.” Such was the algebra of the ancient Hindus.[226]

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224 P. Adams Sitney, *Eyes Upside down: Visionary Filmmakers and the Heritage of Emerson* (Oxford: Oxford University Press, 2008), 104-5.
225 Peter Gidal, “Theory and Definition of Structural/Materialist Film,” in *Structural Film Anthology*, ed. Peter Gidal (London: British Film Institute, 1976), 4.
226 Frampton, “A Pentagram for Conjuring the Narrative, 144.

This well-known problem was originally posed in the *Līlāvatī*, a treatise by Indian mathematician Bhāskarāchārya written in 1150, whose title translates to "playful."[227] Although this is *one* narrativization, is it the only perfect interpretation of this expansion?

One of the major problems with Brakhage's Theorem is that Frampton does not define the term "perfectly." Perfection is subjective given that there is no way of objectively quantifying it in this case. Without an objective way of quantifying perfection, it would always be possible to find someone who is unsatisfied, no matter how "perfect" an explanation seems. Using this, it is fairly easy to argue against Frampton's conjecture – simply consider an eternally unsatisfiable person who will never concede that every element is perfectly accounted for. It is also worth observing that the *uniqueness* of the narrative also depends on Frampton's definition of perfection. In order to eliminate these problems, it is possible to revise Brakhage's Theorem without the requirement of perfection nor uniqueness as follows:

> For any finite series of shots ['film'] there exists a rational narrative such that every cinematic element is entirely accounted for.

Both versions of Brakhage's Theorem are existence claims and, as such, they do not provide a method for constructing this narrative, although Frampton has suggested that "an algorithm derived from Brakhage's Theorem" exists, implying that "narrative appears to be axiomatically inevitable."[228] It is highly unlikely that such an algorithm exists; rather, this statement was likely intended as a tongue-in-cheek jab at Gidal's arguments against narrative. At this point in time, there exists an entire school of thought devoted to rationalizing every cinematic element of a film – namely, those who subscribe to American cinema scholars David Bordwell and Kristin Thompson's conception of film form.[229]

227 Bhāskarāchārya, "Līlāvatī," in *Algebra, with Arithmetic and Mensuration, from the Sanscrit of Brahmegupta and Bhāscara*, trans. Henry Thomas Colebrooke (London: John Murray, 1817), 25. In the *Līlāvatī* the problem is formulated as follows: "The third part of a necklace of pearls, broken in an amorous struggle, fell to the ground: its fifth part rested on the couch; the sixth part rested on the couch; the sixth part was saved by the wench; and the tenth part was taken up by her love: six pearls remained strung. Say, of how many pearls the necklace was composed."
228 Ibid.
229 See David Bordwell, Kristin Thompson, and Jeff Smith, *Film Art: An Introduction,* Eleventh edition (New York: McGraw-Hill Education, 2017).

Likewise, Shannon's Fundamental Theorem does not provide us with methods of designing *effective* coding systems; rather, it only states that *there exists* some coding system such that the output of the source can be transmitted over the channel with an arbitrarily small frequency of errors and finding these efficient coding systems remains an active area of mathematical research. By the same token, many experimental media producers are developing their own idiosyncratic encoding systems in order to develop new forms of cinematic expression or to re-evaluate existing, established conventions.

Using idiosyncratic or ambiguous encoding techniques is another way in which experimental media allows for original forms of communication. When the work is encoded in a way that deviates from traditional methods of encoding, the viewer must work out the encoding technique employed, providing the viewer with a novel aesthetic experience or new insights into the media and how it functions. These new encoding/decoding techniques can also function as a form of game between the producer and the viewer, with the viewer attempting to figure out the intended meaning of the producer, with the potential allowing for new forms of perception. Granted, many filmmakers attempt to incorporate the ways of decoding the work into the work itself. For instance, in an interview with cinema scholar Scott MacDonald, Frampton explains:

> One of the things that goes on in *Critical Mass* [1971] (this is also true of much of the rest of my work and of the work by others I admire) is a process of training the spectator to watch the film. The work teaches the spectator how to read the work.[230]

By teaching “the spectator to read the work,” Frampton is attempting to incorporate a way of decoding the work into the work itself. By encoding ways of decoding the work into the work itself, the filmmaker is teaching the spectator alternative ways to engage with media and new ways of reading images. Just like mathematicians are experimenting to develop efficient coding systems, experimental filmmakers are often experimenting with ways of encoding messages in order to allow them to express ideas that are outside of the repertoire used by mass media.

230 Scott MacDonald, *A Critical Cinema: Interviews with Independent Filmmakers* (Berkeley: University of California Press, 1988), 65.

In the encoding of mainstream media messages, there is a delicate balancing act between originality and cultural redundancy in order to ensure that the messages are received by the audience in the way that they were intended. For instance, consider the television show *Twin Peaks.* When it first aired, the show was quite original, imaginative and outside of the mainstream repertoire; however, it was bursting with cultural redundancy making it accessible to a mass audience. Within the avant-garde, the desire is to avoid cultural redundancy in order to produce new forms of expression, or the expression of complex ideas. The conventions established through and by mass media are effective for encoding messages for the masses but may not be as effective for other kinds of messages, for instance, uniquely challenging personal, poetic, political, or spiritual modes of communication.

In *Devotional Cinema*, American filmmaker Nathaniel Dorsky suggests a form of cinema that is a religious or spiritual experience. He clarifies, "not where religion is the subject of a film, but where film is the spirit or experience of religion."[231] Using the analogy of a heartfelt conversation between friends, Dorsky describes how moving beyond cultural redundancy can potentially lead to ideas and expressions that are transformative:

> Transformative film rests in the present and respects the delicate details of its own unfolding. How is this small miracle achieved? How do we manifest nowness in the ongoing context of the relative? It is not unlike having a heartfelt discussion with a friend. You hear what your friend says, and you respond from a place you may never have responded from before. You hear your friend again, you wait a second, and there's an actual moment of connection, a genuine exploration that touches upon things never quite touched on before. [...] We are certainly all familiar with moments that are *not* like this. Conversations can often be an exhausting exchange of self-confirming, predigested concepts with no real exploration: everything is already "known" and is motivated by a need to maintain the status quo of oneself in relation to the other person.[232]

The conversations with "no real exploration" are precisely those that are culturally redundant, and creating work from that "place you have never responded from before" necessarily means creating work that avoids this form of redundancy. Dorsky suggests one way of achieving this, namely, by rejecting predetermined symbolic meaning in order for the world to be seen for what it truly is:

231 Nathaniel Dorsky, *Devotional Cinema* (Berkeley: Tuumba Press, 2003), 15.
232 Ibid., 32.

> When we take an object and make it mean something, what we are doing, in a subtle or not so subtle way, is confirming ourselves. We are confirming our concepts of who we are and what the world is. But allowing things to be seen for what they are offers a more open, more fertile ground than the realm of predetermined symbolic meaning. After all, the unknown is pure adventure.[233]

In other words, rejecting the cultural redundancy of predetermined symbolic meaning frees the viewer from preconceived notions, allowing for alternative meaning making within the uncertainty produced. In general, avoiding cultural redundancy or avoiding the repertoire used by mass media is one of the ways to enter that "place you have never responded from before." Through this, the producer is increasing the information of the message – that is, creating complexity – which in turn potentially allows for unique and novel forms of political, aesthetic and personal expression.

The expanded Ross-Hall model provides insight into these types of experimental media practices, namely, practices that challenge traditional forms of communication and that expand conventional repertoires. By aligning this cultural model with Shannon's mathematical model of communication, it has been demonstrated that some of Shannon's mathematical theories also have cultural implications. As previously argued, the underlying model, namely Hall's model, contains a seed of mathematical thought, demonstrating one of the ways mathematics has infiltrated media studies. Although many of the concepts differ slightly between the cultural model and the mathematical model, as Weaver suggested it is possible to apply Shannon's theory of communication to a much broader definition of communication. This model is one such cultural adaptation.

233 Ibid., 36.

CHAPTER FOUR: PRODUCTIVE MISREADINGS AND MATHEMATICAL METAPHORS

"We think in generalities, but we live in details."
– Alfred North Whitehead, *Modes of Thoughts* (1938)

Kepler's model for the solar system, as previously argued in Chapter Two, was chosen due to the formal beauty of the Platonic Solids. Nevertheless, this model led to many scientific advancements, since Kepler attempted to justify it by using empirical evidence, and science until that point in time was mainly descriptive.[234] Kepler's model can be seen as a form of *productive misreading*, a concept previously introduced in Chapter One and which will be explicitly defined and further examined here. In this chapter, I will argue that productive misreadings have the potential to lead to original concepts, and are not necessarily detrimental to the social sciences, as physicist Alan Sokal and others contend. In particular, I will argue that French philosopher Alain Badiou's claim that "mathematics is ontology" is based on a mistake analogous to Kepler's – namely, that Badiou basing the underlying structure for his ontological claims on set theory due to its perceived beauty is much like Kepler basing his underlying structure for the solar system on the Platonic solids for similar reasons. In spite of this, it will be shown that Badiou's conceptualization is quite innovative and original, and allows for new ontological insight. Finally, examples of productive misreadings will be explored in media art.

4.1 Beautiful Monsters: Productive Misreadings of Mathematics

In his 1973 book *The Anxiety of Influence*, Harold Bloom argues that every new poem is a misreading or misinterpretation of an earlier work. This idea emerges from Bloom's theory that aspiring poets experience anxiety caused by comparing their own work to that of their literary antecedents, whom Bloom refers to as *strong poets*. His theory was developed initially in relation to early nineteenth-century romantic poetry, and was based on his belief that original poems do not exist. In essence, every

234 Kepler eventually gave up his belief in the model since he could not get it to match empirical evidence; however, he did re-publish *Mysterium Cosmographicum* without the model 25 years later with significant corrections and improvements. Despite creating a false model, his scientific contributions were a result of attempting to expand this model through observing and calculating planetary orbits. Through these observations and calculations, Kepler advanced the Copernican system of planetary motion beyond its reliance on Ptolemaic epicycles.

poet is working under the influence of the works that have inspired them. Bloom argues that this weight of influence provokes anxiety in the poet, and is an obstacle young authors must confront. In order to overcome this anxiety, the poet must evoke a form of "poetic misreading or misprison" which Bloom defines as a *clinamen.*[235] Bloom explains:

> I take the word from Lucretius, where it means a "swerve" of the atoms so as to make change possible in the universe. A poet swerves away from his precursor, by so reading his precursor's poem as to execute a *clinamen* in relation to it. This appears as a corrective movement in his own poem, which implies that the precursor poem went accurately up to a certain point, but then should have swerved, precisely in the direction that the new poem moves.[236]

A productive misreading is similar to Bloom's concept of a clinamen, extended beyond the scope of literary influence.

The concept of a productive misreading deviates from Bloom's clinamen as follows. First, it does not imply any of the pseudo-physiological underpinnings of Bloom's clinamen, since it is not infused with concerns around anxiety. Bloom's idea of the anxiety of influence is not necessary for a misreading to generate novel ideas, and the anxiety Bloom describes is not necessarily universally felt by poets, but is more likely a description of Bloom's own anxieties. For instance, Bloom suggests that "every reader" has an inner poet that experiences an anxiety we have "learned to neglect, to our own loss and peril."[237] Yet have most readers *really* simply neglected their own feelings of anxiety to the detriment of their inner poet? Is anxiety a necessary condition for becoming a great poet or artist? Rather than worrying about the psychological issues artists suffer from (and, believe me, it is more than simple anxiety), it seems more productive to look at some of the ways these misreadings, misinterpretations, or *swerves*, have led to innovative results.

A second fundamental difference between Bloom's concept of the clinamen and the concept of the productive misinterpretation is related to aesthetic judgement. For instance, Bloom sees poets that

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235 Harold Bloom, *The Anxiety of Influence: A Theory of Poetry* (Oxford: Oxford University Press, 1997), 14.
236 Ibid.
237 Ibid., 25. [Emphasis in original.]

work solely under the influence of other poets as “minor or weaker.”[238] He suggests that in order to avoid the pitfalls associated with poetic influence, there must always be a shift, a swerve, a misreading:

> Poetic influence – when it involves two strong, authentic poets – always proceeds by a misreading of the prior poet, an act of creative correction that is actually and necessarily a misinterpretation. The history of fruitful poetic influence is, which is to say the main tradition of Western poetry since the Renaissance, is a history of anxiety and self-saving caricature, of distortion, of perverse, wilful revisionism without which modern poetry as such could not exist.[239]

In other words, a weak poet simply imitates, while strong poets alleviate anxiety through a form of creative correction – a misinterpretation of prior poets. Bloom continues:

> Let us make then a dialectical leap: most so-called “accurate” interpretations of poetry are worse than mistakes; perhaps there are only more or less creative or interesting misreadings, for is not every reading necessarily a *clinamen*? Should we not therefore, in this spirit, attempt to renew the study of poetry by returning yet again to fundamentals? No poem has sources, and no poem merely alludes to another. Poems are written by men, and not anonymous Splendors. The stronger the man, the larger his resentments, and the more brazen his *clinamen*. But at what prices, as readers, are we to forfeit our own *clinamen*?[240]

Putting aside the sexism contained within Bloom's formulation, we can see Bloom is reinforcing his belief that no one is without influence and that creativity involves misreading or misinterpreting one's prior influences in an attempt to overcome anxiety. By contrast, there is no aesthetic judgement or concerns around authenticity associated with a productive misreading – it is simply one of the ways in which discourse evolves. In other words, being directly influenced by and expanding on the ideas of others under this model does not lead to *weaker* or *minor* discourse. For instance, in the sciences and mathematics, it is quite common to build upon the works and ideas of others. Furthermore, many results are obtained through experimentation, trial and error, and other methodologies that are no less valid than the productive misreading.

Finally, in order to avoid the pitfalls of complete relativism, it is worth stressing the *productive* aspect of this form of misreading. A productive misreading is a misreading that generates new ideas and new forms of knowledge while honestly attempting to engage with and to understand the original

238 Ibid., 30.
239 Ibid.
240 Ibid., 43.

concepts. One of the major problems associated with the humanities borrowing from the sciences arises when an idea borrowed from the sciences is used to justify an idea from the social sciences; therefore, a productive misreading should not use a scientific concept as support for a new claim, unless the author is certain that the new claim satisfies the criteria of the original concept. For instance, a productive misreading of the Axiom of Choice should not be used to justify a position regarding freedom of choice simply because they both involve the word choice, since the axioms of set theory which include the Axiom of Choice were not constructed to deal with issues concerning pregnancy.[241]

Given that all communication is imperfect, at least to some degree, some have argued that every interpretation is a form of misinterpretation. For instance, philosopher Slavoj Žižek reinforces this idea in his book *Organs Without Bodies*, claiming that the entire history of philosophy is based on productive misreadings. He writes,

> As Alain Badiou put it, philosophy is inherently *axiomatic*, the consequent deploying of a fundamental insight. Hence, all great "dialogues" in the history of philosophy were so many cases of misunderstanding: Aristotle misunderstood Plato, Thomas Aquinas misunderstood Aristotle, Hegel misunderstood Kant and Schelling, Marx misunderstood Hegel, Nietzsche misunderstood Christ, Heidegger misunderstood Hegel [...] Precisely when one philosopher exerted a key influence upon another, this influence was without exception grounded in a *productive misreading* – did not the entirety of analytic philosophy emerge from misreading the early Wittgenstein?[242]

Following a trajectory similar to Bloom, Žižek argues that "strong" philosophers develop out of productive misreadings of prior philosophers. In contrast to Bloom, for Žižek misreadings are not a result of anxiety within the philosopher, but are due to the fact that dialogue (as opposed to logical reasoning deduced from axioms) is imperfect. For instance, Žižek suggests many philosophers hold different positions and cannot come to agreement precisely due to the fact that they misinterpret each other and often are "speaking different, totally incompatible, languages, with no shared ground between

241 This was one of the arguments used in Sokal's paper "Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity." Sokal hilariously argues, "just as liberal feminists are frequently content with a minimal agenda of legal and social equality for women and "pro-choice," so liberal (and even some socialist) mathematicians are often content to work within the hegemonic Zermelo-Fraenkel framework (which, reflecting its nineteenth-century liberal origins, already incorporates the axiom of equality) supplemented only by the axiom of choice. But this framework is grossly insufficient for a liberatory mathematics, as was proven long ago by Cohen (1966) (Sokal, *Fashionable Nonsense*, 245).

242 Slavoj Žižek, *Organs without Bodies: Deleuze and Consequences* (New York: Routledge, 2004), ix.

them."[243]

Žižek's idea for the productive misreading is borrowed from Deleuze, who believed that the history of philosophy is not actually about dialogue, nor a search for truth, but a series of productive misreadings that have led to the production of "monstrous" new ideas. Deleuze uses the act of buggery as a metaphor for productive misinterpretation:

> I suppose the main way I coped with it at the time [an aversion to the academic history of philosophy, which Deleuze saw as repressive] was to see the history of philosophy as a sort of buggery or (it comes to the same thing) immaculate conception. I saw myself as taking an author from behind and giving him a child that would be his own offspring, yet monstrous. It was really important for it to be his own child, because the author had to actually say all I had him saying. But the child was bound to be monstrous too, because it resulted from all sorts of shifting, slipping, dislocations, and hidden emissions that I really enjoyed.[244]

In other words, Deleuze is suggesting productive misinterpretation gives rise to ideas that are mutated and deformed versions of ideas held by previous philosophers, born out of the impossibility of remaining true to another author in spite of the reader's best intentions. By re-imagining the history of philosophy as a form of buggery (combined with immaculate conception), Deleuze is queering it while being blasphemous; an impressive manoeuvre despite the fact that it inherently reinforces a form of misogyny in which one male genius inseminates other, and even completely eliminates women from the cycle through the unnecessary introduction of immaculate conception.

If we attempt to accurately interpret Deleuze, a gesture which he might argue is impossible, he seems to be arguing that the monstrous offspring of ideas mutated beyond the original author's intent arrives by immaculate conception, implying that these ideas arrive without any real fixed explanation. In spite of the best intentions of the reader to accurately understand the original author, new deformed ideas miraculously arrive. In contrast, it is possible to view these misinterpretations not simply as monstrous reproductions or inaccurate interpretations, but as informed interventions that constitute an attempt to push beyond the original text or context. For instance, mathematical and scientific ideas are

243 Ibid., 47. This reference is specifically directed at Deleuze and Derrida, but is intended to reinforce his argument.
244 Gilles Deleuze, *Negotiations, 1972-1990* (New York: Columbia University Press, 1995), 6.

often appropriated by artists and theorists, and forced into a new (and often unintended) context that allows for the generation of new ideas outside of their original sanctioned environment, forcing a form of misinterpretation or misreading. Of course, this form of experimentation is not always successful. However, when it is, it potentially has the power to generate new ways of thinking about the universe – simply recall Kepler's model of the solar system.

4.2 Zermelo-Fraenkel Mysticism: Rationalizing Ontology

Badiou's magnum opus *Being and Event* was first published in French as *L'Etre et Evénement* in 1988. Almost twenty years later, the book was released in an English translation. *Being and Event* is widely discussed, and is often considered to be the foundation of Badiou's entire philosophical framework.[245] Moreover, the core principle of Badiou's philosophical framework is fundamentally the equivalence between mathematics and philosophy, a proposition succinctly summarized by Badiou in his most well-known slogan: "mathematics *is* ontology."[246] In "Ontology," philosopher Alex Ling reinforces the mathematical foundations of Badiou's entire philosophical project:

> Fundamental to Badiou's later philosophy is his declaration in *Being and Event* that "mathematics is ontology." Everything that follows from this assertion – from the structure of situations and their states all the way to events and the subjects of truths they engender – must be understood as the carefully drawn-out consequences of this properly philosophical decision. One could even argue – such is the rigour with which Badiou constructs *Being and Event* – that those who reject Badiou's core philosophy do so foremost because they reject his initial thesis on the equivalence of mathematics and ontology. For if this thesis is unfounded, so too is Badiou's entire philosophy.[247]

In this section, I will argue against Badiou's methodological approach, challenging his argument that "mathematics is ontology." I am not arguing against the equivalency of mathematics and ontology per se, although this is not a belief to which I personally ascribe; I am simply suggesting that Badiou fails

245 For instance: "*Being and Event* is an extremely remarkable book, presenting in just over 430 pages in the English translation a fundamental ontology, an account of the subject relative to this ontology, and a presentation of the ways in which novelty can come to restructure what is given in the socio-historical formations of being. The ambition of the book is equalled by the range of its references, from set-theoretic mathematics to psychoanalytic theory, and by the strength of its conviction, which is unwavering. The claims of *Being and Event* represent the very heart of Badiou's philosophical endeavour." Jon Roffe, "Book Review: Alain Badiou's Being and Event," *Cosmos and History: The Journal of Natural and Social Philosophy* 2, no. 1–2 (2006), 328.
246 Alain Badiou, *Being and Event* (London: Continuum, 2005), 4. [Emphasis in original.]
247 Alex Ling, "Ontology," in *Alain Badiou: Key Concepts*, ed. A. J. Bartlett and Justin Clemens (Durham: Acumen, 2010), 48.

to provide a compelling argument for this claim based on an aesthetic desire – namely, misapplying a mathematical concept due to its perceived beauty. Furthermore, I reject Ling's claim that "if this thesis is unfounded, so too is Badiou's entire philosophy," since this claim only appears to make sense if one assumes that mathematics is also epistemology. In other words, I am suggesting that although Badiou's methodology may be cause for concern, I am not entirely convinced that his philosophical arguments *necessarily* need a mathematical basis in order to be considered valid, nor do they need to directly correspond to the mathematics following the rigorous reasoning presented in *Being and Event*.

In *Being and Event*, Badiou is arguing for a mathematical basis to ontological claims which by extension include a social and political dimension. As such, Badiou is potentially providing the foundations for a new culture: one that does not separate the humanities from the sciences, but instead evokes mathematics to radically rethink the limits of our contemporary truth claims concerning the existence of entities, or *being*. Furthermore, Badiou is attempting to navigate what lies beyond the knowable, the unforeseeable, or *events.* According to Badiou, "working mathematicians" need assistance in interpreting the implications of the mathematics they are working with.[248] Frustrated with both analytic philosophers that avoid serious engagement with real mathematics and working mathematicians who dismiss philosophers' interpretations as mathematically misinformed, Badiou rigorously and meticulously engages with set theory to provide illumination into issues that are normally outside the scope of most mathematicians' concerns.

The framework of *Being and Event* is not entirely novel, and its basis can be found in a form of mathematical reductionism, a branch of mathematics that argues numbers are sets, or that set theory is the ontological basis of mathematics. Most famously, this view is presented in W.V. Quine's 1960 book *Word and Object;* however, Badiou's use of set theory as a foundation for ontology is far more radical

248 Badiou also describes working mathematicians as "ontologists without knowing so." For instance, "the new theses on being qua being are indeed nothing other than the new theories, and the new theorems to which working mathematicians – 'ontologists without knowing so' – devote themselves; but this lack of knowledge is the key to their truth." Badiou, *Being and Event*, 13.

than Quine's own philosophical framework, which was a form of scientific empiricism used in combination with quantified first-order predicate logic. To Badiou, mathematics has been a sub-genre of philosophy for too long, reduced to the use of mathematical logic or the area of specialization known as philosophy *of* mathematics. In contrast, Badiou argues philosophy is, in actuality, a sub-genre of mathematics: "*philosophy must enter into logic via mathematics, not into mathematics via logic*."[249] Specifically, "mathematics is the science of being *qua* being"[250]; or, mathematics *is* ontology.

Badiou's claim that ontology (or the science of being *qua* being) is mathematical does not imply that being is mathematical in nature. According to Ling, Badiou argues mathematics "figure[s] the *discourse* on being"[251]; or perhaps more specifically, according to Badiou, "mathematics through the entirety of its historical becoming, pronounces what is expressible of being *qua* being."[252] Moreover, it is only today that we can know this, since the development of Zermelo–Fraenkel set theory with the Axiom of Choice (ZFC) occurred in the early twentieth century. Zermelo-Fraenkel set theory, named after mathematicians Ernst Zermelo and Abraham Fraenkel, is an axiomatic system that, when combined with first-order logic (or predicate logic), provides a satisfactory and generally accepted formalism for almost all current mathematics.[253] At this point in time, ZFC is generally considered by most working mathematicians as the foundations for mathematics, but other less popular axiomatic systems do exist. It is within ZFC that Badiou finds the basis for his philosophy, which I will now attempt to clearly and succinctly summarize.

The foundational claim of Badiou's ontology is found in the statement: *the one is not*. This is the very kernel of Badiou's ontology, and a fairly original rethinking of traditional ontological claims

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249 Alain Badiou, *Theoretical Writings*, ed. Ray Brassier, Alberto Toscano, and Alberto Toscano, trans. Ray Brassier (London: Continuum, 2004), 15. [Emphasis in original.]
250 Ibid.
251 Ling, "Ontology," 48.
252 Badiou, *Being and Event*, 8.
253 First-order logic is the standard for the formalization of mathematics into axioms, but also is used in philosophy, computer science and linguistics. First-order logic is an extension of propositional logic, which deals with logical connectives, to include quantified variables.

where *what is* is one and *what is there* is multiple. Badiou explains:

> We find ourselves on the brink of the decision, a decision to break with the arcana of the one and the multiple in which philosophy is born and buried, phoenix of its own sophistical consumption. This decision can take no other form than the following: *the one is not*.[254]

To Badiou, there is no unity or consistency to being, making his ontology ultimately anti-theological and ideal for an age where God is dead. In other words, being *qua* being is an inconsistent multiplicity making ontology the science of the pure multiple. Every moment is a tiny fragment selected from the multiples of multiples.

In order to unpack this, let us consider three key terms in Badiou's text, namely "situation," "count," and "void." First, what *is there* is the presentation of the multiplicity, that is, a rendering consistent of the inconsistent. This unified presentation is, according to Badiou, a *situation*. In Ling's words, "a situation is the constitution of inconsistent multiplicity"[255]; or to Badiou, "the place of taking-place."[256] Second, the way in which pure multiplicity is *situated* or unified is, according to Badiou, the *count-as-one* or the *count*. For instance, in cinematic terms, the editing of a film leads to pure multiplicity at every cut, but the editor must count-as-one, situating the film. On the one hand, this can seem like a rather pretentious way of saying an editor makes choices in order to complete a film. On the other hand, experimental filmmakers often think about the pure multiplicity at every cut, an act that sometimes allows them to overcome predetermined conventions by expanding the lexicon. Finally, according to Badiou, the *void* is the space between the situation and its underlying being or more precisely, "every structured presentation unpresents 'its' void, in the mode of this non-one which is merely the subjective face of the count."[257] Ling uses this idea to further argue, "first, according to the situation, the void is the proper name of being; and second, that everything that *is* is woven from the void."[258] Or in other words, this is much Badiou about nothing.

254 Badiou, *Being and Event*, 23. [Emphasis in original.]
255 Ling, "Ontology," 50.
256 Badiou, *Being and Event*, 24.
257 Ibid., 25.
258 Ling, "Ontology," 51.

In *Being and Event,* Badiou is attempting to demonstrate that ZFC correlates to these ontological claims, justifying his controversial claim that mathematics *is* ontology. As Ling argues,

> Badiou's position on the multiple leads him to conclude that mathematics *is* ontology. After all, his two major ontological doctrines – that the science of being qua being (ontology) can only be the theory of pure or inconsistent multiplicity, and that all that *is* is woven from the void – are precisely mathematics – or more precisely axiomatic or Zermelo-Fraenkel set theory [with the Axiom of Choice] (ZFC) – thinks.[259]

In other words, Badiou sees a direct correlation between his ontological arguments and ZFC. The first major connection is between the void in Badiou's ontology and what is referred to as the *empty set*, *void set*, or *null set* in ZFC, traditionally denoted Ø. One of the axioms of ZFC is the Axiom of Empty Set, which asserts there exists a set which has no elements; however, it is significant that this axiom can be deduced from two other axioms, namely, the Axiom of Subsets and the Axiom of Infinity, implying that asserting it is redundant. Moreover, it is possible to deduce that the empty set is unique through the Axiom of Extensionality. Badiou argues,

> In its technical formulation - the most suitable for conceptual exposition - the axiom of the void-set will begin with an existential quantifier (thereby declaring that being invests the Ideas), and continue with a negation of existence (thereby un-presenting being), which will bear on belonging (thereby unpresenting being as multiple since the idea of the multiple is $\in$). Hence the following (negation is written ~):
>
> $$(\exists\beta)[\sim(\exists\alpha)(\beta \in \alpha)]$$
>
> This reads: there exists β, such that there does not exist any α which belongs to it.[260]

He continues:

> The mathematicians say in general, quite light-handedly [or more accurately, logically], that the void-set is unique 'after the Axiom of Extensionality'. Yet this is to proceed as if 'two' voids can be identified like two 'something's', which is to say two multiples of multiples, whilst the law of difference is conceptually, if not formally, inadequate to them. The truth is rather this: the unicity of the void-set is immediate because nothing differentiates it, not because its difference can be attested. An irremediable unicity based on in-difference is herein substituted for unicity based on difference.[261]

Finally, he concludes, "it is because *the one is not* that the void is unique."[262]

Given that this is one of the ways in which Badiou connects his ontological framework to ZFC, it is worth pointing out one major flaw, namely, that Badiou seems to have privileged knowledge about

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259 Ibid., 52. [Emphasis in original.]
260 Badiou, *Being and Event*, 68.
261 Ibid.
262 Ibid., 69. [Emphasis changed from original.]

void-ness. For instance, Badiou simply asserts that the unicity of the void-set is *immediate* because nothing differentiates it; but how does Badiou have such knowledge? The *only way* that we have any knowledge about the empty set is through ZFC – the concept of the empty set does not have any implicit properties, and its uniqueness is obtained directly through the Axiom of Extensionality. There even exists a set theory where it is impossible to determine if the empty set is unique, namely, the set theory that consists of only the Axiom of Empty Set. In this ontological system, all that *is* is void. In other words, its uniqueness is contingent on the set of axioms, not a fundamental truth as Badiou claims, and unless we have some implicit or privileged knowledge of void-ness, we cannot determine if it directly corresponds to ZFC. Badiou is also correct in asserting that the *law of difference* is inadequate to mathematicians, but this is because it cannot be deduced from the axioms and is therefore irrelevant within the formal system. Does it just happen that Badiou's ontology corresponds to ZFC, or does the mathematics dictate his ontological claims?

The set-theoretic axioms weren't deduced in order to provide ontological arguments, but were formulated in order to produce a theory of sets that avoided paradoxes such as Russell's paradox.[263] In "Matheme and Mathematics," mathematician Maciej Malicki further suggests that Badiou does not sufficiently or explicitly explain the connection between mathematical axioms and physical reality:

> One also needs to answer the question about the role played by axioms in the structure of *historical* situations. If in the domains of specific languages (of politics, science, art or love) the effects of event are not visible, the content of *Being and Event* is an empty exercise in abstraction: even science – perhaps excluding some entirely formalized areas of theoretical physics – let alone art or love – cannot for obvious reasons be exhaustively described solely in terms of the relation of belonging.[264]

In one specific instance, Badiou attempts to explain the French Revolution in terms of his conception of the event. His explanation is consistent within his own terminology; however, he does not explicitly show how this could be reduced solely to relation of belonging and the axioms of set theory.

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263 Russell's Paradox: Let *S* be the set of all sets that are members of themselves. If *S* is a member of itself, it is not a member of itself; if *S* is not a member of itself, it is a member of itself. Informally, consider the sentence: This sentence is false. If it is true, it is false; if it is false, it is true. Formally, let $S = \{ x : x \notin x\}$ then $S \in S$ if and only if $S \notin S$.
264 Maciej Malicki, "Matheme and Mathematics: On the Main Concepts of the Philosophy of Alain Badiou," *Logique et Analyse* 58, no. 231 (2015), 440.

It is worth stressing that Badiou's comprehension of the mathematics is, in my opinion, irrefutable. Badiou is not simply superficially engaging with mathematical ideas even if he makes the odd mathematical mistake (and every working mathematician makes the odd mistake); however, his competence does not mean that his *interpretations* are necessarily valid. Although Badiou convincingly demonstrates a sophisticated grasp of the mathematics he is using, he must also provide a satisfactory conceptual justification for his interpretations, and this is the major source of controversy surrounding his book. One of the major debates surrounding *Being and Event* took place in *Critical Inquiry* between the father and son duo of mathematician Ricardo Nirenberg and historian David Nirenberg, and philosophers A.J. Bartlett and Justin Clemens. The debate is similar in tone to that of the Snow and Leavis debate that took place decades earlier, and many of the arguments presented therein seem like extensions of the line of reasoning made by Alan Sokal and Jean Bricmont in their 1998 book *Fashionable Nonsense*, a critique of the misuse of mathematics and science by French and American intellectuals.[265]

In a review of Badiou's *Numbers and Numbers*, philosopher John Kadvany defends Badiou against a Sokal-esque claim that Badiou is simply misusing scientific and mathematical vocabulary as a form of pretension:

> Badiou, probably not noticed by Sokal, is in this way a *conservative* French philosopher, accepting modernist heterogeneity, but believing it to be mere appearance. The structure of Being, for Badiou, enables us to cognize it in excessively, possibly disastrously, manifold ways, exploring paths of innumerable options, scenarios, frames, and templates, with the whole an inconsistent multiplicity made up of Being's constituent elements. Our world, any world, is a tiny fragment selected from Being's "multiples of multiples." It's not that being is mathematical, but that mathematical discourse "pronounces" what is expressible of "being qua being." Theories of anything, but mostly the natural and social world as described using numeric methods, are re-presentations of this ontology. Consistent with the primacy of natural science, numbers and numeric structure have to be "immanent", and especially, not "constructed" via syntax, grammar or other inductive procedures, of which Badiou is completely disdainful: "if it is true that mathematics, the highest expression of pure thought, in the final analysis consists of nothing but syntactical apparatuses, grammars of signs, then a fortiori all thought falls under the constitutive rule of language." No Sapir-Whorf hypothesis for this fellow. The need is for an

265 For instance, Badiou calls the Nirenbergs his "adversaries," and suggests they are "obscure, ignorant, and impassioned," make "beginner's errors" and "constant confusion dominates their thought" while their critics, Bartlett and Clemens, are "informed, calm, and independent." See Alain Badiou, A. J. Bartlett, and Justin Clemens, "To Preface the Response to the 'Criticisms' of Ricardo Nirenberg and David Nirenberg," *Critical Inquiry* 38, no. 2 (2012): 362–64.

> immanent structure of number and numbers, overwhelmingly efflorescent in its structure, persistently unbounded, always already beyond completion in every detail.[266]

Beyond giving a beautifully succinct overview of Badiou's overarching project (complete with Badiou's slightly idiosyncratic use of language), Kadvany is arguing that Badiou is not attempting to abuse mathematical ideas to further his own philosophical agenda, but rather attempting to create a unifying, mathematically based, philosophical framework. Moreover, by doing this, Badiou, like Sokal, is attempting "to undo the disastrous consequences of philosophy's 'linguistic turn'."[267] Badiou's conviction in the highest expression of pure thought, mathematics, and his mathematical comprehension are beyond question, unlike many other postmodern philosophers who use and abuse mathematics, as demonstrated by Sokal and Bricmont.

One of the major points of contention in the *Critical Inquiry* debate was "the Matheme of the Event." According to Malicki, matheme to Badiou is "understood as a philosophical idea subjected to rigours of deduction, and opposed to the pre-platonic poem."[268] Badiou defined the matheme of the event as:

$$e_X = \{x \in X, e_X\}$$

where $X \in S$ [that is, X belongs to S, or, using Badiou's terminology, X is *presented* by S] and S is a situation. [269] Badiou refers to X as the evental site, so e_X is the event of the site X. In other words, the site of the event is composed of elements of X and the event itself. To Badiou,

> [The *evental site* is] an entirely abnormal multiple; that is, a multiple such that none of its elements are presented in the situation. The site, itself, is presented, but 'beneath' it nothing from which it is composed is presented. As such, the site is not a part of the situation. I will also say of such a multiple that it is *on the edge of the void*, or *foundational*.[270]

266 John Kadvany, "Review of Number and Numbers by Alain Badiou," *Notre Dame Philosophical Reviews* (October 2, 2008), <https://ndpr.nd.edu/news/number-and-numbers/>. [Emphasis in original.]
267 Badiou, *Theoretical Writings,* 16.
268 Malicki, "Matheme and Mathematics," 434. Malicki also observes, "the very term 'matheme' comes from late writings of Lacan, which are an important reference point for Badiou. There it denotes mathematical objects such as the Boromean knot or the Klein bottle – allowing to grasp the order of the real extending beyond the reach of language. According to this understanding, a matheme would be a place in philosophy, where mathematics attains an autonomous status, completing philosophical discourse, and generating statements that are binding for it."
269 Badiou, *Being and Event*, 179. [I have corrected Badiou's slightly flawed notation.]
270 Ibid., 175. [Emphasis in original.]

He later clarifies, “I term event of the site *X* a multiple such that it is composed of on the one hand, elements of the site, and on the other hand, itself.”[271]

The definition of *event* is one of the major points of contention for the Nirenbergs. They argue that e_X is not a set in conventional set theory:

> His “set” e_X contains “an inventory,” or “the historical approach” – namely, $x \in X$ – but also, as we can see, something else: it contains itself. Rather than being defined in terms of objects previously defined, e_X is here defined in terms of itself; you must already have it in order to define it. Set theorists call this a *not-well-founded* set. This kind of set never appears in mathematics – not least because it produces an unmathematical *mise-en-abîme*: if we replace e_X inside the bracket by its expression as a bracket, we can go on doing this forever – and so can hardly be called “a matheme.”[272]

More precisely, it can be shown that Badiou's formulation of an event is not a set in ZFC due to the Axiom of Foundation, which states that for every non-empty set there is an element of the set that shares no member with the set. Basically, this is the axiom that exists to prevent Russell's Paradox. Žižek, in *Organs Without Bodies*, presents this inconsistency in a slightly different way:

> One should reject Badiou's notion of mathematics (the theory of pure multiplicity) as the *only* consistent ontology (science of being): if mathematics is ontology, then, to account for the *gap* between Being and Event, one either remains stuck in dualism *or* one has to dismiss the Event as an ultimately illusory local occurrence within the encompassing order of Being. Against this notion of multiplicity, one should assert as the ultimate ontological given the gap which separates the One from within.[273]

In other words, Žižek is arguing that the space between being and event, *the edge of the void*, leads to a form of dualism or remains outside of being.

In a review of *Being and Event*, philosopher Paul Livingston is a bit more generous, suggesting that this is not a mathematical mistake at all, but that Badiou intended for the event to be outside of ZFC. According to Livingston, “Badiou terms the 'event,' that which (as he argues) escapes any possible ontological reckoning, but is nevertheless at the core of history and the basis of any possible intervention in it.”[274] As Badiou argues, “the event belongs to that-which-is-not-being-qua-being.”[275] As

271 Ibid., 179. [Emphasis changed.]
272 Ricardo L. Nirenberg and David Nirenberg, “Badiou’s Number: A Critique of Mathematics as Ontology,” *Critical Inquiry* 37, no. 4 (2011), 598–599.
273 Žižek, *Organs Without Bodies*, 107.
274 Paul Livingston, “Review of Being and Event,” *Inquiry* 51, no. 2 (April 2008), 218.
275 Badiou, *Being and Event*, 189.

if directly responding to the Nirenbergs' objection Badiou states,

> The Axiom of Foundation de-limits being by the prohibition of the event. It thus brings forth that-which-is-not-being-qua-being as a point of *impossibility of the discourse on being-qua-being*, and it exhibits its signifying emblem: the multiple such as it presents itself, in the brilliance, in which being is abolished, of the mark-of-one.[276]

In other words, Badiou suggests that his definition of event lies beyond the scope of ZFC precisely due to the Axiom of Foundation. Livingston reinforces this reading:

> As further set-theoretical reflection has shown, however, the Axiom of Foundation, though the most direct way to avoid Russell's paradox, is not strictly necessary for the logical coherence of an axiomatization of the nature of sets; various versions of "non-well founded" set theory take up the consequences of its suspension. Most directly, suspending the axiom of foundation means that sets can be, as Badiou suggests they inherently are, infinite multiplicities that never "bottom out" in a simplest or most basic element. And this infinite multiplicity is indeed essential, on Badiou's accounting, to the potentiality of the event to produce novelty. The schema that portrays this infinite potentiality breaks with the axiom of foundation by explicitly asserting the self-membership of the event. For Badiou, however, this is not the basis of a rejection of the axiom itself as a fundamental claim of ontology, but rather an index of the event's capability to go beyond ontology in introducing happening into the intrinsically non-evental order of being.[277]

As Livingston observes, an event isn't un-mathematical, but purposefully outside of ZFC in what is called a non-well-founded set theory, a branch of mathematics originally initiated by Dmitry Mirimanoff between 1917 and 1920. In fact, Badiou explicitly states, "sets which belong to themselves were baptized *extraordinary* sets by the logician Mirimanoff," and continues, "we could thus say the following: an event is ontologically formalized by an extraordinary set."[278] Unfortunately, Badiou is not correct when he asserts that "event is prohibited" by being since, as Malicki observes, "the axiom of foundation may be consistently replaced with its negation – for example, the Aczel anti-foundation axiom is consistent with the remaining axioms of set theory."[279]

In their response paper, Bartlett and Clemens deliberately choose not to address the Nirenbergs' criticism that Badiou's definition of event is not well-founded. This prompted the Nirenbergs to retort, "we note that they do not respond to this, or any other of our specific arguments about Badiou's

276 Ibid., 190. [Emphasis added.]
277 Livingston, "Review of *Being and Event*," 225.
278 Badiou, *Being and Event*, 190.
279 Malicki, "Matheme and Mathematics," 446.

mathematics."[280] Given that Badiou explicitly addresses several of the Nirenbergs' criticisms, if there was some generosity (on both sides), this debate could have been more productive by actually providing clarification. Another more substantial critique put forward by the Nirenbergs is that Badiou's "mathematical ontology disguises the contingent in robes of necessity."[281] Even the axioms Badiou has chosen are contingent. Badiou argues,

> We definitely have the entire material for an ontology here [namely, ZFC]. Save that none of these inaugural statements in which the law of Ideas is given has yet decided the question: 'Is there something rather than nothing?' [...] The solution to the problem is quite striking: maintain the position that nothing is delivered by the law of the Ideas [namely, ZFC; specifically the Axiom of the Empty Set], but make this nothing be through the assumption of a proper name. In other words: verify, via the excedentary choice of a proper name, the unpresentable alone as existent; on its basis the Ideas will subsequently cause all admissible forms of presentation to proceed.[282]

From the Axiom of the Empty Set, there is something rather than nothing and "out of *nothing* (which Badiou interprets the set Ø to be) the whole cosmos, he will show us, will be created or rather deduced."[283] Of course, this is an overstatement since Badiou is not attempting to define the *whole* cosmos; nevertheless, as previously observed, the Axiom of the Empty Set isn't a necessary axiom since it can be deduced from the Axiom of Subsets and the Axiom of Infinity. Moreover, as the Nirenbergs argue, it is possible to obtain the empty set from the Existence Axiom, which guarantees the existence of some set and the Separation Axiom. In other words, from the Existence Axiom, we begin with something beyond the void, prompting a totally new Badiou-ean interpretation that can be deduced from the law of Ideas (ZFC), namely, *separation produces the void*.[284]

Another problem with Badiou's ontological reductionism is analogous to one of the major objections to the reduction of numbers to sets; namely, there are many ways to reduce arithmetic to set theory. Here are two of the most standard interpretations presented by von Neumann and Zermelo

280 Ricardo L. Nirenberg and David Nirenberg, "Reply to Badiou, Bartlett, and Clemens," *Critical Inquiry* 38, no. 2 (2012), 385.
281 Nirenberg and Nirenberg, "Badiou's Number," 612.
282 Badiou, *Being and Event*, 66–7.
283 Nirenberg and Nirenberg, "Badiou's Number," 590. [Emphasis in original.]
284 Just to be extremely clear, this is purely intended to be tongue-in-cheek and is not an endorsement for this type of haphazard natural language interpretation of mathematical results.

respectively. Take 0 to be Ø. Next, there are two natural ways to define the successor of x, either as $x \cup \{x\}$ or as simply $\{x\}$. In other words, depending on which system you subscribe to, the number two is interpreted as { Ø ∪ {Ø} } or {{Ø}}. As philosopher Paul Benacerraf argues, "any feature of an account that identifies a number with a set is a superfluous feature of the account (i.e. not one that is grounded in our concept of number)."[285] Therefore, Benacerraf concludes numbers cannot be sets. In "Reducing Arithmetic to Set Theory," Alexander Paseau addresses some of these concerns, ultimately arguing that the arbitrary nature of the interpretation is irrelevant and that "reductionism is not damaged by the availability of incompatible reductions."[286] While Paseau's claim may be true for numbers, the problem is much more significant for Badiou given the availability of totally incompatible interpretations, ultimately suggesting that Badiou's ontological claims are contingent on their interpretation. In other words, Badiou's interpretations of mathematical results seem to determine his ontological claims.

