Order and Chaos:
Approaching Modern Dance Choreography in America
Through a Mathematical Lens

by

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Class of 2013

A thesis submitted to the
faculty of Wesleyan University
in partial fulfillment of the requirements for the
Degree of Bachelor of Arts
with Departmental Honors in Dance

Middletown, Connecticut        April, 2013
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ACKNOWLEDGEMENTS

This thesis was conceived, rooted, and expanded by the guidance and questioning of several individuals, all of whom have offered valuable insight and inquiry along the way.

First and foremost, I offer my sincerest gratitude to Susan Lourie for her endless support and honorable patience as my thesis adviser. Without her guidance and questioning, I would not have been able to tackle this subject.

Thank you to Katja Kolcio for giving me the foundations I needed to begin this research and for giving me the space I needed to explore. Thank you to Nicole Stanton for teaching me what it means to really see and to Pedro Alejandro for inviting me into the wonderful world of dance at Wesleyan.

A sincere thanks to Michele Olerud for all of her time and energy spent on our thesis productions and for putting up with the chaos that always seems to precipitate last minute. To Patricia Beaman, Urip Sri Maeny, and Idrissu Saaka, thank you for welcoming me into your space and planting the seeds for this research. A huge thanks to my mechanical and technological superheroes: Charlie Carroll, Suzanne Sadler, and Bob Russo. Thank you for all of your help and tolerance in building my grid, hanging the projector, and setting up the video screen.

A special thanks to my fellow dancers: Lindsay Kosasa, Matt Carney, Kate Finley, Caleb Corliss, Jonathan Sung, Judy Lee, Emily Pfoutz, Naya Samuel, Louis
Lazar, and Zach Libresco. Your creative souls and dynamic bodies have inspired me and opened up the doors to endless possibilities. I am forever grateful to Christian McLaren, Melanie Hsu, Evan Okun, and Sam Friedman for your creative collaborations and inspiration for my work.

Last, but certainly not least, thank you to my family for always supporting me in my endeavors. Even my most absurd explorations were conceivable in your eyes. Thank you.
I find my needs cannot be wholly satisfied by one art.
I like to mix my magics.

- Alwin Nikolais
INTRODUCTION

The concept behind this research began with an interest in two distinct worlds: a structured, mathematical one and an unrestricted, movement one. Individually, these two worlds take on discrete identities well understood by those who study them. When placed together, however, they connect in a way unclear to most. Through this research, my goal is to better understand the connection these two worlds share. How do mathematical structure and order apply to creative and free movement? How does chaos play a role in an ordered world of mathematics as well as dance? Is there a way to connect science and art in a less abstract matter?

The initial interest in this topic stemmed from a desire to understand science and art as one. As a young girl, I was preoccupied with the arts as both a dancer and a gymnast. I was enrolled in ballet class, as well as hip-hop and jazz, and trained in gymnastics at least three days a week. I surrounded myself with music, dance and free expression of the body. In school, nevertheless, I excelled in my math classes and often found myself solving puzzles or logic problems in my spare time. While I was unaware of the evident connection between math and the arts at that time, I somehow understood that there was an innate reason why I would be interested in both problem solving and dance.

As a double major in mathematics and dance, I often found myself connecting these two fields unconsciously. What I viewed as a normal bond between the two was deemed unnatural to most people, even those in either one of the fields. In the fall of 2011, I took a class cross-listed in both music and computer
science. As a student in Professor Ron Kuivila’s and Professor James Lipton’s Composing, Performing, and Listening to Experimental Music class, I was able to see the connection between mathematical structures and experimental music composition. Without hesitation, I understood and dove into the material as the two overlapped. The computational, mathematical thinking on one side allowed me to enhance my visual, aural, and temporal experiences of listening to experimental music.

Noticing that my intrinsic interest in both math and dance was rather unique, I began to research the distinction between sciences and the arts. Science, viewed as a factual practice in search of understanding the world’s truths, differs greatly from the arts, a practice of fiction and creativity in search of understanding the internal layers of the world and of ourselves. I began to see how prevalent this distinction was in our own society and how this practice of labeling has separated the two fields more than it has helped to connect the two. If we did not label our learning into categories, specifically the sciences versus the arts, would it be easier for us to make the connection between the two areas? How can the truths of our world relate to or influence our own creativity and vice versa? How connected are the two in actuality?

In this research I will explore the field of mathematics, its history and concepts of space, time and energy, in relation to how it influences, inspires, and deciphers the creative process of modern dance choreography. My focus is on modern dance in America, over other classical dance forms such as ballet, because
there is a greater challenge here. Modern dance formed as a refutation of classical
dance, rejecting its notions of structure, order, and overt clarity. Understanding how
mathematics, a field that studies quantity, structure, space and change, relates to an
expressive, free-movement form is not as straightforward as understanding how it
relates to a very structured one.