Badiou's claim that "mathematics is ontology" is also heavily compromised in light of the fact that there are many different ways to axiomatize mathematics – some of which, as previously demonstrated, lead to conflicting interpretations. Badiou is fundamentally making a much weaker (and less quotable) claim, namely, ZFC is ontology. In other words, Badiou's ontological framework is relative to the axiomatic system chosen. Malicki further provides a mathematical argument to demonstrate that Badiou's ontological claims are true only if one neglects some of the results of ZFC. Using the logic of ZFC, Malicki demonstrates Badiou's "generic theory of truth and his philosophy of event can coexist only at a price of selective and instrumental interpretation of the mathematical component."[287] In other words, Badiou is fundamentally making an even weaker claim, namely, that some selective portion of ZFC is ontology. From this, Malicki concludes, "*Being and Event* provides

285 Paul Benacerraf, "What Numbers Could Not Be," *Philosophical Review* 74, no. 1 (1965), 52.
286 Alexander Paseau, "Reducing Arithmetic to Set Theory," in *New Waves in Philosophy of Mathematics*, ed. Otávio Bueno and Øystein Linnebo (London: Palgrave Macmillan, 2009), 51.
287 Malicki, "Matheme and Mathematics," 446.

no grounding for a deep ontological structure behind the realms of science, art, love and politics, and that the mathematical formulation of the theory of event has no positive content."[288]

Being and Event may not provide an ontological structure for science, art, love and politics; however, Badiou's attempted endeavour is quite admirable and not, like Malicki asserts, without positive content. As Livingston argues,

> From these results of set theory [Badiou] draws a host of provocative conclusions about being, knowledge, language, and truth, the paradoxical "event" that interrupts them, and the structure of a reconceived subjectivity whose essence is "fidelity" to its consequences. In deriving this wide-ranging philosophical discourse, Badiou treats the axioms and theorems of set theory (on one of its various possible formulations) as if they were something like a revelatory text in which one can directly read the contours of being itself, as well as their inherent limitations. One of the most fundamental (though unargued) claims of the book is, indeed, Badiou's identification of mathematics (or standard set theory) with ontology *simpliciter*. This identification, like other decisive claims throughout the text, is not the result of any deductive or inductive argument, but rather of a basic and free decision, which Badiou likens to the mathematician's decision to adopt or refuse a particular axiom in the course of speculative mathematical thinking.[289]

Once again, the "free decision" Badiou is making is precisely what weakens his claim for an ontological basis; however, this does not make his other insights less illuminating. As observed by Kadvany, "Badiou's ontological narrative is allusive, poetic, and deeply metaphorically *inspired* by his understanding of modern set theory."[290] This, in essence, can be read as the heart and soul of the Nirenbergs' actual criticism:

> In deducing philosophical and political consequences from his set-theoretical arguments, Badiou confuses contingent attributes of informal models with necessary consequences of the axioms (we will call this type of confusion a *Pythagoric snare*). The politico-philosophical claims that result have no grounding in the set theory that is deployed to justify them.[291]

To this, Barlett and Clemens have responded, "that mathematics is ontology means precisely and decisively that philosophy does not do ontology and that mathematics does not determine philosophy. Nor does mathematics constitute truth. Nor does being subject on Badiou's terms mean, as Nini brazenly claims, that 'our only choice lies with the axioms of set theory'."[292] Despite the fact that it is

288 Ibid.
289 Livingston, "Review of *Being and Event*," 219.
290 Kadvany, "Review of *Number and Numbers.*"
291 Nirenberg and Nirenberg, "Badiou's Number," 590.
292 A. J. Bartlett and Justin Clemens, "Neither Nor," *Critical Inquiry* 38, no. 2 (2012), 368.

incredibly bad form to argue something *precisely and decisively* in the negative, it is worthwhile to heed their criticisms in the light of Kadvany and Livingston's idea of creating an ontological narrative based on set theoretical claims.

In spite of its major shortcomings, *Being and Event* is an example of an incredibly productive misinterpretation of set theory. Using ZFC as a basis, Badiou produces a consistent ontology, one that doesn't necessarily follow from its mathematical inspirations, but is nevertheless a highly creative misinterpretation of the mathematics that it attempts to mirror. As Kadvany argues,

> I think Badiou has the roles of informal mathematical narrative and proof exactly reversed. He believes, like set theorists of old, in mathematical *realism*. But that's not what counts in mathematics, Gödel's platonism notwithstanding. Believe what you want. What matters are new systems, logics, heuristics, conjectures, counterexamples, theorems, proofs. However you explain these is fine, but don't take mathematical metaphors too seriously, even as these are essential to understanding, communication, and teaching. In particular, the idea that ZF, or other set theories, provide "foundations" is itself a metaphor, true in part, but today far from having the ultimate status envisioned by Frege, Russell, or Gödel.[293]

The ontology created by Badiou is one that deviates through a productive misinterpretation. The ideas it presents lay the foundations for an ontology that moves beyond theological or mystical ideas (which have no place in mathematics nor ontology), and attempts to provide an ontological framework outside of language and hermeneutics. There are also some connections between Badiou's ontological framework and the world. As argued by philosopher Christopher Norris, many of Badiou's key concepts "posit a direct equivalence – not just a loose analogy or suggestive structural kinship – between the two domains of set theory and political philosophy"[294] For instance, Norris suggests that Badiou's concept of the "count-as-one" can be applied to the ways in which political systems exclude and disenfranchise those who do not "count-as-one" within the system, like unrecognized immigrants. Once again, this is highly speculative, since the rules of set theory were constructed to provide foundations of mathematics without considering potential legal interpretations. Moreover, studying set theory to better understand a system in which being *accounted* for determines a person's political status

293 Kadvany, "Review of *Number and Numbers.*"
294 Christopher Norris, *Badiou's Being and Event: A Reader's Guide* (London: Continuum, 2009), 7.

seems akin to studying the retinal system to better understand those who exist on the *periphery* of a system. Nevertheless, if the theory Badiou has developed around his ontological claims can be used to provide insight into the contemporary political situation, it is worth taking into consideration.

At this point, I feel safe in asserting that Badiou's claim that ontology *is* mathematics is fairly unsatisfactory. Like Kepler's model in his *Mysterium Cosmographicum*, Badiou has put too much faith in the underlying mathematics and mathematical metaphor. From Kepler's model, it is possible to see one of the ways to transform an "error" into an advancement of knowledge. By observing the ways in which the empirical evidence deviated from the model, it was possible to build upon and transform Kepler's model into a more accurate model, one that reflects the real world. In other words, Kepler's model was a starting point, not an end point. Returning to Badiou's model, this is precisely the way in which it can be used. Badiou is basing his ontological arguments on what he perceives to be a perfect model, namely ZFC, an idealistic pursuit similar to Kepler. Badiou's model and methodology are flawed; however, if this model is to be useful, its utility will be found in observing the ways in which deviates from empirical evidence. Like Kepler's model, Badiou's model should not be seen as a final philosophical system but as setting the foundations for a new approach.

4.3 Experimental Mathematics: Productive Misreadings of Mathematics in Media Art

In this section, two of the ways in which moving image artists use mathematics in their work will be examined in detail. First, I will examine a selection of works by artists who, like Badiou and Kepler, have productively misread or misinterpreted mathematics in the production of their artworks. It would be unfair to presume that artists who appreciate and explore mathematical ideas in their work fully understand the underlying mechanics. For instance, many people understand the implications of Gödel's Incompleteness Theorems without necessarily having the mathematical abilities to fully comprehend their formal proofs. Moreover, no one would require a mathematician to have the skills to create a painting in order to understand the cultural significance of an artwork. Second, I will examine moving image artists who use mathematics as a form of metaphor to explore aesthetic, historical, social and cultural concerns, as well as to invoke the spiritual.[295]

Conceptual artist Francesco Gagliardi's video *Mental Task 3: Cantor-Bernstein-Schröder Theorem* (2007), explores the mental exertion of performing a mathematical proof by repositioning this activity as a performance. In this performance video, philosopher Imogen Dickie performs an unrehearsed proof of the Cantor-Bernstein-Schröder Theorem. The Cantor-Bernstein-Schröder Theorem formally states for any two sets A and B:

$$\text{If } |A| \leq |B| \text{ and } |B| \leq |A| \text{ then } |A| = |B|.$$

The cardinality of any set S, denoted $|S|$, is the concept of size extended to sets. For finite sets, it is simply the size of the set; for infinite sets, the behaviour is slightly more complex. Two sets A and B have the same cardinality, $|A| = |B|$, if there exists a *bijective* function between them, that is, there exists a mapping between the elements of two sets such that each element of one set is paired with exactly one element of the other set, and each element of the other set is paired with exactly one element of the first set. In other words, every element of both sets has a pair.[296] In terms of cardinality, A has cardinality less than or equal to the cardinality of B, denoted $|A| \leq |B|$ if there is a one-to-one function from A to B, or a function that is a function that preserves distinctness.[297] This makes the Cantor-Bernstein-Schröder Theorem useful for ordering the cardinal numbers.

In the video, Dickie informally sketches the proof. Given that it is an unrehearsed performance, she makes many formal errors, hesitations and missteps. Gagliardi explains the significance of its

295 Of course, moving image artists aren't the first to do this. For instance, consider Tolstoy's use of integration as metaphor in *War and Peace*, or Edwin Abbott's use of higher dimensions as a metaphor for notions of higher consciousness or his use of polygons to illuminate issues surrounding class inequality in his book *Flatland: A Romance of Many Dimensions* originally published in 1884. For an interesting article on Tolstoy's use of integration see: Stephen T. Ahearn, "Tolstoy's Integration Metaphor from *War and Peace,*" *The American Mathematical Monthly* 112, no. 7 (2005): 631–38.
296 A *function* is a relation that associates each element x of a set X, the *domain* of the function, to a single element y of another set Y, the *codomain* of the function and is denoted $f: X \rightarrow Y$, where X and Y may or may not be the same set. A function is bijection if it is *one-to-one* (or *injection*) and *onto* (or *surjection*). A function f with domain X is *one-to-one* function, for a and b in X, if $f(a) = f(b)$, then $a = b$. A function $f: X \rightarrow Y$ is *onto* if for every element y in Y, there is at least one element x in X such that $f(x) = y$.
297 See previous footnote for a formal definition of a one-to-one function.

unrehearsed nature:

> In *Mental Task 3: Cantor-Bernstein-Schröder Theorem*, Imogen Dickie, who is a philosopher of language, is proving a theorem of set theory on the blackboard. She knows how the proof works, but she is working outside of her area of expertise, and hasn't rehearsed the proof in a while, so she hesitates and makes mistakes. The film is a single take, and it ends when she manages to work out the entire proof. I didn't want to film someone who could perform elegantly a well-rehearsed proof, I was looking for the struggle.[298]

In other words, by transforming the process of constructing a proof into a performance, Gagliardi is intending to demonstrate the mental task of constructing a proof, including the various ways in which mathematicians logically work through abstract ideas in order to demonstrate a result. His main concern is not to present a formal proof of the theorem, although Dickie does accurately present it eventually.

In the construction of the proof, Dickie makes many formal errors, since she is working informally – that is, in a manner similar to the way all mathematicians work while exploring ideas. For instance, she even incorrectly states the antecedent of theorem itself as "$A < B$ and $B < A$", which is meaningless since $A < B$ is undefined in terms of sets. Moreover, from the statement $|A| < |B|$ and $|B| < |A|$, it would *not be possible* to prove $|A| = |B|$. By definition, $|A| < |B|$ means that there is an injective function from A to B, but that there is no bijective function from A to B, or explicitly is the statement that $|A| \neq |B|$ (recall, by definition $|A| = |B|$, means there exists a bijective function from A to B).[299] By providing documentation of an unfamiliar proof, Gagliardi is not only documenting the act of someone performing a mental task, he is also capturing a rare moment: the translation of pure mathematical ideas into a form that is expressible to other people.

Humorously, the original title for the film was going to be *Zorn's Lemma,* a reference to Hollis Frampton's film *Zorns Lemma* (1970), which only alluded to the axiom (the film will be discussed in greater detail in Chapter Eight). Gagliardi explains:

298 Mike Hoolboom, "A Record of Its Own Making: An Interview with Francesco Gagliardi," (January 2017), <http://mikehoolboom.com/?p=18376>.
299 The statement that $|A| < |B|$ and $|B| > |A|$ is not inherently a contradiction unless one assumes the Axiom of Choice which is equivalent to the statement $|A| \leq |B|$ or $|B| \leq |A|$ for every set A and B.

> The original plan was to shoot someone proving Zorn's Lemma, I thought it would be funny to make a film called *Zorn's Lemma* which consisted of a single take of someone actually carrying out the proof, but at the last minute, the logician that had agreed to do it backed out. I suspect that he felt self-conscious about being caught on camera hesitating and making mistakes. He asked me if he could rehearse, I said no. I tried to explain what I was after, but he pulled out.[300]

Through this explanation, Gagliardi reveals that the concept for the film was based on a mathematical misunderstanding – namely, Zorn's Lemma is not actually a lemma, it is a misnamed axiom[301] – however, one can be assured that his nervous logician friend was going to attempt to prove the equivalence between the Axiom of Choice and Zorn's Lemma, which is a slightly more difficult proof to perform from memory than the Cantor-Bernstein-Schröder Theorem.

Hollis Frampton is perhaps the best-known experimental filmmaker who has often turned to mathematics for inspiration. One of Frampton's most inspired mathematical moments, or the most productive use of a mathematical misinterpretation, comes in section "V" of his text "A Pentagram for Conjuring the Narrative,"[302] a section which provides insights into how Frampton constructed narratives from abstract concepts, as previously discussed in Chapter Three in relation to Brakhage's Theorem. In this section, Frampton follows a line of inquiry in which he confesses, "any discerning reader will be finding this a long winded, pointless joke in poor taste."[303] He uses the equation of the line as a metaphor to discuss the life, or "the true accounts of suffering of x," of various storytellers.[304]

The standard equation for a line in slope-intercept form is given as:

$$y = mx + b$$

where m and b are constants and y is a function dependent on x. When the function is graphed in the Cartesian coordinate system as $(x, mx + b)$ it forms a line with slope m and y-intercept b, that is, when

300 Hoolboom, "A Record of Its Own Making."
301 Mathematician Serge Lang observes most mathematicians reluctance to consider Zorn's Lemma an axiom: "Zorn's Lemma could be just taken as an axiom of set theory. However, it is not psychologically completely satisfactory as an axiom, because it is too involved, and one does not visualize easily the existence of the maximal element asserted in the statement." Serge Lang, *Real and Functional Analysis* (Berlin: Springer, 2012), 12.
302 A pentagram is a five-sided object, that can be constructed inside a regular pentagon. See Fig. 1.
303 Frampton, "A Pentagram for Conjuring the Narrative," 147.
304 Ibid., 146. Frampton's use of life as suffering comes from Joseph Conrad's insistence that people's lives can be reduced to three events: "He was born. He suffered. He died."

$x = 0$ we obtain the point $(0, b)$, the place where the line crosses the y-axis. Frampton states the equation of a line as follows:

$$ax + b = c$$

where it can be assumed that a and b are constants (or *knowns*) and c is a function of x.[305] Frampton suggests that through algebraic manipulation it is possible to obtain "the viewpoint of its other main characters" as follows:[306]

$$a = \frac{c-b}{x}$$

$$b = c - ax$$

$$c = ax + b$$

But, as we would never have to *solve* for the "other characters" a and b since they are *known*, these equations would only be helpful for further algebraic manipulation. Frampton further suggests through algebraic manipulation it is possible to obtain the "Supreme Unity," or one[307]:

$$1 = \left(\frac{c-b}{a}\right) - x$$

and "the unbiased spectator," or zero[308]:

$$0 = \left(\frac{c-b}{ax}\right)$$

In spite of the fact that these equations are misstated,[309] Frampton is narrativizing the numbers in a manner similar to the Pythagoreans. For instance, as explained by Greek historian Constantine J. Vamvacas,

> The Pythagoreans would relate numbers to pure intangible concepts, such as: the *one* related to intellect and being; the *two* to thought; the *four* to justice ($2 \times 2 = 4$; 'equally even'); but also as the *tetractys* (the

305 Ibid.
306 Ibid.
307 Ibid.
308 Ibid.
309 This was more than likely a typo since the equations are correct but reversed. They should be:

$$1 = (c - b)/ax \text{ where } a \neq 0 \text{ and } x \neq 0,$$
$$0 = ((c - b)/a) - x \text{ where } a \neq 0.$$

triangular figure based on the number 4), related to the whole of nature; the *five* to marriage; the *six* to embodiment of the soul; the *seven* to weather, light, health; the *eight* to friendship and love; while the 'perfect' *ten* "comprises in itself the whole nature of number."[310]

Given the title of Frampton's article, "A *Pentagram* for Conjuring the *Narrative*," one could speculate that his essay can be read as piece of Pythagorean writing, since the Pythagoreans saw the pentagram as sign of membership and were known for assigning meaning to (or narrativizing) numbers and symbols.[311] Frampton seems to confirm this reading when he suggests

> The algebraic equation for
> $$ax + b = c$$
> is *our* name for a stable pattern of energy through which an infinity of numerical *tetrads* [also known as the *tetractys,* see Fig. 14] may pass. A story is a stable pattern of energy through which an infinity of personages may pass, ourselves included.[312]

The reference to the tetrads is an explicit reference to the symbol which the Pythagoreans saw as "a sacred numerical symbol"[313] since it represents what they saw as the "perfect" number – namely, the number ten – visually as the sum of the first four numbers. This suggests that the "*our*" in Frampton's statement is actually referring to the Pythagoreans, of which he considers himself a member, and his text is an expansion of their methodology to include the equation of the line.

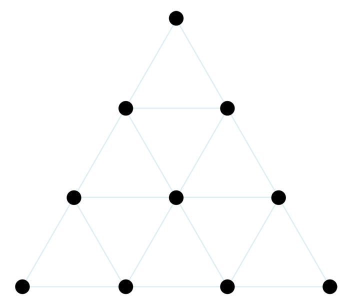

Fig. 14 – Tetractys.

Frampton uses variations of equation of the line as a metaphor for "suffering" endured by four storytellers – Gertrude Stein, Rudyard Kipling, Ambrose Bierce, and Henry James, whose writing famously increases in complexity from Stein to James – represented respectively as follows:[314]

$$x = x$$

$$x = \frac{c - b}{a}$$

310 Constantine J. Vamvacas, *The Founders of Western Thought: The Presocratics: A Diachronic Parallelism between Presocratic Thought and Philosophy and the Natural Sciences,* trans. Robert Crist (Berlin: Springer, 2009), 72. [Emphasis in original.]
311 Ibid., 65.
312 Frampton, "A Pentagram for Conjuring the Narrative," 147. [Emphasis added.]
313 Vamvacas, *The Founders of Western Thought,* 69.
314 Frampton, "A Pentagram for Conjuring the Narrative," 146.

$$x=\sqrt[3]{\frac{2c(c-b)}{a^2}}$$

$$x=\frac{2c(c^2-2cb+2b^2)}{c^3-3bc^2+3b^2c-b^3}$$

Frampton suggests that “any schoolboy algebrist will readily see all four are variations upon the same hackneyed plot,”[315] namely, the suffering alluded to earlier. I am convinced Frampton intended these all to be the same equation represented differently. However, there are a few problems, the most major being that for all of these equations except Kipling's we would already have to assume beforehand that $ax + b = c$. For instance, consider Stein's equation, $x = x$. This equation is simply the identity equation, and every value of x satisfies it; however, this equation alone doesn't satisfy Frampton's equation of the line, nor does it implicitly suggest $ax + b = c$. Similarly, if we assume Frampton's equation for the line, Bierce's equation reduces as follows:

$$x=\sqrt[3]{\frac{2c(c-b)}{a^2}}=\sqrt[3]{\frac{2c(c-b)}{\left(\frac{c-b}{x}\right)^2}}=\sqrt[3]{\frac{2c\,x^2}{c-b}}$$

From this, I believe that Frampton assumed that

$$\frac{2c}{c-b}=x$$

since then

$$x=\sqrt[3]{\frac{x^2\,2c}{c-b}}=\sqrt[3]{x^3}=x$$

However, it can be shown that this equivalence holds if we replace $2c$ in the equation with ax^2 or if the slope of Frampton's line was actually his Supreme Unity, that is, if $a = 1$.[316] Moreover, I believe there is a typo in James' equation and it should be

315 Ibid.

316 Since $2c/(c-b) = x$ which implies $2c/ax^2 = 1$. As previously shown, $1 = (c-b)/ax$. Hence, $2c/ax^2 = (c-b)/ax$. Therefore, $ax = 2c/(c-b) = x$. Hence, $a = 1$ (provided $x \neq 0$).

$$x = \frac{2\mathrm{c}\left(c^2 - 2\mathrm{cb} + b^2\right)}{c^3 - 3\mathrm{bc}^2 + 3\mathrm{b}^2 c - b^3}$$

since, if we assume both Frampton's equation for the line and his previous error, it reduces as follows:

$$x = \frac{2\mathrm{c}\left(c^2 - 2\mathrm{cb} + b^2\right)}{c^3 - 3\mathrm{bc}^2 + 3\mathrm{b}^2 c - b^3} = \frac{2\mathrm{c}\left(c - b\right)^2}{\left(c - b\right)^3} = \frac{2\mathrm{c}}{c - b} = x$$

In spite of Frampton's mathematical errors and typos, he was attempting to suggest that despite the different perceived levels of complexity in our lives they all amount to the same suffering as suggested by Conrad in his statement: “They were born. They suffered. They died.” Beyond this, Frampton further suggests another possible interpretation for Stein's equation:

> The equation I attributed to Miss Stein may be inverted [by subtracting *x* from both sides] to read as follows:
>
> $$x - x = 0$$
>
> That says, in English, that anything diminished by something of its own magnitude amounts to nothing. If we care to personify, it suggests that, in the absence of equals, any man is diminished to a cipher. And *that* smacks painfully enough of folk wisdom to have interested Gertrude Stein...even if I can't state it in her own idiom.[317]

Using the observation that $x = x$ is a tautology (and nothing more), it is possible to suggest another interpretation of Stein's equation, namely, that Stein's life implies a form of truth. Given these mathematical insights, I, like Frampton, leave the other equations as homework for future literary scholars.

Contemporary moving image artist Isiah Medina often uses mathematics as inspiration for his art, in particular, in his development of ideas concerning infinity in relation to the frame and the cut. Medina is openly opposed to the dichotomy proposed in the two cultures debate. He states,

> I hate this whole belief that art isn't science or art isn't math so we should stop trying to bring those ideas in there. They can still take inspiration from each other. There's beauty in a math proof and there's hypothetical experimentation that can happen in art.[318]

Medina treats philosophy, mathematics and cinema as a form of free association, a methodology of philosophic freestyle, or academic hip hop. Medina speaks both eloquently and fairly accurately about

317 Ibid., 147. [Emphasis in original.]
318 Medina quoted in Vivian Belik, “A Provocative New Canadian Doc: A Review of *88:88,*” *Point of View Magazine* (February 2, 2016), <http://povmagazine.com/articles/view/review-8888>.

relatively difficult mathematical concepts, in particular those related to infinity and logic. Through applying this methodology, Medina has produced numerous philosophical and cinematic insights, a few of which I will here discuss in detail. Medina's work and research is also influenced by the work of Badiou, with portions of Badiou's texts read in a whisper throughout Medina's debut feature, *88:88* (2015).

88:88 blends diaristic filmmaking, formal experimentation, and staged scenarios, presenting brief glimpses and fragmented moments, often including multiple images superimposed on the screen, frames within frames, and video feedback. The sound design is often jarring, with text and music cut abruptly, and with much of the fragmented texts whispered to the audience. The texts themselves are cut up and layered, and come from numerous sources including readings of philosophy and poetry, hip hop and personal conversations between friends. Through brief glimpses and snippets of conversations, the film creates an intimate portrait of life in the West End of Winnipeg, documenting Medina's friends and the poverty and social injustice many of them face. Reading the film in the diaristic tradition, the images and recorded conversations can be seen as documenting Isiah's external life, his interactions with his friends and daily experiences, while the spoken texts can be seen as framing Isiah's internal life, as materials that inform some of his worldviews and perspectives.

The title *88:88* is a reference to the graphical display that is left on a digital clock when there is no power, or the graphical default that blinks on and off on a digital clock to indicate a power outage. Medina provides a political reading, stating “88:88 (or --:--) appears if you cannot afford to pay your bills, demonstrating that people who live in poverty live in suspended time.”[319] Film critic Benjamin Crais extends this reading, suggesting its connection to the void and Badiou's concept of the pure multiplicity:

> With *88:88*, Isiah Medina gives a name to nothing. 88:88 signifies no money, no electricity, but also no time: a digital clock reads a time that does not exist, that has never and will never come. Yet, in giving it a

319 Clint Enns, “Towards Infinite Light: An Interview with Isiah Media.,” *BlackFlash* 32, no. 1 (January 2015), 9.

> name, Medina grants nothing a positive existence. It is not only a lack, but what the philosopher Alain Badiou calls a pure multiplicity or inconsistency: the "stuff" that is ordered and structured in the presentation of being. 88:88 – an image that contains every possible readout a digital appliance can present (11:35, 02:50, 12:00, etc.). Nothing – 88:88 – thus becomes the ground from which all articulations can emerge, a pure potential from which individual existences are cut.[320]

In other words, Crais sees Medina's use of 88:88 as the void and as a metaphor for pure multiplicity. Medina further re-enforces this observation, suggesting cinema is a no-thing to see (or in Badiou's terminology inconsistent or a pure multiplicity) before it is realized (made consistent or situated or count-as-one). Isiah argues "there will always have been no-thing to see, but this inconsistent no-thing, the interval, must be given structure, must be made consistent."[321]

Almost following directly from Badiou's conception of the void, Medina defines *88:88* similarly:

> There is no given, and even if when in poverty you can say "I have nothing," to be completely clear, this nothing is itself not given. So poor, even nothing itself is not given. So we need a new name of nothing. Our own name, to be able to begin. And that name for us was 88:88.[322]

To express this idea in the film, Medina samples a line from the American rapper Big L: "I wasn't poor, I was po! I couldn't afford the – 'or.'"[323] This lyric can be interpreted in a few ways: too poor to be able to afford an education to correctly pronounce "poor"; too poor to be able to afford the operating room (O.R.); too poor to be able to afford gold, given "or" is "gold" in French. In the case of Medina, there is also "so poor, even nothing itself is not given," a new conceptualization of the void, the space of total poverty. To live in this space means to embody pure multiplicity and to not count-as-one.

The concept of infinity also plays a role in *88:88.* Graphically, ∞ is simply the number 8 turned on its side. As observed by Crais, "it is only a matter of orientation to conceive nothing (88:88) as

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320 Benjamin Crais, "Program Notes for *88:88*," (screening in Atlanta Georgia, 2016), <http://kenotype.tumblr.com/post/149485926871/program-notes-from-the-8888-screening>.
321 Phil Coldiron, "Necessary Means: Isiah Medina on 88:88," *Cinema Scope* 64 (Fall 2015), <http://cinema-scope.com/cinema-scope-magazine/necessary-means-isiah-medina-on-8888/>.
322 Isiah Medina, "Isiah Medina Introduces *88:88,*" *MUBI Notebook* (March 11, 2016), <https://mubi.com/notebook/posts/director-s-statement-isiah-medina-introduces-88-88>. Isiah explicitly references the symbol ∞ in the film as a shadow on the ground formed by a bike rack, however, many lines from *Being and Event* are read throughout the film and a well thumbed copy of the book makes an appearance as well.
323 From Big L.'s "Lifestylez Ov Da Poor And Dangerous."

infinity (∞ x 4)."[324] In the film, while one of Medina's friends discusses hearing voices, he mentions losing his trust in infinity. Medina responds "Wait?! So you lost trust in infinity?"[325] Medina connects his friend's schizophrenic episode to his temporary loss of faith in the infinite (among other things), an idea that seems as problematic as equating schizophrenia to a loss of faith in God.[326] In another scene, a woman dressed as a revolutionary wears a red armband with a black ω symbol on it. In set theory, ω usually denotes the first infinite ordinal. Informally, an ordinal is simply a generalization of the concept of the natural numbers.[327] Ordinal numbers were first explored by Georg Cantor in the late nineteenth century to conceptualize infinite sequences.[328] In order of increasing size, the ordinal numbers are 0, 1, 2, 3, ... , ω, ω+1, ω+2, ω+3, ... , ω·2, ω·2 + 1, ω·2 + 2, ... , ω·3, ... , ω·4, ... , ω^2, ... , ω^3, ... , ω^ω, ...[329] By placing the ω on the armband of a revolutionary, Medina is suggesting its revolutionary potential.

In an interview about *88:88*, Medina associates ω with the cut, hence asserting the revolutionary potential of montage in his filmmaking. Medina explains:

> The shot inevitably comes to an end, and let us call ω the end of this repetitive model of succession; ω ends the repetition of *n* +1. A historical interruption to the tendency of naturalization in a tracking shot. It is not considered in frame, nor does it succeed it – as a point it surpasses the potential "tracking shot"

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324 Crais, "Program notes for *88:88*."
325 In another section of the film, Medina discuss feeling crazy as not simply conforming to society's established norms.
326
In the film, two arguments are presented:
1) Berg: "...I thought I was hearing voice, but it was just having no words. Like being relegated to being an animal that is only sure of its own death. "
Medina: "Like finitude basically. So you felt like you were hearing voices after, because were an animal."
2) Medina: "There is no thought without madness. You know, like Cartesian doubt?"
327 The natural numbers, N* = {1, 2, 3 ...}.
328 It takes a little to define an ordinal number formally. A relation ≤ is *total order* on the set *S* such that if the following holds for all elements *a*, *b* and *c* of *S*:
(i) If $a \leq b$ and $b \leq a$ then $a = b$.
(ii) If $a \leq b$ and $b \leq a$ then $a \leq c$.
(iii) $a \leq b$ or $b \leq a$.
A *well-ordering* on a set *S* is a total order on *S* with the property that every non-empty subset of *S* has a least element in this ordering. A *well-ordered set* is the *S* with this well-ordering. Basically, a totally ordered set is one in which given any two elements one can define a smaller or a larger one in a coherent way. A well-ordered set is a totally ordered set in which there is no infinite decreasing sequence; however, infinite increasing sequences are allowed. Every well-ordered set is associated with an order type called its ordinal number. The ordinal of all the natural non-negative numbers is ω.
329 Ordinals have their own arithmetic that is slightly different than arithmetic on the natural numbers, N* = {1, 2, 3 ...}. For finite cases, the rules for ordinal numbers are essentially the same as for natural numbers; However in the infinite cases, ω + 1 is not the same as 1 + ω, since 1+ ω = ω. Moreover, ω + ω = ω and ω·ω = ω. For more, see: Constance Reid, *From Zero to Infinity: What Makes Numbers Interesting* (Wellesley: A K Peters, 2006).

> not by adding to it, but by being the horizon of its succession. A cut, ω, retroactively totalizes the potentially infinite shot, and becomes its *limit.* We can succeed by applying the same operation, $\omega + 1$, reopening succession. But ω is not a successor to the first succession; ω was itself a support for the prior potentially infinite succession. The consequence is that there is more than one form of the *intervallic*. The space between frames is not the same one, because, if so, then we are, despite appearances, still within a tracking shot, within the one, within the same form of succession that is $n + 1$, and no cut has taken place.[330]

Given that cinema is a *finite* sequence of shots, Medina sees the cut, or ω, as the point that lies just beyond the finite (recall that ω is the first infinite ordinal), as having the potential to open up the finite sequences of shot (or the finite images of our world) to their infinite potential, since anything is possible at the cut. Medina reinforces this reading by arguing that "Cantor would claim there are infinite paradises, infinitely new forms of the cut (the mark of infinity, the end of repetition), in the finite images of our world."[331] In other words, at every cut a new realm of possibilities is opened up, or "without the cut, we remain in finitude."[332] By viewing the cut in these terms, Medina is attempting to use mathematics to expand and rethink the concept of the cut beyond its traditional uses, joining a long tradition of other avant-garde filmmakers.[333]

To Medina, it is through the cut that cinema begins to represent the filmmaker's thoughts. As he suggests, "there is a mental image and a material image, but these are held together by the cut."[334] It is at the place of the cut that we begin to see the filmmaker's perspective, remembering "that there must be a cut before the shot even begins and a cut for the shot to end."[335] That is, in order to construct a shot, the filmmaker must cut it from reality. Through the cut, Medina believes that it is possible to free the footage from one subjective perspective. He argues,

> Without the subjective action of cutting creating new exclusions, true lines of division, we will only have one interval. There will only have been one cut, and the cut will be an objective law, rather than the infinite, subjective production of new truths.[336]

330 Coldiron, "Necessary Means."
331 Enns, "Towards Infinite Light."
332 Coldiron, "Necessary Means."
333 For just one instance, see Keewatin A. Dewdney, "DISCONTINUOUS FILMS," *Canadian Journal of Film Studies* 10, no. 1 (Spring 2001): 96-105. "For some reason we are now released from continuity" [98].
334 Coldiron, "Necessary Means."
335 Ibid.
336 Ibid.

Although the cut may have the potential for “the infinite, subjective production of new truths,” in the end there will be only one film. Doesn't this, using Medina's logic, make it an objective law? In contrast, even if the filmmaker chooses only one shot, *only one interval* without a cut, they have chosen that shot, as Medina has previously argued, from all of the infinite shots available potentially allowing for the infinite, subjective production of new truths.

Finally, the graphical representation of infinite, ∞, resemble handcuffs, which also play a role in Medina's film. With his hands cuffed behind his back, Medina is shown walking through downtown Toronto. Chained by the infinite, Medina, shot from below, walks past massive skyscrapers and through a field of shadowy 8s. As Crais suggests, “Medina equates 88:88 with imprisonment, with numerous 8s forming the material out of which a chain-link fence is constructed” [see Fig. 15].[337]

88888888
88888888
88888888

Fig. 15 – 88:88 as a prison.

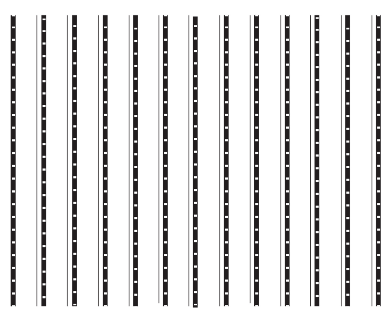

Fig. 16 – Film as a prison.

The revolutionary potential of the infinite is juxtaposed with the reality that those who deviate too far from societal norms are punished. Medina presents this argument in a slightly different form in the film while comforting a friend – he suggests that those who feel crazy are simply those who believe in

337 Crais, “Program notes for *88:88*.”

certain norms, stating "when people think they're crazy, they just assume a certain way of being in the world is correct."[338]

Where Badiou uses mathematical concepts to develop an ontological framework, Medina uses mathematics to develop a cinematic framework. Through the use of mathematics, Medina is attempting to see cinema in new ways. Like Badiou, he is also applying the same mathematical systems in an attempt to understand social, legal and psychological systems to explore problems beyond the underlying logic of ZFC – an axiomatic system not conceived with these concerns in mind. Nevertheless, by evoking the infinite, Medina is pushing the poetic potential of cinema by thinking through every cut as the potential for new possibilities. In thinking through the infinite, Medina is attempting to conceptualize the infinite possibilities of cinema, a cinema beyond that which has already been presented to us.

338 Text heard in *88:88*.

CHAPTER FIVE: VISUAL SYMMETRY AND MEDIA ART

Without maths we're lost in a dark labyrinth.
It's the glue that binds scientific and artistic cultures.
The language of numbers and symmetry is spoken everywhere.
– Marcus du Sautoy,
"Speech as the Simonyi Professor for the Public Understanding of Science"

This chapter provides an overview of visual symmetry from a mathematical perspective. The main concepts to be explored in this section are symmetry groups, frieze patterns, wallpaper patterns, and Platonic solids. A history of the term "symmetry" will be explored, given this is one of the ways in which mathematics has been aestheticized. In particular, the interconnection of notions of symmetry and harmony will be examined. Symmetry will also be discussed from a group theoretic perspective since "numbers measure size, *groups measure symmetry*."[339] For instance, mathematicians use symmetry groups in order to measure the symmetry of a cube or a square. A formal definition of a symmetry group will be provided, since both understanding and recognizing symmetry allows us to observe and analyze it in cinema and media art and, equally important, to recognize its absence. As Magdolna and István Hargittai observe in their book *Visual Symmetry*, "we live in a world of symmetries in which the absence of symmetry may be as interesting and often more important than its presence. Our reference point is usually symmetry, and being aware of it makes it easier to recognize its absence and various imperfections."[340] Examples of symmetry groups found in media art will be analyzed in detail. Moreover, this chapter will explore works that connect symmetry to Pythagorean notions of harmony, and works that use symmetry to demonstrate the limitations of human visual perception. Finally, the literary concept of the palindrome will be expanded to include moving image works, given that this is a strategy that has been employed by artists to create symmetry within their work. To this end, a classification system for filmic palindromes will be provided.

339 M. A. Armstrong, *Groups and Symmetry* (New York: Springer-Verlag, 1988), vii.
340 Magdolna Hargittai and István Hargittai, *Visual Symmetry* (Singapore: World Scientific, 2009), i.

5.1 Visual Symmetry: A Mathematical Overview

The word "symmetry" is derived from the Greek word *symmetria,* which translates to "the common measure of things."[341] Its use in relation to physical beauty is usually attributed to Polykleitos, who, according to secondary sources, wrote about this in the *Canon* of Polykleitos*,*[342] a lost but influential text on sculpture that mathematically bridges "the Egyptian Twenty-sixth Dynasty and the canon of Vitruvius."[343] Plato "held Polykleitos in high esteem,"[344] and the structure of Vitruvius' canon was undoubtedly influenced by Polykleitos. According to the physician Galen of Pergamon, Polykleitos' view was that symmetry, in terms of proportion and beauty (in his case, physical beauty), is related to the symmetry or proportion of its members (in this case, other related body parts). Galen writes,

> For he [Chrysippus, a stoic philosopher] distinguished them accurately in the case of the body, placing health in the proportion [*symmetria*] of the elements, and beauty in the proportion [*symmetria*] of the members. He showed this clearly in the passage I quoted a short time ago, in which he says that health of the body is proportion [*symmetria*] in things hot, cold, dry and wet, which are obviously elements of bodies; but he believes that beauty does not lie in the proportion of the elements but of the members: of finger, obviously, to finger of all the fingers to palm and wrist, of these to forearm, of forearm to upper arm, and of all to all as is written in Polykleitos' *Canon*.[345]

Polykleitos' *Canon*, as reconstructed through secondary sources by historian Hugh McCague, closely follows the Pythagoreans' conceptions with regards to beauty. Since Galen wrote after Vitruvius and was familiar with his writing, it is difficult to determine Vitruvius' influence on Galen's description of Polykleitos' *Canon*.

Polykleitos' *Canon* is slightly different from other conceptions of symmetry at the time, since it is not based on equilibrium, but on mathematical ratios. His view of symmetry was more "organic" than the Egyptian concept which, according to Umberto Eco, "prescribed fixed quantitative

341 György Darvas, *Symmetry: Cultural-Historical and Ontological Aspects of Science-Arts Relations : The Natural and Man-Made World in an Interdisciplinary Approach*, trans. David Robert Evans (Basel: Birkhäuser, 200), 2.
342 See: E. R. Swart, "The Philosophical Implications of the Four-Color Problem," *The American Mathematical Monthly* 87, no. 9 (November 1980): 697–707. For more see Hugh McCague, "Pythagoreans and Sculptors: The Canon of Polykleitos," *Rosicrucian Digest* 87, no. 1 (2009): 23–29.
343 McCague, "Pythagoreans and Sculptors: The Canon of Polykleitos," *Rosicrucian Digest* 87, no. 1 (2009), 25.
344 Ibid., 26. Also see Plato, *Philebus*, sec. 55e.
345 Galen, *On the doctrines of Hippocrates and Plato*, sec. 5.3.15. The original statue titled *Doryphoros* (also called the *Canon*) no longer exists; however, Roman marble copies of the original have been made.

measures."[346] In other words, "the proportions of the parts were determined according to the movement of the body, changes in perspective, and the adaptation of the figure in relation to the position of the viewer."[347] In other words, his idea was not strictly mathematical in nature.

Similar to Polykleitos, Pythagorean philosophy was central to Vitruvius' canonic description of the harmonious proportions of the human body, which was also the foundation of his architectural principles.[348] As Vitruvius argues,

> Eurythmy is beauty and fitness in the adjustments of the members. This is found when the members of a work are of a height suited to their breadth, of a breadth suited to their length, and, in a word, when they all correspond symmetrically.[349]

Umberto Eco suggests in the *History of Beauty* that "Vitruvius was to distinguish proportion, which is the technical application of the principle of symmetry, from eurhythmy ('venusta species commodus que aspectos'), which is the adaptation of proportions to the requirements of sight," in the Platonic sense, "from the standpoint of which the figure is viewed."[350] Vitruvius further defines symmetry as follows:

> Symmetry is a proper agreement between the members of the work itself, and relation between the different parts and the whole general scheme, in accordance with a certain part selected as standard.[351]

In other words, to Vitruvius, symmetry is not only a relationship between the parts, but a proper arrangement of the parts to the whole. He later clarifies:

> Proportion is a correspondence among the measures of the members of an entire work, and of the whole to a certain part selected as standard. From this result the principles of symmetry. Without symmetry and proportion there can be no principles in the design of any temple; that is, if there is no precise relation between its members, as in the case of those of a well shaped man.[352]

Although he is referring to architecture and physical beauty, Vitruvius' concept of symmetry can extend beyond these applications, further suggesting a connection between beauty and proportions – that is, a

346 Umberto Eco, *History of Beauty*, trans. Alastair McEwen (New York: Rizzoli, 2004), 74.
347 Idid, 75.
348 McCague, "Pythagoreans and Sculptors," 26.
349 Vitruvius, *The Ten Books on Architecture*, sec. 1.2.3.
350 Eco, *History of Beauty*, 75.
351 Vitruvius, *The Ten Books on Architecture*, sec. 1.2.4.
352 Ibid., sec. 3.1.1.

connection between aesthetics and mathematics. Moreover, this can be seen as developing symmetry as one standard of beauty.

Another concept that is closely related to proportions and symmetry is *harmony*. As Darvas asserts,

> "Hidden harmony is stronger than explicit," wrote Heraclitus at the beginning of the fifth century BC. And what did harmony mean for Heraclitus and his age? Essentially it meant what we now term symmetry. [...] According to ancient thought, harmony pervades nature and its laws, at once expressing artistic harmony, proportion and beauty.[353]

Alternatively, Eco argues:

> Heraclitus was to propose a different solution [than the Pythagoreans who believed that in two contrasting propositions only one of them represents perfection]: if the universe contains opposites, elements that appear to be incompatible, like unit and multiplicity, love and hate, peace and war, calm and movement, harmony between the opposites cannot be realized by annulling one of them, but by leaving both to exist in a continuous tension. Harmony is not the absence of but the equilibrium between opposites.[354]

Eco's argument demonstrates the tension between the harmony found in the two types of symmetries – that is, one based on equilibrium and the other based on proportion. Twentieth-century mathematician Andreas Speiser connects this mathematical concept of symmetry, expressible through group theory, to an aesthetic history connected to harmony:

> The group represents the principles of integral ratios which in antiquity ruled the search for the laws of nature under the poetic name of the 'harmony of the spheres,' and built the basic laws of the world for Kepler. The Greeks called such a law 'logos,' which today includes the approach to nature on the macro and micro levels; it is a group concept. It allows us to chart the form of the cosmos as well as demonstrate the possible arrangements of atoms in the crystal. Art also should be based on symmetry.[355]

Speiser's assertion that art should be based on symmetry may have been influential to artists, given his connection to the Swiss art scene.[356]

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353 Darvas, *Symmetry*, 44.

354 Eco, *History of Beauty*, 72.

355 Translation in Gamwell, *Mathematics + Art*, 268.

356 Gamwell explains: "Speiser became particular friendly with Le Corbusier because of their interest in art and geometry. In recognition of Le Corbusier's work on a theory of proportion for architecture, Speiser recommended him for an honorary doctorate in mathematics, which he was awarded in 1931 by the University of Zurich" [Gamwell, *Mathematics + Art*, 266–7]. Gamwell also observes that Le Corbusier had no interest in group theory, but many other artists of the era did like artist Max Bill and Camille Graeser. Gamwell, *Mathematics + Art*, 267 and 270.

An interesting side note related to the Golden Ratio and productive misinterpretation from Gamwell: "Although Speiser encouraged La Corbusier's search for the ideal proportions, he discouraged the architect's interest in the Golden Section.

A *symmetry* of an object, in mathematics, is a *rigid transformation*; that is, a mapping of an object onto itself which preserves the distance between any two points on the object.[357] The rigid transformations are: the *identity* (or doing nothing to the object) simply leaves the object fixed; a *reflection* (or flipping the object) about the line of reflection in two dimensions or the plane of reflection in three-dimensions, where the line/plane of reflection acts similar to a mirror; a *rotation* (or turning the object) about a point in two dimensions or a line in three dimensions by the angle of rotation, where the point or line is the pivot point of the rotation; a *translation* (or sliding an object) by the vector of translation[358]; and any combination of these transformations, in particular, the *glide reflection* as the composition of a reflection and a translation. The *symmetry group* of an object lists all of its symmetries that preserve the object or leave the object fixed. In other words, the symmetries which do not change the appearance of the object [Fig. 18]. Informally, a symmetrical object is one that looks the same after it is "flipped," "turned," or "slid."

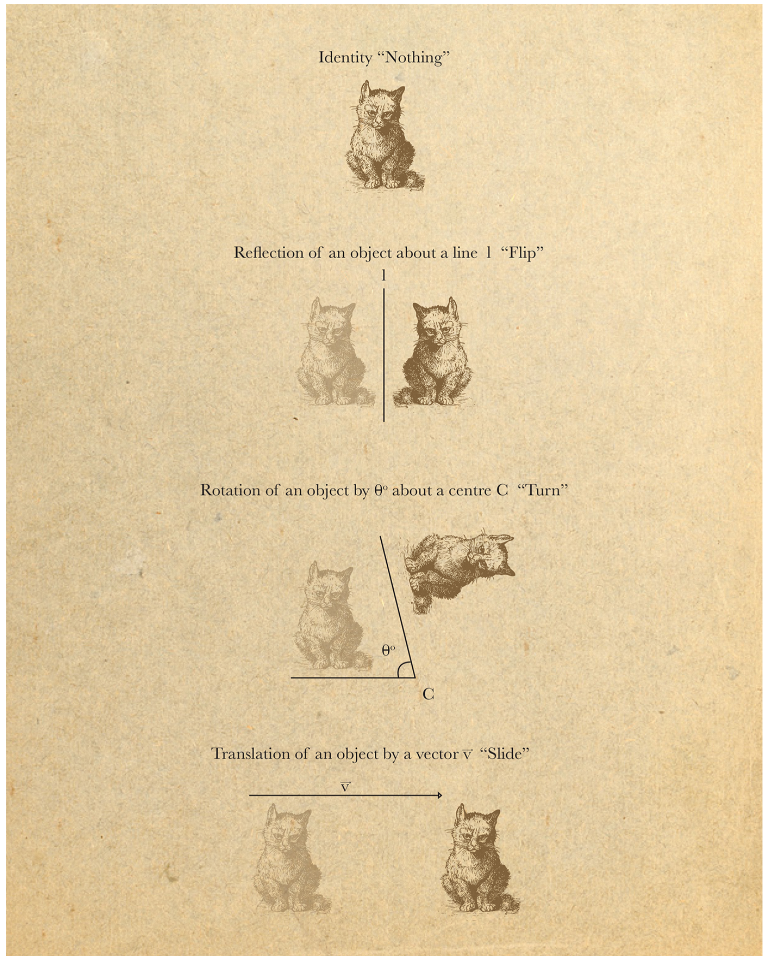

Fig. 17 – The basic types of rigid transformations. (The basic types of symmetries.)

When Le Corbusier conjectured the Golden Ratio is embedded in the (alleged) spiralling of the planets, Speiser informed the architect that Johannes Kepler had determined that planets travel in elliptical orbits (Kepler's first law of planetary motion)" Gamwell, *Mathematics + Art*, 529).
357 Explicitly, a *transformation* is a function that maps a set to itself. A rigid transformation is a transformation that preserves distance between points.
358 A *vector* is a mathematical object that denotes a magnitude and a direction. The magnitude is the length of the translation.

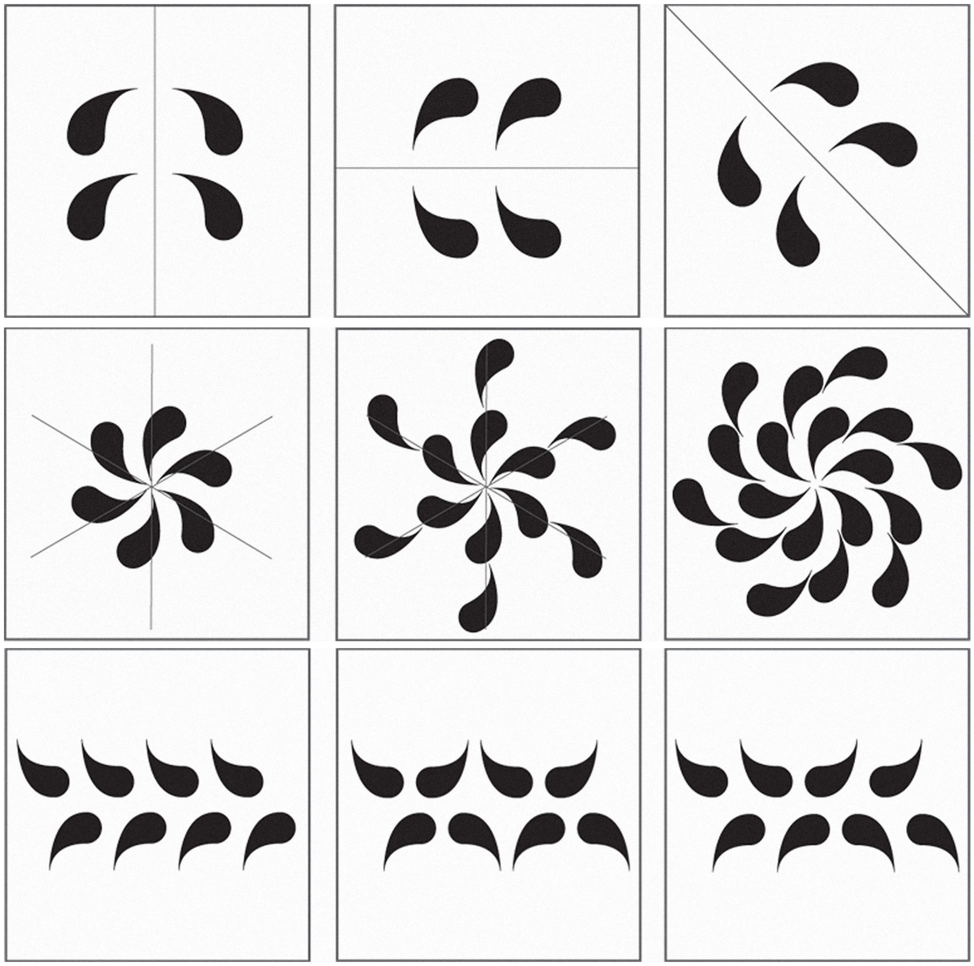

Fig. 18 – Symmetrical objects preserved under different reflections (top), rotations (middle) and translations (bottom).

It is possible to observe the following basic properties about symmetries: a rotation about any point or axis by 360° is the identity; a reflection about any line or plane followed by a reflection about the same line or plane is also the identity; a translation by a vector with zero magnitude in any direction is also the identity; every symmetry group contains the identity, since a transformation that does nothing is invariant; and only an unbounded object can contain a translation in its symmetry group, otherwise the translation would change the object simply by moving it outside of the region bounding it. The circle is the most symmetrical two-dimensional bounded object with its symmetry group containing the identity, a reflection about every line through the centre of the circle and a rotation about the centre of the circle by any angle greater than 0° and less than 360°. Similarly, the sphere is the most symmetrical three-dimensional bounded object.

Frieze patterns are two-dimensional objects that repeat indefinitely along one direction in the plane, forming a strip or infinitely wide rectangle. A symmetry group of a frieze pattern must contain a translation (and, hence, infinitely many translations) along a vector parallel to the strip, and may contain a reflection along a line parallel to the strip, reflections along lines perpendicular to that strip, 180° rotations and glide reflections. Mathematicians have demonstrated there are seven different distinct frieze groups.[359] *Wallpaper patterns* are slightly more complex than frieze patterns, and are composed of patterns repeated indefinitely in two directions that may contain other nested symmetries. Mathematicians have demonstrated that there are seventeen distinct wallpaper groups.[360] The natural extension of wallpaper patterns to three dimensions is the *space group* – a pattern that is repeated indefinitely in three directions. It has been demonstrated by mathematicians that there are 230 distinct space groups (or 219 if certain pairs are considered equivalent).[361]

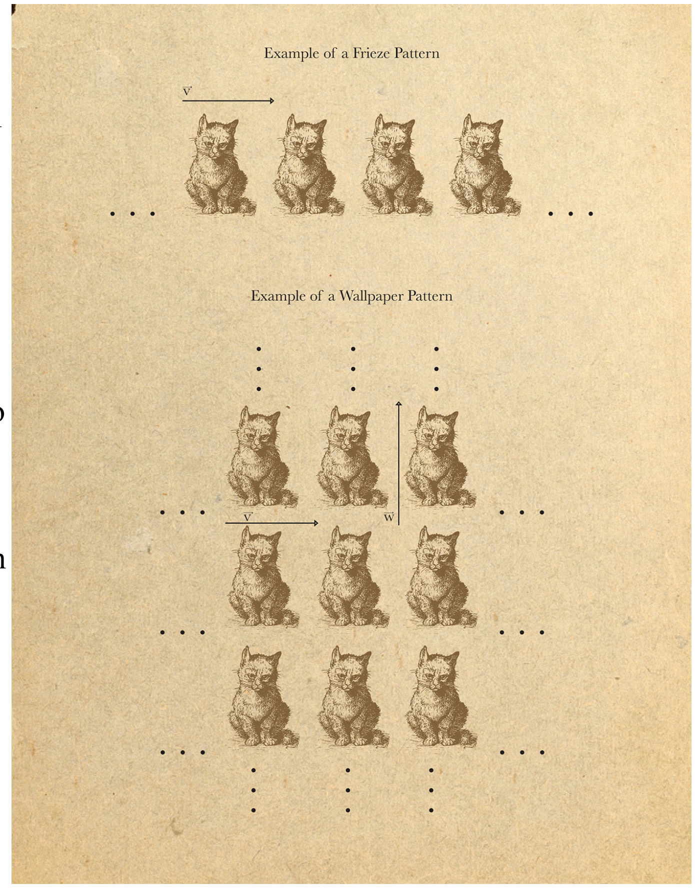

Fig. 19 – Example of a frieze pattern and a wallpaper pattern.

Three key concepts that are directly related to symmetry are *asymmetry*, *dissymmetry* and *antisymmetry*. Asymmetry is used to denote the absence of symmetry, i.e., an object is asymmetrical if

359 Armstrong, *Groups and Symmetry*, 164.
360 Ibid., 155.
361 Darvas, *Symmetry*, 164.

the only element in its symmetry group is the identity. Dissymmetry is used to discuss any characteristics of an object that break its otherwise symmetrical form. One might be tempted to view this as an "imperfection"; however, there are other more positive ways to view dissymmetry. For instance, the French physicist and crystallographer Pierre Curie argues:

> *The characteristic symmetry of a phenomenon is the maximum symmetry compatible with the existence of the phenomenon. A phenomenon may exist in a medium having the same characteristic symmetry or the symmetry of a subgroup of its characteristic symmetry.*
>
> In other words, certain elements of symmetry can coexist with certain phenomena, but they are not necessary. What is needed is that some elements of symmetries do not exist. *It is dissymmetry that makes the phenomenon.*[362]

In other words, it is at the point of a dissymmetry that scientific researchers discover phenomenon, not at the points of symmetry. Thomas Mann provides a poetic argument in favour of dissymmetries:

> Yet each, in itself – this was the uncanny, the anti-organic, the life-denying character of them all – each of them was absolutely symmetrical, icily regular in form. They were too regular, as substance adapted to life never was to this degree – the living principle shuddered at this perfect precision, found it deathly, the very marrow of death – Hans Castorp felt he understood now the reason why the builders of antiquity purposely and secretly introduced minute variation from absolute symmetry in their columnar structures.[363]

In this passage, Mann is arguing against the coldness of absolute mathematical symmetry. In an interview with Philip Taaffe, filmmaker Stan Brakhage makes a similar argument about absolute mathematical symmetry:

> PT: Symmetry is death. Nature forbids symmetry.
>
> SB: Yes, and you avoid it. I fear symmetry very much. I've used it in some films, but always delicately off balance. It is to me, if not necessarily evil, something tangent to that: dangerous.[364]

Both Brakhage and Mann are suggesting that absolute mathematical symmetry is unaesthetic, dreadful

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362 The original in French:
La symétrie caractéristique d'un phénomène est la symétrie maxima compatible avec l'existence du phénomène. Un phénomène peut exister dans un millieu possè de sa symétrie caractéristique ou celle d'un des intergroupes de sa symétrie caractéristique.
Autrement dit, certains éléments de symétrie peuvent coexister avec certains phénomènes, mais ils ne sont pas nécessaires. Ce qui est nécessaire, c'est que certains éléments de symétries n'existent pas. *C'est la dissymétrie qui crée le phénomène* [Pierre Curie. "Sur la symétrie dans les phénomènes physiques, symétrie d'un champ électrique et d'un champ magnétique," *Journal de Physique* 3, no. 1 (1894), 400]. [Emphasis in original.]
363 Thomas Mann, *The Magic Mountain,* trans. H.T. Lowe-Porter (New York: Alfred A. Knopf, 1972), 480.
364 Philip Taaffe, "With Stan Brakhage," in *Stan Brakhage: Interviews*, ed. by Suranjan Ganguly (Jackson: University Press of Mississippi, 2017), 136.

and something to be avoided.

Finally, an antisymmetrical object is one that becomes its inverse through a transformation. For instance, a chessboard or the yin-yang symbol are antisymmetrical since when they are rotated by 180° about the centre, they appear the same but their colours are inverted (everything white has become black, and everything black has become white). As observed by physicist György Darvas, "the world, while appearing to us to be asymmetrical in general, can be regarded as the unity of symmetry and antisymmetry."[365] Surprisingly, Darvas argues the foundation for this claim can be found in quantum physics, asserting that it is not simply a philosophical claim. The basis of his argument is that physical "operators can always be broken down into a symmetrical and an antisymmetrical component."[366] Moreover, Darvas demonstrates a technique that shows every image can be broken into a symmetrical and an antisymmetrical image that, when combined, reproduce the original.[367]

Let us now consider three-dimensional objects. Perhaps the most discussed symmetrical three-dimensional objects are the Platonic solids. A regular solid that has identical, regular faces (that is, all the angles are equal and all the sides are equal), with the same number of faces meeting at each vertex, is known as a Platonic solid. There are five such solids: the tetrahedron (constructed from four equilateral triangles), the cube (constructed from six squares as faces), the octahedron (constructed from eight equilateral triangles), the dodecahedron (constructed from twelve pentagons), and the icosahedron (constructed from twenty equilateral triangles). A mathematical description of the Platonic Solids is given by Euclid in the last book of the *Elements*, and a geometric proof that there are only five

365 Darvas, *Symmetry*, 26.
366 Ibid.
367 Ibid., 26-27.

is sketched.[368] In fact, it has been argued this was the chief goal of the *Elements*.[369] In the dialogue *Timaeus*, Plato discusses the role of the Platonic solids in relation to the construction of the universe by a divine Craftsman who uses mathematics to impose order on a pre-existent chaos. The divine Craftsman uses four out of five of the Platonic Solids as the basis components of the elements: fire (the tetrahedron), air (the octahedron), water (the icosahedron), earth (the cube). The remaining solid, the dodecahedron, "God used in the delineation of the universe."[370]

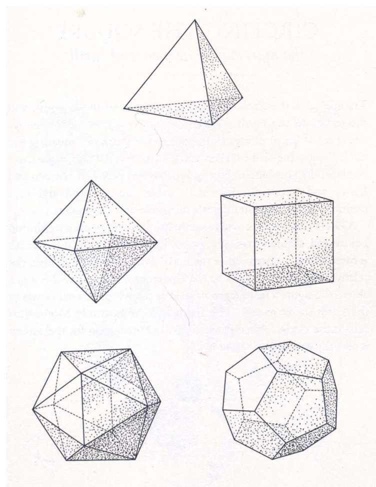

Fig. 20 – The five Platonic solids.

As observed by mathematician Hermann Weyl in his book *Symmetry*, "because of their complete rotational symmetry, the circle in the plane, the sphere in space were considered by the Pythagoreans the most perfect geometric figures, and Aristotle ascribed spherical shape to the celestial

368 Here is a sketch of the most common version of the proof, similar to the one in Euclid's *Elements*:
1.Each vertex must have at least three faces.
2. The sum of the angles that meet at the vertex must be less than 360°.
3. Since the angles must be all equal and there are at least faces that meet at each vertex, the angle of each must be less than 360°/3 = 120.
4. It can easily be shown that for any regular polygon, the angles are 180° – (360°/*n*) where *n* is the number of sides. Hence, regular polygons that have six or more sides would have angles greater than 120°, leaving the pentagon (108°), the square (90°) and the equilateral triangle (60°).
5. There can be only three, four or five equilateral triangles meeting at any vertex, namely, the tetrahedron, octahedron, and icosahedron respectively. There can be only four squares meeting at any vertex, namely, the cube. There can only be three pentagons meeting at each vertex, namely, the dodecahedron.
6. Therefore, there are exactly five Platonic Solids.
369 Hermann Weyl, *Symmetry* (Princeton: Princeton University Press, 1952), 74. Weyl argues that mathematician Andreas Speiser advocates this position. "A. Speiser has advocated the view that the construction of the five regular solids is the chief goal of the deductive system of geometry as erected by the Greeks and canonized in Euclid's *Elements*."
370 Plato, *Timaeus*, Sec. 55c.

bodies because any other would detract from their heavenly perfection."[371] Like the circle, the sphere is the most symmetrical bounded object with its symmetry group containing the identity, a reflection about every plane through the centre of the circle and a rotation about any line through the centre of the circle by any angle greater than 0° and less than 360°.

5.2 Visual Harmony: Symmetry in Media Art

As suggested by film scholar Aimee Mollaghan in her book *The Visual Music Film*, the idea of visual music can be traced back to the Pythagorean concept of the music of the cosmos, or the music of the spheres.[372] Film scholar Gene Youngblood further solidifies this connection in *Expanded Cinema* by referring to Jordan Belson's films as "cosmic cinema."[373] As previously argued, symmetry is closely related to harmony; however, within the artworks of John Whitney, the two concepts seem to have been conflated and symmetrical objects are considered harmonious.

In *Digital Harmon*y, a collection of his writings on visual music, Whitney explains that his book "documents how the application of graphic harmony, in the 'real' sense of ratio, interference and resonance, produces the same effects that these physical facts of harmonic force have upon music have upon musical structures."[374] Every image produced by Whitney for *Digital Harmony* contains some aspect of reflectional or rotational symmetry, visually suggesting that Whitney's idea of harmony is based in the concept of symmetry. Unfortunately, Whitney's book does not explicitly connect these two concepts, nor does Mollaghan in her chapter on conceptions of harmony in Whitney's work.[375] Instead, Mollaghan implies a connection between symmetry and harmony when she argues that Whitney creates a form of "visual music where the sound and image share the same mathematical code, a visual music

371 Weyl, *Symmetry*, 5.
372 Aimee Mollaghan, *The Visual Music Film* (Hampshire: Palgrave Macmillan, 2015), 1.
373 Youngblood, *Expanded Cinema*, 157.
374 John H. Whitney, *Digital Harmony: On the Complimentarity of Music and Visual Art* (Peterborough: Byte Books, 1980), 5.
375 In all fairness, her chapter begins with a quote about symmetry by Marcus du Sautoy, the same one used at the beginning of this chapter.

in which we are literally seeing the sound."[376]

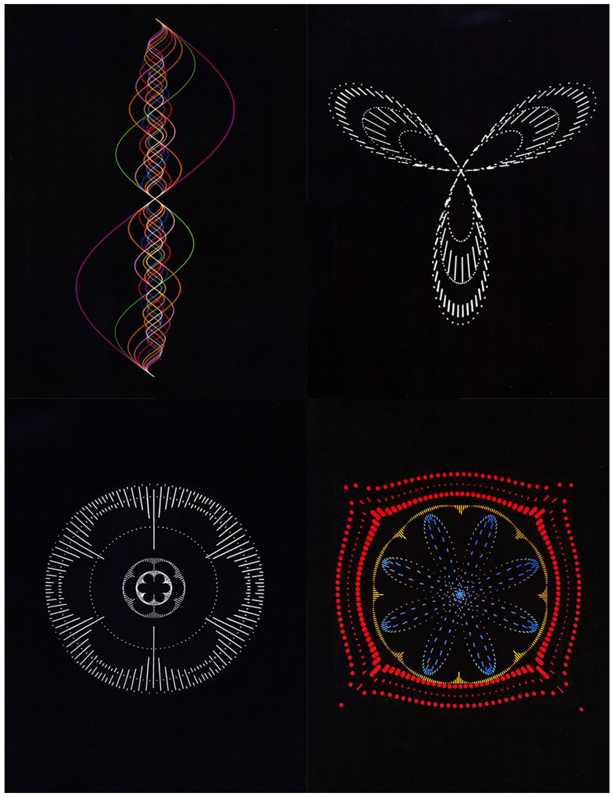

Fig. 21 – Four computer-generated images used to introduce different chapters in Whitney's Digital Harmony.

Whitney's conception of digital harmony is a combination of visual symmetry and harmony found in a musical form. He strived to make computer graphics that followed the harmonic laws dictated by physics, stating, "today we apply [he applies] harmonic laws to build visual structures."[377] Given Whitney's devotion to harmony, it is worth considering his stance on disharmony in music, a concept he saw in opposition to the harmonic laws of physics. Whitney explains:

> Yet the art of music deals with harmonic laws of physics. The basic intervallic ratios of tuning and tone sequence exist simply as physical fact. Arnold Schoenberg told John Cage, "in order to write music, you must have a feeling for harmony." The truth of this remark is not diminished by Cage's protest that he had no such feeling for harmony – just as the truth of physical law would not diminish were the late sculptor David Smith to have protested that he had no feel for the weight and mass of steel.[378]

Cage, who embraced dissonance, saw disharmony as "simply a harmony to which many are

376 Mollaghan, *The Visual Music Film*, 140.
377 Ibid., 16.
378 Ibid., 15–16.

unaccustomed."[379] In contrast, Whitney takes a more classical approach suggesting that "harmony, consonance-dissonance, order-disorder, tension-resolution are interrelated terms in the lexicon of music."[380] In other words, he saw dissonance as something to be resolved or balanced with consonance in order to be in harmony, and disharmonious otherwise.

One of the key visual strategies of Whitney's work is the visual resolution of asymmetry through symmetry. Whitney created visual tension through the use of asymmetrical objects, which he resolves through their transformation into symmetrical objects. For instance, in *Permutations* (1966), dots move around the screen randomly forming asymmetrical objects. Eventually, they move into positions that form different types of symmetrical objects. While discussing this film, Whitney suggests that it is the visual equivalent to the resolution of tension created through the relationship of consonance and dissonance in music:

> In an aesthetic sense, they [action sequences proceeding from order to disorder] have the same effect; the tensional effects of consonance and dissonance. The scattered points fall into some ordered symmetrical figure when all the numerical values of the equation reach some integer or whole number set of ratios. The effect is to subtly generate and resolve tension – which is similar to the primary emotional power of music composition.[381]

Given his devotion to harmony, Whitney's use of asymmetry is only in the service of symmetry, where the climax or the release of tension occurs when asymmetrical objects transform into symmetrical objects. Like in music, Whitney argues that there is also an emotional impact to visual resolution:

> It followed that if moments of resonance resolve tension [caused through dissonance], certain factors must be at work as complementary forces to build tension. Though I little understood the details, it seemed clear I had discovered a clue to a force-field of visual perception. What I knew about music confirmed for me that emotion derives from the force-fields of musical structuring in tension and motion. *Structured motion begets emotion*. This, now, is true in a visual world, as it is a truism of music.[382]

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379 John Cage, *Silence: Lectures and Writings* (Middletown: Wesleyan University Press, 1961), 12.
"For this music is not concerned with harmoniousness as generally understood, where the quality of harmony results from a blending of several elements. Here we are concerned with the coexistence of dissimilars, and the central points where fusion occurs are many: the ears of the listeners wherever they are. This *disharmony*, to paraphrase Bergson's statement about disorder, is simply a harmony to which many are unaccustomed." [Emphasis added.]
380 Whitney, *Digital Harmony,* 54.
381 John Whitney, "Notes on Permutations," *Film Culture,* No. 53-54-55 (Spring, 1972), 78.
382 Whitney, *Digital Harmony,* 54. [Emphasis in original.]

At this point we can identify the “structured motion” to which Whitney is referring: the movement between asymmetrical and symmetrical forms.

Deborah Stratman's video *Xenoi* (2016) explores an entirely different form of visual music, that is, “resonant sonic forms as shapes.”[383] In the video, a camera pans across the various landscapes found on the Greek island of Syros, including “Armeos Beach, Pherecydes' Cave, Ano Syros spring, Ermoupolis, Kastri, the Apollo Theater, Anemogenitries hilltop, and at various hillside yapia.”[384] The landscape is visited by “a series of unexpected guests. Immutable forms, outside of time, aloof observants to human conditions.”[385] The guests take the form of five Platonic solids, each with their own sonic palette, in addition to the appearance of an ever-changing digital animation that amalgamates various bank logos. The Platonic solids appear in natural landscapes and at the Apollo Theater, a cultural icon of Ermoupolis in Syros, and are physically constructed from a reflective material that both mirrors and illuminates the natural landscape, while the amalgamated bank logos only appear in front of Alpha Bank, one of the four major banks in Greece.

The Platonic solids connect the contemporary Greek landscape to its distant past. They appear at Pherecydes' Cave where it is mythologized that Pherecydes of Syros taught Pythagoras, who is often credited as discovering some of the Platonic solids.[386] The Platonic solids were associated with the four natural “elements” (fire, air, water, earth) as written about in Plato's dialogue *Timaeus*, another reason they appear in nature in Stratman’s video. They also appear in the hillsides which feature yapia – unfinished, abandoned buildings – which became increasingly prevalent after Greece's 2009 economic

383 Deborah Stratman, “About Xenoi,” *Urban Video Project* (2017). <http://www.urbanvideoproject.com/artists/deborah-stratman-recent-video-work/>.
384 Deborah Stratman, “Xenoi.” *Pythagoras Film* (2016) <http://www.pythagorasfilm.com/xenoi.html>.
385 Ibid.
386 Although Pythagoras is credited for the discovery of some of the Platonic solids, it was most likely Theaetetus of Athens, a contemporary of Plato, who first provided a mathematical description of all of the solids in addition to a proof that there are only five of them. As argued by Boyer and Merzbach “a scholium (of uncertain date) to Book XIII of Euclid’s *Elements* reports that only three of the five solids were due to the Pythagoreans, and that it was through Theaetetus that the octahedron and the icosahedron became known. It seems likely that in any case, Theaetetus made one of the most extensive studies of the five regular solids, and to him probably is due the theorem that there are five and only five regular polyhedral.” Boyer and Merzbach, *A History of Mathematics*, 76.

crisis. The yapia are reminiscent of the ruins usually associated with ancient Greece, further solidifying the connection between ancient and contemporary Greece.

The ever-changing digital animation that amalgamates the various bank logos suggest a form of insubstantiality, especially in relation to the immutable Platonic solids. In *Xenoi*, the Platonic solids are physically constructed, however, they are eternally defined by their properties. By contrast, the amalgamated bank logos are digitally constructed and in constant flux, and represent a banking system that is externally defined by the global economic market. The animation appears in a panning shot from a parking lot in front of the Alpha Bank – a shot that also reveals a long line of people waiting to get into the bank, surely a result of Greece's economic situation. The Alpha Bank is in the middle of the market, a place that in ancient Greece represented a public assembly space (the *agora*) that was the centre of the athletic, artistic, spiritual and political life of the city, and which has now become the centre of consumer culture.

The literal translation of the word *xenoi* is foreigner or stranger, a person who temporarily visits a place as an outsider. In the video, the word foreigner implies both the Platonic solids and Stratman herself, who made this work as part of a residency in Greece. It also refers to Greece's status as a tourist destination, which seemed unaffected by the country's economic crisis. As an outsider, how do you make sense of the contemporary landscape, one that carries a history and that is littered with contemporary ruins? Just as Stratman describes the Platonic solids as "aloof observers," most tourists, whose presence can be felt in the streets, are equally distant. The same aloof observers who attend shows at the Apollo Theatre are unaware of the behind-the-scenes labour to which the Platonic solids bear witness in the video. Through introducing the Platonic solids, Stratman connects the modern landscape with its ancient history, juxtaposing the eternal and stable nature of the Platonic solids with the instability of the economic market while questioning what it means, as a stranger, to bear witness.

A practical use of visual symmetry occurs in computer animator Lillian Schwartz's 1984 short documentary, *The Hidden Mona Lisa*, in which symmetry is one of the tools used in order to reveal the secret behind Leonardo da Vinci's most enigmatic painting, the *Mona Lisa* (*La Gioconda*, c. 1503–06).[387] Through the use of symmetry – in particular, a reflection over a line down the centre of the subject's face – and a composite with Leonardo's sketch *Portrait of a Man*, often assumed to be a self-portrait,[388] Schwartz produces a visual argument that the *Mona Lisa* was modelled using Leonardo's own features, with the body resembling Isabella, the Duchess of Aragon, who posed in a similar manner for him in an earlier sketch. Schwartz describes the process:

> I asked Gerard [Holzmann] to flip one-half of the *Self-Portrait* [*Portrait of a Man*] so that I could juxtapose Leonardo with one-half of the *Mona Lisa*. As you know by now, operations such as "flip" ["mirror"] or "rotation" merely move the pixels of an image to a new position on the screen. Apart from placement, the operations do not affect the image. I then had Gerard align the two halves to produce the composite for comparative purposes [*Mona Leo*].[389]

After producing the composite, Schwartz than analyzed it using a computer, verifying the symmetry between the face in the *Mona Lisa* and the *Portrait of a Man*.

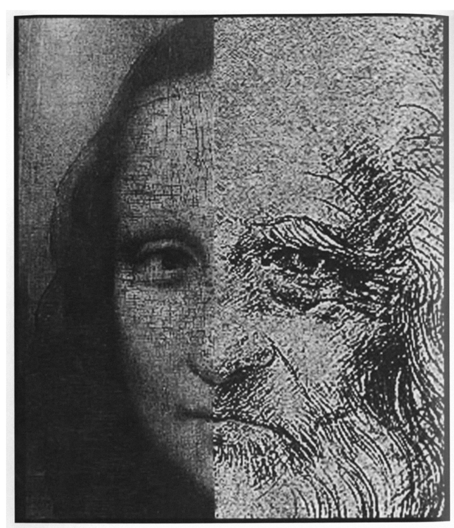

Fig. 22 – Schwartz's Mona Leo.

By placing the two images side by side, as shown in *Mona Leo* [Fig. 22], Schwartz then used

387 The identity is often assumed to be Lisa del Giocondo, the wife of Francesco del Giocondo, or Isabella, the Duchess of Aragon. For a history concerning the identity of the Mona Lisa see Clark, "Mona Lisa."
388 Others have speculated that this is a portrait of his father or uncle, given that the man looked significantly older than da Vinci would have been at the time it was drawn. This does not significantly change Schwartz's argument, who is arguing that the features in the Mona Lisa match those in this sketch.
389 Lillian Schwartz and Laurens R. Schwartz, *The Computer Artist's Handbook: Concepts, Techniques, and Applications* (New York: Norton, 1992), 273.

software to verify the perceived visual reflectional symmetry. For instance, if a line segment perpendicular to the line of reflection is drawn between any two matching points, say the corner of the eyes, then the line of reflection should cross at the midpoint of the line drawn if the object is symmetrical. Schwartz used this method to test several distinguishing facial features and concluded that the *Mona Leo* was indeed symmetrical, concluding that both images were modelled after the same person.[390] Schwartz solidified her argument by demonstrating that the underlying portrait for the *Mona Lisa* was not actually Isabella through the use of traditional x-ray technologies and by comparing it to a photograph of an earlier sketch of Isabella, namely, a photograph of the sketch before it was "restored" (read: "modified") to resemble the *Mona Lisa*. Schwartz further justifies her conjecture by stating that it has been established that Leonardo was not able to proficiently paint objects that were not directly in front of him, and since he no longer had access to Isabella to use as a model, she concludes that he finished the painting using his own face.[391]

T. Marie's *Optra Field* video series (2006–11) demonstrates the intersection between op art (short for optical art) and symmetry.[392] Using wallpaper groups and other periodic structures, the series functions similarly to black and white op art paintings. Art theorist Cyril Barrett provides a description of Op art, which easily passes as a description of T. Marie's videos:

> The eye (and the mind) is threatened with a complete breakdown in its power to control or structure what it sees. It is overwhelmed with contradictory information, much of it created by its own mechanism, which in less extreme conditions, serve to stabilize perception. [...] The realization of the picture's simplicity, if intellectual, is not on that account an observation detached from the experience of the work, but a part of the total experience. As in figurative painting our attention may shift from the scene to the surface pattern and back again, so in Op there is a constant shifting of attention from the simple structure to its complex effects and back.[393]

390 Lillian Schwartz, "The Mona Lisa Identification: Evidence from a Computer Analysis," *The Visual Computer* 4, no. 1 (1988), 43. "The line of the foreheads and chins fall into place. The eyes and the brows line up. A reduction of the pouch under Leonardo's eye produced a match to the horizontal lid. When measurements were taken, it was found that the distance between the inner canthi (the inner corners of the eye), deviated by less than two percent. To the accuracy of our measurements, the two portraits, one of the old man and the other of a mysterious 'woman,' portray the same face."
391 While not as bold as Schwartz's claim that Leonardo could not paint objects that were not in front of him, art historian Kenneth Clark re-asserts Schwartz's claim, arguing "the close continuous modelling of the Mona Lisa's face can hardly have been done from memory." Kenneth Clark, "Mona Lisa." *The Burlington Magazine* 115, no. 840 (1973), 147.
392 *Optra Field I-III* (2006), *Optra Field III-VI* (2009), *Optra Field VI-XI* (2011).
393 Cyril Barrett, *Op Art* (London: Studio Vista, 1970), 44.

T. Marie’s work is digitally constructed from simple periodic structures, two-dimensional repetitive patterns that repeat indefinitely in two directions. The repeated patterns form wallpaper groups if one imagines them repeating indefinitely in both directions beyond the screen. The infinite nature of the work is reinforced by the title, as T. Marie explains: “'Optra' is a term I use to signify a visual mantra (Op-tra).”[394] Given that mantras are intended to be repeated infinitely, one can assume that the optical fields created in T. Marie's *Optra Field* series are intended to be repeated beyond the confines of the screen.

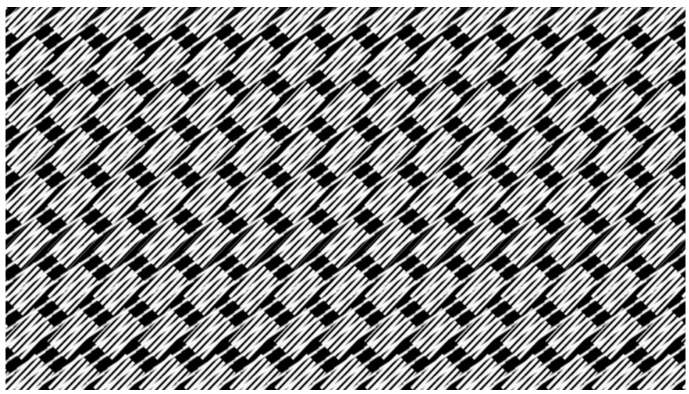

Fig. 23 – Still from T. Marie's Optra Field VIII.

Unlike traditional wallpaper designs, T. Marie's wallpaper designs slowly and subtly transforms using a technique the artist has described as “utilizing the pixel as a drawing medium.”[395] Like Bridget Riley's work, the images produce retinal discomfort and the eye often loses its ability to perceive the image in spite of the fact that the overall patterns and transformations are easy to comprehend. While watching the work, the eye occasionally fills in or misinterprets the image, or introduces its own movement, creating “an unyielding dialogue between the eye and the screen.”[396] Similar to other op art works, it transforms the optical nerve from a tool for observation into a generative instrument due to

394 “The Optra Fields series investigates the materiality of the projected video image, by utilizing the pixel as a drawing medium. In these works, I explore the propinquity between space, time, movement, perception and opposites, specifically those relating to the pixel and grid. ‘Optra’ is a term I use to signify a visual mantra (Op-tra).” T. Marie, artist statement for *Optra Field V*.
395 Ibid.
396 T. Marie, quoted in “TIFF's self-indulgent side.” *CBC News*, (September 07, 2011), <http://www.cbc.ca/news/business/tiff-s-self-indulgent-side-1.1088892>.

the way it misinterprets the image. T. Marie's piece is dedicated to sound artist Maryanne Amacher, who developed a similar technique for music. Amacher describes the experience:

> When played at the right sound level, which is quite high and exciting, the tones in this music will cause your ears to act as neurophonic instruments that emit sounds that will seem to be issuing directly from your head. In concert, my audiences discover music streaming out from their head, popping out of their ears. [...] These virtual tones are natural and very real physical aspects of auditory perception, similar to the fusing of two images resulting in a third dimensional image in binocular perception.[397]

A similar result occurs in visual op art – the human perceptual system is transformed into a personal instrument, not simply observing the work but actively co-constructing the work.

The generation of movement through the optical senses is one of the characteristics of static op art paintings, leading film critic Michael Sicinski to the conclusion that T. Marie's *Optra Field* series is ultimately redundant since the movement introduced is unnecessary and ultimately detracts from the original (e/a)ffect of op art. Sicinski argues,

> Although these three “canvases” are clearly as meticulous as Marie's earlier efforts, the decision to explore the black and white lines and forms of Op Art seems redundant, if not wrongheaded. Op Art, with its almost neurological play on the standard sensorium, is already functioning “in time.” Setting forth an electronic Op field and then gradually shifting it is, in some sense, gilding the perceptual lily. In fact, this activation, together with the light quality and pixel shifting of video (as opposed to the latex matte of actual Op Art painting), threatens to place the spectator in a position so passive as to cancel “painting time” altogether.[398]

Sicinski's critique that video is viewed in “real time” as opposed to “painting time” could equally be applied to any video, but, does this in conjunction with the light quality of the video, actually lead to passive spectatorship? In opposition to Sicinski, one could easily argue that the black-and-white, high-definition video image is the ideal medium for op art, given that its luminosity contributes to the dramatic nature of the optical effect by allowing for far greater image contrast. Furthermore, some optical effects occur only through movement – the classic example being Marcel Duchamp's *Anemic Cinema* (1926).

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397 Maryanne Amacher, *Sound Characters: Making the Third Ear* [CD essay] (New York: Tzadik, 1998).
398 Michael Sicinski, “2011 Toronto International Film Festival.” *Academic Hack (*2011), <http://academichack.net/TIFF2011.htm>.

5.3 Visual Palindromes: In girum imus nocte et consumimur igni

A palindrome is a literary device describing words or phrases that read the same backward as forward. For instance, consider the following four well-known palindromes:

Madam, I'm Adam
A man, a plan, a canal: Panama[399]
Never odd or even
Murder for a jar of red rum

One can deduce from the above examples that palindromes generally allow for adjustments in punctuation and word breaks. In order to expand on this concept, a palindrome can be created using moving images in a few different ways. First, we could require that the moving image work mimic the literary style in form, that is, where shots function like a letter of the palindrome with the last image the same as the first, the second to last the same as the second, and so on. In this case, like with the literary palindrome where we don't require that the letters are reversed in the second half, the work will not necessarily play the same backwards and forwards. Second, we could require that the moving image work play (or read) the same backwards as forwards. Third, we could require that both the moving image work play the same backwards as forwards and mimic the literary style in form.

It is worth observing that playing a moving image backwards and forwards is a medium-specific property. Although all three types of palindromes are the same for digital video, they are quite different for film given that a film played backwards produces an image that is upside down. Moreover, if you play a single-perforation 16mm filmstrip backwards, the image is not only upside down but the emulsion is on the wrong side, making the film more susceptible to damage and requiring the projector to be re-focused. To produce a 16mm film similar to the literary device in form and that plays the same backwards as forwards requires the use of mathematical symmetry. Let us consider two films that experiment with the creation of palindromic structures using moving images: Bruce Conner's BREAKAWAY (1966), and Hollis Frampton's *Palindrome* (1969).

399 This palindrome was used in Owen Land's *Wide Angle Saxon* (1975). Land also uses the palindrome Malayalam.

BREAKAWAY is a psychedelic dance film starring Toni Basil [credited under her full name Antonia Christina Basilotta]. The film uses a song composed by Ed Bobb and sung by Basil, making the film a proto-music video. In the film, Basil dances seductively for the camera wearing various forms of lingerie that would have been typical for pin-up models of the era. Images of Basil gyrating are rhythmically intercut with black leader, creating a stroboscopic or psychedelic effect. The second half of the film is the first half of the film played in reverse, including the music, with two additional shots: a close-up of Basil's face in sunglasses and a full shot of Basil posing as a pin-up model. In this sense, the structure of BREAKAWAY is symmetrical in nature, with the last two shots and the titles creating an intentional dissymmetry.

Bruce Conner's BREAKAWAY is a filmic palindrome made on a 16mm filmstrip with single perforations (since it has a soundtrack). In order to deal with the symmetric in the film, we will ignore the dissymmetries, namely, we will exclude the titles and the last two additional shots. Ignoring the dissymmetries, the second half of the film is the first half played in reverse, and the first and last images of are identical [Fig. 24]. In this way, the film mimics the literary palindromic structure in form. BREAKAWAY would play the same backwards as forwards (not including titles and the two additional two shots at the end of the film) as a video; however, as a 16mm film this is not the case.

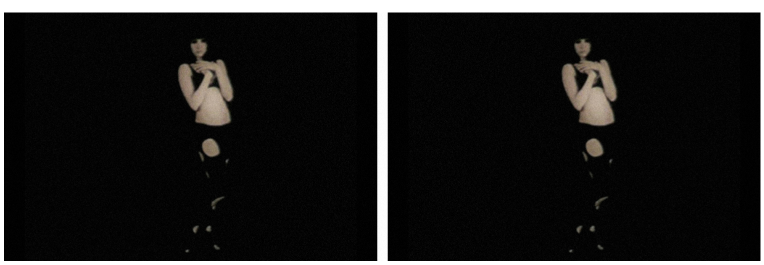

Fig. 24 – First and last image of BREAKAWAY.

To produce a 16mm film with single perforations that plays the same backwards as forwards would require that the first half of the film be reflected about the centre of the filmstrip (leaving the soundtrack alone, since it is already backwards – that is, it is already reflected about the centre of the film strip) [Fig. 25]. In other words, the images in the second half of the film would have to be upside down if one wanted to see the same film played the same backwards as forwards. But, this produces an unintentional byproduct: the film would no longer mimic the literary form, since the last image would not be the same as the first.

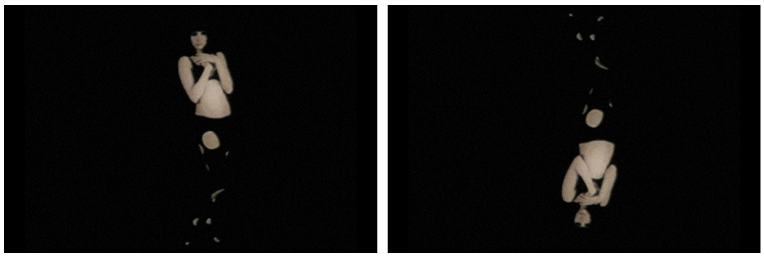

Fig. 25– First and last image of BREAKAWAY if it were to play the same backwards and forwards as 16mm film with a soundtrack.

In order to produce a film that both plays the same backwards as forwards and mimics the literary form would require the additional property that each image would be the same when flipped vertically [Fig. 26].[400]

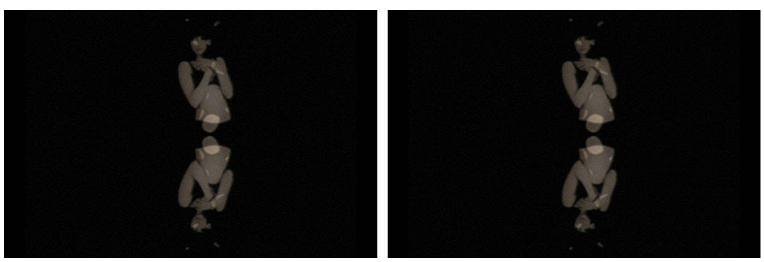

Fig. 26 – First and last image of BREAKAWAY if it were to play the same backwards as forwards as 16mm film with a soundtrack and mimic the literary form.

In *Palindrome*, Frampton constructs his palindrome in a slightly different way. In “Propositions for the Exploration of Frampton's *Magellan*,” theorist Brian Henderson concisely describes some of the difficulties involved with creating a filmic palindrome:

> In 1969, Frampton made a twenty-two minute film called *Palindrome* (969 is a palindrome, so is 22). Making a filmic palindrome is far more difficult than making one of words or numerals or a series of heading; while words, numerals, and headings need not be legible upside down to be palindromes, a film

400 It is worth asserting that I am not suggesting any aesthetic judgement as to which is better, a film that mimics both the literary form, one that plays the same backwards and forwards, or one that does both. I am merely attempting to demonstrate how one would construct such a film.

> must be so. Assuming the requisite double sprocket holes on a given print, *Palindrome* would maintain its identity shown backwards – not only in reverse order but upside down. In principle, at least, the film need not ever be rewound.[401]

Observe the first and the last image of *Palindrome* (excluding titles) [Fig. 27]. The last image is simply the first image rotated about the centre of the frame by 180 degrees, which demonstrates that Henderson's observation about the necessity of double sprocket holes is indeed correct, since the 16mm film would need to be reversed and flipped on playback. It is for this reason that the film does not mimic the literary palindromic form. Moreover, Frampton's *Palindrome* is not literally a filmic palindrome and would not actually be identical shown both forwards and backward for reasons that, I believe, ultimately, contribute to the aesthetic success of the work.

Fig. 27 - First and last image of Palindrome.

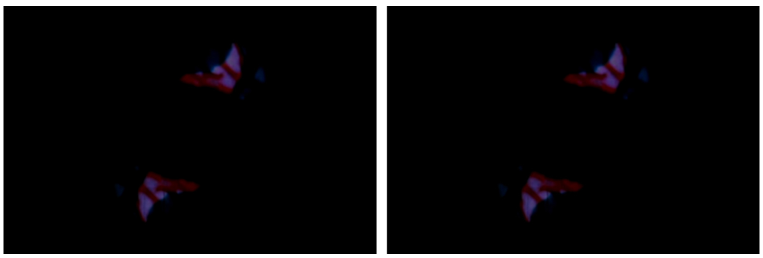

Fig. 28 – First and last image of Palindrome if it were to play the same backwards and forwards as a 16mm film and mimic the literary form.

One of the main reasons the film is not a perfect filmic palindrome is that different variations of the same footage are used. Frampton explains:

> Forty phrases of twenty-four single frames were generated by animation. Then a set of variations was made at the lab which produced the following: an image of the original roll (colour, single layer); a continuous tone black & white version; a black and white negative; and a colour negative. Other sets were produced by printing the original roll superimposed on itself, so that the blocks of image fall on each other, but so that we see images first to last on one level, last to first on the other. A colour positive,

401 Brian Henderson, "Propositions for the Exploration of Frampton's 'Magellan,'" *October* 32 (1985), 137. However, the projector would need to be re-focused given that the emulsion would be on the opposite side of the film strip.

> colour negative, black-and-white positive, and black-and-white negative were made that way. Then came a set made from the black and white; on the forward pass, the original was printed through a yellow filter, and on the reverse pass, through a blue; and others were done the same way except with magenta and green filters. Those generated rolls were intercut with each other, interwoven around the centre point.[402]

In other words, Frampton used many variations of the same footage in the construction of the film. In order to produce a perfect filmic palindrome, every image in the first half of the film must occur rotated in the second half of the film; however, in *Palindrome* the image may not be perfectly duplicated and may appear in negative or in a superimposition contributing to the overall aesthetic of the work. Just like the literary palindrome allows for some variations (i.e. adjustments in spacing and punctuation), the filmic palindrome should be given a similar aesthetic leeway allowing for images to appear in negative, etc.

By employing negative elements in the final film, Frampton also made visible one of the typically invisible aspects of commercial film production. In fact, the images used in *Palindrome* are themselves the detritus of commercial film production. According to Frampton,

> At the time the material for *Palindrome* was collected, I was working in a lab where professionals brought in sheets and rolls of film for processing. All the processing was done by automatic machinery. The waste at both ends of the roll, where the machine's clips had been attached, was cut off and tossed into the wastebasket. The physical deformation caused by the clips and the erratic way in which the clips let in chemicals to work on the emulsion produced images. It struck me that by far the most interesting images produced by the process went into the wastebasket. The dull ones were put in boxes and sent back to the customers. I began collecting the waste images and mounting them as slides.[403]

Through the use of internegatives and the byproducts of industrial filmmaking, Frampton reveals a side of commercial filmmaking that the general public never gets to see. Moreover, the film is produced using elements that seem randomly produced through both chemical and physical deformations in an automated production. The use of byproducts "naturally" produced in a mechanical process is a source of tension within the film, between the organic and mechanical.

The underlying palindromic structure of *Palindrome* creates a further tension between the

402 Ibid.
403 MacDonald, *A Critical Cinema*, 45.

generative nature of the work and the viewer's ability to decode the structure. Frampton relates this to a similar tension that one experiences while listening to serial music:

> Unless one spends a long time with the score, and sometimes not then, one can never quite get back the full set of rules. There's always a certain tension, a certain malaise in listening: one listens with double effort, a double concentration because it seems at once an oddly willful, mutable music, and yet at the same time it is not the willfulness of a composer, of an artist, that one is hearing but the generative power of the set of rules whose consequences are being systematically worked out. That fascinates me.[404]

Frampton's choice of source material and variations within the palindromic structure is one of the ways he inserts himself into "the generative power of the set of rules whose consequences are being systematically worked out." In other words, deviations from the overall underlying structure create a space within the system for the artist to operate.

Finally, Frampton incorporated *Palindrome* into his most ambitious project *Magellan*, an unfinished thirty-six-hour film cycle. As observed by Henderson,

> Given the importance of the palindrome figure throughout *Magellan*, it is entirely appropriate that the film [*Palindrome*] appear among the *Dreams,* that is, in that section devoted to *Magellan*'s unconscious, wherein the material of the cycle as a whole is recycled in condensed, displaced form.[405]

In his current research into *Magellan*, film scholar Michael Zryd examines one of the major tensions Frampton is navigating in the cycle, namely, the tension between fragmentation and totality.[406] One of the ways a fragment can be turned into a totality is through the loop. Frampton alludes to the cyclic nature of the work by including the Latin phrase "et consumimur igni"[407] in the film, which translates to "and are consumed by fire." This phrase is the second half of the Latin palindrome "In girum imus nocte et consumimur igni" which translates to "We go wandering at night and are consumed by fire"; however, "in girum ire" literally (and poetically) means to "go in a circle."

Given the cyclical nature of the palindrome and its role in *Magellan*, it is worth asking what

404 Ibid., 46.
405 Henderson, "Propositions for the Exploration of Frampton's *Magellan*," 137. An excellent resource for information about the palindromic nature of *Magellan*.
406 Michael Zryd, "Hollis Frampton's Comic Inventory: Parables of Photography and Totality in *Magellan,*" (work-in-progress presented at ProprioMedia: Colloquium Series in Media Studies at OCAD University in Toronto, Ontario on October 24, 2014).
407 ET CONSVMIMVR IGNI

type of structure a filmic palindrome is. Creating a loop out of Frampton's *Palindrome* (on a film strip with double sprockets) forms a Möbius strip, a non-orientable surface with only one side and one edge.[408] The Möbius strip raises cosmological questions about the shape of our universe. In addition, it challenges many common intuitions (for instance, that a flat surface must have two sides). Finally, the structure of *Palindrome* provides the viewer with an additional way of thinking about the underlying structure of *Magellan* which, if finished, would have been "the largest loop film ever made, the longest film ever looped."[409]

J.J. Murphy's *Print Generation* (1973-4) is a perfect example of a film that mimics the literary form of the palindrome without the film playing the same backwards and forwards. In great detail, cinema scholar Scott MacDonald describes the film's construction:

> Specifically, *Print Generation* is the result of Murphy's exploration of contact printing, a method of generating a print through direct contact, by laying print stock along an original. Having made a one-minute film of sixty one-second personal images, Murphy had a lab make a print of this film, then a print of the print, then a print of the print of the print, and so forth. Since each generation of printing subtracted from the photographic quality of the original images, it was inevitable that if he printed prints of prints long enough, the images would entirely disappear. He had the lab make prints until he had fifty generations, which he then proceeded to arrange. Since each successive generation of contact printing produces a mirror image of the original it is made from, an adjustment was necessary. Murphy divided the generations into A-wind (the twenty-five generations of one configuration) and B-wind (the twenty-five generations of the opposite configuration) and arranged them so that in 16mm prints the imagery is in the same configuration throughout. We first see "A-wind," starting with the imagery in its most disintegrated state and moving progressively up through the generations until it has completely evolved. After several credits, "B-wind" moves progressively back toward the imagery in its most disintegrated state.[410]

Through the use of A-winds and B-winds,[411] Murphy produces a film where the second half is simply the first half with the shots in the reverse order. In the first half of the film, the viewer watches the disintegrated images eventually transform into images. If Murphy was attempting to make a film that was simply a formal gesture, it would be enough to simply reveal the way in which the repeated

408 In simple terms, a non-orientable surface is one in which it would be impossible to distinguish between left and right. In contrast, creating a loop out of a film with single sprockets creates a two-sided, double-edged object with an orientable surface.
409 Henderson, "Propositions for the Exploration of Frampton's *Magellan*," 136.
410 Scott MacDonald, "Print Generation by J. J. Murphy," *Film Quarterly* 32, no. 1 (Autumn 1978), 59–60.
411 A-wind film unwinds clockwise with the image viewed through the emulsion, B-wind film unwinds counter-clockwise with the image viewed through the base.

printing of a film eventually leads to abstraction. But, by also showing the process in reverse, Murphy uses the structure of the literary palindrome to produce an intense phenomenological experience in the viewer, namely, the experience of memory loss.

By the second half of the film, the viewer has already seen Murphy's sixty one-second personal images twenty-five times with various degrees of abstraction. Since these images play in the same order every time, the viewer begins to internalize them. In the second half of the film, as the images become more abstract, the viewer begins to forget some of them, despite having seen them more than twenty-five times at that point. Through the film, Murphy is demonstrating the limits of human memory and allowing people to experience the act of forgetting, or memory loss, in real time. Given that sixty images are beyond the average person's cognitive capacity to store in their active memory, the film uses the literary palindromic structure to demonstrate memory loss.

The soundtrack of the film also mimics the literary form. The film uses a one-minute long tape recording of ocean sounds that were re-recorded over and over again until they become abstracted, in a manner similar to the images. The level of abstraction of the sound is opposite of the images, meaning the film begins with the actual sound of waves crashing which eventually transforms into abstract noise in the first half of the film and plays in the reverse order in the second half of the film. The sound of the waves seems to ground the abstract images. At the end of the film, the viewer will have forgotten many of the images they have seen, but are soothed by the sounds of the waves.

5.4 How to Construct Six Types of Palindromes on 16mm Film

The following text provides instructions for how to create different types of palindromes on 16mm film. For a visual description, see the illustration provided by artist Leslie Supnet [Fig. 30].

> *Variation/Illustration 1*: (For 16mm films with single or double perforations)
> This construction will create a filmic palindrome that will mimic the literary form. The last shot frame (or shot) of the film should be the same as the first frame (or shot) of the film, the second to last frame (or shot) should be the same as the second shot and so on. If the frame (or shot) count is odd, the frame (or shot) in the exact middle of the sequence does not need to be duplicated. For instance, consider the C in the palindrome ABCBA.

Variation/Illustration 2: (For 16mm films with double perforations)
This construction will create a filmic palindrome that allows the film to play forward as backward. The last frame should be the first frame of the film rotated about the centre of the frame by 180°, the second to last frame should be the second frame of the film rotated about the centre of the frame by 180°, and so on. If the frame count is odd, the frame in the exact middle of the sequence must remain the same image when it is rotated about the centre of the frame by 180°.

Variation/Illustration 3: (For 16mm films with single perforations)
This construction will create a filmic palindrome that allows the film to play forward as backward. The last frame should be the first frame of the film reflected about a horizontal line through the centre of the frame, the second to last frame should be the second frame of the film reflected about a horizontal line through the centre of the frame, and so on. If the frame count is odd, the frame in the exact middle of the sequence must remain the same image when it is reflected about a horizontal line through the centre of the frame.

Variation/Illustration 4: (For 16mm films with double perforations)
This construction will create a filmic palindrome that mimics the literary form and allows the film to play forward as backward. The last frame of the film should be the same as the first frame, the second to last frame should be the same as the last frame of the film and so on. In addition, all of the frames of the film must remain the same image when they are rotated about the centre of the frame by 180°. If the frame count is odd, the frame in the exact middle of the sequence does not need to be duplicated, however, it still must remain the same image when it is rotated about the centre of the frame by 180°.

Variation/Illustration 5: (For 16mm films with single perforations)
This construction will create a filmic palindrome that mimics the literary form and allows the film to play forward as backward. The last frame of the film should be the same as the first frame, the second to last frame should be the same as the last frame of the film and so on. In addition, all of the frames of the film must remain the same image when reflected about a horizontal line through the centre of the frame. If the frame count is odd, the frame in the exact middle of the sequence does not need to be duplicated, however, it still must remain the same image when it is reflected about a horizontal line through the centre of the frame.

Variation/Illustration 6: (For 16mm films with single or double perforations)
This construction will create a filmic palindrome that mimics the literary form and allows the same film to play forward as backward. If the film is created using only coloured frames without images, the last frame of the film should be the same as the first frame of the film, the second to last frame should be the same as the second frame and so on. If the frame count is odd, the frame in the exact middle of the sequence does not need to be duplicated and can be any colour.

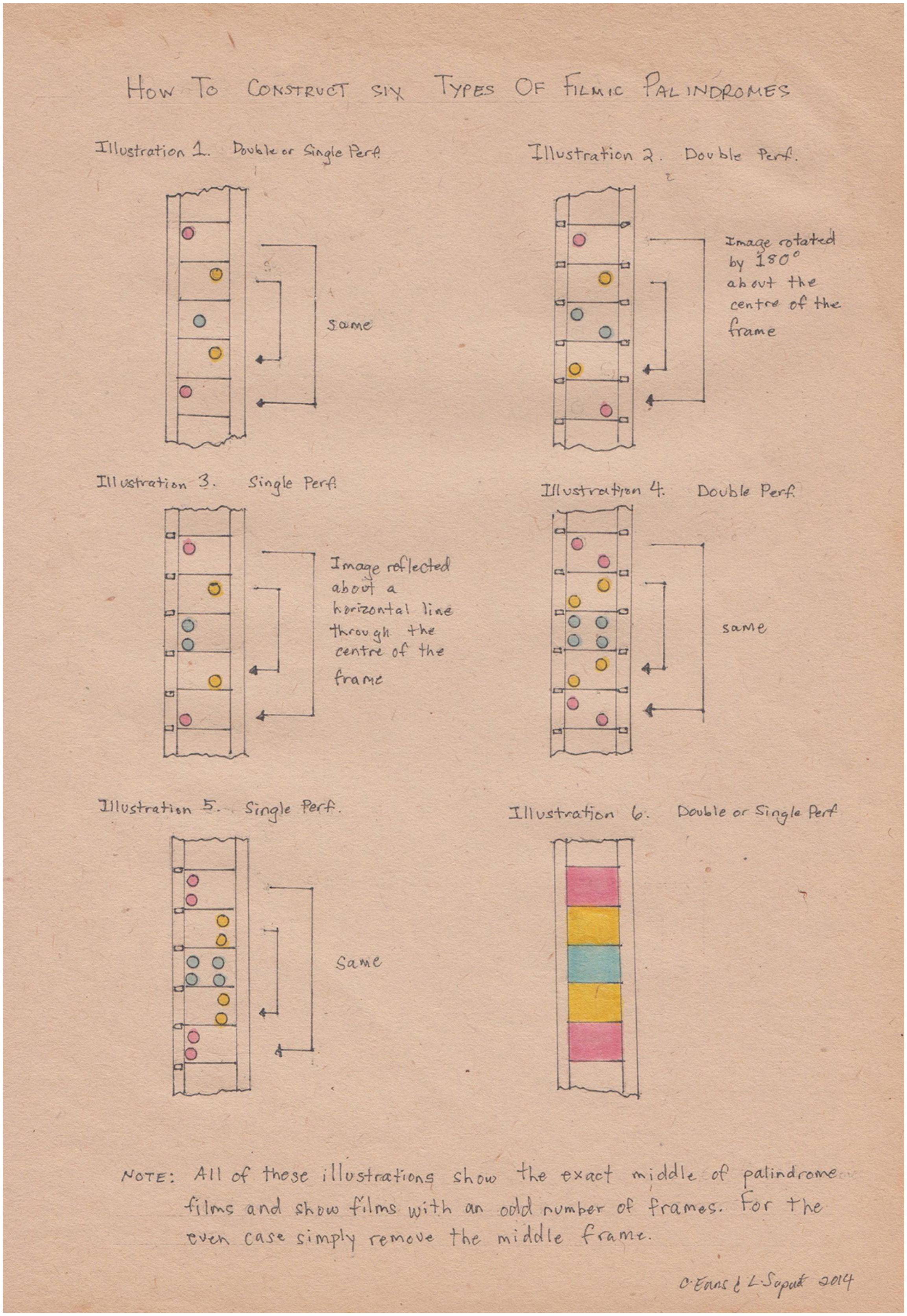

Fig. 29 – How to Construct Six Types of Filmic Palindromes.

CHAPTER SIX: FRACTALS AND MEDIA ART

If you have a hammer, use it everywhere you can, but I do not claim that everything is fractal.
– Benoît B. Mandelbrot

In this chapter, two types of fractals will be explored: iterative fractals and escape-time fractals. Both types of fractals will be defined mathematically, and explanations of how to construct and recognize them will be provided. I will then explore a selection of experimental moving image artworks that connect the idea of fractals to video feedback. Moreover, I will explore the concept of iterative fractals and use it to suggest that it isn't necessarily the medium of video that lends itself to a form of narcissism, as argued by theorist Rosalind Krauss, but the self-similar nature of the fractal itself. Finally, I will provide a mathematical explanation of Thorsten Fleisch's *Gestalt* (2003/2008), one of the rare artist-made videos exploring complex escape-time fractals.

6.1 Fractals: A Mathematical Overview

Visually, fractals are patterns that have some degree of self-similarity, as a pattern that is repeated at different scales. In a mathematical fractal, such as the famous Mandelbrot set [Fig. 31], this self-similarity extends into infinity, with each pattern made up of smaller copies of itself, and those smaller copies made up of even smaller copies of themselves, and so on. The term *fractal* was coined by mathematician Benoît B. Mandelbrot in 1975.[412] Mandelbrot explains his choice of name:

> I coined fractal from the Latin adjective *fractus*. The corresponding Latin verb *frangere* means "to break": to create irregular fragments. It is therefore sensible – and how appropriate for our needs! – that, in addition to "fragmented" (as in *fraction* or *refraction*) *fractus* should also mean "irregular," both meanings being preserved in fragment.[413]

Informally, Mandelbrot defined a fractal as follows:

> A fractal is a shape made of parts similar to the whole in some way.[414]

412 Benoit B. Mandelbrot, *The Fractal Geometry of Nature* (San Francisco: W.H. Freeman, 1983), 2.
413 Ibid, 4. [Emphasis in original.]
414 Jens Feder, *Fractals*, Physics of Solids and Liquids (New York: Plenum Press, 1988), 11. Formally: "A fractal is by definition a set for which the Hausdorff-Besicovitch dimension strictly exceeds the topological dimension" (Mandelbrot, *The Fractal Geometry of Nature*, 15). Although mathematically precise, this definition is quite cumbersome. Mandelbrot later retracted this definition in favour of this simplified and looser definition.

There is one key difference between a symmetrical object and a self-similar object, namely, that a self-similar object involves scaling since it can be subdivided in parts – each of which resemble a reduced-size copy of the whole in some way. Mandelbrot summarized fractals in seven simple words, "beautiful, damn hard, increasingly useful. That's fractals."[415] This looser definition will be far more useful for our study of media art.

Despite the mathematical difficulty associated with fractals, approximate fractals (finite, self-similarity with minor variation) can often be found in nature. For instance, consider the ways in which trees branch into smaller and smaller versions of themselves, or the Romanesco cauliflower appears to be constructed from smaller and smaller versions of itself. Moreover, fractals can often appear unconsciously or semi-consciously within systems, from the ways termite mounds are formed to examples of decorative designs where the artist understands the pattern, but not necessarily the mathematics involved in creating it.[416] Moreover, visual fractals are easy to create (or to write computer programs to create) once the underlying mathematical concepts are understood.

The two main types of fractals are *escape-time fractals* and *iterative fractals*. Iterative fractals are visually self-similar and are created by applying a simple set of rules to a set of geometric shapes and repeating the process indefinitely. Escape-time fractals apply a recursive formula to each point in a given space and are generated with the aid of computers. Given that the process is repeated indefinitely, fractals can only be conceptualized and constructed up to a finite number of iterations. The resulting images can be incredibly sophisticated despite the simple rules involved. Moreover, it is possible to create objects that have counter-intuitive properties, like an object with an infinite parameter that has a finite area, or objects without any area, despite being bounded. One of the standard ways of visually exploring a fractal is through a fractal zoom that, in the case of an iterative fractal, produces a loop, and

415 Mandelbrot, "24/7 Lecture on Fractals" for the 17th Ig Nobel Prize Ceremony in 2006.
416 See Ron Eglash, *African Fractals: Modern Computing and Indigenous Design* (New Brunswick: Rutgers University Press, 1999). Eglash examines this spectrum in depth, suggesting that fractal geometry and mathematics are prevalent in African art, games, divination, trade, and architecture. He also suggests an alternative genealogy of fractals.

in the case of an escape-time fractal, allows us to visually examine its inner complexities.

Let us consider one of the standard iterative fractals, the Koch curve. Begin with a line segment. Divide each of the line segments into three segments of equal length, construct an equilateral triangle over the middle segment and remove the base of the triangle.[417] Now repeat this process on each of the new line segments indefinitely. The result is the Koch fractal [Fig. 30]. The Koch fractal has some surprising characteristics. For instance, at each iteration, the length of the curve increases by a factor of 4/3 – thus the curve is bounded, but of infinite length, as it is constructed of infinite iterations. It can also be demonstrated that the fractal dimension of the Koch curve strictly exceeds its topological dimension.[418] Moreover, the construction makes the self-similar nature of the curve quite obvious.

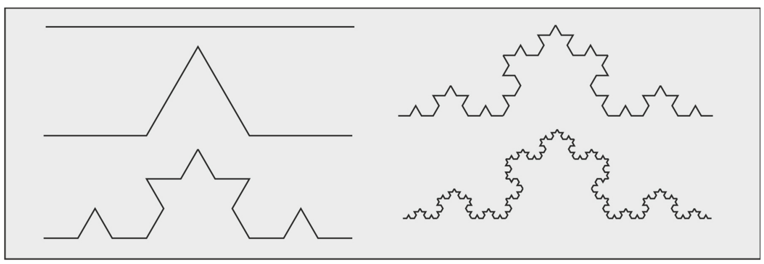

Fig. 30 – Construction of a Koch Curve (four iterations).

Escape-time fractals are generated by iteratively applying a formula on each point in a given space. If a point diverges as the formula is iterated, it escapes; otherwise, it remains bounded. Escape-time fractals are purely mathematical objects and their self-similarity is created through the application of the same mathematical formula over and over again. Two of the best-known escape-time fractals are the Mandelbrot set, defined and named by Adrien Douady in tribute to the mathematician Benoît Mandelbrot, and the Julia set, named after the French mathematician Gaston Julia.[419] Here we will consider the Mandelbrot set since it is perhaps the best-known example of mathematical visualization,

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417 An equilateral triangle is one in which all the sides are of equal length. The angles of an equilateral triangle are all 60°.
418 Using standard definitions, it is possible to calculate the fractal dimension of the Koch curve as the value of d such that $3^d = 4$. Hence, $d = \ln(4)/\ln(3) = 1.2618590714$. This value is greater than its topological dimension which is the topological dimension of a line, namely, 1.
419 See Adrien Douady and John H. Hubbard, *Etude dynamique des polynômes complexes* (Orsay: Universite de Paris-Sud, 1984).

and it provides for a better understanding of other escape-time algorithms that are being experimented with both by mathematicians and media artists. In order to understand the Mandelbrot set, I will first discuss complex numbers since the Mandelbrot set is defined using them.

A complex number z is a number of the form $a + bi$, where a and b are real numbers and $i^2 = -1$. It is common to plot imaginary numbers on the Cartesian plane, referred to as the *complex plane*, using the horizontal axis as the real axis and the vertical axis as the imaginary axis. In other words, z would be plotted as (a, b). Finally, the absolute value of a complex number is usually interpreted as the distance z is from the origin in the complex plane.[420] The formula used for generating the Mandelbrot set is $f(z) = z^2 + c$, where c is a complex number. For each value c in the complex plane, $z_0 = 0$ and the sequence $z_n = f(z_{n-1})$ for $n > 0$ is calculated. The values of c for which z_n stays close to 0 for large values of n are coloured black and make up the Mandelbrot set. The other points in the complex plane are said to *escape* and are coloured based on how quickly they escape. The behaviour of the Mandelbrot set is *chaotic* since points close to each other often demonstrate dramatically different behaviour, and the points around the edge of the Mandelbrot set are impossible to predict whether or not they will escape.[421] A fractal zoom can be used to visually explore the behaviour points around the edge and can sometimes produce beautiful and unexpected results.[422]

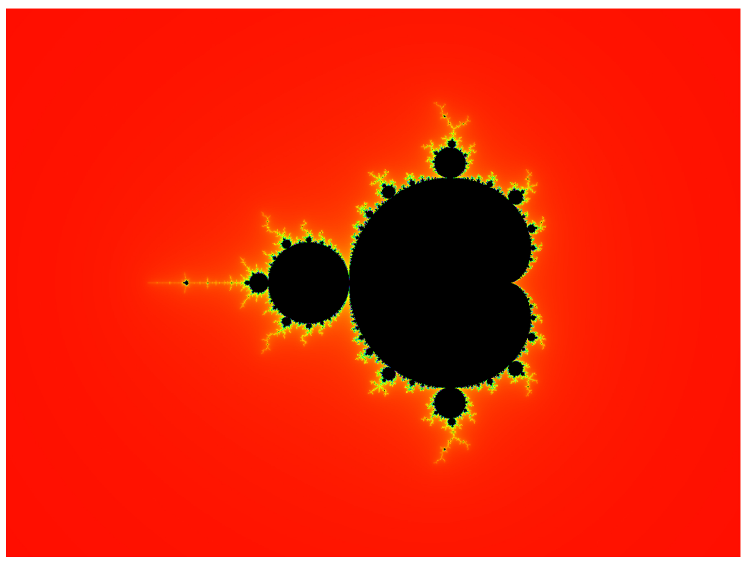

Fig. 31 – Mandelbrot Set

420 Namely, $|z|$ is the square root of $a^2 + b^2$ based on Pythagoras' theorem.
421 The Julia set is similar to the Mandelbrot set except c is fixed and for each point z in the complex plane, the sequence $f^n(z)$ for $n \geq 1$ is calculated. The points in this series that do not diverge form the Julia set, the others are usually coloured based on the rate at which they diverge.
422 For instance, see: Jason Kottke, "Insanely deep fractal zoom" (February 11, 2010), <https://kottke.org/10/02/insanely-deep-fractal-zoom>.

6.2 The Narcissistic Image: Iterative Fractals in Media Art

In art theorist Rosalind Krauss' 1978 essay "Video: The Aesthetics of Narcissism," she explores the question, "what would it mean to say, 'the medium of video is narcissism?'"[423] It is possible to reframe one section of Krauss' essay to tease out her core argument related to "reflection" and "reflexiveness" in a slightly different way using two mathematical concepts related to symmetry and fractals. By reframing her argument in terms that explore the difference between a system that is *reflective* (a concept related to symmetry) and a system that generates visual *self-similarity* (a concept related to iterative fractals), it is possible to extend Krauss' concept of narcissism beyond its application to the medium of video. In her essay, she poses the question: "Aside from their divergent technologies, what is the difference, *really*, between Vito Acconci's *Centers* (1971) and Jasper Johns' *American Flag* (1954–55)?"[424] Through these two works, Krauss explores the difference between a "reflection" and "reflexiveness." Perhaps a slightly different way to pose this question is to ask: what is the difference, *really*, between a mirror and a video camera attached to a monitor? This is, in actuality, the crux of Krauss' essay.

The major difference between a mirror and a video camera is that the surface of a mirror cannot look at its own image – or, as Krauss puts it, "can only produce external symmetry" – whereas a video camera attached to a monitor can – this, according to Krauss, "is a strategy to achieve a radical *a*symmetry, from within."[425] A mirror is literally the plane of reflection that mathematically defines a *reflection*, meaning that it is a reflective system, while a video camera with a monitor can produce self-similarity (smaller and smaller versions of itself), meaning it is a self-reflexive system or, as Krauss

423 Rosalind Krauss, "Video: The Aesthetics of Narcissism," *October* 1 (1976), 50.
424 Ibid., 56. [Emphasis in original.] In *Centers*, Acconci faces a camera and points to its centre, thereby pointing at himself being taped. On playback, Acconci is seemingly pointing at the audience. Jasper Johns' *American Flag* is literally a painting of the American flag. Krauss suggests: "The flag is thus both the object of the picture, and the subject of a more general object (Painting) to which *American Flag* can reflexively point."
425 Ibid. The term asymmetry refers to the absence of symmetry. Krauss is suggesting symmetry is not necessary, in contrast to the mirror. It is worth observing that a self-similarity does not require symmetry; however, many self-similar objects are symmetrical.

puts it, generates “reflexiveness.” Of course, it is possible for a mirror to transform into a self-reflexive system simply through introducing a second mirror – consider the effect in *Citizen Kane* (1941) [Fig. 33]; however, a mirror alone cannot accomplish this. It is from this mathematical distinction that Krauss forms her argument. Krauss uses the distinction between the reflective and the reflexive in order to suggest that narcissism is inherent in the video medium.

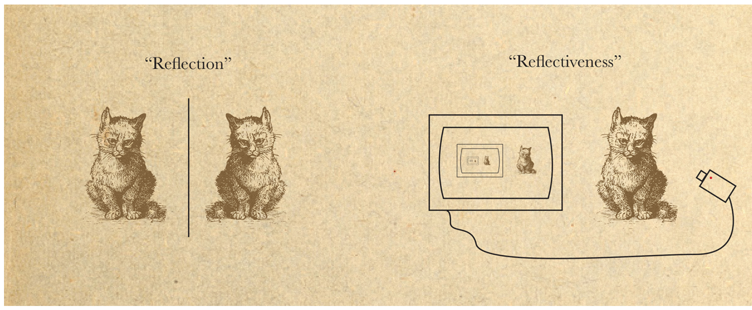

Fig. 32 – Difference between a reflection and reflexiveness.


Fig. 33 – The Hall of Mirror effect in Citizen Kane.

Continuing this line of reasoning, artist, curator and art critic Catherine Elwes observes that the video camera and its monitor also allowed the viewer access to areas of the body that were previously inaccessible:

> Video was also the perfect medium of self-contemplation and offered views of the body that were normally inaccessible, such as the back of the head. [...] By means of live feedback, the video artist was able to see the self as it appeared to others. Gazing into the mirror of the feedback loop allowed entry into a locked-in world of self and self as other in the reflecting pool of the technology.[426]

426 Catherine Elwes, *Video Art: A Guided Tour* (London: I.B. Tauris, 2005), 17.

Although one is able to watch oneself in the “reflecting pool of the technology,” the camera offers a view beyond the mirror alone, that is, the camera offers the ability to watch oneself watching oneself.[427] For instance, in addition to being able to see the back of the head, one is able, through the technology, to watch oneself watching the back of one's head, allowing the artist to, as Elwes implies, enter into the feedback loop.

Through video feedback, created by the fairly simple procedure of pointing a camera at a monitor displaying its own feed, artists were able to create real-time, iterative fractals. Video feedback satisfies the definition of a fractal, “a shape made of parts is similar to the whole,” where the whole is the entire screen, which consists of smaller and smaller versions of itself formed within the screen – an infinite regression of images all displaying the same feed. Through this process, the screen is transformed into an iterative fractal, since each image within the screen is constructed from a smaller version of itself. Video feedback demonstrates the complicated nature of iterative fractals, given the visual complexity of the images that can be produced despite the relatively simple process used to generate them.

An example of complex fractal generation through relatively simple means is Steve Partridge's *Monitor* (1974). In the piece, an iterative fractal, an infinite succession of images of monitors within monitors, is created using a time-delayed signal and video feedback [Fig. 34]. In this early video piece, the monitor being used to create the video feedback is rotated by the hand. The result is an iterative fractal which reveals the process through which it was created. Through the use of a time-delayed signal Partridge is not simply creating an optical trick, but revealing the difference between real-time and screen-time.

427 It is worth noting that it is possible to look at the back of one's head (and to watch oneself watching oneself) with the introduction of a second mirror.

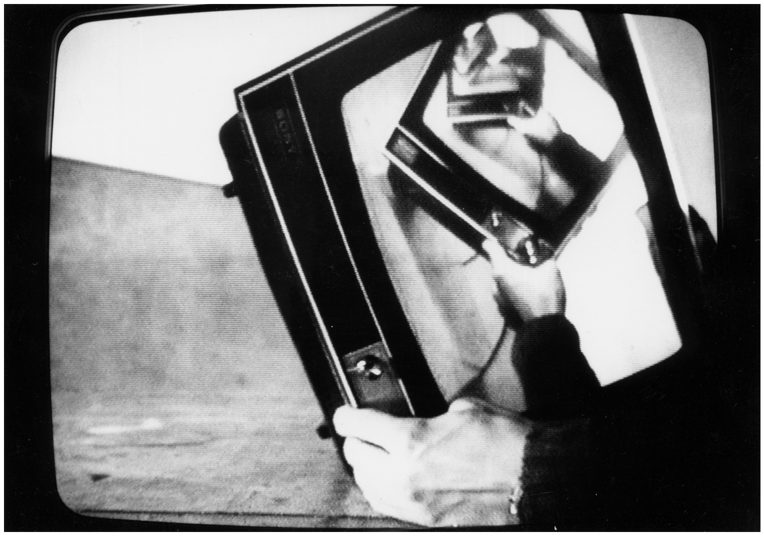

Fig. 34 – Still from Monitor.

Given the simplicity of this process, videos constructed using video feedback are quite common, with many producing sophisticated visual results. In this way, the underlying mathematics of the iterative fractal is often reduced to an optical trick. Furthermore, not all videos that involve feedback reveal their own construction. As Elwes observes, "the feedback loop being produced by the camera and monitor may not reproduce the external appearance of the machines, but it is an accurate visualization of the internal workings of both and their structural interaction."[428] While it is debatable if this is an *accurate visualization* of the internal workings, it is without a doubt a *visual representation* of the inner workings and their structural interaction.[429]

Moving images that construct iterative fractals can also be produced without the use of a video camera, as demonstrated by Takashi Ito in his 1981 film *Spacy*. In this 16mm film, Ito transforms the ordinary architecture structure of a gymnasium into a three-dimensional, iterative fractal. The film begins by revealing a gymnasium which contains photographs on stands placed equal distance from each other near the walls. Beginning at the centre of the room, the camera pushes into different photographs, eventually reaching the photographs and entering them.[430] Since each of the photographs

428 Elwes, *Video Art*, 28.
429 The actual internal working of a video camera and monitor are quite complex.
430 *Spacy* was constructed from 700 still photos that were re-photographed frame by frame [See Norio Nishijima, "The Ecstasy of Auto-Machines," *Image Forum* (1996), <http://www.imageforum.co.jp/ito/introduction_e.html>].

contains a shot from the centre of the room, once Ito's camera reaches a photograph, the camera returns to the centre of the room. Ito's film creates the illusion that the photographs contain actual physical spaces, replicas of the original space. In this sense, the film creates the illusion of self-similarity and conceptually forms an iterative, three-dimensional fractal. In addition, the camera pushing into the various photographs in the space can be seen as a fractal zoom.

The conceptual space created by Ito is beyond physical reality due to its potentially infinite nature. Moreover, the space created also changes over time. When the camera pushes into one of the photographs late in the film, the film returns to the initial position, but the new space entered is "flickering" between two different spaces. It is this flickering that makes the space created only representable in a *time-based medium*. In particular, in one of the spaces the images flicker between the left side of the room and the right side of the room: in one frame the camera is moving left, and in the next the camera is moving right. In other words, the orientation of that space changes with respect to time. Ito reinforces these observations:

> Film is capable of presenting [an] unrealistic world as a vivid reality and creating a strange space *peculiar to the media*. My major intention is to change the ordinary everyday life scenes and draw the audience (myself) into a vortex of supernatural illusion by exercising the magic of films.[431]

It is the magic of cinema that allows us to move through such a strange three-dimensional fractal space.

Some critics have read the work as depicting a form of madness, while others have read it in terms of play. For instance, film critic Catherine Munroe Hotes suggests, "in just 10 minutes, Ito aimed to depict visually the madness within himself as a human being."[432] Artist Sylvia Schedelbauer reinforces this position:

> The spacious gym depicted in the photographs becomes a claustrophobic trap. In a way, the camera perspective could be experienced as a subjective point-of-view. The photos, frames within frames, are like windows, like doors; one always hopes to find a way out, to see what's beyond. But each time the camera perspective approaches what could be some type of opening, one is thrown back to the centre of

431 Quoted in ibid. [Emphasis added.]
432 Catherine Munroe Hotes, "Takashi Ito's Film Work." *MidnightEye,* (August 10, 2010), <http://www.midnighteye.com/reviews/takashi-itos-film-works/>.

> the gym. The logic of this cinematic illusion defines a system one can't break out of.[433]

Schedelbauer is arguing that the self-similarity contained within the space is claustrophobic and impossible to escape. In slight contrast, film critic Yaron Dahan argues,

> Play is the exact word to define Ito Takashi's game on the court, for as in every game, this film posits its arbitrary constraints (the limited space of the basketball court, right angle turns, animated stop motions in black and white). Ito Takashi's game begins following the filmic rules, before evolving quickly into one of inventiveness and surprise. The camera moves along invisible geometric patterns (not unlike the lines which define the game of basketball), and the spectacle of space is reinvented.[434]

In the film, not only does the camera push into the stands holding the photographs, but the stands also move around forcing the camera to chase them as one would in a game. Moreover, the anxiety that is created by the strobe effect can be read in two ways, as the internal state of the artist or as the anxiety induced through competitive play. Both readings are compelling and not necessarily in conflict.

At the end of the film, Ito presents a self-portrait with his camera aimed at the audience [Fig. 35]. Film scholar and critic Norio Nishijima argues, "the last shot where the camera and the filmmaker (self-portrait) come into the same frame indicates the *self-reflexive* characteristic of his work."[435] The last image of Ito's film points to the self-reflexive nature of the work; however, so does the self-similar structure he has created. Returning to Krauss' argument, it seems that medium specificity is irrelevant. In light of Ito's film, I am suggesting a new version of Krauss' claim that narcissism is inherent within the medium of video: *Any system that allows for visual self-similarity can be used by artists to generate art that is self-reflexive*. To be explicit, I am not stating that all uses of visual self-similarity lead to artworks that are self-reflexive, in Krauss' use of the term. As previously argued, many forms of video feedback are simply optical tricks. I am arguing that any system that allows for visual self-similarity allows the artist to potentially see themselves seeing, thus generating a form of self-

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433 Sylvia Schedelbauer, "Poetics of an Urban Darkness: Takashi Ito's Spectral Cinema," *OtherZine* 20 (Spring 2011), <http://www.othercinema.com/otherzine/archives/index.php?issueid=25&article_id=121>.
434 Yaron Dahan, "Ghosts of Time and Light: The Experimental Cinema of Ito Takashi." *MUBI,* (June 4, 2015), <https://mubi.com/notebook/posts/ghosts-of-time-and-light-the-experimental-cinema-of-ito-takashi>.
435 Norio Nishijima, "The Ecstasy of Auto-Machines," *Image Forum* (1996), <http://www.imageforum.co.jp/ito/introduction_e.html>

reflexivity.

Fig. 35 – Ito's self-portrait in Spacy.

6.3 Mandelbrot Movies: Escape-time Fractals in Media Art

Escape-time algorithms are used in the generation of escape-time fractals. For each point in a space, escape-time algorithms apply a predetermined function repetitively in order to generate a sequence which will either converge or diverge. The points that generate sequences that converge are coloured one colour while the points that generate sequences that diverge are assigned a colour based on how quickly the sequence diverges. Practically speaking, it is only possible to produce a finite sequence at any given point and an empirical method must be used to determine divergence.[436] There are many escape-time algorithms that exist for media artists to experiment with and they often require very little mathematical knowledge to use.

The accessibility of escape-time algorithms has prompted some criticism. In his "Fractal Art Using Variations on Escape Time Algorithms in the Complex Plane," Sisson argues that it is important to understand the mathematics employed, suggesting that "a reliance on existing software and a

436 In practice, the maximum number of iterations (or the number of times the function will be applied to any point) is set and an upper bound is set. The number of iterations required to break the upper bound determines the sequence's rate of divergence and therefore the points colour. If after the maximum number iterations the sequence hasn't crossed the upper bound, the point is said to converge. For more details, see P. D. Sisson, "Fractal Art Using Variations on Escape Time Algorithms in the Complex Plane," *Journal of Mathematics and the Arts* 1, no. 1 (March 1, 2007): 41–45.

reluctance to delve into the mathematics of fractal art is inherently limiting and holds the threat of stagnation."[437] Although Sisson is correct in his assumption that writing your own algorithms provides more artistic control, the relative simplicity of some existing escape-time algorithms have made them accessible to artists to use without having to totally understanding the mathematics or the coding involved. One of the better examples of an artist experimenting with these tools is Thorsten Fleisch's *Gestalt* (2003/2008), which makes use of an escape-time algorithm referred to as *Quat*. Thorsten and I discussed his film in a collaborative interview titled "Escaping Time" for *INCITE*; the following is an excerpt from that interview discussing Fleisch's use of *Quat*:

> CE: Many of your works have a basis in mathematics. How did you become interested in that field? Have you received any formal training?
>
> TF: Nothing beyond my high school education. My brother is a computer scientist and we sometimes talk about mathematics. He even helped me with some of the coding on *Gestalt.* In the early 90s, when I was still in school, we worked with the Mandelbrot fractal and I would take single shots of the monitor with a super 8 camera. The result was a bit too dark, though.
>
> I have always liked mathematics. I find the logic can be very soothing but I'm also excited by the chaos in it. A lot of modern mathematics is really weird and esoteric.
>
> CE: In *Gestalt*, you create a gorgeous escape time fractal using the function $x_{n+1} = (x_n)^p - c$ and *Quat*, a program which generates quaternion fractals. Can you explain this program a bit?
>
> TF: First, it is probably important to explain the concept of a quaternion number and of an escape time fractal. A quaternion number is equivalent to a complex number, which consists of two parts: one real, one imaginary. A typical imaginary number can be written as $a + bi$ where a and b are real numbers and $i^2 = -1$. Analogously, a quaternion number consists of four parts, a real part and three imaginary parts. A typical quaternion number can be written as $a + bi + cj + dk$ where a, b, c, and d are real numbers and $i^2 = j^2 = k^2 = ijk = -1$. Hence, four dimensions (a, b, c, d).
>
> When generating an escape time fractal we basically pose the question for each point in the plane: does the iterative sequence – determined by our function and the point – escape or not? Mathematically speaking, if the sequence heads towards infinity then it has escaped; otherwise, the sequence will converge towards a fixed point or oscillates periodically between some values and does not escape. If the sequence has not escaped, the point is included; if the sequence has escaped, the point is not included. The Mandelbrot fractal is an example of an escape time fractal that uses complex numbers.
>
> Basically *Quat* generates escape time fractals using quaternion numbers and the function given. I can't say that I totally understand all of this but I do find these types of objects very interesting and strange. It's fairly esoteric, maybe not for a mathematician, but definitely for me.
>
> CE: That is a wonderful explanation. The images from *Gestalt* really help to clarify what you're talking

437 P. D. Sisson, "Fractal Art Using Variations on Escape Time Algorithms in the Complex Plane," *Journal of Mathematics and the Arts* 1, no. 1 (March 1, 2007), 42

about. Given that this work is so computationally intensive, how long did it take you to render each image and how long did it take to complete the film?

TF: At first I experimented with a very low resolution to orient myself in this unfamiliar world. I spent a lot of time rendering short sequences with small changes to the parameters for each image. I think it took about a year of just exploring and collecting sequences I liked. I then selected the ones that I thought would fit together to create a dramatic arc and rendered them in a higher resolution (720x576). That probably took 8-10 months of rendering. Back then, I was stealing a lot of computer time from my family and friends. At the time, my computer had a 1 Ghz CPU. I later re-rendered the film in HD resolution (1920x1080), which only took about three months, using a quad-core CPU that I over-clocked to 3 Ghz. It was very satisfying to push that CPU to the limit. There were always four instances of the program rendering at the same time. I would never have been able to complete the HD version of this film in 2003 with my 1Ghz computer.[438]

The program used by Fleisch, *Quat,* generates quaternion Julia set fractals. The function $x_{n+1} = (x_n)^p - c$ is determined by the user selecting the constant c and the prime p. For each quaternion point, x_0, in the quaternion space, the formula given generates a sequence which either converges or diverges. If the sequence converges, the point is part of the Julia set. If not, the point escapes and is coloured based on how quickly it escapes. Given that it is impossible to draw four-dimensional objects, *Quat* draws a "slice" of four-dimensional quaternion fractals. In other words, the four-dimensional solid is intersected with a plane, in essence making one of the quaternion components dependent on the other three. Fleisch created his animation by smoothly moving between the slice planes. Despite Fleisch's incomplete understanding of the mathematics involved, the images in his film transcend the typical videos that make use of escape-time algorithms, the majority of which are simply fractal zooms. Moreover, by choosing a grayscale image, Fleisch avoided some of the gaudier colour palettes typical of fractal generation tools.

Fig. 36 – Still from Gestalt.

Through smoothly moving between the slice planes, Fleisch is, in essence, exploring a four-

438 Clint Enns, "Escaping Time With Thorsten Fleisch," *INCITE! Journal of Experimental Media*, Back & Forth (December 1, 2010), <http://www.incite-online.net/fleisch.html>. The mathematical notation has been formatted incorrectly in the online version and has been corrected here. In order to avoid plagiarizing myself, while conducting the interview I helped Fleisch formalize the mathematical portion of the text. My response, "that is a wonderful explanation," was intended as an inside joke.

dimensional space. Working with four spatial dimensions (and beyond) is not unusual for mathematicians, in spite of the common assumption that time is the fourth dimension. Fleisch explains:

> *Gestalt* works with four-dimensional geometry and almost everybody was telling me that time is the fourth dimension. However, time isn't the only thing that can be added to the three spatial dimensions. In fact, *Gestalt* doesn't explore time as the fourth dimension. It explores a fourth *spatial* dimension that is not possible in reality, but that is mathematically possible.[439]

In other words, the space which Fleisch is exploring exists purely in the realm of mathematics, with his video providing a two-dimensional visualization of the four-dimensional space.

439 Enns, "Escaping Time."

CHAPTER SEVEN: PERMUTATIONS AND MEDIA ART

All of life's wisdom can be found in anagrams. They never lie.
– Anu Garg

In this chapter, the mathematical concept of a permutation will be explored. The concept will be defined formally and some of its mathematical properties will be explored. Permutations are relevant to cinematic production, since, it will be argued, they are related to the way in which one orders a set of shots. The discourse regarding permutations that is used by experimental filmmakers will be examined and cinematic examples will be given. Finally, the literary concept of the anagram will be expanded to include moving image works, given that this is a strategy that has been employed by artists to use the concept of permutations within their work.

7.1 Permutations: A Mathematical Overview

In mathematics, there are several ways to define a *permutation*, with the most general definition as follows:

A permutation of an arbitrary set X is a *bijection* from X to itself.[440]

In other words, a permutation pairs every element in X with another element in X. A version more relevant to time-based media exists and formally states:

A permutation of a set X is a linear ordering of X.

Less formally, a permutation is simply an ordering of a set of objects where every object occurs exactly once. For instance, the permutations of {1, 2, 3} are 123, 132, 213, 231, 312, 321 and the permutations of {1, 2, 2} are 122, 212 and 221. The number of permutations on a finite set X with distinct elements can be shown to be

$$|X|! = |X| \cdot (|X| - 1) \cdot \ldots \cdot 1$$

440 A *bijection*, in mathematics, is a function that is *one-to-one* and *onto*. A function is *one-to-one* if every element of the codomain is mapped to by at most one element of the domain and a function is *onto* if every element of the codomain is mapped to by at least one element of the domain. In other words, a function is a *bijection* if every element of the codomain is mapped to by exactly one element of the domain.

where $|X|$ is the size of the set and "$n!$" denotes the product of all positive integers less than or equal to n. For instance, the number of permutations of the set {1, 2, 3, 4, 5, 6} is $6! = 6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 = 720$. Since every element of the set can only be used once, there are initially $|X|$ choices for the first position, $|X| - 1$ choices for the second position, ..., until there is only one choice left for the last position. In a finite set X with repeated elements it can be shown that the number of permutations is

$$\frac{|X|!}{|X_1|! \cdot |X_2|! \cdot \ldots \cdot |X_r|!}$$

where X consists of r distinct types of elements and $|X_1|$ is the number of objects of the first repeated type, $|X_2|$ is the number of objects of the second repeated type, ..., and $|X_r|$ is the number of objects of the r^{th} type.[441] For example, the number of permutations of {1, 2, 2, 2, 3, 3} is

$$\frac{6!}{1! \cdot 3! \cdot 2!} = 60$$

since there is one element of type "1," there are three elements of type "2," and there are two elements of type "3."

Even with this elementary mathematical knowledge, it is possible to see the role permutations play in cinema, given that films are in essence a linear ordering of a set of shots. For instance, consider James Benning's *13 Lakes* (2004), a film consisting of thirteen different shots of lakes, each ten minutes in length. From these thirteen shots, Benning would be able to construct $13!$ films, that is, approximately six billion different films simply by changing the shot order.[442] In fact, given that 100 feet of 16mm is approximately 4000 frames, if every frame were unique, it would be possible to construct $4000! = 4000 \cdot 3999 \cdot \ldots \cdot 2 \cdot 1$ different films simply by rearranging the frames.[443] This number is beyond astronomically large; from this one roll of film, it would be possible to construct vastly more

441 It is worth observing that $|X| = |X_1| + |X_2| + \ldots + |X_r|$.
442 James Benning is perhaps the most mathematically literature filmmaker of his generation holding a master's degree in mathematics from the University of Wisconsin-Milwaukee. There is much more to can be said about the use of mathematics in Benning's work, a subject that is potentially worthy of a single manuscript.
443 4000! is larger than 10^{12673}.

films than the estimated number of stars in the observable universe.[444]

Conventional cinema makes use of permutational strategies at the editing stage of production simply by ordering the shots. Given that permutational strategies are one element of cinematic production, there have been many filmmakers that have attempted to isolate, explore and emphasize this stage of the cinematic process. The next section will attempt to further understand permutational strategies in experimental time-based media by exploring several different uses and approaches.

7.2 Permutational Strategies: The Moving Image Collection at the Library of Babel

Working through different permutations of words, images and sounds has been a strategy employed by many media artists, poets and composers.[445] In his book *Dreams of Chaos, Visions of Order*, film theorist James Peterson suggests that films that use a simple schema, in particular simple numerical and permutational schema, form an important subset of structural films, a controversial and often contested sub-genre of experimental cinema coined by film theorist P. Adams Sitney.[446] In the chapter "Film that Insists on Its Shape: The Minimal Stain,"[447] Peterson provides a brief history of visual artists engaging with permutational structures in order to provide a historical context for Sitney's concept.[448] Peterson

444 Astronomer David Kornreich's extremely conservative "rough estimate" is that there are 10^{24} stars in the universe. He obtained this number using the current estimates that there are 10 trillion galaxies in the universe and that the Milky Way has a 100 billion stars and believes that this is a gross underestimate. Elizabeth Howell, "How Many Stars in the Universe," *Space* (May 17, 2017), <https://www.space.com/26078-how-many-stars-are-there.html>.
445 In this section, I focus on moving image artworks, but there is a long history of permutational strategies being employed in poetry and sound art. For instance, consider the concept of combinatoriality in music or the artworks of OuLiPo (Ouvroir de Littérature Potentielle, or Potential Literature Workshop), a collective of writers and mathematicians who produced writings using various algorithmic and mathematical techniques. OuLiPo was founded in 1960 by writer Raymond Queneau and scientist François Le Lionnais and can be seen as a direct response to the 'two culture' dichotomy proposed by Snow. Queneau's work *Cent Mille Milliards de Poèmes* [*One Hundred Thousand Billion Poems*] (1961), is an example of a permutational flipbook. The book consists of ten sonnets, each printed such that the fourteen lines that make up the sonnet exist on individual strips, making it possible to replace any line of the poem by a corresponding line from any of the other poems, preserving both the rhyming scheme and rhyming sounds.
446 As the story goes, in 1969 Sitney defined structural film in *Visionary Film* as "a cinema of structure in which the shape of the whole film is predetermined and simplified, and it is that shape which is the primal impression of the film" (368). He insists, "the structural film insists on its shape, and what content it has is minimal and subsidiary to the outline" (370). In *Dreams of Chaos, Visions of Order*, Peterson presents a synthesis of the critical discourse surrounding Sitney's contested term. See: James Peterson, *Dreams of Chaos, Visions of Order: Understanding the American Avante-Garde Cinema* (Detroit: Wayne State University Press, 1994).
447 Given the nature of this dissertation, it is worth noting the title of the article that portions of this chapter originally appeared, namely, "The Artful Mathematicians of the Avant-Garde," *Wide Angle* 7.3 (1985): 14–23.
448 Peterson suggests, "Sitney was wrong about one aspect of the history of structural film when he introduced he term in 1969: a cinema of structure had not 'suddenly emerged'." James Peterson, *Dreams of Chaos, Visions of Order:*

suggests that structural film "was only one facet of a long tradition in the arts."[449] Peterson provides different strategies for engaging with works that make use of *simple permutational schema*.

In Peterson's taxonomy, there are two types of permutational strategies, *open* and *closed*. A closed permutational strategy is one that "defines a limited set of possible elements" and an open permutational strategy is one that does "not define a limited set of features."[450] Without rejecting Peterson's taxonomy entirely, there is perhaps a better way to classify permutational strategies, namely, as *exhaustive* and *non-exhaustive*. An *exhaustive permutational strategy* is a permutational schema that exhausts all of the permutational possibilities and a *non-exhaustive permutational strategy* is a permutational schema that only uses a small subset of all the permutational possibilities.

Exhaustive permutational strategies can be quite simple or complex without limiting the scope of the work. For instance, filmmaker Takahiko Iimura's *24 Frames Per Second* (1975–78) evokes a simple exhaustive strategy. In the film, he attempts to list all possible permutations of any consecutive number of white frames within a one second strip of film. Peterson describes the schema:

> The film is constructed solely of black and white frames. It is divided into twenty-four sections, each of which has a permutational schema. The first section begins with the title "1/24." Following this are forty-eight twenty-four frame sets: the first set is twenty-three frames of black with a single frame of white inserted somewhere; the next set is twenty-three frames of white with a single black frame. The film alternates between black-dominated and white-dominated sections until the inserted frame has occupied every position in the twenty-four-frame set. The second section begins with the title "2/24" and repeats the permutational schema with two frames of black among twenty-two frames of white. The film continues through section "24/24." Each section is permutational because it lists, in no particular order, all the possible positions for the inserted frames. At the most global level, the film is numerical because the number of inserted frames grows larger with each passing section, and the film ends when the number of frames can grow no more.[451]

Despite accurately describing the structure of the film, Peterson's description is incorrect in suggesting that Iimura's film exhaustively lists all of the possible permutations for inserting any number of consecutive white frames within a one second strip of black frames in *no particular order*, which

Understanding the American Avante-Garde Cinema (Detroit: Wayne State University Press, 1994), 97. Although, Sitney does not provide a comprehensive history of structural film, he also does not suggest that it "suddenly emerged."
449 Peterson, *Dreams of Chaos, Visions of Order*, 97.
450 Ibid., 105.
451 Ibid., 104.

ultimately changes Peterson's formal reading of the film.

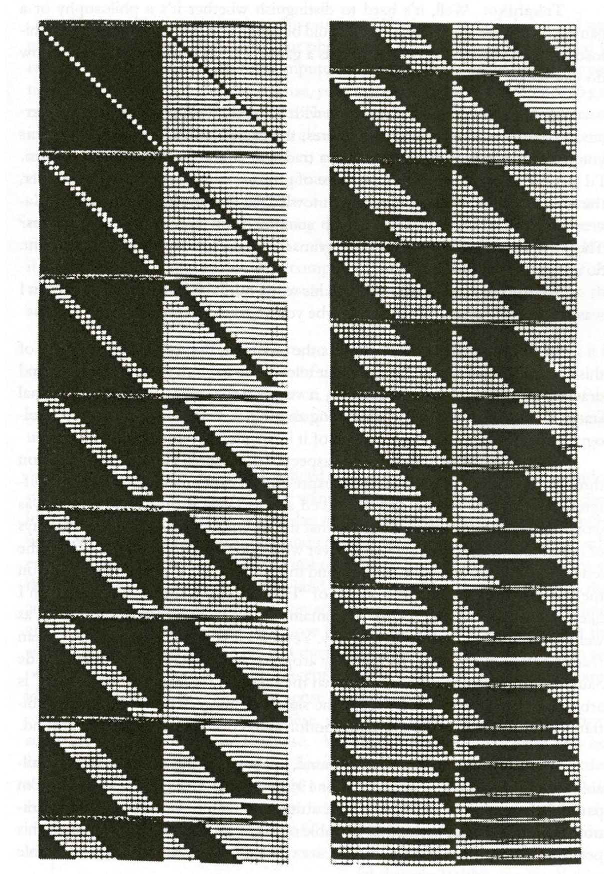

Fig. 37 – Score for 24 Frames Per Second.

By reviewing the score for *24 Frames Per Second*, included in *The Collected Writings of Takahiko Iimura*, and by using Peterson's methodology, we observe that the film is locally and globally both permutational and numerical, since Iimura *systematically* exhausts all of the ways in which any number of consecutive white and black frames can be inserted into a one second strip of consisting only of black and white frames. That is, in each section Iimura inserts the sequence of consecutive white frames into the first position, then into the second position, and so on, until the sequence of consecutive white frames reaches the end of the one second strip of film. Using this methodology, it is further possible to observe in the first section there are twenty-four ways to insert one white frame among twenty-three black frames, there are twenty-three ways to insert two consecutive white frames into a one second strip of film, and so on, until there is only one way to insert twenty-four consecutive white frames into a one second strip of film.[452] From this analysis, it is possible to determine the entire structure of the film. Unfortunately, this seems to be the limit of this type of formal analysis.

Despite its inclusion in a section titled “The Minimal Strain,” Peterson does not comment on the Zen or yin-yang aspects of Iimura's work, which plays out in the film through the use of negative images that create a form of balance where it becomes impossible to distinguish positive from negative or negative from positive at any specific moment, only in reference to each other. Iimura explains:

> Within the positive there is negative, and within the negative there is positive. [...] I was influenced by the Eastern concept where positive and negative are the same. Whether you say yes or no doesn't matter; eventually they're the same, though to say it like this seems very contradictory. It's not Western logic. People may see this as mystical, but I'm trying to prove that a contradiction exists within the logic of film.[453]

In other words, if the viewer were shown any frame, it would be impossible for them to determine if they were in a positive or negative section of the film; they would need to be shown a larger section of the film.

Since each permutation is immediately followed by its negative, we not only obtain all of the possible permutations for inserting any number of consecutive white frames within a one-second strip of black frames, but also all of the possible permutations for inserting any number of consecutive black frames within a one-second strip of white frames. Consequently, there are two consecutive lists of permutations being developed at the same time, as Iimura notes:

> I put both positive and negative together, so that there is no middle point where you switch from one to the other. In the revised version the two progressions happen at the same time. This dual cycle merges at the end, although the second progression is hard to perceive. Positive becomes negative; negative, positive. Whenever I speak about this piece, I relate it to the ancient Chinese yin-yang symbol, which I tried to translate into filmic time. [454]

In other words, Iimura is utilizing this basic permutational structure in order to achieve a more

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452 There are twenty-four ways in which one white frame can be inserted amongst twenty-three black frames since $24!/(1!\cdot 23!) = 24$. There are twenty-three ways in which two consecutive white frames can be inserted into 22 black frames since the two consecutive white frames function as one single frame and $23!/(1!\cdot 22!) = 23$.
453 MacDonald, *A Critical Cinema*, 129. In this description, Iimura is referring to “A Line,” one of the sections of *Models, Reel 2* (1972), but this description accurately describes *24 Frames Per Second* given its structure.
454 Ibid., 132. In the original version, the film progresses with successively larger groups of white frames and the negative version is shown once the positive has finished.

sophisticated result, namely, to explore filmic time and its effect. By reducing the work to black and white frames, Iimura eliminates the basic element traditionally associated with all forms of cinema: the image, abstract or otherwise.

Moreover, Iimura distinguishes the work from other experimental black and white flicker films – in particular, Peter Kubelka's *Arnulf Rainer* (1960) and Tony Conrad's *The Flicker* (1965) – by not concerning it with rhythmic elements, but by mapping out concrete intervals of time. In an interview with cinema scholar Scott MacDonald, Iimura explains this distinction:

> Kubelka and Conrad are much concerned with rhythm. When rhythm gets accelerated as in Conrad's *The Flicker*, it creates optical illusions. The Kubelka film creates afterimages, psychological effects. Although I appreciate their works very much, I try to avoid optical illusions. My concern is not with rhythm but with intervals of time, with concrete duration as material.[455]

Iimura is, in essence, reducing the cinematic frame to its purest form, namely, a concrete unit of time, most commonly, 1/24 of a second. By experimenting with this form of cinematic time, he is ultimately experimenting with the viewer's perception of cinematic time. Iimura suggests,

> In my film *24 Frames Per Second*, I wanted to place the notion of time at the forefront. As one frame is the shortest duration achievable in cinema, I wanted to see to what extent such a short time is visible to the human eye.[456]

It appears that cinematic time is traced out through the consecutive white frames; however, it is only in relation to the black frames that these frames register time, reinforcing the idea that white and black only exist in relationship to each other.

It can be demonstrated that Iimura's choice to use consecutive white frames, despite tracing time, is also a mathematical conceit, since the number of permutations increases substantially if you choose not to. For instance, let us consider the section 12/24. The twelve frames showing consecutive white frames function as single frames amongst the twelve remaining black frames giving

$$\frac{13!}{1!\cdot 12!}=13$$

455 Ibid., 127.
456 Julian Ross, "Interview: Takahiko Iimura," *Midnight Eye* (September 30, 2010), <http://www.midnighteye.com/interviews/takahiko-iimura/>.

different permutations. If the twelve white frames were not consecutive there would be

$$\frac{24!}{12!\cdot 12!}=2704156$$

permutations. This is a substantially larger number of permutations and would take approximately 752 hours (or 32 days) to present, even though each permutation is only one second in length.[457] And this would be *only one of the sections of twenty-four sections!* This suggests it would be nearly impossible to create a 16mm film that demonstrates all of the permutations of white and black frames on a one-second strip of film.

The restriction of working with 16mm film makes the task of working through all the permutations impossible. In contrast, new media artist John F. Simon, Jr.'s *Every Icon* (1997), is a 32 x 32 grid that attempts to produce every black and white icon that can be rendered in this space by systematically producing all of the permutations of black and white squares. The brief description on the page reads: "Given: An icon described by a 32 x 32 grid. Allowed: Any element of the grid to be coloured black or white. Shown: Every icon."[458] Over an *extremely* long period of time, every 32 x 32 black and white icon will appear for approximately 1/100th of a second. The project began on "January 14, 1997, 9:00:00PM,"[459] and is, at the time of this writing (over twenty years later), still only working on the second line. As Smith observes in his artist statement:

> *Every Icon* starts with an image where every square is white and progresses through combinations of black and white squares until every square is black. The piece will show every possible image. Although it takes only 1.36 years to display all of the variations along the first line, it takes an exponentially longer 5.85 billion years to complete the second line. Even in this limited visual space, there are more images than the human mind can experience in many lifetimes.[460]

The piece visually allows us to conceptualize the mathematical concept of a permutation and its seemingly uncountable iterations. At any given moment we would be able to produce any individual

457 Approximately 1502 hours (or 63 days) if the negative of each permutation were also presented.
458 See Fig. 38.
459 Ibid.
460 John F. Simon (Jr.), "Artist Statement: Every Icon," (1996), <http://www.numeral.com/artworks/artAppliances/1998_2000/everyicon.php>.

iteration, while the sum total of all the iterations is simply beyond our conception.

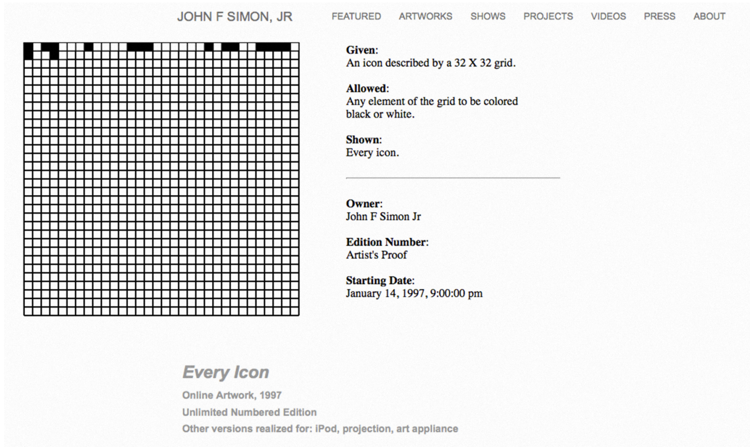

Fig. 38 – Screen grab of Every Icon.

Vancouver artist Stan Douglas is another artist to use an exhaustive permutational strategy. In his 16mm film installation, *Journey into Fear* (2001), a permutational strategy is used to create an algorithmically edited multimedia piece. The installation exhausts 625 possible permutations of sound and image, creating a work that lasts approximately 157 hours, or roughly six and a half days. Douglas explains:

> *Journey into Fear* is a film installation in which a picture track loops while its dialogue tracks are constantly changing. The timeline is broken in four positions (1-4) to permit branching. At these junctures, a computer randomly chooses which one of the five dialogue variations (A-E) will be performed. Each time the picture track repeats, a different combination of dialogue segments is heard until all permutations have been presented.[461]

The image loop itself is only fifteen minutes (with its own built-in variations), however, at each of the four junctions there are five different dialogues that could be performed.[462] Hence, there are $5^4 = 5{\cdot}5{\cdot}5{\cdot}5 = 625$ different dialogue combinations. The structure of the work suggests an endless array of possibilities, with each new iteration creating a unique narrative. Although each film segment forms a "coherent" narrative, art historian and curator Achim Borchardt-Hume observes that *Journey into Fear* abandons "linear narrative in favour of the cyclical and relentless repetition of comparatively short film

461 Stan Douglas, *Journey into Fear* (London: Serpentine Gallery, 2002), 26.
462 A description of the complete picture track is provided here: Douglas, *Journey into Fear,* 26.

segments, with results in no clear beginning or ending and no sense of progression."[463] In contrast to Iimura's work, which systematically exhausts every permutation creating a sense of progression, Douglas' work loses its sense of time through fragmentation, lost in an endless cycle of time.

Although the overall structure of the work does not easily lend itself to a cohesive global narrative, it is quite likely that a viewer watching a shorter segment of the film will be able to construct a narrative from the elements provided. Through employing a permutational structure, Douglas removes himself as an authoritative author of each segment. As Borchardt-Hume explains, "Douglas himself challenges the authority of the author by calling upon the viewer to become a collaborator in the unfolding meaning of his installation."[464] *Journey into Fear* invites the viewer to play an active role in meaning making. Moreover, its hyper-referential nature suggests potential readings of the work.

The scenes in Douglas' work are highly theatrical, and were inspired by Daniel Mann's 1975 film of the same name. Mann's film was itself a remake of Norman Forster's 1943 film, which was based on a 1940 novel with the same name by Eric Ambler. The book is considered "one of the twenty best spy novels of all time" by the Telegraph. It established many of the genre's conventions and influenced later works such as the James Bond series.[465] The book and the first film adaptation are set in World War II. An arms dealer named Graham, who has just successfully negotiated a deal to rearm the Turkish Navy, is forced to flee Istanbul on a commercial trawler which is also occupied by an assassin hired to kill him and his employer, Möller. Möller gives Graham an ultimatum: to be killed en route, or to feign an illness, which would delay the shipment of arms. Mann's version is set during the 1970s oil crisis; Graham is recast as an oil surveyor who is investigating oil deposits in Turkey. Möller provides a similar ultimatum to Graham, as a delay in the information reaching America would be beneficial to the company he represents.

463 Stan Douglas and Achim Borchardt-Hume, "Journey into Fear: An Introduction," in *Journey into Fear* (London: Serpentine Gallery, 2002), 9.
464 Ibid.
465 "The Twenty Best Spy Novels of all Time," *The Telegrap*h (January 6, 2017).

Douglas' video is yet another contemporary remake of the novel. Like the two films, Douglas' version takes place on a container ship, but this time the ship is travelling from Asia to Vancouver. The scenes are conversations between a man and woman based on the two characters of Graham and Möller. Through the dialogue, Möller is trying to convince Graham to delay a container, which would leave another company's shares vulnerable to an aggressive takeover. By referencing a work with various iterations, Douglas' video begins to take on meaning. The 1973 version of the film suggests that global domination occurs through the financial market, an update to the 1940 version which suggests global domination occurs through war. In both versions, Graham survives assassination attempts by Möller, providing these versions with closure; however, through the permutational structure of Douglas' work, the conversations between Graham and Möller seem to go nowhere, perhaps suggesting an allegorical reading for this contemporary form of globalization in which there are no easy solutions, just endless dialogue.

The dialogue in the work (written by Douglas and Michael Turner) follows many of the tropes of conventional narrative cinema. In addition, it is open-ended, allowing each part to function within different permutational configurations. Moreover, the dialogue is consciously out of sync with the images. This dubbed quality is a result of the fact that the picture track is intended to work with an array of different audio tracks; however, it also provides the illusion that the film is poorly dubbed from another language.

Finally, it is worth observing that the use of a computer allows Douglas to realize his vision in *Journey to Fear*. In his work, it is the soundtrack that is permuted, not the images (which are simply repeated with some minimal variation). Given that the images are on 16mm, it can be argued that Douglas is making a medium-specific argument, gesturing towards the contrast between the malleability of the digital and the rigidness of film. With this in mind, if we return to Iimura's *24 Frames Per Second* it is easy to imagine a digital version of this work, similar to Simon's *Every Icon*, that pursues every possible permutation of black and white frames on a one-second second strip of film, but, as previously discussed, this version is nearly impossible to create *on* film due to its length.

24 Frames Per Second and *Journey into Fear* both use exhaustive permutational strategies, the former experimenting with filmic form and the latter with narrative form. In reality, every film can be seen as using a non-exhaustive permutational strategy since every film is one permutation of the shots gathered during production. It is for precisely this reason that this mathematical structure is of interest to those producing media art. Furthermore, for a non-exhaustive permutational strategy to be of interest to those challenging conventional structures, it must contain more than one permutation. An example of a non-exhaustive permutational strategy that includes more than one permutation is filmmaker and cinema scholar R. Bruce Elder's *Permutations and Combinations* (1976).

Elder describes the structure of his film in an unpublished manuscript titled *Permutation, Collage and Film Form*:

> Many years ago, I made a film entitled *Permutations and Combinations* that used a small set of images, some of which had sounds associated with them, and which presented serially the set of permutations of those images (and sounds) arranged in such a way that the film had a mirror structure, so that the second half of the film is simply the first half shown in reverse (what interested me in the result was that both the first half and the second seemed to have an accelerando form, when one would have expected that if the first half of the film appeared to speed up, that the mirror image of the first half would seem to slow down; that there was no real speeding up or slowing down, since every image was presented for just one frame, also intrigued me.)[466]

The film starts with a finger pointing to a chalk line on black. Next, twenty-one still images, three of which have sound, are repeated three times, each time with increasing speed: the number 1; an old man; a young girl; a wall; a detail from Jan Vermeer's *The Love Letter* (1666); an image from a comic book reading “-ESTROYE-”; a drawing of trees; a text on set theory; a four-frame animated sequence of a square beam showing it from different angles; a sequence of six abstract images, red paint and blue paint splattered on paper; and three clear sequences with different sounds. As the images are repeated, an offscreen voice humorously states “Yeah...ah, the point of this repetition is largely mnemonic. That's

466 R. Bruce Elder, “Permutation, Collage and Film Form,” (unpublished manuscript from 2004).

all.” Next, a title card reads *Permutations and Combinations* followed by a text reading: “Being an inquiry into a manner of conjuring illusions conducted by employing aleatory devices.” Finally, various permutations of the listed images are shown until an end credit reading: “© R. Bruce Elder 1976” appears and the film plays in reverse. It is worth observing that there are 21! permutations of the images listed above, and Elder's film only presents an infinitesimally small fraction of them. By playing the film in reverse, the film forms a loop, or “a closed container for the film's chance elements.”[467]

Elder describes one of the impulses for pursuing permutational strategies in the creation of experimental cinema:

> Structures that derive from permutational methods of the sort just described [those controlled by stochastic processes] have interested me as well because they [have] non-hierarchic structures (since a set of permutations accords absolutely equal value to each of the elements of the set that undergoes permutation, as every element appears an equal number of times in the permutation set, and in every possible position in the permutation set); and I believe it an unwarranted aesthetic restriction to work with established forms of construction (for example, perspectival or narrative constructions, or harmonic-tonal musical constructions) that result in privileging some of the works elements over other[s]. Structures that derive from permutational methods of the sort just described have interested me for another reason: anyone who has toyed with permutations knows that, as more elements are introduced, the number of permutations of those elements rises rapidly, and so [it] attains staggeringly large dimensions. Structures that derive from permutational methods therefore furnish a means for demonstrating the imagination's vertiginous freedom.[468]

Elder is suggesting that permutational structures provide a non-hierarchical structure where every shot is given equal value – a way to remove our pre-existing aesthetic biases. Artist and curator Catherine Elwes reinforces this position while discussing Douglas' chance-based artworks, which include *Journey into Fear*:

> The arbitrary nature of language and its tenuous hold over meaning constitute the overriding themes in such works [those generated through chance operations]. Their refusal of linearity in the development of narrative themes promotes a less goal-oriented secure conceptual framework and introduces a more maze-like, aleatory and non-hierarchical approach to storytelling. Chance in art, as in life, throws up the real challenges and surprises.[469]

Permutations and chance operations are ways of generating and developing ideas, establishing

467 Program notes for a screening of the film on February 6, 1982 at *Millennium*.
468 Ibid.
469 Elwes, *Video Art*, 187.

connections that may not be immediately obvious. For instance, editors will often play around with different permutations of shots while editing in an attempt to generate original ideas, or to tease out different ideas.

Elder also acknowledges that the number of permutations drastically increases with every element that is added to the set, attaining staggeringly large dimensions. He further argues that human beings' capacity to work through and comprehend the vast number of permutations which occur even with relatively few elements is a testament to our creative freedom and imagination. When attempting to comprehend the vast number of permutations that occur, the most familiar comparison is to Jorge Luis Borges' conception of the Library of Babel.[470] Imagine the moving image collection at the Library of Babel, that is, different combinations of existing moving images, where moving images are the base elements of construction as opposed to letters.

Like the book section at the Library of Babel, most of the moving images would simply be a random selection of moving images; nevertheless, all of the great filmic works would exist, although they would be incredibly difficult to find. It is worth observing that the meaning of images or shots is infinitely more malleable than letters or words – nevertheless, like the vast majority of the books, most would not be worth watching. In this sense, Elder is correct: human beings have created ingenious and imaginative works despite the fact that, within the Borges allegory, the vast majority of works in the media collection at the Library of Babel would have no redeeming qualities – simply a random selection of images. Moreover, to obtain a truly imaginative work, the artist has to recognize that ingenious permutations and select them from the immense number of permutations available.

At this point in time, it is easy to imagine that the moving image collection at the Library of Babel houses an astronomically large digital collection of moving images. Like Borges' physical library where people spend lifetimes wandering the stacks, the digital version would be equally as chaotic

470 The Library of Babel is a vast library containing all possible 410-page books. See Jorge Luis Borges, “The Library of Babel,” in *Collected Fictions*, trans. Andrew Hurley, (New York: Pengiun, 1998).

without ways of navigating the collection.[471] In contrast, a well-indexed collection would allow artists new ways to re-configure this collection. As early as 1982, artist Bill Viola was imagining new ways to create work in such a space. In an essay titled "Will There Be Condominiums in Data Space?" Viola imagines ways of navigating such a space:

> Soon, the way we approach making films and videotapes will drastically change. [...] Editing will become the writing of a software program that will tell the computer how to arrange (i.e., shot order, cuts, dissolves, wipes, etc.) the information on the disc, playing it back in the specified sequence in real time or allowing the viewer to intervene. Nothing needs to be physically 'cut' or re-recorded at all. [...] New talents and skills are needed in making programs—this is not editing as we know it.[472]

Viola's dream of editing films through programming was eventually realized in a form of editing referred to as algorithmic editing, a concept that will be further discussed in Chapter Nine.

Joyce Wieland's film *Reason Over Passion* can be seen as both demonstrating the hazards and utopian potentials of permutational strategies. In collaboration with Wieland, Hollis Frampton created 537 algorithmic permutations of the letters in the words "reason over passion," which occupy the bottom of the image during the two main landscape sections of Wieland's film. Using this permutational strategy, Wieland transforms Pierre Elliott Trudeau's statement into words that do not have meaning in any language. By placing these subtitles over beautiful, but equally incomprehensible, images of the Canadian landscape, Wieland is allowing every viewer to experience a Canadian landscape that does not speak their language. Furthermore, as observed by Elder, "the film associates

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471 Even in the early days of modern computing, computer scientists were thinking about innovative ways in which to navigate digital information. For instance, see: Ted H. Nelson, "Complex Information Processing: A File Structure for the Complex, the Changing and the Indeterminate," in *Proceedings of the 1965 20th ACM National Conference* (New York: ACM, 1965).

472 Bill Viola, in *Reasons for Knocking at an Empty House: Writings 1973-1994*, ed. Robert Violette (Thames and Hudson, 1995), 130. This essay was originally published in *Video* 80, no. 5 (1982): 36-41.
In the essay, Viola goes further and imagines being able to structure information in such a way to able to travel into digital spaces as follows,
"This would be a non-linear array of information. The viewer could enter at any point, move in any direction, at any speed, pop in and out at any place. All directions are equal. Viewing becomes exploring a territory, traveling through a data space. [...] We are moving into *idea* space here, into the world of thoughts and images as they exist in the brain, not on some city planner's drawing board. With the integration of images and video into the domain of computer logic, we are beginning the task of mapping the conceptual structures of our brain onto the technology. After the first TV camera with VTR gave us an eye connected to a gross form of non-selective memory, we are now at the next evolutionary step—the area of intelligent perception and thought structures, albeit artificial" (132). [Emphasis in original]

language with reason."[473] Given that Wieland was "devoutly nationalist,"[474] placing these "new" words without any meaning generated using permutational reasoning over images that were passionately created, Wieland is problematizing Trudeau's motto. In other words, the rational permutational strategy renders the passionate words meaningless.

In an interview with Kay Armatage, Wieland suggested that this permutational strategy was being used to generate an entirely "new language."[475] In this light, Wieland might be offering one solution to a nation struggling with the problems associated with bilingualism over a vast landscape. In Wieland's production notes for *Reason Over Passion*, she writes:

> FRENCH LESSON
> IS A DIRECT REFERENCE TO TRUDEAUS, IDEA OF BILINGUALISM...WE MUST ALL SPEAK FRENCH SO THAT THE FRENCH CANADIAN WILL FEEL AT HOME IN HIS OWN COUNTRY
> (I LIKE THE IDEA)
> I FOUND THE TEACHING RECORD IN 0 STACK OF OUR OLD RECORDS LUCKILY THE MAN ON THE DISK PHETENDIN TO BE A SCHOOL CHILD S NAME IS PIERRE AND HE IS SUPPOSEDLY ONLY EIGHT YEARS OLD...YOUNG LIKE OUR ETERNALLY YOUNG PRIME MINISTER.[476]

In the film, the scene is shown as a French lesson in a classroom, without English subtitles. Pierre is connected to the former Canadian Prime Minister Pierre Elliot Trudeau, whose political philosophy is reflected in the phrase "La raison avant la passion; c'est le thème de tous mes écrits."[477] From this phrase, Weiland obtained "reason over passion" and applied permutational strategiesto systematically transform it into nothing more than a random collection of letters. However, if these random letters actually do suggest the possibilities of generating a new language, it is possible that this language might have the potential to unite a divided, bilingual Canada, alluding to the utopian possibilities of such a strategy. Given that these strategies are also the same ones used to remove their meaning,

473 R. Bruce Elder, "Notes after a Conversation between Hollis and Joyce," in *The Films of Joyce Wieland*, ed. Kathryn Elder (Toronto: Cinémathèque Ontario, 1999), 187–8.
474 Ibid., 188.
475 Kay Armatage, "Kay Armatage Interviews Joyce Wieland," in *The Films of Joyce Wieland*, ed. Kathryn Elder (Toronto: Cinémathèque Ontario, 1999), 157.
476Joyce Wieland, "Notes on Reason Over Passion," *Canadian Journal of Film Studies* 15, no. 2 (2006), 122–23. [Capitalized form and spelling in original.]
477 "Reason over passion; that is the theme of all my writing."

Wieland is demonstrating both the utopian potential as well as the destructive power of permutational strategies. Given that this section was made in collaboration with Frampton, this opposition makes sense; as Elder describes, “Wieland's celebration of passion contrasts with Frampton's outlook, for his intelligence was of an exceedingly discursive variety.”[478]

Some filmmakers have argued that there is a spiritual dimension to removing the author and giving yourself over to chance. As observed by filmmaker Harry Smith in an interview with P. Adams Sitney,

> Somebody, perhaps Burroughs, realized that something was directing it, that it wasn't arbitrary, and that there was some kind of what you might call God. It was just chance. Some kind of universal process was directing these so-called arbitrary processes; and so I proceeded on that basis: Try to remove things as much as possible from consciousness or whatever you want to call it so that the manual processes could be employed entirely in moving things around. As much as possible, I made it automatic.[479]

Exploring stochastic permutations is one way for the artist to surrender control to another power. On the one hand, this has the potential to open the work up to something beyond the author, provided that one has faith that a higher power will guide the work. On the other, the work produced might simply be like the mountainous number of mundane works in the media collection at the Library of Babel that offer nothing to the viewer other than a random collection of images. Given that every film is a permutation of shots, permutational strategies are integral to filmmaking in general, hence working through permutational strategies and their potentials remains an admirable pursuit.

7.3 Words in Disarray: The Art of Anagrams

An anagram is a permutational structure that involves reordering letters of a phrase to produce a new phrase by using all the original letters exactly once. The influential experimental filmmaker Maya Deren, in her book *An Anagram of Ideas on Art, Form and Film*, explains:

> An anagram is a combination of letters in such a relationship that each and every one is simultaneously an element in more than one linear series. This simultaneity is real and independent of the fact that it is usually perceived in succession. Each element of an anagram is so related to the whole that no one of

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478 Elder, “Notes after a Conversation between Hollis and Joyce,” 188.
479 P. Adams Sitney, “Harry Smith Interview,” in *Film Culture Reader*, ed. P. Adams Sitney (New York: Praeger Publishers, 1970), 272.

them may be changed without affecting its series and so the whole. [...] In an anagram all the elements exist in a simultaneous relationship. Consequently, within it, nothing is first and nothing is last; nothing is future and nothing is past; nothing is old and nothing is new... except, perhaps the anagram itself.[480]

Through her description, Deren reinforces the non-hierarchical structure of permutations but she also stresses the importance of each individual element in relation to the whole. It is also worth observing that Deren's writing is allegorical, since she is not only referring to anagrams, but also to ideas. Deren's interest in anagrams derived from the influence of Surrealist poetry, where Unica Zürn's anagram poetry helped to establish this form of wordplay as an artistic endeavour. Moreover, Marcel Duchamp's film *Anémic Cinéma* (1926), a film full of wordplay and puns, and whose title makes use of the anagram, was clearly influential to Deren, who sought him out to collaborate on a film project, entitled *The Witch's Cradle* (1943, unfinished).

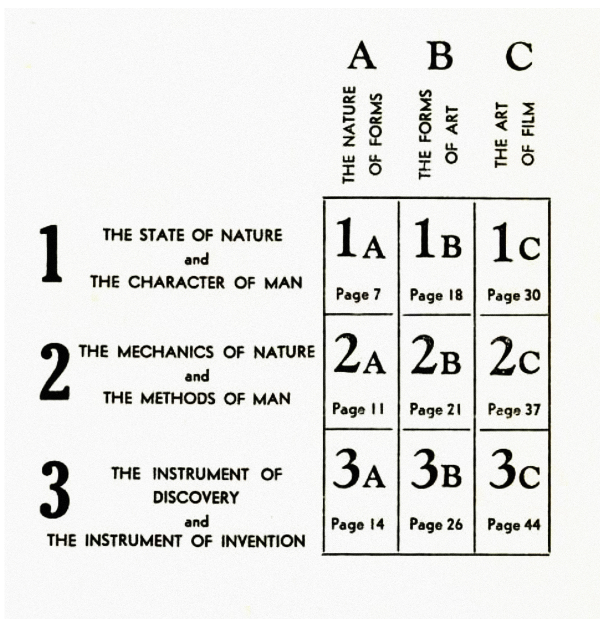

Fig. 39 – Opening diagram from An Anagram of Ideas on Art, Form, Film

An Anagram of Ideas on Art, Form and Film is divided into nine sections, each of which has a position within a 3 x 3 grid. Deren suggests that the essay can be read anagrammatically:

In this essay the element is not a single letter, but an idea concerned with the subject matter of its position in the anagram; that is, 2B, for instance, deals with the forms of art [denoted by B in Deren's

480 Maya Deren, *An Anagram of Ideas on Art, Form and Film* (Yonkers: Alicat Book Shop Press, 1946), 5-6.

> grid] in reference to the mechanics of nature and the methods of man [denoted by 2 in her grid system]. In every other respect the principles governing an anagram hold.[481]

Just as Deren was writing allegorically about anagrams, the structure of her book acts as a metaphor for cinema itself. As observed by film scholar Orit Halpern in "Anagram, Gestalt, Game in Maya Deren," the anagram, to Deren, "is both a theory of cinema and an instructional blueprint for cinematic production."[482] In other words, Halpern contends that Deren views cinema as a permutational structure. Through reading the anagram as a metaphor for cinema, Halpern also illuminates Deren's cryptic statement, "Nothing is old and nothing is new... except, perhaps the anagram itself":

> This is a curious statement, and it denotes a subtle ontological shift. Nothing is new in that the forms and images come from the past; what is new, for Deren, is the process by which an already known and recorded world is reformulated. The anagram is this process, and its novelty lies in producing a whole that exceeds its parts and emerges as art. The anagram, therefore, is an auto-poietic form bridging past and future, producing possibilities for cinematic practice out of the remains of the past.[483]

Halpern is, once again, suggesting that Deren was demonstrating the permutational nature of cinema, where past images are linearly ordered to create films, with each part related to the whole in such a way that moving any of them would change the meaning of all of them.

Although anagrams are a permutational strategy, only permutations that form phrases or that make even a modicum of sense are considered, a limitation which greatly reduces the number of permutations available. Given that permutational strategies generate a gigantic number of results, as previously argued, this is one way of rejecting a vast number of results produced by generating all permutations. Anagram generation avoids some of the problems associated with other permutational strategies, in that it provides structure, eliminating purely random sequences of letters. Unfortunately, this type of reduction is more difficult in the production of cinema since the meaning of images is more malleable than that of letters or words.

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481 Ibid., 5.
482 Orit Halpern, "Anagram, Gestalt, Game in Maya Deren: Reconfiguring the Image in Post-War Cinema," *Postmodern Culture* 19, no. 3 (May 2009) <http://www.pomoculture.org/2013/09/05/anagram-gestalt-game-in-maya-deren-reconfiguring-the-image-in-post-war-cinema/>.
483 Ibid.

Experimental cinema is rife with literary anagrams. For instance, in *Wide Angle Saxon* (1975), Owen Land has the protagonist, Earl Greaves, watch a film within the film titled *Regrettable Redding Condescension* by Al Rutcurts. This film within a film is a parody of Hollis Frampton's *(nostalgia)* (1971), and a wordplay on an earlier film made by Land, namely, *Remedial Reading Comprehension* (1970). Al Rutcurts name is an anagram of “structural,” gesturing to Sitney's conception of structural film, Frampton's work, and Land's own perceived association with the movement.[484] In an interview with Mark Webber, Land explains why he chose to lampoon *(nostalgia)*:

> It has to do with my disappointment with conceptual art, and with the conceptual tendency. I thought that particular film was hindered by its over-conceptualization.[485]

Land saw Frampton's film as overly conceptual and used humour as a way to critique it.

As observed by Sitney, the term “condescension” has a double meaning.[486] The work is condescending or patronizing towards the audience, posing the question “Look at it. Do you see what I see?” as red paint bubbles on a hot plate, a visual reference to Frampton's film in which photos are burned, and to the final line on the soundtrack. However, the condescension is also “the act of God the Father manifesting himself among men as the Son” providing a religious interpretation of Greaves' awakening.[487] Scholar J.D. Connor provides one further reading, suggesting that the film’s punning transforms the screen’s ability “to be read,” explored in *Remedial Reading Comprehension*, into something that is literally going “to be red.”[488]

The voice-over for both films was provided by Michael Snow, another so-called structural experimental filmmaker who experimented with anagrams, and who performed the voiceover for both

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484 Land further parodies structural film in his film *On The Marriage Broker Joke As Cited By Sigmund Freud In Wit And Its Relation To The Unconscious, Or Can The Avant-Garde Artist Be Wholed?* (1978). In the film, a panda asks another panda, “what's a 'structural film'?” The second panda responds: “That's easy, everybody knows what a structural film is. It's when engineers' design an aeroplane, or a bridge, and they build a model to find out if it will fall apart soon. The film shows where all the stresses are.”
485 Owen Land, *Two Films by Owen Land*, ed. Mark Webber (London: LUX, 2005),104.
486 Sitney, *Visionary Film*, 380.
487 Ibid.
488 J.D. Connor, “What Becomes of Things on Film on Film: Adaptation in Owen Land (George Landow),” *Adaptation Vol. 2, No. 2* 2, no. 2 (July 2009), 166.

(nostalgia) and *Remedial Reading Comprehension*. For instance, his 1974 film *'Rameau's Nephew' by Diderot (Thanx to Dennis Young) by Wilma Schoen* contains an anagram of his name.[489] Moreover, the opening credits contain many anagrams of Snow's name including: Male Cow Shin, Nice Slow Ham, Wilma Schoen, Naomi S. Welch, El Masochism, Noel W. I. Chasm, Lemon Coca Wish, Malice Shown, etc. Snow further enhances this joke by having someone, seemingly impromptu, read the credits to the audience out loud as they quickly scroll across the screen, complete with mispronunciations. In an interview with filmmaker Mike Hoolboom, Snow alludes to the permutational nature that underlies cinema:

> The film is based on a sentence structure, where each scene is imagined as a word. Some words are long and take more time, while others are short. It's like Lego in a way – you can arrange all these different things in different ways, but they each have their own individual significance, origin, and etymology. The film could be rearranged to make another sentence.[490]

Through the use of anagrams, Snow is further reinforcing the connection between permutational structures and cinema. Moreover, through his careful anagram selection (he only selects the ones that "make sense") it is possible to see that Snow does not simply believe that all permutations are created equal. This is further supported by his description of editing the film:

> I wanted to make every shot discrete, established by the preceding one by contrast. So if there was a horizontal pan in one shot, the next might have a vertical pan. If one shot was close-up, the next might be distant. There are so many elements in the shots there was no way I could totally classify everything, but I made lists. I also wanted connections to be made over long periods.[491]

In other words, like Deren, Snow believes each part affects the whole.

Carrying on the tradition, filmmaker Stephen Broomer's *Hang Twelve* (2014) is an anagram of the word "wavelength," referencing Michael Snow 1967's film of the same name. *Hang Twelve* also contains a poem read out loud by the filmmaker:

Nice Eyes Revolt
Encores live yet
Slice every note, each notice sincere in secret

489 Wilma Schoen is an anagram of Michael Snow.
490 Michael Hoolboom, *Inside the Pleasure Dome: Fringe Film in Canada* (Toronto: Coach House Books, 2001),14.
491 Ibid.,18. The running time *'Rameau's Nephew'* is 266 minutes.

Lovers covet eyeliner
to recite in vein or vesicle
Clever noise, silence or else

This poem consists of anagrams of many anagrams. The below is an anagram of the poem that I created; readers are encouraged to create their own.

Serene Velocity
Serene Velocity
Serene Velocity – Insert a conscience cite here
Vision lover in revolt
I revere eyes eclectic tone
Sincere love, I enclose reels

The title *Nice Eyes Revolt* is an anagram of "serene velocity," suggesting the influence of Ernie Gehr's 1970 film of the same name. More than being a simple homage, Broomer's anagrams provide the key to decoding the structure of this work – through their references they allude to the underlying algorithms that Broomer used to construct his film.

Both *Wavelength* and *Serene Velocity* are works that experiment with cinematic space through structuring their work around the focal length of a zoom lens. Similarly, *Hang Twelve* is a work that is structured around focal length but Broomer expands on this previously explored theme by connecting it to the RYB colour wheel, a circle consisting of twelve equidistant colour sections arranged as follows: red; orange-red; orange; yellow-orange; yellow; yellow-green; green; blue-green; blue; blue-violet; violet; red-violet. At first glance these two concepts may seem disconnected; however, light (and more specifically, the refraction of light through a lens) and colour are both products of the same physical phenomenon, namely, electromagnetic radiation.

Hang Twelve is divided into twelve parts, not including the prologue and epilogue. For the twelve sections, the focal length of the zoom lens was divided into twelve equal intervals. The first section begins with the focal length set at 12mm, for the second section the focal length is set at 24mm, continuing until the focal length for the twelfth final section is 144mm. In other words, the film is structured around the zoom. In the final section of the film, Broomer reads the poem *Nice Eyes Revolt* on screen before committing one final random act, the throwing of a pitcher of water at the camera, with the tossed water blocked by a window.

Each section is framed by one of the primary colours, continuously cycling through red, blue and yellow in that order. Between each section is a six-second cycle of twelve static frames representing the colour wheel, that is, the solid colours beginning with red and ending with red-violet. Finally, the prologue consists of twelve seconds of solid red and the film ends with twelve seconds of solid red-violet. One of the more interesting aspects of the video occurs in the epilogue, where the entire space is revealed in negative and the colour wheel is also shown one final time, this time in negative. Through inverting the colours, Broomer estranges the space and seems to allude to the limitations of his predetermined system and, potentially, the RYB colour system itself.[492]

Finally, the use of anagram explored in this chapter suggest another one of its functions in experimental cinema, that of intertextuality, and citation, all common tropes of experimental films. By its very nature, an anagram is a form of reference. Using anagrams requires that the viewer decode the original source. As such, the anagram can be seen as another way of introducing uncertainty into a work. As discussed in Chapter Three, experimental filmmakers often use idiosyncratic or ambiguous encoding techniques in order to increase uncertainty and to allow for the production of original forms of communication. The anagram can be seen as one such strategy; however, like all forms of experimentation, the more it is used, the less original it is.

492 There are certain colours which cannot be expressed within a particular colour model, often referred to as colours out of gamut. One of the standard examples is pure red which can be expressed in the RGB colour space and cannot be expressed in the CMYK colour space.

CHAPTER EIGHT: THE AXIOM OF CHOICE AND MEDIA ART

"I'm starting to resent *Zorns Lemma* SLIGHTLY, telling people that I have in fact made 14 other films etcetera"
– Hollis Frampton, in a letter to Sally Dixon, 1970

In this chapter, the mathematical concept of the Axiom of Choice will be introduced. The concept will be defined formally, together with some of its equivalent statements, in particular, Zorn's Lemma and the Hausdorff maximality principle, a close approximation to the mathematical statement used by filmmaker Hollis Frampton as the impetus for his film *Zorns Lemma* (1970). I will argue that *Zorns Lemma* is a cinematic/poetic demonstration of the Axiom of Choice and, hence, a mathematical demonstration of the axiom the film is named after. Moreover, the consequences of such an interpretation will be explored. Finally, a theoretical framework for some cinematic applications of the Axiom of Choice will be developed by working through a purely conceptual model: *the infinite film*.

8.1 The Axiom of Choice: A Mathematical Overview

The Axiom of Choice was first formulated by Ernst Zermelo in 1904, and formally states the following:

> For every family F of non-empty sets, there is a function f defined on F such that $f(S) \in S$ for each set S in F. [493]

In other words, for each set in F there is a function that *chooses* an element of that set. For this reason, the function f is referred to as a *choice function* on F. Invoking the Axiom of Choice was at one time controversial among mathematicians. As mathematician Thomas Jech observes, "no postulate since Euclid's Parallel Axiom aroused so much excitement in mathematical circles and led to so many philosophical arguments about the foundations of mathematics."[494] The controversy around the Axiom of Choice ultimately stems from its "non-constructive nature"[495]: the axiom states that there exists a choice function, but it does not provide a way of constructing it. Moreover, as Jech reminds us,

493 Thomas J. Jech, *The Axiom of Choice* (Amsterdam: North-Holland Publishing Company, 1973), 8.
494 Ibid., 346.
495 Ibid.

“traditionally, until the late nineteenth century, existence in mathematics was synonymous with construction.”[496]

This is not the only reason the Axiom of Choice has remained controversial. As Jech further notes, “the Axiom of Choice can be used to prove theorems which are to a certain extent 'unpleasant', and even theorems which are not exactly in line with our 'common sense' intuition.”[497] For instance, the Axiom of Choice is used in the proof of the Banach–Tarski paradox, an extremely counter-intuitive result that contradicts our basic geometric intuition. The Banach–Tarski paradox states that given a solid ball in three-dimensional space, there exists a decomposition of the ball into a finite number of disjoint subsets, which can be reconstructed in a different way that creates two identical copies of the original ball. If the Axiom of Choice holds, then the decomposition in the Banach–Tarski paradox exists. Although this result is counter-intuitive, human beings have no real intuition about the infinite. Moreover, the Axiom of Choice is consistent with the other axioms of Zermelo–Frankel set theory, as shown by Kurt Gödel in 1940, and is now commonly used by most mathematicians.

The following demonstration is one way to conceptualize the Axiom of Choice. Suppose we are given bins each containing at least one object. The Axiom of Choice states that it is always possible to select exactly one object from each bin. Of course, only in special cases do we actually need to evoke such a powerful tool. For instance, in cases where there are only a finite number of bins, we do not need to use the Axiom of Choice since there is an obvious procedure for selecting objects from the bins. That is, we can enumerate the bins and then select an object from the first bin, an object from the second bin and so on. As there are only a finite number of bins, this procedure will eventually end. The selection process becomes a bit trickier, however, in the case of an infinite number of bins. Such a scenario was the impetus for a famous aphorism attributed to Bertrand Russell that states, “to select one sock from each of infinitely many pairs of socks requires the Axiom of Choice; but for shoes the

496 Ibid.
497 Ibid., 2.

Axiom is not needed."[498] In the case of an infinite number of shoes, you can always select the left (or, equivalently, the right) shoe. In the case of socks, however, it is not possible to assume that such a choice function exists, since there is no intrinsic way of distinguishing between the two socks. In other words, the choice is truly arbitrary, forcing one to invoke the Axiom of Choice.

8.2 Substituting the Cut: A Mathematical Interpretation of *Zorns Lemma*

Zorns Lemma is a complex and fascinating film that has a labyrinthine structure alluding to a mathematical reading of the work as a visual metaphor for mathematician Max Zorn's famous axiom, Zorn's Lemma.[499] The film is composed of three distinct sections. The first section consists of a female narrator reading verses from an eighteenth-century text, *The Bay State Primer*, set to a black screen. Each verse focuses on a word beginning with a letter from the Roman alphabet – a twenty-four-letter predecessor to the contemporary English alphabet, in which I/J and U/V are considered equivalent.

The second section – the "main section"[500] and the portion that I will focus on – is silent and consists of "2,700 one-second cuts, one-second segments, and twenty-four frame segments."[501] This section begins by traversing an iteration of the Roman alphabet, which was "typed on tinfoil and photographed in one-to-one close-up."[502] In the following iterations, each letter sequentially gets replaced by a word that begins with the same letter and that preserves lexicographic ordering. The words themselves were selected using a chance operation and were found

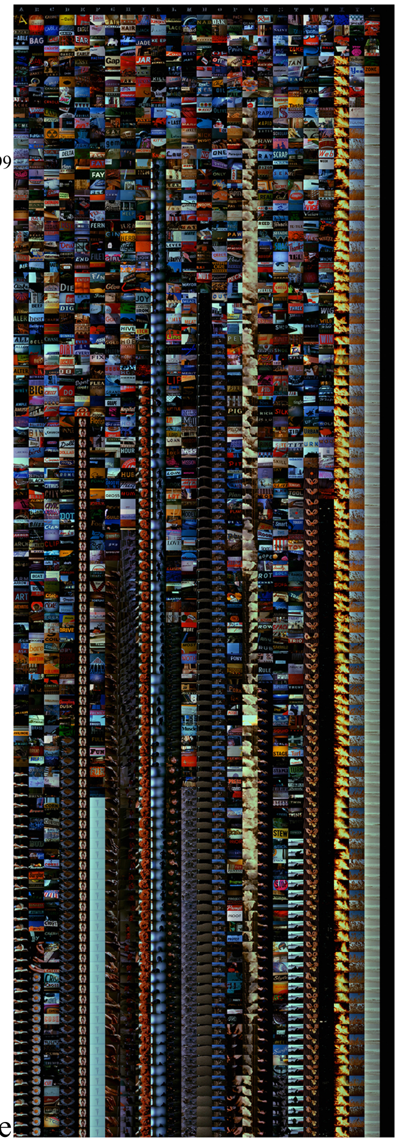

Fig. 40 – Image montage of the second section of Zorns Lemma.

498 Eric Schechter, *Handbook of Analysis & Its Foundations* (New York: Academic Press, 1997), 140.
499 Note the spelling difference between Zorn's axiom and the title of Frampton's film.
500 Peter Gidal, "Interview with Hollis Frampton," *October* 32 (Spring 1985), 94.

embedded in an urban environment.[503] Finally, each letter is gradually replaced by a wordless image that runs for one second per iteration until the letters are all replaced, concluding the section [see Fig. 40].

In the final section, a man, a woman, and a dog cross a snow-covered field from foreground to background, while six women read, at a rate of one word per second, sections from Robert Grosseteste's *On Light, or the Ingression of Forms*, an eleventh-century text discussing the nature of the universe.

Zorn's Lemma (also known as the Kuratowski–Zorn lemma), is named after mathematicians Max Zorn and Kazimierz Kuratowski, first proved by Kuratowski in 1922 and independently by Zorn in 1935. Zorn's Lemma explicitly states:

> Let (S, <) be a nonempty, partially ordered set and let every chain in S have an upper bound. Then S has a maximal element.

Informally, Zorn's Lemma states that if certain ordering conditions are met on a set, then that set contains at least one maximal element, that is, an element that, with respect to the ordering, no other element strictly exceeds. It has been shown that Zorn's Lemma is equivalent to Zermelo's Axiom of Choice.[504] While discussing Zorn's Lemma, Frampton actually refers to one of its many equivalent statements. He explicitly uses the following formulation:

> Every partially ordered set contains a maximal fully ordered subset.[505]

When the word *fully* is replaced by the correct, mathematically loaded term *totally*, it can be shown that Frampton's statement is equivalent to the Hausdorff maximality principle, first proved by Felix

501 Ibid.
502 Ibid.
503 Ibid., 96.
504 For an explicit proof that Zorn's Lemma is equivalent to the Axiom of Choice see Jech, *The Axiom of Choice*, 10.
505 Hollis Frampton, "Zorns Lemma: Scripts and Notations," in *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, ed. Bruce Jenkins (Cambridge: MIT Press, 2009), 195. The Hausdorff maximality principle is a slightly different statement but is equivalent to Frampton's statement. In any partially ordered set, every totally ordered subset is contained in a maximal totally ordered subset.

Hausdorff in 1914.[506] Furthermore, it can also be shown that the Hausdorff maximality principle is equivalent to Zorn's Lemma.[507] Finally, given that Zermelo's Axiom of Choice is equivalent to Zorn's Lemma, the Axiom of Choice is therefore mathematically equivalent to Frampton's version of Zorn's Lemma.

Before providing a mathematical interpretation of the film *Zorns Lemma*, it is worth stating that Frampton did not plan for his film to be interpreted this way; however, he did not discourage such a reading. Frampton states:

> I did not set out to provide a cinematic demonstration of a mathematical proposition. On the other hand, I don't mind that the work should respire that possibility.[508]

Frampton explains his interest in Zorn's Lemma, given that it was not his intention to provide a cinematic demonstration of the mathematical proposition:

> One of the strivings of mathematics and one of its grand problems has been to make mathematics internally self-proving and to attempt to find out whether in fact it is or not. [...] In recent times there are two particular mathematicians whose work has given special attention to this question. The first is Kurt Gödel, who devised a method for testing mathematical propositions to see whether they generated certain kinds of symmetries that would suggest whether they could be self-proving. The method is extremely elegant. His finding was that mathematics could not be proved within itself. The other mathematician is Max Zorn, whose work was concerned with the question of whether it was possible to make exact statements about the amount and kind of order that was to be found within sets, including the set of all propositions and proofs that constitutes mathematics itself. The result was Zorn's Lemma. There was for a long time considerable question about whether Zorn's Lemma is part of mathematics; the answer to that question naturally reflects upon the ultimate horizons of mathematical endeavour. Recently I find that the word is out that Zorn's Lemma is part of mathematics.[509]

The theorem Frampton is referring to by Kurt Gödel is his Second Incompleteness Theorem, previously discussed in Chapter Two, which states that no consistent axiomatic system, including Peano’s arithmetic, can prove its own consistency.[510] Gödel's Incompleteness Theorems are two theorems of mathematical logic that demonstrate the inherent limitations of the non-trivial axiomatic systems that

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506Gregory H. Moore, *Zermelo's Axiom of Choice: Its Origins, Development, and Influence* (New York: Springer-Verlag, 1982), 140. For an explicit proof that Frampton's statement is equivalent to Hausdorff maximality principle see John L. Kelley, *General Topology* (New York: Springer-Verlag, 1955), 33.
507 For an explicit proof that Hausdorff maximality principle is equivalent to Zorn's Lemma see John L. Kelley, *General Topology* (New York: Springer-Verlag, 1955), 33.
508 MacDonald, *A Critical Cinema*, 52.
509 Ibid., 51.
510 Peano arithmetic provides a rigorous foundation for arithmetic operations on the natural numbers, $N^* = \{1, 2, 3 ...\}$, and their properties.

allow for basic arithmetic.

In Frampton's discussion of Max Zorn, he seems to be referring to another equivalent statement of Zorn's Lemma: the Well-Ordering Theorem, which states that every set can be well-ordered.[511] More importantly, through his discussion of Zorn and Gödel and the ways in which they challenged the limits of mathematics, Frampton is suggesting that through his film he is attempting to challenge the limits of cinema. Frampton slyly suggests the parallel histories between his film and these mathematicians' theorems:

> The film seems to have had a sort of parallel history. When it first appeared, it was regarded as an unclassifiable nonesuch, a thing that looked like a film, probably, but did some odd things. It seemed not to make many assumptions about what a film was supposed to be but simply to hold up a set of given assumptions, exercise them in their extreme cases as a test of their validity, and put them back down again without comment. It would appear that since it was finished [in 1970], *Zorns Lemma* has come to be regarded as part of that large body of work called film.[512]

In other words, Frampton is asserting that his film challenges the boundaries of cinema, similar to the ways in which Zorn's Lemma challenged the boundaries of set theory and Gödel's theorem challenges the limits of mathematical logic. Through these challenges, these experiments expand the boundaries of their fields, and then join them.

One of the standard interpretations of Frampton's film involves viewing it in terms of "cuts." There is evidence that Frampton was interested in exploring this concept in *Zorns Lemma*, as indicated in a 1964 letter to his friend Reno Odlin:

> The excernment [sic] of the fully ordered set constitutes a cut. Where there are several possible cuts, the set of all cuts constitutes the maximal ordered set.[513]

Melissa Ragona has suggested that the sculptor Carl Andre might have first introduced Frampton to thinking about mathematical cuts in a filmic context, based on a discussion that the two had in the early 1960s regarding the mathematical concept known as the Dedekind cut.[514] Ragona goes on to suggest

511 There is a well known mathematical joke about the equivalence of Zorn's Lemma, the Axiom of Choice and the Well-ordering theorem: "The Axiom of Choice is obviously true, the well-ordering principle obviously false, and who can tell about Zorn's Lemma?"
512 MacDonald, *A Critical Cinema*, 51–2.
513 Hollis Frampton, "Letters from Framp 1958-1968," *October* 32 (Spring 1985), 47.
514 The Dedekind cuts are one method for constructing real numbers, first introduced by Richard Dedekind. The method is

that this idea sparked Frampton's “interest in analyzing the 'cut' in film as the 'cut' in the order of film.”[515]

In my interpretation of *Zorns Lemma*, I am less concerned with the notion of the cut, and more with the act of substitution. In order to interpret *Zorns Lemma* as a visual demonstration of the Axiom of Choice, let us first think of the letters of the Roman alphabet (that is, where I/J and U/V are considered equivalent) as enumerating the bins. For the first substitution, that is, the first application of the Axiom of Choice, the family of sets consists of the set of all of the words that begin with A, the set of all the words that begin with B, the set of all the words that begin with C, and so on. By applying the Axiom of Choice, a word is selected from each of the above *finite* sets. Through each iteration different words are selected demonstrating the arbitrary nature of the choice. It is important to note that evoking the Axiom of Choice is excessive in this case since there are only a finite number of letters in the Roman alphabet and a finite number of words to choose from. In fact, this was implicitly observed by Frampton:

> Most words (not all, but most) were from the environment; they're store signs and posters and things like that, and one finds out very quickly that very many words begin with *c* and *s*, and so forth; very few begin with *x* or *q*, or what have you. One quickly begins to run out of *q*'s and *x*'s and *z*'s.[516]

For the second substitution, the family of sets consists of the set of all moving images of pages being turned in a book (replacement for A), the set of all moving images of an egg frying (replacement for B), the set of all moving images of a red ibis flapping its wings (replacement for C), etc.[517] By applying the Axiom of Choice, a moving image is selected from each of the above *infinite* sets. Once again, invoking the Axiom of Choice is superfluous since there are only a finite number of letters in the Roman alphabet, despite the fact that each of the moving image sets is infinite since there are infinite

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based on a construction similar to the one used in Euclid's *Elements* to define proportional segments. The technique is considered quite ingenious if fairly esoteric by many mathematicians. One of the advantages of Dedekind's construction is that each real number corresponds to a unique cut.

515 Melissa Ragona, “Hidden Noise: Strategies of Sound Montage in the Films of Hollis Frampton,” *October* 109 (Summer 2004), 101.

516 Gidal, “Interview with Hollis Frampton,” 96.

517 For a complete list see: Frampton, “*Zorns Lemma*,” 193 and 200-1.

ways to shoot pages being turned in a book, etc.

It is possible to imagine a case in which the Axiom of Choice is actually needed. For instance, simply consider the natural numbers, $N^* = \{1, 2, 3 ...\}$. For each number, choose a shot from the set of all possible cinematic images. By applying the Axiom of Choice to the family of sets that consists of all cinematic images, one obtains an infinite film. In a metaphysical reading of *Zorns Lemma*, film scholar Allen S. Weiss writes,

> We find here an expression of the infinite cinema of which Frampton writes: God is the infinite film projector; world and humankind and language are the film that is projected by means of pure, white, Divine light. And my life, and yours are partially ordered sets of that maximally ordered set. As is that synecdoche of the infinite film, Frampton's *Zorns Lemma*.[518]

Despite the poetic nature of Weiss' description of *Zorns Lemma*, perhaps he is jumping the gun in suggesting that the film functions as genus for the infinite film. In contrast, the film demonstrates one of the ways in which an infinite film can be obtained, namely, through the Axiom of Choice.

8.3 The Infinite Film: Representing the Universe through Cinema

If *Zorns Lemma i*s a demonstration of the Axiom of Choice, then it is the artist that plays the role of the choice function given that the artist *chose* the shots, the content within shots, the sequence in which each shots are shown, the duration of the shots, etc. In *Zorns Lemma* Frampton even *chose* "to incorporate deliberately a series of kinds of errors."[519] Applying the Axiom of Choice to the family of sets which consists of all possible types of cinematic shots provides us with a conceptual procedure for eliminating what Frampton refers to as "*nominally* subjective, 'thumbprint' procedures"[520] – one of the broader goals of Frampton's film- and art-making.

This interpretation can also be read as the personification of an abstract concept, an idea that interested Frampton as demonstrated by his homage to Scottish physicist James Clerk Maxwell in his 1968 film *Maxwell's Demon*. Maxwell's Demon is a thought experiment in which a demon sits between

518 Allen S. Weiss, "Frampton's Lemma, Zorn's Dilemma," *October* 32 (Spring 1985), 128.
519 Gidal, "Interview with Hollis Frampton," 97.
520 Frampton,"*Zorns Lemma*," 226. [Emphasis in original.]

two chambers only allowing hot molecules to pass, causing one of the chambers to heat up and the other one to cool down. In essence, the demon acts as a molecular gatekeeper that allows the Second Law of Thermodynamics to be violated. Moreover, the Axiom of Choice has even been referred to as the “'mathematicians' Maxwell's Demon.”[521] In other words, through *Zorns Lemma,* Frampton is assuming the role of the mathematical Maxwell's Demon since he is acting as the choice function.

Frampton's unfinished film cycle *Magellan* can be seen as an attempt to use cinema to create an epistemological model of the universe, a cinematic Library of Babel, “more poignant”[522] than its text-based predecessor. To Frampton, “the infinite film contains an infinity of endless passages wherein no frame resembles any other in the slightest degree, and a further infinity of passages wherein successive frames are as nearly identical as intelligence can make them.”[523] Moreover, Frampton discusses the storage of the film, the universe transformed into images, “if we are indeed doomed to comically convergent task of dismantling the universe and fabricating from its stuff an artifice called *The Universe,* it is reasonable to suppose that such an artifact will resemble the vaults of an endless film archive built to house, in eternal cold storage, the infinite film.”[524] This eternal cold storage is, indeed, the media collection at the Library of Babel. Curator and cinema scholar Bruce Jenkins reinforces this reading in “The Red and The Green”:

> Frampton makes frequent use of such filmic quotations and aesthetic homages throughout *Magellan* – simulating a sort of high-tech retrieval system able to key up disparate fragments of visual discourse stored on the reels of the “infinite film.”[525]

With the advent of the computer and Internet, this high-tech instant retrieval system has been manifested and one could imagine the media collection at the Library of Babel existing as a database.

Frampton realized it was impossible to actually generate “the infinite cinema,” but believed he

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521 Schechter, *Handbook of Analysis and its Foundation*s, 140.
522 Gidal, “Interview with Hollis Frampton,” 98.
523 Hollis Frampton, “For a Metahistory of Film: Commonplace Notes and Hypotheses,” in *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, ed. Bruce Jenkins (Cambridge: MIT Press, 2009), 137.
524 Ibid.
525 Bruce Jenkins, “The Red and The Green,” *October* 32 (Spring 1985), 87.

could "generate a grammatically complete synopsis of it."[526] With *Magellan*, Frampton was attempting to use film to create an epistemological model of the universe through cinema. At first glance this may seem ridiculous, however, physicists often use mathematics to create epistemological models of the universe. It is through *Zorns Lemma* that Frampton provides a theoretical framework for constructing an infinite film, namely, by invoking the Axiom of Choice. It proposes the possibility of the infinite film, *The Universe*, the moving image collection at the Library of Babel, consisting of every possible film, past and present. Although Frampton didn't believe he was creating a cinematic demonstration of a mathematical principle, this interpretation demonstrates that many of the concepts being worked though in *Zorns Lemma* formed a conceptual basis for his unfinished film *Magellan*, the actual synecdoche of *The Universe*.[527]

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526 Bill Simon, "Talking about Magellan: An Interview," in *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, ed. Bruce Jenkins (Cambridge: MIT Press, 2009), 241.
527 A further connection between *Magellan* and *Zorns Lemma* can be made: The image that replaces A in the second section of Zorns Lemma is the turning of pages from "the Old French version of Antonio Pigafetta's diary of the voyage of Magellan, which figures in a future film." (Frampton, "*Zorns Lemma*," 200.)

CHAPTER NINE: ALGORITHMIC EDITING AND MEDIA ART

Ideas are not separable from an autonomous sequence or sequencing of ideas in thought that Spinoza calls *concatenatio*. This concatenation of signs unites form and material, constituting thought as a spiritual automaton.
− D.N. Rodowick, *The Virtual Life of Film*

We will see that many of the principles… [of new media] are not unique to new media, but can be found in older media technologies as well.
– Lev Manovich, *The Language of New Media*

Algorithmic art is produced by following an algorithmic process, that is, it is art produced by following *a finite list of well-defined instructions or by following a procedure*. Contemporary artists who produce algorithmic art are sometimes referred to as algorists, a term coined by Jean Pierre Hebert who also wrote an algorithm that is now often referred to as "the algorist manifesto."[528] The algorithm is as follows:

if (creation && object of art && algorithm && one's own algorithm)
{include * an algorist * }
elseif (!creation || !object of art || !algorithm || !one's own algorithm)
{exclude * not an algorist * }[529]

Although the use of computers is usually associated with algorithmic art, computers are not an essential part of the process; however, algorithms are essential to the computer's operation since they are the procedures the machine follows. For instance, computer software is merely a collection of computer programs and computer programs are simply computer algorithms that process and manipulate data.

Despite the fact that algorithms follow a step-by-step procedure, the user cannot expect the same output every time since algorithms often contain random or pseudo-random processes. Chance operations are equally important to artistic production, since they are one way to remove the artist, allowing the artwork produced to move beyond the artist's expectations. Similarly, the computer can be programmed to produce results that are unexpected, a feature that is often exploited by artists creating algorithmic art. Finally, algorithms are often designed to require input from the user in order to perform

528 Verostko, "The Algorists."
529 Ibid.

their tasks, allowing the user to maintain, at the very least, the semblance of control, providing the computer artist with a sense of authorship.

Algorithmic editing refers to any method of editing based on direct procedural approaches and can be seen as a form of algorithmic art. In other words, algorithmic editing can be seen as a technique for cutting and reassembling raw footage by following a schema or score. Here is an example of a simple, one-line algorithm that could be used to algorithmically edit a film. *Sequentially use every odd frame from one sequence of film and every even frame from another sequence of film to assemble a new film which alternates between the odd and the even frames.* The resulting algorithmically edited flicker film would rapidly alternate between the two sequences. Creating this film using two film strips would be difficult without the use of an optical printer, a device which mechanically links a film projector to a movie camera for the purposes of re-photography, and is controlled through a basic sequencer operating on both the camera and the projector. Similarly, producing this film from two video sequences would be difficult without the use of a script or a specially made plug-in.

As with most new media, *algorithmic editing* is not new and its roots can be seen in the earliest attempts to formalize/theorize the practice of cinematic editing. This chapter will explore algorithmic editing and its relationship to database cinema. It will be argued that algorithmic editing traces back to Soviet montage theory of the 1920s through 1940s, and was further developed through the work of structural filmmakers in the late 1960s and early 1970s, through the production of score-based work and through access to the optical printer, a device which allowed for the creation of slightly more complex schema through the use of a programmable sequencer. A history of algorithmic editing will be outlined, and examples of algorithmic editing will be discussed. Furthermore, some of the philosophical questions concerning the consequences of employing algorithmic editing will be explored and examined.

9.1 Simple Schema: A History of Algorithmic Editing

One of the earliest attempts to theorize algorithmic editing occurs in Vertov's 1929 essay “Kino-Eye to Radio-Eye,” where he describes one stage of editing as a “*numerical* calculation of the montage groupings.”[530] Vertov explains that editing is “the combining (addition, subtraction, multiplication, division, and factoring out) of related pieces.”[531] By describing editing in terms of mathematical process, Vertov is invoking the language of algorithms. Moreover, Vertov implies that every well-equipped editing table should contain “definite calculations, similar to systems of musical notation, as well as studies in rhythm, 'intervals,' etc.,”[532] and that it is the editor's job to “reduce this multitude of 'intervals' (the movements between shots) to a simple visual equation.”[533] To this end, Vertov often experimented with graphically charting or scoring a montage. By frame-counting and viewing the work as an equation, Vertov demonstrated his interest in algorithmic editing. In practice, by editing according to a schema, Vertov was able to create film poems by structuring the montage according to rhyming schemes similar to those found in poetry and music. As explained by film critic Carloss James Chamberlin, Vertov was

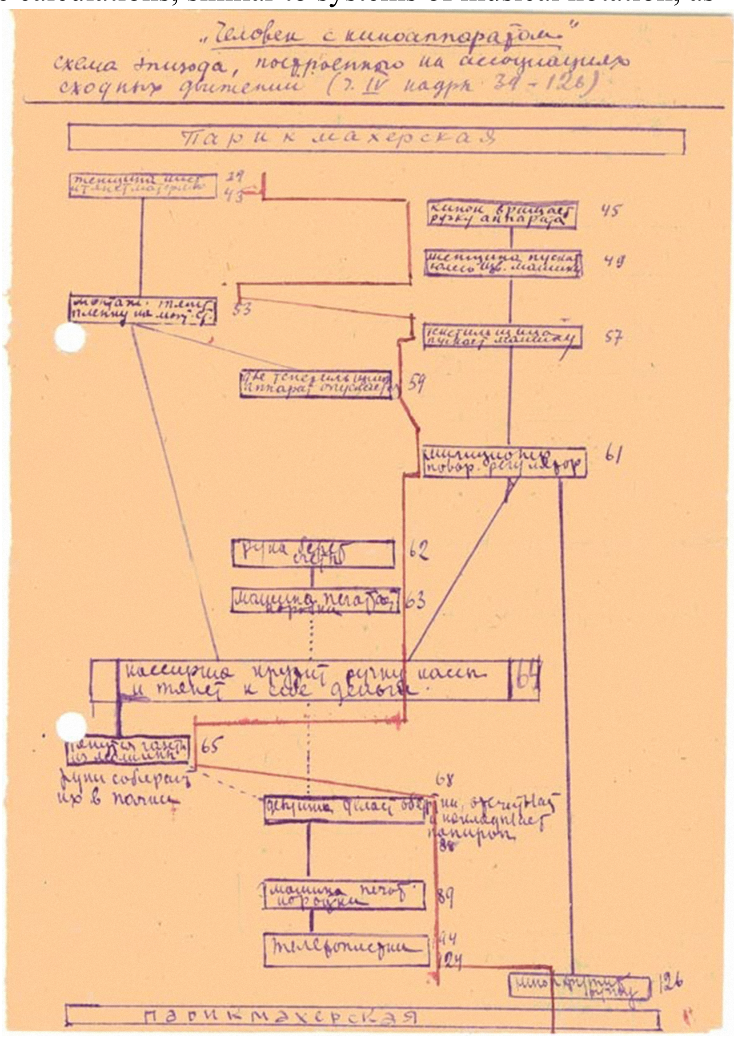

Fig. 41 – Editing chart employed by Vertov for Man With A Movie Camera (1929).

530 Vertov, “Kino-Eye to Radio-Eye,” 90.
531 Ibid.
532 Ibid., 100.
533 Ibid., 91.

primarily interested in “the gaps between the shots which, properly handled, yielded a beautiful pattern of variation – a tactility – a new sonically inspired aesthetic.”[534]

In “Methods of Montage,” a 1929 essay by Sergei Eisenstein, another early formulation of algorithmic editing is introduced. In this essay, Eisenstein proposes *metric montage* as an editing technique fundamentally concerned with “the *absolute lengths* of the pieces.”[535] The technique is created by editing sequences together according to their lengths in “a formula-scheme corresponding to a measure of music.”[536] In essence, this technique involves counting and the application of a simple procedure, or algorithm, to these frames. Eisenstein theorized that “tension is obtained by the effect of mechanical acceleration by shortening the pieces while preserving the original proportions of the formula.”[537] That is, metric montage could be used to intensify a sequence; however, if the pattern became too complex, then the use of metric montage could produce a “chaos of impressions, instead of a distinct emotional tension.”[538]

A classic example of metric montage occurs in Eisenstein's *October* (1928). A long shot of a large crowd of protesting Bolsheviks is interrupted by a series of two alternating shots, each one or two frames in length, one of a machine gun and the other of a gunner's face. Eisenstein uses metric montage to heighten the tension, and, with the use of this technique, one can almost hear the pounding of the machine guns firing. Produced the same year, Vertov's *The Eleventh Year* (1928) also made use of metric editing.[539] Eisenstein criticized the mathematical complexity of the editing used to create Vertov’s film as “so complex in the way its shots are juxtaposed that one could establish the film's structural norm only with a ‘ruler in hand', that is, not by perception but only by mechanical [metric]

534 Carloss James Chamberlin, “Dziga Vertov: The Idiot,” *Senses of Cinema* 41 (November 2006), <http://www.sensesofcinema.com/2006/feature-articles/dziga-vertov-enthusiasm/>.
535 Sergei Eisenstein, “Methods of Montage,” in *Film Form: Essays in Film Theory*, ed. and trans. Jay Leyda (New York: Harcourt, Brace & World, 1949), 72. [Emphasis added.]
536 Ibid. [Emphasis added.]
537 Ibid. [Emphasis in original.]
538 Ibid.. [Emphasis in original.]
539 Vlada Petrić, *Constructivism in Film: The Man with the Movie Camera : A Cinematic Analysis* (Cambridge: Cambridge University Press, 2012), 183.

measure."[540] Through his criticism, Eisenstein confirms Vertov's film as an early example of cinema that employs the use of algorithmic editing.

Soviet montage theory in the period between the 1920s and 1930s is instrumental for tracing the roots of algorithmically edited cinema. Eisenstein's film editing techniques have since become commonplace in filmmaking and advertising, and examples of metric and rhythmic montage are quite common.[541] In experimental film and media, visual music sometimes employs a form of metric or rhythmic editing where some of the films were constructed to match a musical score.[542] In this type of visual music, the musical score also functions as an editing score. For instance, consider Evelyn Lambart and Norman McLaren's *Begone Dull Care* (1948). In his essay "Foundations of Visual Music," art historian Brian Evans suggests that *Begone Dull Care* is an example of metric montage based on the music of the Oscar Peterson Trio, which was used on the soundtrack:

> *Begone Dull Care* is an enjoyable example of metric montage. Strips of clear celluloid were painted, scratched, textured, and processed in a variety of ways. They cut the strips into cell lengths to match with music by the Oscar Peterson Trio.[543]

Although many artists were experimenting with metric and rhythmic editing schemes after the introduction of Soviet montage theory, it wasn't until the late 1960s and early 1970s that there seemed to be a renewed interest in algorithmic editing, when artists began experimenting with other forms of schemata.

Artists began to experiment with algorithmic editing in the late 1960s due to an intellectual and aesthetic preoccupation with filmic structure by experimental filmmakers in the United States. In *Dreams of Chaos, Visions of Order*, James Peterson observes that many structural filmmakers were producing films using algorithmic editing. Peterson introduces the term "simple schematic films" to

540 Ibid., 59. [Note: This translation differs slightly from Jay Leyda's translation in *Film Form*, 73.]
541 Standard teaching examples include the shower scene in *Psycho* (Alfred Hitchcock, 1960) or the car chase scene in T*he French Connection* (William Friedkin, 1971).
542 It is worth observing that Eisenstein also employed the musical analogy of the orchestral score to describe his ideas on editing. For more see: Mollaghan, *The Visual Music Film.*
543 Brian Evans, "Foundations of a Visual Music," *Computer Music Journal* 29, no. 4 (December 1, 2005), 19–20.

describe a subset of structural films “whose global template schemata – those that structure the film as a whole – are exceedingly simple and very predominate”[544]; Peterson further describes two types of these global templates used to produce such works. The first schema, simple numerical schema, involves enumeration, whereas the second schema, simple permutational schema, involves the unordered rearrangement of an image set. It can easily be argued that employing a simple schema does not necessarily limit the scope of the work. For instance, consider Peter Greenaway's first feature-length film *The Falls* (1980), a fascinating work produced using a simple numerical schema, of lexicographical ordering. The work itself proposes systematically to examine ninety-two (fictional) people whose surnames begin with the letters “FALL-.” Despite the relatively simple structure, the stories intertwine, and the film slowly reveals the idiosyncratic nature of the bureaucracy that produced the directory entries upon which the film is based.

Peter Kubelka's *Arnulf Rainer* (1960) is an elegant, algorithmically edited film that is completely determined by its editing schema. To produce *Arnulf Rainer*, Kubelka used an editing chart to create a film consisting solely of black and white frames. Kubelka's film reduces cinema to its logical extremes: black and white frames, silence and noise. Originally, the film was commissioned by the Austrian painter Arnulf Rainer to document his practice.[545] When Kubelka was unsatisfied with the footage he shot of Rainer, he made the ultimate homage – a film that would “survive the whole of film history because it is repeatable by anyone.”[546] Kubelka even proclaimed he would commit the script to stone so that the film would “last 20,000 years, if it is not destroyed.”[547] Of course, Kubelka wasn't the only one who produced flicker films based on scores during this period; other notable examples include

544 Peterson, *Dreams of Chaos, Visions of Order*, 93.
545 Sitney, *Visionary Film*, 288-9. “Arnulf Rainer, a Viennese painter and close friend of the film-maker, commissioned a portrait of himself and his work. In the course of making it, Kubelka became interested first in a film of pure colors, then one in black- and-white, sound and silence, alterations. He titled it as a dedication, and perhaps as an apology for not completing the commission for which he was paid.”
546 Peter Kubelka, “The Theory of Metrical Film,” in *The Avant-Garde Film: A Reader of Theory and Criticism*, ed. P. Adams Sitney (New York: New York University Press, 1978), 159. Later, Kubelka made another film about Arnulf Rainer titled *Pause!* (1977), a film in which Rainer performs his body art.
547 Ibid.

Tony Conrad and Paul Sharits. As observed by art critic William S. Smith, “the 1960s were something of a golden age for flicker film.”[548]

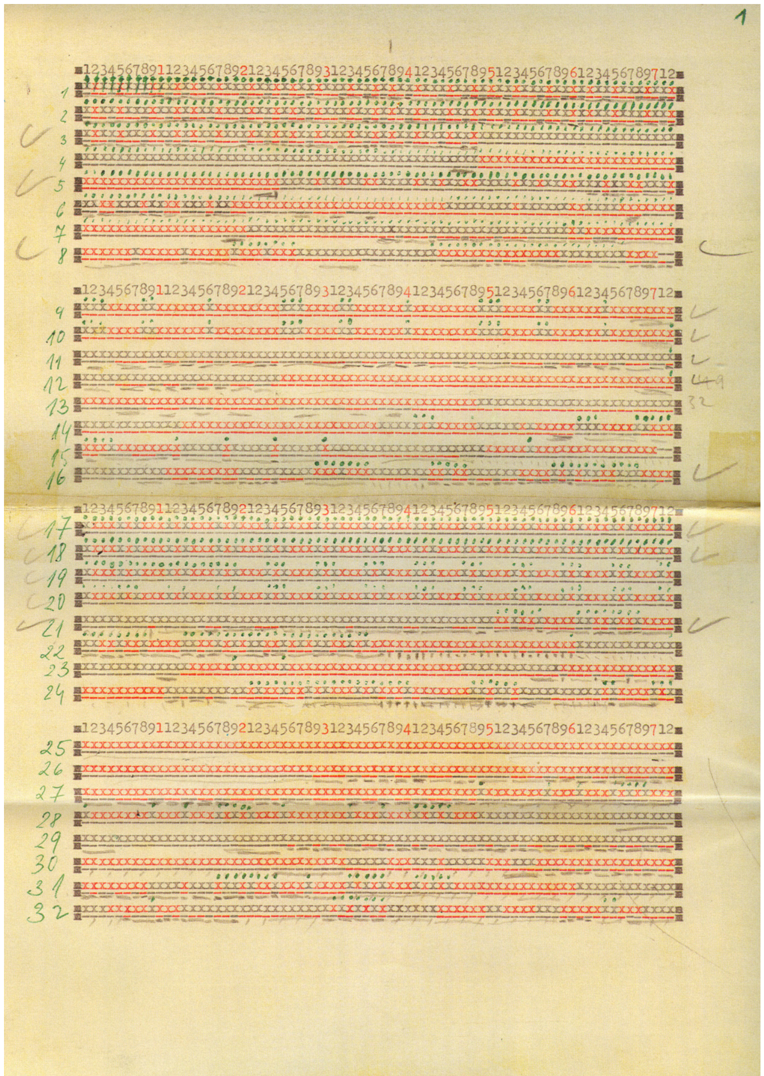

Fig. 42 – Score for Arnulf Rainer.

Kubelka also made an antisymmetrical version of *Arnulf Rainer* in 2012, titled *Antiphon* (2012). In *Antiphon* all the black frames of *Arnulf Rainer* become white, all the white frames become black, all the noise becomes silence, and all the silence becomes noise. Film critic Stefan Grissemann describes the title:

> “Antiphon” is a term used in church music to signify the response, the counter-chant, in a choral piece. It's an appropriate title for a film that will mirror an older one, and it ties in nicely with Kubelka's idea of

548 William S. Smith, “A Concrete Experience of Nothing: Paul Sharits’ Flicker Films,” *RES: Anthropology and Aesthetics* 55/56 (Spring - Autumn 2009), 280.

cinema as an alternative form of liturgy.[549]

The chant and counter-chant nature, or the antisymmetrical nature of the *Antiphon*, is reinforced if *Arnulf Rainer* and *Antiphon* are played superimposed, as in one of the versions of Kubelka's *Monument Film* (2012). Conceptually, the result would be pure projector light and sound for the duration of the films; however, in reality, there will also be slight variations between the two 35mm projectors, leading to deviations from the conceptual model which, as Kubelka suggests, "articulate[s] the materiality of classic cinema."[550]

Kurt Kren's *6/64: Mama und Papa* (1964) is another film edited algorithmically by using a simple numerical schema. Filmmaker Peter Tscherkassky provides a wonderful anecdote about the editing of this film:

> In 1964, Wien Film Laboratories refused to print *6/64: Mama und Papa*. When Kurt Kren submitted the original, the film grader said with an undertone of sympathy that, given the number of cuts, one would not be able to make out anything anyway. His worries were groundless; when Kren came to pick up the print, some technicians with flushed faces left the projection room, telling him to get out and never to come back again.[551]

One can observe that the film was cut by hand, since the splice lines are visible, adding a violent vibrating line to the foreground against the backdrop of Otto Müehl throwing blood and urine on another performing artist. The violent and systematic cutting of the film elegantly blends two of the ideas that were predominant in the Austrian experimental art scene at that time: Viennese Actionism, an art movement that replaced the canvas with the human body, and systematic art, made by employing

549 Stefan Grissemann, "Frame by Frame: Peter Kubelka," *Film Comment* (October 2012) <https://www.filmcomment.com/article/peter-kubelka-frame-by-frame-antiphon-adebar-arnulf-rainer/>.

550 There are two versions of *Monument Film*, one in which *Arnulf Rainer* and *Antiphon* are superimposed and another in which played simultaneously side-by-side. Kubelka explains: "*Monument Film* appears in TWO forms:
I) analogue projection in a dark and silent space of:
1) *Arnulf Rainer* 2) *Antiphon* 3) *Arnulf Rainer* and *Antiphon* projected at the same time, side by side. The appearance is continuous light alternating in space between two projectors and continuous sound alternating between two speakers. 4) *Arnulf Rainer* and *Antiphon* projected at the same time on one screen by two projectors with two speakers. The appearance theoretically is a continuous projection of WHITE light and continuous sound. But there is a slight alternation between the two machines, articulating the materiality of classic cinema.
II) installation in a bright rectangular space defined by three white walls. The films are cut, each, in 128 strips of equal length, which hang on nails and are arranged in a rectangular, metric form." Peter Kubelka, artist statement for *Monument Film*.

551 Peter Tscherkassky, "Lord of the Frames: Kurt Kren," trans. Elizabeth Frank-GroBebne, *Millennium Film Journal* 35/36 (Fall 2000), 147.

mathematical structures and rigour.

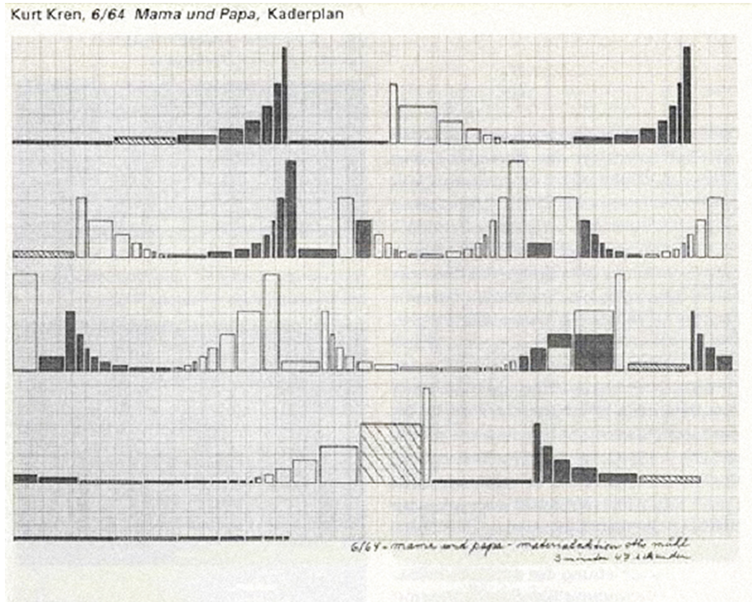

Fig. 43 – Editing chart for 6/64: Mama und Papa.

As argued by John Powers, “during the 1970s and 1980s avant-garde filmmakers mastered a device traditionally used for Hollywood special effects: the optical printer.”[552] Increased artist access to the optical printer was another key component in the development of algorithmic editing. One of the printer's strengths is the sequencer, a programmable mechanism that controls the communication between the camera and the projector, transforming the printer into a compositional device that can be programmed to perform complex algorithms. In fact, using the optical printer as a compositional device can be seen as the filmic predecessor of the computer.

Experimental filmmaker Standish Lawder saw his homemade printer, which was equipped with a sequencer, as “a little slow motion computer.”[553] Lawder appeared on Robert Gardner's *Screening Room* in 1973 to discuss his newly constructed optical printer with Gardner and Stanley Cavell. Powers observes:

> Lawder was fascinated by the printer's ability to carry out computer-like applications [...] Lawder's language in the *Screening Room* segment, which invokes computers, predetermined filmic algorithms,

552 John Powers, “A DIY Come-On: A History of Optical Printing in Avant-Garde Cinema,” *Cinema Journal* 57, no. 4 (Summer 2018), 71.
553 Standish Lawder on Robert Gardner's *Screening Room* in 1973.

and medium specificity, suggests that his appreciation for optical printing was linked to ideas associated with Structural film, the reigning formal paradigm of the era.[554]

In this way, the optical printer can be seen as a predecessor to the computer as a device used to create algorithmically edited moving images. Although Lawder's handmade printer was “a one-of-a-kind machine, too gigantic, complex, and unwieldy to be mass produced, even on a small scale,” the introduction of the JK optical printer in 1971-72 made optical printing available to artist-run co-ops, colleges and arts institutions, many of which came complete with a programmable sequencer that allowed the user to control exposure time and to step-count between the camera and projector.[555]

A film that could not have been made without using the optical printer, and one which demonstrates how the printer allowed artists to execute more complicated schemata, is Dana Plays' *Grain Graphics* (1978). Edgar Daniels describes the film as follows:

> Another entirely structural film is *Grain Graphic*s, which begins with two frames of a film strip, one above the other, occupying the middle of the screen, flanked by two vertical filmstrips with smaller frames. In grainy negative, a small number of figures interact in various ways in each of the frames. Gradually, as if the camera were drawing away, this pattern grows smaller and its units increase correspondingly in number, until at the end there appear to be hundreds of rectangles, all with figures busy in motion.[556]

The construction of the growing pattern of moving images within the film follows a relatively simple schema. In theory, the first iteration consists of two larger moving images stacked in the centre of the screen and three smaller images on each side, totalling eight different moving images on the screen at once. In the next iteration, this same pattern is repeated four times to fill the screen, producing $32 \cdot (4 \cdot 8)$ different moving images on the screen at once (or $8 \cdot (4 \cdot 2)$ large ones and $24 \cdot (4 \cdot 6)$ smaller ones). In the next iteration, the previous iteration is repeated four times, producing $128 \cdot (4 \cdot 32)$ moving images on the screen (or $32 \cdot (4 \cdot 8)$ large ones and $96 \cdot (4 \cdot 24)$ smaller ones). This pattern could be repeated indefinitely: at the n^{th} iteration there would be $4^{n-1} \cdot 8$ different moving images on the screen (or $4^{n-1} \cdot 2$ larger ones and

554 Powers, “A DIY Come-On,” 84–5.
555 Ibid., 87. The JK optical printer was invented by Jaakko Kurhi. In “A DIY Come-On,” Powers provides a comprehensive history of the JK printer.
556 This is the description from the Canyon Cinema Catalog.

$4^{n-1} \cdot 6$ smaller ones).[557] The previous iterations are used in the printing of the next iteration using the optical printer, demonstrating how it is possible to use the printer to generate more increasingly complex images through previously constructed material. Moreover, this film is an example of an iterative fractal, a concept discussed in Chapter Six.

In practice, Plays' moving images do not totally fill the screen, since the optical printing is not perfect, with many of the images overlapping in the final sections of the film. This can be seen as a flaw; however, in between each section, Plays optically zooms into the image revealing the image's own imperfections – that the image is not continuously constructed, but made of film grain. Through the imperfect printing, the images interact with each other in a more organic and less mechanical way, seemingly bringing the images created to life. In a final self-reflexive maneuver, Plays uses her complex optically printed moving images as the underlying basis for one of the moving images that constructed it. Through this gesture she is further commenting on the organic nature of her optically print moving images by suggesting their similarity to film grain.

Fig. 44 – Still from Grain Graphics.

Hollis Frampton's *Critical Mass* (1970) is another film that could not have been made on film

557 It is worth observing $(4^{n-1} \cdot 2) + (4^{n-1} \cdot 6) = 4^{n-1} \cdot (2 + 6) = 4^{n-1} \cdot 8$.

without the aid of the optical printer. The repetition of the images of the film, which Frampton describes as "going two steps forward and only one back," can easily be programmed using an optical printer while the sound manipulation must be done separately, leading to the asynchronous nature of the work. Frampton describes the structure and some of the process involved in the creation of the film:

> The whole film, of course, was shot as two long takes; the original material is two 100-foot rolls. The sound was continuous; the Nagra was simply left on and that's why you hear the squeals of the slate. Except for that very brief opening passage in which it starts out in sync and immediately disintegrates, it's divided very roughly into fourths, with the passage in the dark forcing two pairs apart. At first, they match, and then in the dark, where there is only sound, each segment of sound, instead of going two steps forward and only one back, is simply repeated exactly three times. When the imagery reappears, the temporal overlap resumes, but the unit of sound cutting is slightly larger. Typically it's about six frames (or a quarter of a second) larger than the image unit, which means that once every four seconds they will coincide exactly.[558]

Melissa Ragona, in "Hidden Noise," provides one reading of this asynchronicity:

> While in the first section of the film, relationships between the speaking subjects and language remain somewhat intact, by the end of the film gendered as well as syntactical arrangements of speaking dissolve: the female speaker's voice seems to come from the male speaker (and vice versa) and often, especially during the sections where the image goes to black, their voices merge into a glossolalia of phonemic utterances.[559]

Although it is possible to theorize about the lack of sync in the film,[560] it also must be observed that Frampton didn't have much choice, since syncing the film "by hand" would have been incredibly laborious.[561] In other words, given that the sound and images were necessarily manipulated separately and the film was synced by hand, totally syncing the film would have been beyond arduous. By contrast, if this work had been manipulated on video or on a computer, it would have been relatively easy to maintain sync.

558 MacDonald, *A Critical Cinema*, 65.
559 Ragona, "Hidden Noise," 110.
560 Frampton was no stranger to non-synchronization. For instance, *(nostalgia)* (1971) directly confronts this issue. Moreover, Frampton quotes the following line from Eisenstein in defence his film: "THE FIRST EXPERIMENTAL WORK WITH SOUND MUST BE DIRECTED ALONG THE LINE OF ITS DISTINCT NON-SYNCHRONIZATION WITH THE VISUAL IMAGES." [Hollis Frampton "Letter to the Editor, *Artforum,*" in *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, ed. Bruce Jenkins (Cambridge: MIT Press, 2009), 163. [Capitalized form in original.]
561 MacDonald, *A Critical Cinema*, 65–6. Frampton states, "They [the sound and image] rotate in and out of sync with each other until finally, they lose sync entirely and are out of step first by one repetition of the word "bullshit" and then by two repetitions of the word "bullshit," which happens to be a particularly easy word to sync on, if you're syncing by hand, which I was. The head-end slate was lost, and in any case, everything had to be laid in by hand."

By 1977, the Digital Arts Lab – a graduate level workshop at State University of New York at Buffalo initiated by Frampton, and Woody and Steina Vasulka – was experimenting with writing their own computer software. One of the computer programs that the students were working on was called OPOS (Optical Printing Operating System), a program which "emulates a film technician."[562] Given its name, it is possible to speculate that this either allowed the computer to act as programmable sequencer for an optical printer, potentially allowing the user the ability to perform more complex operations than allowed by a standard sequencer, or that this was a program that digitally emulated the "effects" of the optical printer. Given the programmable nature of the printer this initiative seems quite natural, and contemporary computer software like After Effects often replicates or emulates optical printer effects.

The avant-garde has always been ahead of its time; therefore, in order to understand the present condition, it is often beneficial to understand the avant-garde of the past. Currently, we are at the point where computer users have the ability to retrieve multimedia information from enormous, well-indexed databases. One of the ways to access these databases is through algorithmic editing. By establishing the origins of algorithmic editing, it is possible to better understand its contemporary aesthetic and socio-cultural aspirations.

9.2 Complex Schema: The Future of Algorithmic Editing

As argued, the roots of algorithmic editing can be found in Soviet montage theory and were further developed through artists' experimentation with schema in the late 1960s and early 1970s. With the introduction of the computer, artists are able to create more complex editing schema than those of their predecessors, including filmmakers discussed above like Eisenstein, Vertov, Sharits, Kubelka, Iimura and Kren. Algorithmic editing with the use of a computer is fairly new. Below, I will explore its use in database cinema and discuss some of its characteristics. Moreover, I will explore some of the philosophical questions and concerns that arise through the use of algorithmic editing.

562 Hollis Frampton, "About the Digital Arts Lab," in *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, ed. Bruce Jenkins (Cambridge: MIT Press, 2009), 274.

Database cinema, as introduced by Lev Manovich in *The Language of New Media*, is a new media form that takes advantage of the computer's ability to manipulate, analyze, organize and arrange multimedia data. Being less than efficient, traditional video editing software is not the ideal platform for producing database cinema. Despite the fact that video editing software systems allow for direct access to any frame without requiring the sequential navigation through adjacent footage, they are still heavily rooted in a film-based editing paradigm. Database cinema borrows one of its key concepts from computer science; namely, it explores how the computer accesses its database, that is, through algorithms. Many artists are already learning from and exploiting the computer's relationship to the database through the technique of algorithmic editing.

In *The Language of New Media*, Manovich asks, "how can our new abilities to store vast amounts of data, to automatically classify, index, link, search and instantly retrieve it lead to new kinds of narratives?"[563] In order to answer this question, I propose an intermediate step – a method for converting the database structure into a narrative structure. As Manovich has suggested, "once digitized, the data has to be cleaned up, organized, and indexed. The computer age brought with it a new cultural algorithm: reality → media → data → database."[564] By developing Manovich's cultural algorithm further, I suggest expanding this diagram to: reality → media → data → database → algorithmic editing → new forms of narrative. To Manovich, cinema "is the intersection between database and narrative,"[565] therefore, the expansion of the database must lead to more innovative and complex narratives.

As early as 1974, Malcolm Le Grice noted that computers "are ideally suited to dealing with complex relationships of data precisely and very rapidly, and they are being developed towards highly efficient indexing and retrieval capability."[566] In fact, this trend has continued and is precisely the

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563 Lev Manovich, *The Language of New Media* (Cambridge: MIT Press, 2001), 237.
564 Ibid., 224.
565 Ibid., 237.
566 Malcolm Le Grice, *Experimental Cinema in the Digital Age* (London: BFI, 2001), 220.

reason computers are ideal for creating database cinema. Currently, computer users have the ability to retrieve multimedia information from enormous, well-indexed databases. In *Experimental Cinema in the Digital Age,* Le Grice conjectures that the three most important functions performed by the computer in relation to cinema are "systems of incrementation, permutation and random number generation."[567] To this I would add the computer's ability to access large amounts of data, its ability to manipulate and analyze data, and its ability to efficiently copy and paste. Unfortunately, efficiency doesn't guarantee something is cinematic. This brings us to a question raised by Barbara Lattanzi which doubles as the title to one of her essays, namely, "what is so cinematic about software?"[568]

Lattanzi is a new media artist who develops her own original, open-source software to algorithmically edit films from a database.[569] Lattanzi uses software consisting of "simple, dynamically-modifiable algorithms" to encode and emulate editing techniques of seminal avant-garde films.[570] Her software, *AMG Strain* (2002), *HF Critical Mass* (2002) and *EG Serene* (2002), emulates the editing schema of Anne McGuire's *Strain Andromeda The* (1992), Hollis Frampton's *Critical Mass* (1971) and Ernie Gehr's *Serene Velocity* (1970), respectively. By referencing other work, Lattanzi observes that "the simulation of film structure in a software algorithm – where the software becomes **referential** to a specific film experience – *paradoxically registers a narrative in the algorithm,* a narrative with concrete reference within an abstraction."[571] I would argue that reference to another film's structure is not enough to produce narrative, although it is enough to enter a cultural dialogue with the original artist's work. Equally as important are the clips the software is referring to, namely, it is the database the artist is engaging with that plays a key role in contributing to the narrative or content

567 Ibid.
568 Barbara Lattanzi, "What Is So Cinematic About Software?" (presented at *Connectivity* at Connecticut College, Ammerman Center, 10th Biennial Symposium on Arts and Technology on March 31 & April 1, 2006).
569 Lattanzi did her graduate studies at State University of New York at Buffalo and was actively involved in the Digital Arts Lab.
570 Ibid.
571 Barbara Lattanzi,"Critical Mass, the Software," (presented at *Gloria! The Legacy of Hollis Frampton* at Princeton University, Visual Arts Program on November 5 & 6, 2004). [Emphasis in original.]

of the film. In other words, as Lattanzi observes, the "software is not narrativising in itself." She continues, "Software is not about something. Software *performs* something."[572] In the case of Lattanzi's software, it performs something to a specific video clip from a database of video clips, and the choice of the clip is significant. For instance, *Critical Mass*, *Serene Velocity* and *Strain Andromeda The* are considered works of cultural significance precisely because the artists carefully considered the content to which they applied their editing schema. The editing schema in and of itself was not enough.

As previously argued, algorithmic editing has been used at least since the 1920s; however, the term *algorithmic editing* was first coined by Lev Manovich in an artist statement for *Soft Cinema* (2002), a collaborative project with Andreas Kratky that attempts to navigate the database in new and innovative ways. In his artist statement, Manovich theorizes about algorithmic editing without providing a precise definition.[573] Although the work seeks to explicitly make use of algorithmic editing, it ultimately fails due to the seemingly arbitrary nature of the editing. Although the clips are associated through keywords that account for their content and formal properties, it is impossible for the viewer to decipher the underlying logic being employed, thus making the clip selection appear arbitrary. However, experimenting with database cinema allows Manovich to theorize about one of the potential benefits of algorithmic editing:

> Different systems of rules are possible. For instance, one system selects clips closest in colour, or type of motion to a previous one; another matches the previous clip in content and partially in colour, replacing only every other clip to create a kind of parallel montage sequence, and on and on.[574]

In this description, Manovich alludes to the computer's ability to analyze specific properties in each of the clips in a database. In other words, a computer can analyze each of the clips in a database looking

572 Ibid. [Emphasis in original.]
573 Lev Manovich, *Soft Cinema* (Karlsruhe: TKM, 2002), 5. "*Soft Cinema* is based on four ideas: The first is the algorithmic editing of media materials. Each video clip used in *Soft Cinema* is assigned certain keywords that describe both the "content" of a clip (geographical location, presence of people in the scene, etc.), and its "formal" properties (i.e., dominant color, dominant line orientation, contrast, camera movement). Some of the keywords are automatically generated by an image-processing software (written in VideoScript), while others are input by hand. The program (written in LINGO) assembles the video track by selecting clips one after another using a system of rules (i.e. an algorithm)."
574 Manovich, *Soft Cinema*, 5.

for specific types of motion, sound, colour, etc., and this information can be used to re-edit the clips.

One example of an algorithmically edited work that takes advantage of the computer's ability to analyze and sort data is artist Cory Arcangel's *Drei Klavierstücke op. 11* (2009). In the piece, Arcangel analyzes sounds found in various YouTube clips and edits the appropriate clips together according to the schema of a musical score. To be specific, Arcangel humorously composes Arnold Schoenberg's 1909 *Op. 11 Drei Klavierstücke* using various YouTube videos of cats playing piano. *Op. 11 Drei Klavierstücke* is generally considered the first piece of atonal music – a form of music that does not conform to any particular key signature. Despite the technical knowledge required to both perform and compose atonal works, to the unsophisticated listener, atonal works sound like a cat playing the piano, an act that is undeniably cute and hence requires recording and uploading to YouTube. Ironically, the act of creating an atonal work from videos of cats playing the piano is a fairly sophisticated process which Arcangel informally describes on his website as follows:

> So, I probably made this video the most backwards and bone headed way possible, but I am a hacker in the traditional definition of someone who glues together ugly code and not a programmer. For this project, I used some programs to help me save time in finding the right cats. Anyway, first I downloaded every video of a cat playing piano I could find on YouTube. I ended up with about 170 videos. Then I extracted the audio from each, pasted these files end to end, and then pasted this huge file onto the end of an audio file of Glenn Gould playing *Op. 11*. I loaded this file into Comparisonics. Comparisonics, a strange free program I found while surfing one night, allows users to highlight a section of audio, and responds by finding "similar" sounding areas in the rest of the audio file. Using Comparisonics I went through every "note" (sometimes I also did clusters of notes) in the Gould. I then selected my favourite "similar" section Comparisonics suggested and wrote it in the score. After going through the 1000's of "notes," the completed scores were turned into a video by some PERL scripts I wrote which are available here[575] if you wanna do something similar.[576]

Arcangel has since improved this technique for another video, *Paganini's 5th Caprice* (2011), composed from hundreds of different guitar instructional videos found on YouTube. By re-using his code, Arcangel is demonstrating that, although both videos make use of the same structure, it is possible to make very different types of work simply by choosing different content. Moreover,

575 <http://www.coryarcangel.com/wp-content/uploads/2010/07/Gould_Pro_v.01_PreAlpha.zip>.
576 Cory, Arcangel. "*Drei Klavierstücke Op. 11* (2009)," *Cory Arcangel's Internet Portfolio Website and Portal* (2009), <http://www.coryarcangel.com/things-i-made/dreiklavierstucke/>.

Arcangel makes his techniques available, allowing others to experiment with them.

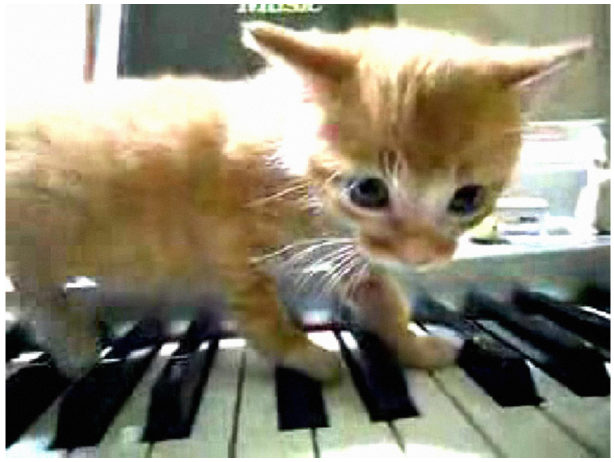

Fig. 45 – Still from Drei Klavierstücke op. 11.

Another work that makes use of algorithmic editing is Doug Goodwin's *Mersenne Devil Twister* (2011), a simple video sketch that edits together four to twelve frame sequences selected randomly from a clip, in a process Goodwin describes as "desequencing."[577] By writing code to algorithmically edit a video segment, in this case a clip from Peter Yates' *Bullitt* (1968), Goodwin produces a segment whose movement is jarring and unusual yet strangely mesmerizing and beautiful. The title itself refers to Nic Collins's album *Devil's Music* (1985), which was created using a similar technique applied to sound clips; and the Mersenne twister, an algorithm for generating pseudo-random numbers. In using this title, Goodwin reveals both a mathematical influence and the process involved in the making of the video. Finally, Goodwin has also made the code available on his website, thereby encouraging others to further develop this technique.[578]

Knowledge sharing is an important part of glitch and open-source culture. As observed by Tom McCormick, "glitchers seem eager to share their strategies. Part of this probably has to do with the fact that many new media artists are code junkies who come directly out of the open source movement; but then the open source movement may have equal roots in functional programming and media art."[579]

577 Doug Goodwin, "mersenne video twister," *cairndesign: since 1996* (March 4, 2011), <http://cairn.com/wp/2011/03/04/mersenne-video-twister/>.
578 <http://cairn.com/wp/2011/03/04/mersenne-video-twister/>.
579 Tom McCormack, "Code Eroded: At GLI.TC/H 2010, RHIZOME, Oct. 2010," in *GLI.TC/H READER[ROR] 20111*,

This sentiment is reinforced by Arcangel and Goodwin's eagerness to share their processes and Lattanzi's strictly open-source policies. Conceptually, this act carries with it all of the political motivations of the open-source movement; however, it also reveals the importance of content since everyone potentially has access to the same processes and techniques. Open source as a pragmatic methodology is also inherently and directly opposed to commercial or proprietary software practices, as it promotes cooperation, collaboration and community by removing profit incentives.

Through code reusability, the database takes on a new and heightened value since the content of an artwork is at least partially dependent on which database the artists choose. Database cinema is planted firmly in the continuum of found footage filmmaking. While there are many positive aspects to this – for instance, as Michael Zryd suggests in his article "Found Footage as Discursive Metahistory," "the etymology of the phrase [found footage] suggests its devotion to uncovering 'hidden meanings' in film material"[580] – it also raises questions about copyright/ownership of the sources being employed. Many artists blatantly ignore copyright issues. For instance, it can be assumed that Arcangel did not ask individual users for permission to borrow their YouTube clips (though he does acknowledge his source videos, transforming the original authors into unknowing collaborators).

As observed by Amos Vogel in *Film as a Subversive Art*, the "avant-garde offers no solutions or programmatic statements, but a series of intricate challenges, hints, and coded messages, subverting both form and content."[581] Expanding on this, the avant-garde now offers programmatic statements in the form of code and algorithmic editing, one of the ways in which artists challenge and subvert both form and content. Moreover, by directly engaging with algorithmic editing, artists are revealing an editing form that is often used invisibly in different forms of media. Through directly engaging with algorithmic editing many artists are attempting to better understand a technology that is directly

ed. Nick Briz et al. (Chicago: Unsorted Books, 2011), 16.
580 Michael Zryd, "Found Footage Film as Discursive Metahistory: Craig Baldwin's Tribulation 99," *The Moving Image* 3, no. 2 (November 6, 2003),41.
581 Amos Vogel, *Film as a Subversive Art* (New York: Distributed Art Publishers, 2005), 308.

impacting most people's lives.

Despite rendering some of the underlying algorithms invisible, interfaces often help us to better engage with the computer and do not, as glitch theorist and artist Rosa Menkman argues, necessarily restrict creativity.[582] It is not necessary for artists to directly engage with algorithms to produce quality work. Although there is a hint of truth in the idea that only using commercial software can be restrictive, it is ultimately what is created that is at stake. Computer editing software, like the optical printer, is a powerful tool that in the hands of a creative artist can be used to generate new and engaging work. It would be ridiculous to argue that the interface imposed by the optical printer or the Bolex restricts creativity, and it is equally ridiculous to argue that digital interfaces restrict creativity.

With that being said, through writing code and developing video editing tools artists are able to critique industrial modes of filmmaking, both in terms of the tools they employ and in terms of content they are generating. Most commercial video editing software attempts to hide the algorithms it employs, and is unmodifiable. As Barbara Lattanzi states in an interview with artist Keiko Sei,

> I would rather make my own software (what I term idiomorphic software), because the commercial software that I use comes at a price. That price has less to do with money and more to do with a different process of abstraction: the active framing of my work within considerations dictated by irrelevant practices of Design. I make clear with students that I am not interested in their Design clarity and precision, but in their discovering productive ambiguities.[583]

In this statement, Lattanzi points out the role that errors and mistakes play in the artistic process, something commercial software tries to eliminate. This implies that, in spite of embracing a systematic approach to film, some algorithmic artists are also embracing errors and imperfection. This simple act can be seen as subversive in a society where consumer desire thrives on the concepts of "new and improved" and planned obsolescence. In fact, this is one of consumer myths that late capitalism is based upon, namely, the myth that newer is better.

582 For instance in "The Glitch Studies Manifesto," Menkman declares: "Dispute the operating templates of creative practice. Fight genres, interfaces and expectations!" [Rosa Menkman, *The Glitch Moment(Um)* (Netherlands: Institute of Network Cultures, 2011), 11].
583 Keiko Sei, "Productive Unclarities: Interview with Media Artist Barbara Lattanzi," *Springerin Magazine*, no. 4 (December 2001) <https://www.springerin.at/en/2001/4/produktive-unklarheiten/>.

The errors and mistakes offered through writing your own software often produce unexpected results. These glitches sometimes take the form of novel visuals and act to re-mystify the work since the producer will not, at least initially, totally comprehend them. Those exploring algorithmic editing will often incorporate chance procedures into their work in order to induce unexpected forms. In this way, despite writing a precise, mathematical procedure in the form of an algorithm, the artworks maintain unexpected elements.

Algorithmic editing as an approach to the digital database is constantly being used in invisible ways in many forms of media. For instance, it is the current template for many television news channels. News stations bombard the screen with information obtained from different database sources. Current world news, in the form of text, runs across the bottom of the screen, in addition to information about the weather, time and the stock market. It can be assumed that the station is accessing this information from various databases and that the station does not research all of the stories they are broadcasting despite presenting these stories as news. Furthermore, many news stations are potentially accessing the same databases; thus, the news being provided potentially represents one single perspective.

Fig. 46 – News broadcast employing algorithmic editing.

Algorithmic editing techniques are also being applied to Internet search engines in an attempt to provide user-specific content. In *The Filter Bubble,* Eli Pariser develops and explores the controversial concept of his book's title. This concept addresses some of the negative effects of generating user-specific content based on our past viewing behaviours. Through the filtering of information, usually determined by capitalist interests, Pariser is suggesting a bubble is formed around individual users that inhibits intellectual growth by not exposing the user to ideas conflicting with their own ideology, and by not necessarily providing the user with the most accurate information.

By experimenting with algorithmic editing, artists are investigating a concept that is informing and framing the culture in which they live. Through this exploration, artists are able to provide insight into these processes, and, at the very least, are able to reveal and demystify them. By understanding algorithmic editing, the artist is able to provide social and cultural critique. As noted by Barbara Lattanzi,

> The Cultural Producer who samples from the raging flows of media detritus – endless satellite feeds, cable and broadcast transmissions, and the sedimentary layers of these through the past 25-50 years – becomes the heroic Luther, wresting deconstructive (re)form(ations)s out of the desultory, formless industrial wasteland. Deconstructive film- and video-making demonstrate the inherent formlessness of mass media by making it into the "New Nature."[584]

Currently, artists have a seemingly endless supply of material to work with, waiting to be culled from countless, large digital databases. To Lattanzi, this is the inherently formless media detritus that artists are able to reform, deform, reconstruct and deconstruct to make new work, transforming the old media landfill into a new media landscape. Expanding on this, it is not only the database that artists are deconstructing; it is also the techniques used to access the database. By technically understanding algorithmic editing, artists can re-invent and subvert the role that algorithms play in traditional applications.

9.3 The Algorithmic Editing Manifesto

I have written an algorithmic editing manifesto in the same spirit as Jean Pierre Hebert's algorist's

584 Barbara Lattanzi, "We Are All Projectionists," *Millennium Film Journal* 39/40 (Winter 2003), 84.

manifesto also in the form of an algorithm. Here it is in pseudo-code:

```
while (u !=understand) do

{

        read{
                (i) no gui
                        script editing only
                (ii) open source code
                        embedded coding || externally
                (iii) reuse & rework
                        u'r own code & others code

                (iv) encode the avant-garde
                        algorithmitize previous schema
                (v) credit title || code || externally
                        u'rself & others
        }
}
```

In plain language:

While you do not understand, read and re-read the following:

1. No graphical user interface, use only script based editing.[585]

2. Embrace an open-source philosophy. Share your code either in the work itself or make the code available externally.

3. Borrow code from others and continue to rework your own code. This is the benefit of embracing an open-source philosophy, that is, you are able to modify the code of others.

4. There are many interesting algorithmic editing techniques used by filmmakers in the past. Encoding their techniques not only enables you to use their techniques, it also allows you to engage in a cultural dialogue with that filmmaker and it revitalizes their work, in essence further preserving it and its cultural significance.

5. Credit your work and cite your references either in the title of the work, in the code used or externally. This contributes to a positive community attitude and reinforces points 2-4.

585 This is intended to be read as a joke (or potentially as polemical). That is, this criteria is *extremely idealistic* since it is quite difficult to move beyond GUIs, but not impossible; however, this criteria is also not necessary to produce algorithmically edited work.

CHAPTER TEN: CONCLUSION

A proof which offers a probability of truth – and not certainty – is an oxymoron.
– John Horgan "The Death of Proof," *Scientific American* 269 (1993)

The moving image is no evidence.
– Paolo Cherchi Usai, *The Death of Cinema*

In this chapter, I will explore a contemporary parallel in cinema studies and mathematics, namely, the foundational crisis seemingly caused in both disciplines due to the introduction of the computer. The digital proof and the digital image challenged many mathematicians and film scholars' conceptions about their respective fields of study. It will be argued that the digital crises plaguing some mathematicians and media scholars are quite similar and there is much to be learned from their comparison. For instance, just as some media scholars feared the death of cinema with the introduction of digital cinema, some mathematicians feared the death of the proof with the introduction of the digital proof. Moreover, just as many media artists began to use hybrid forms, many mathematicians began to use the computer as a tool for experimentation and as a way to test ideas. These and other similarities will be explored in the first section of this chapter. In the final section of the chapter, I will explore the limitations of this dissertation.

10.1 The Digital Crisis: Digitally Generated Knowledge

The first proof performed by a computer was for the Four Colour Theorem, which states that any map can be coloured using no more than four colours such that no two adjacent regions, regions that share a border, have the same colour. The Four Colour Theorem was first introduced in 1850 by mathematician Francis Guthrie, and proved in 1976 by mathematicians Kenneth Appel and Wolfgang Haken using an exhaustive proof which took a computer approximately 1,200 hours of computation time and which generated heated debate among mathematicians.[586] Some mathematicians didn't trust the proof due to

586 For instance, see Thomas Tymoczko, "The Four-Color Problem and Its Philosophical Significance," *The Journal of Philosophy* 76, no. 2 (1979): 57–83 or E. R. Swart, "The Philosophical Implications of the Four-Color Problem," *The American Mathematical Monthly* 87, no. 9 (November 1980): 697–707. For a nice historical overview of the Four Colour Theorem see Andreea Calude, "The Journey of the Four Colour Theorem Through Time," *The New Zealand Mathematics*

the fact that a computer may be prone to errors, while others were opposed to the proof for aesthetic reasons, uninterested in a proof performed by a computer, especially the use of brute force on a problem as simple and elegant as the Four Colour Theorem. In contrast, there exist mathematicians who find aesthetic pleasure in computer-generated proofs, potentially reducing the argument to a matter of taste and preferences.

When Haken presented the proof as a graduate student at the University of Berkeley, he noticed that the divide between those convinced by the computer-generated proof and those not seemed generational:

> At the end of his talk the audience split into two groups, roughly at age 40. The people over 40 could not be convinced that a proof by computer could be correct, and the people under 40 could not be convinced that a proof that took 700 pages of hand calculations could be correct.[587]

Moreover, simply presenting the results led one mathematician to proclaim

> Since the problem has been taken care of by a totally inappropriate means, no first-rate mathematician would now work any more on it, because he would not be the first one to do it, and therefore a decent proof might be delayed indefinitely. [...] So we have done something very, very bad, and things like that should not be committed again.[588]

This last complaint is clearly absurd, given that mathematicians often work on "solved" problems to obtain more elegant, beautiful and insightful proofs.

After the release of the Four Colour Theorem proof, some mathematicians were vigilant in protecting and preserving the "certainty" of their science from the computer. For instance, consider mathematician Doron Zeilberger's paper, "Theorems for a Price: Tomorrow's Semi-Rigorous Mathematical Culture," a tongue-in-cheek paper in which he argues against the "small group of "rigorous" old-style mathematicians(e.g. A. Jaffe and F. Quinn) who will insist that the true religion is theirs, and that the computer is a false Messiah, they may be viewed by future mainstream mathematicians as a fringe sect of harmless eccentrics, like mathematical physicists are viewed by

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Magazine 38, no. 3 (2001): 1–10.
587 Donald MacKenzie, "Slaying the Kraken: The Sociohistory of a Mathematical Proof," *Social Studies Science* 29, no. 1 (February 1999), 41.
588 Ibid.

regular physicists today."[589] He later states,

> As absolute truth becomes more and more expensive, we would sooner or later come to grips with the fact that few non-trivial results could be known with old-fashioned certainty. Most likely we will wind up abandoning the task of keeping track of price altogether, and complete the metamorphosis to non-rigorous mathematics.[590]

In a satirical tone, Zeilberger is arguing that mathematicians will use proofs that are less and less rigorous and will overlook results that could easily be known through traditional methods.[591] Since computers are fallible and proofs are often costly, mathematicians have not abandoned traditional proof techniques and the computer is often used as a sophisticated tool. As observed by Robin Thomas who re-verified the Four Colour Theorem using a slightly different approach in 1996, a computer-generated proof doesn't really provide any new additional insight into the conjecture itself; it just verifies it.[592] Mathematician Ian Stewart was also apprehensive of the proof for similar reasons, stating that "the mathematician's search for hidden structure, his [/her/their] pattern-binding urge, is frustrated."[593]

Zeilberger's provocative claim generated a response from mathematician George A. Andrews, a friend of Zeilberger, in his equally polemically titled article, "The Death of Proof? Semi-Rigorous Mathematics? You've Got to Be Kidding?" Through the title, Andrews acknowledges Zeilberger's joking tone and provides an argument against Zeilberger's tongue-in-cheek scepticism suggesting that the perceived slippage of mathematics into semi-rigorous mathematics is merely a conjecture, and as a conjecture it requires a proof, not mere speculation. Andrews argues,

> Thus one expects that his [Zeilberger, who Andrews considers a "first rate mathematician"] futurology is based on firm ground. So what is his evidence for this paradigm shift? It was at this point that my irritation turned to horror.[594]

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589 Doron Zeilberger, "Theorems for a Price: Tomorrow's Semi-Rigorous Mathematical Culture," *Mathematical Intelligencer* 16, no. 4 (Fall 1994), 1.
590 Ibid., 14.
591 At the time, getting access to a computer was incredibly expensive. Haken explains, "I am shy of the enormous political effort it requires to get computer time. At that time, using a big computer was something like $1,000 per hour." MacKenzie, "Slaying the Kraken," 33.
592 Robin Thomas, "An Update on the Four Colour Theorem," *Notices of the AMS* 45, no. 7 (August 1998), 848. Thomas states: "It is amazing that such a simply stated result resisted proof for one and a quarter centuries, and even today it is not yet fully understood."
593 MacKenzie, "Slaying the Kraken," 41.
594 George A. Andrews, "The Death of Proof? Semi-Rigorous Mathematics? You've Got to Be Kidding!," *Mathematical*

In other words, Andrews is arguing that Zeilberger is engaging in a form of semi-rigorous speculation. He is also not convinced by Zeilberger's argument that certain "expensive" algorithms will lead mathematicians to give up on the idea of an absolute proof with its "concomitantly great insight and, dare I say it, beauty."[595]

Unfortunately, although a conjecture, Zeilberger's critique is not without some merit, since non-rigorous proofs are incredibly costly in the long run. For instance, consider Italian mathematics in the years 1880-1920, when many false theorems were published since there were no real standards for what constituted a rigorous proof. As Saunders Mac Lane observes, "unverified rumour seems to have it that a real triumph for an Italian algebraic geometer consisted in proving a new theorem and simultaneously proposing a counter-example to the theorem."[596] All of the theorems produced during this era needed to be re-verified. There are even examples of contemporary mathematicians who have used unverified results leading to further false results.

Just as the computer suggested to some the death of the proof and therefore mathematics, a similar debate occurred in cinema studies concerning the death of cinema. In 2001, Wheeler Winston Dixon's article, "Twenty-Five Reasons Why It's All Over," was published in a collection of essays titled *The End of Cinema as We Know It: American Film in the Nineties.* In this article, Dixon suggests that the imminent move from film to digital video production and exhibition will be one of the major factors contributing to the death of cinema as we know it, potentially leading to some as-yet-unforeseen form.[597] Although it is yet to be determined whether the death of cinema as we know it is truly unavoidable, it seems reasonable to assume that commercial cinema will certainly pursue the digital

Intelligencer 16, no. 4 (Fall 1994), 16.
595 Ibid., 17.
596 Saunders Mac Lane, "Despite Physicists, Proof Is Essential in Mathematics," *Synthese* 111, no. 2 (May, 1997), 149.
597 Wheeler Winston Dixon, "Twenty-Five Reasons Why It's All Over," in *The End of Cinema as We Know It: American Film in the Nineties*, ed. Jon Lewis (New York: New York University Press, 2001), 362.

path since it is rapidly becoming less expensive to both produce and distribute films digitally. After all, the explicit goal of *commercial* cinema is to generate revenue.

Although the death of film might be inevitable as a commercial production format it will undoubtedly continue to be used by artists. Filmic practices will continue to exist as long as film enthusiasts exist and will continue to be produced commercially as long as there is a market, even if the market is niche. Furthermore, fluidly moving between media is often beneficial to artists as it allows them to exploit the best (and often cheapest) qualities of the media they wish to use. Similarly, there are many mathematicians that work in a similar hybrid manner producing traditional proofs while using a computer to experiment with their hypothesis. As mathematician Paul Halmos argues,

> Mathematics is not a deductive science – that's a cliché. When you try to prove a theorem, you don't just list the hypotheses, and then start to reason. What you do is trial and error, experimentation, guesswork. You want to find out what the facts are, and what you do is in that respect similar to what a laboratory technician does.[598]

For this trial and error, and experimentation, many contemporary mathematicians often use the aid of a computer even if they intend to prove the result through traditional methods. Just as the computer-generated proof was perceived as a threat to traditional mathematics, the computer-generated image was perceived as a threat to traditional cinema. The computer was supposed to lead both to the death of the proof and the death of cinema. In spite of this, there are contemporary mathematicians and filmmakers who continue to work in traditional ways and who work in hybrid forms using the computer whenever it is convenient, or as a simple tool.

In *The Virtual Life of Film*, David Rodowick shares a personal anecdote of how discovering a Pasolini box set in a Hamden, Connecticut, video store destroyed cinema for him:

> I mark my personal experience of the end of cinema around 1989. It was some time in this year that on entering my local video store in Hamden, Connecticut, I saw Pasolini's entire *oeuvre* was available on videocassette. Five years earlier, I might have prioritized my life around a trip to New York to fill in the one or two Pasolini films I hadn't seen, or to review *en bloc* a group of his films. For when would I have the chance again? That evening, I'm sure I passed on Pasolini and moved on to other things, for opportunity and time were no longer precious commodities. There was time. For film scholars, only a

598 Paul Halmos, *I Want to Be a Mathematician: An Automathography* (New York: Springer-Verlag, 1985), 321.

> few short years marked the transition from scarcity to an embarrassment of riches, though at a price: *film had become video*.[599]

I have always found this anecdote hilariously absurd, similar to the worried mathematician that Haken encountered in the hall before his lecture on the proof of the Four Colour Theorem. In essence, Rodowick is stating that he was aesthetically against watching a VHS copy of Pasolini's work on a small television screen, and that because such a box set exists, maybe Pasolini will never be shown properly again. Similarly, many mathematicians were aesthetically opposed to this new form of proof.

Watching Pasolini on a television set from a VHS tape is a potentially inferior experience to watching it in the cinema, since the quality of the image often doesn't compare to that of a 35mm print, meaning, there is potentially information lost.[600] Similarly, a computer-generated proof is often inferior to a traditional proof since it usually doesn't provide any additional information.[601] Nevertheless, it seems that watching Pasolini's work on VHS is superior to not seeing it at all, just as a computer-generated proof is better than not having any proof. Moreover, it would be extremely unsettling if Rodowick passed on seeing Pasolini's work in the theatre just because he knew that there was a VHS box set sitting in a video store in Hamden, Connecticut.

More realistically, the introduction of the computer called into question assumptions that proofs were supposed to give us *absolute truth* – that is, a computer-generated proof lacks some certitude given the potential for computer errors. Similarly, in film studies, computer-generated images called into question the indexical status of the photographic image to point to the real world. As Rodowick observes, "if analog media record traces of events and digital media produce tokens of numbers, the following may also be asserted: *digital acquisition quantifies the world as manipulable series of numbers*."[602] Moreover, as Rodowick would have us believe, this shift from film to the encoded image

599 D.N. Rodowick, *The Virtual Life of Film* (Cambridge: Harvard University Press, 2007), 26. [Emphasis in original.]
600 Rodowick also argues that high definition transfers seem "'colder' and involving and less pleasurable to watch" [Rodowick, *The Virtual Life of Film*, 108].
601 Similar to Rodowick, to some mathematicians, they seem 'colder.'
602 Rodowick, *The Virtual Life of Film*, 116. [Emphasis in original.]

has major social, political and philosophical implications. Rodowick explains: "as Cavell or Barthes would have it, photographs inspire ontological questions about our relationship to the world and to the past, as well as to the limits of our existence and our powers of reasoning."[603] For instance, to Barthes', the photographic image guaranteed a connection to the past; however, to Rodowick, the encoded image offers no such assurance.

The similarities between the mathematical debate and the photography debate are uncanny, and it is possible to make a few observations. First, the *absolute proof* of traditional mathematics, of course, isn't absolute. There have been countless "proofs" that have contained human error and the proofs depend on the formal system you are working in. Perhaps the most famous flawed proof is mathematician Alfred Kempe's 1879 "proof" of the Four Colour Theorem in his paper "On the Geographical Problem of the Four Colours," which was shown to have a flaw by P.J. Heawood in 1890. In other words, humans, like computers, make mistakes. Similarly, the indexical status of the photographic image, whether digital or filmic, depends on the photograph's relationship to the world, not the medium it was shot on. As Paolo Cherchi Usai claims, "be it ever so eloquent, the moving image is like a witness who is unable to describe an event without an intermediary."[604] Granted, Rodowick is correct that the mediums have different properties; however, like in the mathematical case, neither guarantee absolute truth.

10.2 Exercises Left to the Reader: Limitations of this Present Study and Suggestions for Future Scholarship

In this dissertation, I have not only analyzed media art that uses or alludes to mathematical concepts, I have also tried to provide some tools for media scholars to use in order to further recognize and analyze mathematical content in moving image artworks. I have attempted to keep the mathematics accessible in the hopes that it would inspire other media scholars to engage with it and not simply to be scared of

603 Ibid., 124.
604 Paolo Cherchi-Usai, *The Death of Cinema: History, Cultural Memory and the Digital Dark Age* (London: British Film Institute, 2001), 31.

it. The mathematics explored here is still relatively simplistic relative to the type that working mathematicians engage with, but it is the goal of this writing to inspire mathematical engagement from media scholars who may have peripheral interest in the subject. Moreover, this writing is also intended to be of interest to mathematicians who have an interest in art, hopefully demonstrating that there are mathematical concepts in cinema and media art beyond one or two lines of dialogue, or what is written on blackboards in mainstream movies.[605]

As demonstrated throughout this dissertation, there are close ties between mathematical debates and artistic debates, and there is much to be learned by examining the similarities and differences between these two cultures. The humanities are, by design, attempting to understand our social condition; however, the problems that some contemporary social scientists are dealing with are very similar to the ones that mathematicians are dealing with. While mathematicians are not necessarily considering the social implications of their work, they are often dealing with the conceptual and philosophical implications of their results. In this dissertation, I have attempted to demonstrate that two culture divide proposed by Snow is a false one, suggesting mathematics as one of the bridges between the two cultures.

While not all of the examples discussed use mathematics in the same way, they are all visualizations of mathematical concepts and ideas. In this way, media artists that use mathematical concepts, either in their artworks or to create their artworks, demonstrate the beauty of mathematical thought through their works. In this way, mathematics acts as a bridge between the two cultures, allowing one point of entry for non-specialists to engage with mathematical ideas and concepts. Moreover, as demonstrated, analyzing the mathematical content of artworks that engage with these concepts and ideas, whether implicitly or explicitly, often provides new insights into the work and new readings of the work.

605 See: Polster and Ross, *Math Goes to the Movies*.

Unfortunately, not all of the branches of mathematics that are visually or conceptually relevant to art could be covered in this dissertation, and the branches that I have dealt with have only provided a cursory understanding of the mathematics involved. There are many other topics that could have been covered, given that at the contemporary moment the digital era is transforming both the world we live in and how we interact with each other. For instance, the mathematics of big data is something that few media theorists have examined, yet it is something that affects the way we access information, and the way people are perceived from within a system governed by software. As data scientist Cathy O'Neil argues in her book *Weapons of Math Destruction*,

> The math-powered applications powering the data economy were based on choices made by fallible human beings. Some of these choices were no doubt made with the best intentions. Nevertheless, many of these models encoded human prejudice, misunderstanding, and bias into the software systems that increasingly managed our lives. Like gods, these mathematical models were opaque, their workings invisible to all but the highest priests in their domains: mathematicians and computer scientists. Their verdicts, even when wrong or harmful, were beyond dispute or appeal. They tended to punish the poor and the oppressed in our society, while making the rich richer.[606]

Artists often provide one point of access to the underlying mechanics of big data, usually through innovative forms of data visualization. As data journalist and information designer David McCandless states, "designed information can help us understand the world, cut through BS & fake news, and reveal the hidden connections, patterns and stories underneath. Or, failing that, it can just look cool!"[607] Given this connection between mathematics and visual art, I conjecture that it is worthwhile for contemporary media scholars to look at some of the ways in which mathematicians are approaching such topics as the mathematics of big data and its connection to data visualization. Moreover, cryptography and network theory seem key to further understanding the mechanics of the digital world around us.

The genealogy traced in this dissertation is often speculative, although future scholarship may fill in some of the historical gaps. I have used fairly broad strokes while painting this history in an

606 Cathy O'Neil, *Weapons of Math Destruction: How Big Data Increass Inequality and Threatens Democracy* (New York: Crown, 2016), 3.
607 David McCandless, "About," *Information is Beautiful,* (2017), <https://informationisbeautiful.net/about/>.

attempt to reveal larger cultural movements, relying on the concept of the trace or the cultural zeitgeist in order to observe similarities and differences between movements. Although it is unlikely that there are figures like Maurice Princet ("the mathematician of cubism") involved in every movement, it may be possible to further pinpoint the mathematical connections between certain artists and movements through much deeper and more specialized historical research. With that being said, ideas are often generated in ways that are difficult for historians to inventory, since the winds of time often obliterate the influence that a conversation or book has on a person, given that ideas are not physical objects that can be archived, stored and displayed for the next generation.

The genealogy I have traced is just one of the contemporary attempts to re-think mathematics in respect to art history. Given that my genealogy is slightly speculative, it may be viewed as a productive misinterpretation of history, with the hope of providing some new insights and revealing aspects of history that have been ignored. Similar to Ron Eglash's *African Fractals*, Laura Mark's *Enfoldment and Infinity* or Lynn Gamwell's *Mathematics + Art*, this dissertation traces an alternative genealogy. The idea is not to provide an authoritative, new and revised history, but simply to suggest another way of approaching media art and its history.

Bibliography

"The Hundred Most Influential Books since the War." *The Times Literary Supplement,* October 6, 1995.
"The Twenty Best Spy Novels of all Time." *The Telegrap*h, January 6, 2017.
Ahearn, Stephen T. "Tolstoy's Integration Metaphor from *War and Peace*." *The American Mathematical Monthly* 112, no. 7 (2005): 631–38.
Alberti, Leon Battista. *On Painting.* Translated by Cecil Grayson. London: Phaidon Press, 1972.
Amacher, Maryanne. *Sound Characters: Making the Third Ear.* [CD essay.] New York: Tzadik, 1998.
Andrews, George A. "The Death of Proof? Semi-Rigorous Mathematics? You've Got to Be Kidding!" *Mathematical Intelligencer* 16, no. 4 (Fall 1994): 16–18.
Arcangel, Cory. "*Drei Klavierstücke Op. 11* (2009)." *Cory Arcangel's Internet Portfolio Website and Portal,* 2009. <http://www.coryarcangel.com/things-i-made/dreiklavierstucke/>.
Armatage, Kay. "Kay Armatage Interviews Joyce Wieland." In *The Films of Joyce Wieland*, edited by Kathryn Elder, 153–59. Toronto: Cinémathèque Ontario, 1999.
Armstrong, M. A. *Groups and Symmetry*. New York: Springer-Verlag, 1988.
Arnheim, Rudolf. *Entropy and Art: An Essay on Disorder and Order*. Berkeley: University of California Press, 1971.
Arnold, Matthew. "Literature and Science." In *Complete Prose Works of Matthew Arnold*, edited by Robert Henry Super, 53–73. Ann Arbor: University of Michigan Press, 1960.
Badiou, Alain. *Being and Event*. Translated by Oliver Feltenham. London: Continuum, 2005.
———. *Cinéma*. Edited by Antoine de Baecque. Translated by Susan Spitzer. Cambridge: Polity, 2013.
———. *Number and Numbers*. Cambridge: Polity, 2008.
———. *Theoretical Writings*. Edited by Ray Brassier, Alberto Toscano, and Alberto Toscano. Translated by Ray Brassier. London: Continuum, 2004.
Badiou, Alain, A. J. Bartlett, and Justin Clemens. "To Preface the Response to the 'Criticisms' of Ricardo Nirenberg and David Nirenberg." *Critical Inquiry* 38, no. 2 (2012): 362–64.
Balázs, Béla. *Early Film Theory*. Edited by Erika Carter. Translated by Rodney Livingstone. New York: Berghahn Books, 2010.
Barrett, Cyril. *Op Art*. London: Studio Vista, 1970.
Bartlett, A. J., and Justin Clemens. "Neither Nor." *Critical Inquiry* 38, no. 2 (2012): 365–80.
Belik, Vivian. "A Provocative New Canadian Doc: A Review of *88:88*." *Point of View Magazine,* February 2, 2016. <http://povmagazine.com/articles/view/review-8888>.
Bell, E.T. *Men of Mathematics: The Lives and Achievements of the Great Mathematicians from Zeno to Poincaré.*
New York: Simon and Schuster, 2014.
Benacerraf, Paul. "What Numbers Could Not Be." *Philosophical Review* 74, no. 1 (1965): 47–73.
Bestgen, Barbara J., and Robert E. Reys. *Films in the Mathematics Classroom*. Reston: National Council of Teachers of Mathematics, 1982.
Bhāskarāchārya, "Līlāvatī." In *Algebra, with Arithmetic and Mensuration, from the Sanscrit of Brahmegupta and*
Bhāscara, translated by Henry Thomas Colebrooke, 1-274. London: John Murray, 1817.
Bloom, Harold. *The Anxiety of Influence: A Theory of Poetry*. Oxford: Oxford University Press, 1997.
Bordwell, David, Kristin Thompson, and Jeff Smith. *Film Art: An Introduction*. Eleventh edition. New York: McGraw-Hill Education, 2017.
Borges, Jorge Luis. "The Library of Babel." In *Collected Fictions*, translated by Andrew Hurley, 112–18. New York: Pengiun, 1998.
Boyer, Carl B., and Uta C. Merzbach. *A History of Mathematics*. Hoboken: John Wiley & Sons, Inc., 2011.
Brecher, Kenneth. "Kepler's Mysterium Cosmographicum: A Bridge Between Art and Astronomy?" Proceedings from *Bridges 2011* in Coimbra, Portugal, July 27-31, 2011.
Brockman, John. "Introduction." In *The Third Culture*, edited by John Brockman, 17–37. New York: Simon & Schuster, 1995.
Cage, John. *Silence: Lectures and Writings*. Middletown: Wesleyan University Press, 1961.
———. "The Future of Music: Credo." In *Audio Culture: Readings in Modern Music*, 25–28. New York: Continuum, 2004.
Cajori, Florian. "Origins of Fourth Dimension Concepts." *The American Mathematical Monthly* 33, no. 8 (1926):

397–406.
Calude, Andreea. “The Journey of the Four Colour Theorem Through Time.” *The New Zealand Mathematics Magazine* 38, no. 3 (2001): 1–10.
Cavell, Richard. *McLuhan in Space: A Cultural Geography*. Toronto: University of Toronto Press, 2002.
Chamberlin, Carloss James. “Dziga Vertov: The Idiot.” *Senses of Cinema* 41 (November 2006). <http://www.sensesofcinema.com/2006/feature-articles/dziga-vertov-enthusiasm/>.
Cherchi-Usai, Paolo. *The Death of Cinema: History, Cultural Memory and the Digital Dark Age.* London: British Film Institute, 2001.
Clark, Kenneth. “Mona Lisa.” *The Burlington Magazine* 115, no. 840 (1973): 144–51.
Coldiron, Phil. “Necessary Means: Isiah Medina on *88:88*.” *Cinema Scope* 64 (Fall 2015). <http://cinema-scope.com/cinema-scope-magazine/necessary-means-isiah-medina-on-8888/>.
Collini, Stefan. “Introduction.” In *The Two Cultures*, edited by Stefan Collini, vii–lxxiii. Cambridge: Cambridge University Press, 1998.
———. “Introduction.” In *Two Cultures?: The Significance of C.P. Snow*, edited by Stefan Collini, 1–49. Cambridge: Cambridge University Press, 2013.
Connor, J.D. “What Becomes of Things on Film on Film: Adaptation in Owen Land (George Landow).” *Adaptation Vol. 2, No. 2* 2, no. 2 (July 2009).
Crais, Benjamin. “Program Notes for *88:88*.” Screening in Atlanta Georgia, August 9, 2016. <http://kenotype.tumblr.com/post/149485926871/program-notes-from-the-8888-screening>.
Dahan, Yaron. “Ghosts of Time and Light: The Experimental Cinema of Ito Takashi.” *MUBI*, June 4, 2015. <https://mubi.com/notebook/posts/ghosts-of-time-and-light-the-experimental-cinema-of-ito-takashi>.
Darvas, György. *Symmetry: Cultural-Historical and Ontological Aspects of Science-Arts Relations : The Natural and Man-Made World in an Interdisciplinary Approach*. Translated by David Robert Evans. Basel: Birkhäuser, 2007.
Davis, Philip J., Reuben Hersh, and Elena Anne Marchisotto. *The Mathematical Experience*. Boston: Birkhäuser, 1995.
Deleuze, Gilles. *Negotiations, 1972-1990*. New York: Columbia University Press, 1995.
Deren, Maya. *An Anagram of Ideas on Art, Form and Film*. Yonkers: Alicat Book Shop Press, 1946.
Dewdney, Keewatin A. “DISCONTINUOUS FILMS.” *Canadian Journal of Film Studies* 10, no. 1 (Spring 2001): 96-105.
Dillon, Roberto. *Ready: A Commodore 64 Retrospective.* Singapore: Springer, 2015.
Dixon, Wheeler Winston. “Twenty-Five Reasons Why It's All Over.” In *The End of Cinema as We Know It: American Film in the Nineties*, edited by Jon Lewis, 356–66. New York: New York University Press, 2001.
Dorsky, Nathaniel. *Devotional Cinema*. Berkeley: Tuumba Press, 2003.
Dostoevsky, Fyodor. *The Brothers Karamazov: A Novel in Four Parts with Epilogue*. Translated by Ricard Pevear and Larissa Volokhonsky. New York: Farrar, Straus and Giroux, 1990.
Douady, Adrien and John H. Hubbard. *Etude dynamique des polynômes complexes.* Orsay: Universite de Paris-Sud, 1984.
Douglas, Stan. *Journey into Fear*. London: Serpentine Gallery, 2002.
Douglas, Stan, and Achim Borchardt-Hume. “Journey into Fear: An Introduction.” In *Journey into Fear*, 7–18. London: Serpentine Gallery, 2002.
Dulac, Germaine. “The Avant-Garde Cinema.” In *The Avant-Garde Film : A Reader of Theory and Criticism*, edited by P. Adams Sitney, 43–48. New York: New York University Press, 1978.
———. “The Essence of Cinema: The Visual Idea.” In *The Avant-Garde Film : A Reader of Theory and Criticism*, edited by P. Adams Sitney, 36–42. New York: New York University Press, 1978.
Eco, Umberto. *History of Beauty*. Translated by Alastair McEwen. New York: Rizzoli, 2004.
Eglash, Ron. *African Fractals: Modern Computing and Indigenous Design*. New Brunswick: Rutgers University Press, 1999.
Eisenstein, Sergei. “A Dialectic Approach to Film Theory.” In *Film Form: Essays in Film Theory*, edited and translated by Jay Leyda, 45–63. New York: Harcourt, Brace & World, 1949.
———. “Methods of Montage.” In *Film Form: Essays in Film Theory*, edited and translated by Jay Leyda, 72–83. New York: Harcourt, Brace & World, 1949.
Elder, R. Bruce. *Cubism and Futurism: Spiritual Machines and the Cinematic Effect*. Waterloo: Wilfrid Laurier

University Press, 2018.
———. *Dada, Surrealism, and the Cinematic Effect*. Waterloo: Wilfrid Laurier University Press, 2013.
———. "Permutation, Collage and Film Form." Unpublished manuscript, 2004.
———. "Notes after a Conversation between Hollis and Joyce." In *The Films of Joyce Wieland*, edited by Kathryn Elder, 183–93. Toronto: Cinémathèque Ontario, 1999.
Elwes, Catherine. *Video Art: A Guided Tour*. London: I.B. Tauris, 2005.
Emmer, Michele, ed. *Mathematics and Culture I*. Translated by Emanuela Moreale. Berlin: Springer, 2004.
———, ed. *Mathematics and Culture II: Visual Perfection, Mathematics and Creativity*. Berlin: Springer, 2004.
———, ed. *The Visual Mind: Art and Mathematics*. Cambridge: MIT Press, 1993.
Emmer, Michele, and Mirella Manaresi, eds. *Mathematics, Art, Technology, and Cinema*. Berlin: Springer, 2003.
Enns, Clint. "A Brief Analysis of Hollis Frampton's *Palindrome*; and How to Construct Five Types of Filmic Palindromes." *Millennium Film Journal* 63 (Spring 2016): 65–70.
———. "Charting the Montage: The Roots of Algorithmic Cinema." In *Marshall McLuhan + Vilém Flusser's Communication + Aesthetic Theories Revisited*, edited by Melentie Pandilovski and Tom Kohut, 155–62. Winnipeg: Video Pool Media Arts Centre, 2015.
———. "Escaping Time With Thorsten Fleisch." *INCITE! Journal of Experimental Media*, Back & Forth, December 1, 2010.
<http://www.incite-online.net/fleisch.html>.
———. "Frampton's Demon: A Mathematical Interpretation of Hollis Frampton's *Zorns Lemma*." *Leonardo* 49, no. 2 (April 2016): 156–61.
———. "Navigating Algorithmic Editing: Algorithmic Editing as an Alternative Approach to Database Cinema." *Millennium Film Journal* 56 (Fall 2012): 66–72.
———. "Permutations and Other Schema: A Few Notes on the Films of Stephen Broomer." In *The Transformable Moment: The Films of Stephen Broomer*, edited by Scott Birdwise and Tom McSorley, 25–32. Ottawa: Canadian Film Institute, 2014.
———. "Towards Infinite Light: An Interview with Isiah Media." *BlackFlash* 32, no. 1 (January 2015): 4–9.
Euclid. *Elements of Geometry*. Edited and translated by Richard Fitzpatrick. published by the author, 2007.
Evans, Brian. "Foundations of a Visual Music." *Computer Music Journal* 29, no. 4 (December 1, 2005): 11–24.
Feder, Jens. *Fractals*. Physics of Solids and Liquids. New York: Plenum Press, 1988.
Feferman, Solomon. "Infinity in Mathematics: Is Cantor Necessary?" In *In the Light of Logic*, 28–73. Oxford: Oxford University Press, 1998.
Frampton, Hollis. "A Pentagram for Conjuring the Narrative." In *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, edited by Bruce Jenkins, 140–48. Cambridge: MIT Press, 2009.
———. "About the Digital Arts Lab." In *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, edited by Bruce Jenkins, 272–74. Cambridge: MIT Press, 2009.
———. "For a Metahistory of Film: Commonplace Notes and Hypotheses." In *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, edited by Bruce Jenkins, 131–39. Cambridge: MIT Press, 2009.
———. "Letter to the Editor, *Artforum*." In *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, edited by Bruce Jenkins. 163–5. Cambridge: MIT Press, 2009.
———. "Letters from Framp 1958-1968." *October* 32 (Spring 1985): 25–55.
———. *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*. Edited by Bruce Jenkins. Cambridge: MIT Press, 2009.
———. "Zorns Lemma: Scripts and Notations." In *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, edited by Bruce Jenkins, 192–202. Cambridge: MIT Press, 2009.
Gamwell, Lynn. *Mathematics + Art: A Cultural History*. Princeton: Princeton University Press, 2016.
Gidal, Peter. "Interview with Hollis Frampton." *October* 32 (Spring 1985): 93–117.
———. "Theory and Definition of Structural/Materialist Film." In *Structural Film Anthology*, edited by Peter Gidal, 1–21. London: British Film Institute, 1976.
Gingerich, Owen. "Johannes Kepler." In *Planetary Astronomy from the Renaissance to the Rise of Astrophysics Part A: Tycho Brahe to Newton.*, edited by René Taton and Curtis Wilson, 54–78. Cambridge: Cambridge University Press, 1989.
Goodwin, Doug. "mersenne video twister." *cairndesign: since 1996*, March 4, 2011.
<http://cairn.com/wp/2011/03/04/mersenne-video-twister/>.

Goonatilake, Susantha. *Toward a Global Science*. Bloomington: Indiana University Press, 1998.
Grissemann, Stefan. “Frame by Frame: Peter Kubelka.” *Film Comment* (October 2012). https://www.filmcomment.com/article/peter-kubelka-frame-by-frame-antiphon-adebar-arnulf-rainer/.
Halbeisen, Lorenz J. *Combinatorial Set Theory: With a Gentle Introduction to Forcing*. Berlin: Springer, 2012.
Hall, Stuart. “Encoding/Decoding.” In *Language Culture, Media, Language Working Papers in Cultural Studies, 1972 –79*, edited by Stuart Hall, Dorothy Hobson, Andrew Lowe, and Paul Willis, 128–38. London: Hutchinson, 1980.
Halmos, Paul. *I Want to Be a Mathematician: An Automathography*. New York: Springer-Verlag, 1985.
Halpern, Orit. “Anagram, Gestalt, Game in Maya Deren: Reconfiguring the Image in Post-War Cinema.” *Postmodern Culture* 19, no. 3 (May 2009). <http://www.pomoculture.org/2013/09/05/anagram-gestalt-game-in-maya-deren-reconfiguring-the-image-in-post-war-cinema/>.
Hargittai, Magdolna, and István Hargittai. *Visual Symmetry*. Singapore: World Scientific, 2009.
Henderson, Brian. “Propositions for the Exploration of Frampton's ‘Magellan.'” *October* 32 (1985): 129–50.
Herz-Fischler, Roger. *A Mathematical History of Division and Mean Ratio.* Waterloo: Wilfrid Laurier University Press, 1987.
Holt, Michael. *Mathematics in Art*. London: Littlehampton Book Services Ltd., 1971.
Hoolboom, Mike. *Inside the Pleasure Dome: Fringe Film in Canada*. Toronto: Coach House Books, 2001.
Hoolboom, Mike. “A Record of Its Own Making: An Interview with Francesco Gagliardi.” January 2017. <http://mikehoolboom.com/?p=18376>.
Hotes, Catherine Munroe. “Takashi Ito's Film Work.” *MidnightEye,* August 10, 2010. <http://www.midnighteye.com/reviews/takashi-itos-film-works/>.
Howell, Elizabeth. “How Many Stars in the Universe.” *Space*, May 17, 2017. <https://www.space.com/26078-how-many-stars-are-there.html>.
Huxley, Thomas Henry. “Science and Culture.” In *Science and Culture and Other Essays*, 1–23. London: MacMillan and Co., 1888.
Iimura, Takahiko. *The Collected Writings of Takahiko Iimura*. Rockville: Wildside Press, 2007.
Jech, Thomas J. *The Axiom of Choice*. Amsterdam: North-Holland Publishing Company, 1973.
Jenkins, Bruce. “The Red and The Green.” *October* 32 (Spring 1985): 77–92.
Kadvany, John. “Review of Number and Numbers by Alain Badiou.” *Notre Dame Philosophical Reviews*, October 2, 2008. <https://ndpr.nd.edu/news/number-and-numbers/>.
Kalajdzievski, Sasho. *Math and Art: An Introduction to Visual Mathematics*. Boca Raton: CRC Press, 2008.
Kant, Immanuel. *Critique of Pure Reason.* Translated by Norman Kemp Smith. London: Macmillan, 1929.
Kelley, John L. *General Topology*. New York: Springer-Verlag, 1955.
Kepler, Johannes. *Mysterium Cosmographicum.* Tuebingen: Georg Gruppenbach, 1596.
Kinder, Marsha. “Designing a Database Cinema.” In *The Cinematic Imaginary after Film*, edited by Jeffery Shaw and Peter Weibel, 346–53. Cambridge: MIT Press, 2003.
Kline, Morris. “Geometry,” *Scientific American* 211, no. 3 (September 1964): 60–9.
Knowlton, Ken. “Portrait of the Artist as a Young Scientist,” *Digital Art Guild* (October 2004). <http://www.digitalartguild.com/content/view/26/26/>.
Kostelanetz, Richard. “InferentialArt.” *Columbia Forum* 12, no. 2 (Summer 1969): 19–26.
Kosuth, Joseph. “Art After Philosophy.” In *Art After Philosophy and After.* Cambridge: MIT Press, 1993.
Krane, Harry H., and Gilbert H. Wright. *The Third Culture: A New Education; an Integration of Technology with Art*. Melbourne: Published for International Co-operation for the Integration of Technology with Art by the Melbourne Group, I.C.I.T.A., 1972.
Krauss, Rosalind. “Video: The Aesthetics of Narcissism.” *October* 1 (1976): 51–64.
Kubelka, Peter. “The Theory of Metrical Film.” In *The Avant-Garde Film: A Reader of Theory and Criticism*, edited by P. Adams Sitney, 139–59. New York: New York University Press, 1978.
Kuittinen, Petri. “Computer Demos – The Story So Far.” April 28, 2001. <http://mlab.uiah.fi/~eye/demos/#begin>.
Kuskis, Alexander. “Claude Shannon's Transportation Theory of Communication Versus Marshall McLuhan's Transformation Theory.” *McLuhan Galaxy*, June 27, 2017.

<https://mcluhangalaxy.wordpress.com/2017/06/27/claude-shannons-transportation-theory-of-communication-versus-marshall-mcluhans-transformation-theory/>.
Land, Owen. *Two Films by Owen Land*. Edited by Mark Webber. London: LUX, 2005.
Lang, Serge. *Real and Functional Analysis*. Berlin: Springer, 2012.
Lattanzi, Barbara. “Critical Mass, the Software.” Presented at *Gloria! The Legacy of Hollis Frampton* at Princeton University, Visual Arts Program on November 5 & 6, 2004.
———. “We Are All Projectionists.” *Millennium Film Journal* 39/40 (Winter 2003): 84–87.
———. “What Is So Cinematic About Software?” Presented at *Connectivity* at Connecticut College, Ammerman Center, 10th Biennial Symposium on Arts and Technology on March 31 & April 1, 2006.
Le Grice, Malcolm. *Experimental Cinema in the Digital Age*. London: BFI, 2001.
Leavis, F. R. *Two Cultures?: The Significance of C.P. Snow*. Edited by Stefan Collini. Cambridge: Cambridge University Press, 2013.
Leyda, Jay. *Kino: A History of the Russian and Soviet Film* (London: G. Allen & Unwin, 1960).
Ling, Alex. “Ontology.” In *Alain Badiou: Key Concepts*, edited by A. J. Bartlett and Justin Clemens, 48-60. Durham: Acumen, 2010.
Livingston, Paul. “Review of *Being and Event*.” *Inquiry* 51, no. 2 (April 2008): 217–38.
Livio, Mario. “The Golden Ratio and Aesthetics.” *Plus Magazine*, November 1, 2002. <https://plus.maths.org/content/golden-ratio-and-aesthetics>.
———. *The Golden Ratio: The Story of Phi, the World's Most Astonishing Number*. New York: Broadway Books, 2002.
Mac Lane, Saunders. “Despite Physicists, Proof Is Essential in Mathematics.” *Synthese* 111, no. 2 (May, 1997): 147-154.
MacDonald, Scott. *A Critical Cinema: Interviews with Independent Filmmakers*. Berkeley: University of California Press, 1988.
———. “Print Generation by J. J. Murphy.” *Film Quarterly* 32, no. 1 (Autumn 1978): 58–62.
MacKenzie, Donald. “Slaying the Kraken: The Sociohistory of a Mathematical Proof.” *Social Studies Science* 29, no. 1 (February 1999): 7–60.
MacKillop, Ian. *F.R. Leavis: A Life in Criticism*. New York: St. Martin's Press, 1997.
Malicki, Maciej. “Matheme and Mathematics: On the Main Concepts of the Philosophy of Alain Badiou.” *Logique et Analyse* 58, no. 231 (2015): 433–46.
Mandelbrot, Benoit B. *The Fractal Geometry of Nature*. San Francisco: W.H. Freeman, 1983.
Mann, Thomas. *The Magic Mountain*. Translated by H.T. Lowe-Porter. New York: Alfred A. Knopf, 1972.
Manovich, Lev. *Soft Cinema*. Karlsruhe: TKM, 2002.
———. *The Language of New Media*. Cambridge: MIT Press, 2001.
Marchessault, Janine. *Marshall McLuhan: Cosmic Media*. London: SAGE, 2004.
Marie, T. [Quoted]. “TIFF's [Toronto International Film Festival] self-indulgent side.” *CBC News*, September 07, 2011. <http://www.cbc.ca/news/business/tiff-s-self-indulgent-side-1.1088892>.
Markowsky, George. “Misconceptions about the Golden Ratio.” *The College Mathematics Journal* 23, no. 1 (January 1, 1992): 2–19.
Marks, Laura U. *Enfoldment and Infinity: An Islamic Genealogy of New Media Art*. Cambridge: MIT Press, 2010.
McCague, Hugh. “Pythagoreans and Sculptors: The Canon of Polykleitos.” *Rosicrucian Digest* 87, no. 1 (2009): 23–29.
McCandless, David. “About.” *Information is Beautiful,* 2017. <https://informationisbeautiful.net/about/>.
McCormack, Tom. “Code Eroded: At GLI.TC/H 2010, RHIZOME, Oct. 2010.” In *GLI.TC/H READER[ROR] 20111*, edited by Nick Briz, Evan Meaney, Rosa Menkman, William Robertson, Jon Satrom, and Jessica Westbrook, 15–19. Chicago: Unsorted Books, 2011.
Medina, Isiah. “Isiah Medina Introduces *88:88*.” *MUBI Notebook,* March 11, 2016. <https://mubi.com/notebook/posts/director-s-statement-isiah-medina-introduces-88-88>.
Menkman, Rosa. *The Glitch Moment(Um)*. Netherlands: Institute of Network Cultures, 2011.
Miller, Arthur I. *Einstein, Picasso: Space, Time, and the Beauty That Causes Havoc.* New York: Basic Books, 2001.
Moles, Abraham A. *Information Theory and Esthetic Perception*. Urbana: University of Illinois Press, 1966.

Mollaghan, Aimee. *The Visual Music Film*. Hampshire: Palgrave Macmillan, 2015.
Moore, Gregory H. *Zermelo's Axiom of Choice: Its Origins, Development, and Influence*. New York: Springer-Verlag, 1982.
Nelson, Ted H. “Complex Information Processing: A File Structure for the Complex, the Changing and the Indeterminate.” In *Proceedings of the 1965 20th ACM National Conference,* 84-100. (New York: ACM, 1965.
Nirenberg, Ricardo L., and David Nirenberg. “Badiou's Number: A Critique of Mathematics as Ontology.” *Critical Inquiry* 37, no. 4 (2011): 583–614.
———. “Reply to Badiou, Bartlett, and Clemens.” *Critical Inquiry* 38, no. 2 (2012): 381–87.
Nishijima, Norio. “The Ecstasy of Auto-Machines,” *Image Forum*, 1996. <http://www.imageforum.co.jp/ito/introduction_e.html>.
Norris, Christopher. *Badiou's Being and Event: A Reader's Guide*. London: Continuum, 2009.
O'Neil, Cathy. *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy*. New York: Crown, 2016.
O'Rourke, Karen. “Notes on 'Fax-Art'.” *New Observations* 76 (May-June 1990): 24–5.
Ortolano, Guy. “The Literature and the Science of ‘Two Cultures' Historiography.” *Studies in History and Philosophy of Science Part A* 39, no. 1 (March 2008): 143–50.
Pariser, Eli. *The Filter Bubble: What the Internet Is Hiding from You*. New York: Penguin Press, 2011.
Paseau, Alexander. “Reducing Arithmetic to Set Theory.” In *New Waves in Philosophy of Mathematics*, edited by Otávio Bueno and Øystein Linnebo, 35–55. London: Palgrave Macmillan, 2009.
Paulos, John Allen. *Innumeracy: Mathematical Illiteracy and Its Consequences*. New York: Hill and Wang, 1988.
Pedoe, Daniel. *Geometry and the Visual Arts*. New York: Dover Publications, 1983.
Pesco and Bortolossi, “Matrices and Digital Images.” *The Klein Project,* May 27, 2015. <http://blog.kleinproject.org/?p=588>.
Peterson, James. *Dreams of Chaos, Visions of Order: Understanding the American Avante-Garde Cinema*. Detroit: Wayne State University Press, 1994.
Petrić, Vlada. *Constructivism in Film: The Man with the Movie Camera : A Cinematic Analysis*. Cambridge: Cambridge University Press, 2012.
Pierce, John Robinson. *Symbols, Signals, and Noise: The Nature and Process of Communication*. New York: Harper, 1961.
Poe, Edgar Allan. “Poetic Principles.” In *The Works of Edgar Allan Poe*, Vol. 2, vii–xxvi. New York: W. J.Widdleton, 1863.
Poincaré, Henri. *Science and Hypothesis*. Translated by William John Greenstreet. London: The Walter Scott Publishing Co. Ltd, 1905.
Poincaré, Henri. *Science and Method*. Translated by Francis Maitland. Mineola: Dover Publications Inc. 2003.
Polster, Burkard, and Marty Ross. *Math Goes to the Movies*. Baltimore: Johns Hopkins University Press, 2012.
Powers, John. “A DIY Come-On: A History of Optical Printing in Avant-Garde Cinema.” *Cinema Journal* 57, no. 4 (Summer 2018): 71–95.
Raatikainen, Panu. “Gödel's Incompleteness Theorems.” *The Stanford Encyclopedia of Philosophy*, January 20, 2015. <https://plato.stanford.edu/archives/fall2018/entries/goedel-incompleteness/>.
Ragona, Melissa. “Hidden Noise: Strategies of Sound Montage in the Films of Hollis Frampton.” *October* 109 (Summer 2004): 96–118.
Reid, Constance. *From Zero to Infinity: What Makes Numbers Interesting*. Wellesley: A K Peters, 2006.
Rodowick, D.N. *The Virtual Life of Film*. Cambridge: Harvard University Press, 2007.
Roffe, Jon. “Book Review: Alain Badiou's *Being and Event*.” *Cosmos and History: The Journal of Natural and Social Philosophy* 2, no. 1–2 (2006): 327–38.
Ross, Julian. “Interview: Takahiko Iimura.” *Midnight Eye*, September 30, 2010. <http://www.midnighteye.com/interviews/takahiko-iimura/>.
Ross, Sven. “The Encoding/Decoding Model Revisited.” Presented at the Annual Meeting of the International Communication Association in Boston, Massachusetts on May 25, 2011.
Rule, Alex, and David Levine. “International Art English.” *Triple Canopy* 16 (July 30, 2012). <https://www.canopycanopycanopy.com/legacy/final/international_art_english>.
Russell, Bertrand. *My Philosophical Development*. New York: Simon and Schuster, 1959.

Schechter, Eric. *Handbook of Analysis & Its Foundations*. New York: Academic Press, 1997.
Schedelbauer, Sylvia. “Poetics of an Urban Darkness: Takashi Ito's Spectral Cinema.” *OtherZine* 20 (Spring 2011). <http://www.othercinema.com/otherzine/archives/index.php?issueid=25&article_id=121>.
Schoot, Albert van der. “The Divine Proportion.” In *Mathematics and the Divine: A Historical Study*, edited by Teun Koetsier and Luc Bergmans, 655-672. Amsterdam: Elsevier, 2005.
Schwartz, Lillian. “The Mona Lisa Identification: Evidence from a Computer Analysis.” *The Visual Computer* 4, no. 1 (1988): 40–48.
———, and Laurens R. Schwartz. *The Computer Artist's Handbook: Concepts, Techniques, and Applications*. New York: Norton, 1992.
Scott, Kathleen. “Enfoldment and Infinity: An Islamic Genealogy of New Media Art.” *Screen* 52, no. 4 (December 1, 2011): 553–56.
Sei, Keiko. “Productive Unclarities: Interview with Media Artist Barbara Lattanzi.” *Springerin Magazine*, no. 4 (December 2001). <https://www.springerin.at/en/2001/4/produktive-unklarheiten/>.
Shannon, Claude. *The Mathematical Theory of Communication*. Urbana: University of Illinois Press, 1998.
Sicinski, Michael. “2011 Toronto International Film Festival.” *Academic Hack*, 2011. <http://academichack.net/TIFF2011.htm>.
Simon, Bill. “Talking about Magellan: An Interview.” In *On the Camera Arts and Consecutive Matters: The Writings of Hollis Frampton*, edited by Bruce Jenkins, 232–52. Cambridge: MIT Press, 2009.
Simon, John F. (Jr.). “Artist Statement: Every Icon.” 1996. <http://www.numeral.com/artworks/artAppliances/1998_2000/everyicon.php>.
Sisson, P. D. “Fractal Art Using Variations on Escape Time Algorithms in the Complex Plane.” *Journal of Mathematics and the Arts* 1, no. 1 (March 1, 2007): 41–45.
Sitney, P. Adams. *Eyes Upside Down: Visionary Filmmakers and the Heritage of Emerson*. Oxford: Oxford University Press, 2008.
———. “Harry Smith Interview.” In *Film Culture Reader*, edited by P. Adams Sitney. New York: Praeger Publishers, 1970.
———. *Visionary Film: The American Avant-Garde, 1943-2000*. Third edition. Oxford: Oxford University Press, 2002.
Sito, Tom. *Moving Innovation: A History of Computer Animation.* Cambridge: MIT Press, 2013.
Smith, William S. “A Concrete Experience of Nothing: Paul Sharits’ Flicker Films.” *RES: Anthropology and Aesthetics* 55/56 (Spring - Autumn 2009): 279–93.
Smithson, Robert. “A Cinematic Atopia.” In *Robert Smithson: The Collected Writings*, edited by Jack Flam, 138–142. Berkeley: University of California Press, 1996.
———. “Entropy and the New Monuments.” In *Robert Smithson: The Collected Writings*, edited by Jack Flam, 10–23. Berkeley: University of California Press, 1996.
Snow, C. P. *The Two Cultures*. Cambridge: Cambridge University Press, 1998.
Sokal, Alan, and Jean Bricmont. *Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science*. New York: Picador, 1998.
Stewart, Andrew. “The Canon of Polykleitos: A Question of Evidence.” *The Journal of Hellenic Studies* 98 (1978): 122–31.
Stratman, Deborah. “About Xenoi.” *Urban Video Project,* 2017. <http://www.urbanvideoproject.com/artists/deborah-stratman-recent-video-work/>.
———. “Xenoi.” *Pythagoras Film*, 2016. <http://www.pythagorasfilm.com/xenoi.html>.
Swart, E. R. “The Philosophical Implications of the Four-Color Problem.” *The American Mathematical Monthly* 87, no. 9 (November 1980): 697–707.
Taaffe, Philip. “With Stan Brakhage.” In *Stan Brakhage: Interviews*, edited by Suranjan Ganguly, 130–45. Jackson: University Press of Mississippi, 2017.
Taylor, Richard. “Ideology as Mass Entertainment: Boris Shumyatsky and 193 Soviet Cinema in the 1930s.” In *The Film Factory : Russian and Soviet Cinema in Documents*, edited by Richard Taylor and Ian Christie, translated by Richard Taylor, 193–216. Cambridge: Harvard University Press, 1988.
Thomas, Robin. “An Update on the Four-Colour Theorem.” *Notices of the American Mathematical Society* 45, no. 7,

(August 1998): 848–859.
Thuijs, Stijnie. “Book Review: Enfoldment and Infinity by Laura U. Marks.” *Masters of Media*, September 21, 2011. <https://mastersofmedia.hum.uva.nl/blog/2011/09/21/book-review-enfoldment-and-infinity-by-laura-u-marks/>.
Tolstoy, Leo. *What is Art?* Translated by Richard Pevear and Larissa Volokhonsky. London: Penguin, 1995.
Trilling, Lionel. “The Leavis–Snow Controversy.” In *The Moral Obligation to Be Intelligent: Selected Essays*, edited by Leon Wieseltier, 402–26. New York: Farrar, Straus, Giroux, 2000.
Tscherkassky, Peter. “Lord of the Frames: Kurt Kren.” Translated by Elizabeth Frank-Groeßbne. *Millennium Film Journal* 35/36 (Fall 2000): 146–52.
Turnock, Julie A. “Plastic Reality: Special Effects, Art and Technology in 1970s U.S. Filmmaking.” PhD diss. University of Chicago, 2008.
Tymoczko, Thomas. “The Four-Color Problem and Its Philosophical Significance.” *The Journal of Philosophy* 76, no. 2 (1979): 57–83.
Vamvacas, Constantine J. *The Founders of Western Thought: The Presocratics : A Diachronic Parallelism between Presocratic Thought and Philosophy and the Natural Sciences*. Translated by Robert Crist. Berlin: Springer, 2009.
Verostko, Roman. “The Algorists.” 2014. <http://www.verostko.com/algorist.html>.
Vertov, Dziga. “Kino-Eye to Radio-Eye.” In *Kino-Eye: The Writings of Dziga Vertov*, edited by Annette Michelson, translated by Kevin O'Brien, 85–92. Berkeley: University of California Press, 1984.
Vogel, Amos. *Film as a Subversive Art*. New York: Distributed Art Publishers, 2005.
Voris, Linda. “'Shutters Shut and Open': Making Sense of Gertrude Stein's Second Portrait of Picasso.” *Studies in American Fiction* 39, no. 2 (November 8, 2012): 175–205.
Weaver, Warren. “Recent Contributions to the Mathematical Theory of Communication.” In *The Mathematical Theory of Communication*, 1–28. Urbana: University of Illinois Press, 1998.
Weiss, Allen S. “Frampton's Lemma, Zorn's Dilemma.” *October* 32 (Spring 1985): 119–28.
Weyl, Hermann. *Symmetry*. Princeton: Princeton University Press, 1952.
Whelan, Robert, and Robert Whelan, eds. “Introduction: Any Culture At All Would Be Nice.” In *From Two Cultures to No Culture: C. P. Snow's “Two Cultures” Lecture Fifty Years On*, 1–30. London: Civitas, 2009.
Whitney, John (Sr.). *Digital Harmony: On the Complementarity of Music and Visual Art*. Peterborough: Byte Books, 1980.
———. “Notes on Permutations,” *Film Culture,* No. 53-54-55 (Spring, 1972): 78.
Wieland, Joyce. “Notes on Reason Over Passion.” *Canadian Journal of Film Studies* 15, no. 2 (2006): 123–24.
Wiener, Norbert. *The Human Use of Human Beings*. Boston: Houghton Mifflin Company, 1950.
Wilde, Oscar. “The Decay of Lying.” *Nineteenth Century* 25 (January 1889): 35–56.
Yang, Andrew. “Second Laws, Two Cultures, and the Emergence of an Ecosystem Aesthetics.” *Interdisciplinary Science Reviews* 40, no. 2 (June 1, 2015): 168–81.
Youngblood, Gene. *Expanded Cinema*. New York: Dutton, 1970.
Yuan, Ya-xiang. “Jiu Zhang Suan Shu and the Gauss Algorithm for Linear Equations.” *Documenta Mathematics* Optimization Stories (2012): 9–14.
Yudkin, Michael. “Sir Charles Snow's Rede Lecture.” In *Two Cultures?: The Significance of C.P. Snow*, 31–45. London: Chatto & Windus, 1962.
Zach, Richard. “Hilbert's Program.” *The Stanford Encyclopedia of Philosophy*, Spring 2016. <https://plato.stanford.edu/archives/spr2016/entries/hilbert-program/>.
Zeilberger, Doron. “Theorems for a Price: Tomorrow's Semi-Rigorous Mathematical Culture.” *Mathematical Intelligencer* 16, no. 4 (Fall 1994): 11–14.
Žižek, Slavoj. *Organs without Bodies: Deleuze and Consequences*. New York: Routledge, 2004.
Zryd, Michael. “Found Footage Film as Discursive Metahistory: Craig Baldwin's Tribulation 99.” *The Moving Image* 3, no. 2 (November 6, 2003): 40–61.
———. “Hollis Frampton's Comic Inventory: Parables of Photography and Totality in *Magellan.*” Work-in-progress presented at ProprioMedia: Colloquium Series in Media Studies at OCAD University in Toronto, Ontario on October 24, 2014.