Through this research, I will explore the ways in which structure and order
allow for creative processes to flourish, starting from the very beginning. I will look
at the history of both mathematics and modern dance to ground each field for
further exploration. Through this research, I will strive to understand how, if at all,
mathematical structures are present in an artistic field where mathematics is often
avoided. How can connecting these two fields help either mathematics or dance
advance in the future? By drawing a connection between the two, I hope to diminish
the fears many mathematicians may have of dance as well as the fears many
dancers may have of math. By bridging the gap between the two fields, modern
dance choreographers may then have a stronger sense of what methods they can
employ to reach certain goals in their own choreography. By recognizing these
methods, one can begin to alter these techniques to best utilize space, time and
energy in their own creative works.

For the purpose of this research, most of the comparisons made between the
modern dance world and the world of mathematics will be in terms of geometry,
algebra, and mathematical systems. Chapter One will explore the history of
mathematics as a study and as a language. Chapter Two will investigate the history
and development of modern dance language. Chapter Three will bridge the two languages together in an exploration of how space and time are choreographed using mathematical structures. In Chapter Four I will briefly examine chaos theory in relation to dance forms with the least amount of structure, i.e. dance improvisation. Finally, in Chapter Five I will explain my own process using mathematical concepts as choreographic tools for both of my semester’s works.
CHAPTER ONE

An Introduction to Basic Math Structures & Mathematical Language

“Many people think mathematics is the mechanical pursuit of solving equations. In truth, mathematics is an artistic pursuit.”

(Burger and Starbird, viii)

In order to begin this investigation of mathematics in modern dance, I must explain what I mean when I say “mathematics.” The Merriam-Webster dictionary states that mathematics is “the science of numbers and their operations, interrelations, combinations, generalizations, and abstractions and of space configurations and their structure, measurement, transformations, and generalizations.” Richard Courant and Herbert Robbins, two prominent American mathematicians, express that “Mathematics as an expression of the human mind reflects the active will, the contemplative reason, and the desire for aesthetic perfection.”\(^1\) Mathematics is nothing more than a desire to understand and order the world in which we live. While it may often seem that the study of mathematics is rather straightforward and universally received, it, in fact, has no generally accepted definition.

\(^1\) Courant, Richards and Herbert Robbins. *What is Mathematics? An Elementary Approach to Ideas*
The word “mathematics” stems from the Greek word μάθημα, meaning, “what one learns, what one gets to know.” In about 2000 B.C., recorded mathematics began in the Orient where the Babylonians researched and defined concepts that today would be classified as elementary algebra. A more modern approach to mathematics emerged in later years, during the fifth and fourth centuries B.C. due to increasing contact between the Orient and the Ancient Greeks. The philosophical discussions that flourished in Ancient Greece at the time influenced many mathematical concepts ranging from continuity, motion, and infinity, to the problem of measuring random quantities by given units. One of the most important aspects of Greek mathematics, however, dealt with the application and connection of physical reality to mathematics rather than strict presentation of the material. The Athenians, for example, were taught music and gymnastics at a very early age before learning any form of mathematics in order to achieve both mental and physical graceful perfection. This aspect of Greek mathematics will prove to be very important in later chapters as we look at the physical reality of dance and movement and how mathematical concepts may influence our mental and physical “graceful perfection.”

In 518 BC in Croton, Pythagoras set up a school where the science of numbers was explored and many advances in geometry were made and discussed. The science of numbers explored such things as “perfect, abundant and square

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2 Ibid.
numbers and their properties” and developed into a belief that all things in the world and universe can in some manner be expressed mathematically. It is interesting to note that at Pythagoras’s school, music came to be considered as one of the Mathematical Sciences and was incorporated into the school’s curriculum.

Plato’s Academy, which lasted from about 387 BC to 529 AD when Emperor Justinian I finally closed it down, took a very different approach to the study of mathematics from Pythagoras’s school. Since Plato’s Academy was set up to educate the future politicians and statesmen of Athens, Plato proposed that mathematics be considered the basis of knowledge from which to move into philosophical thought and should be studied for the first ten years of a student’s education. Plato believed that studying mathematics would train the mind to understand relations that cannot be demonstrated physically. He also encouraged his students to train in mathematics in order to understand logical thinking, the most precise and convincing kind of thinking.

While it would be extremely strenuous to look at the precise development of mathematics throughout this era, it is important to note how differently mathematics developed in various parts of the world during this time period. For example, by 3000 BC the Egyptians had already developed their hieroglyphic writing, which gave way to a hieratic script for both writing and numerals. Unlike the Greeks

\[4\] Ibid.
\[5\] Ibid.
and their abstract thinking in mathematics, the Egyptians were explicitly concerned with practical arithmetic and devised systems on how to multiply and divide using addition. Due to their need for trade, the Egyptians needed to be extremely practical in their approach to mathematics and were required to deal in fractions as well. In order to keep track of the flooding of the Nile, the Egyptians kept careful records of the position of the star Sirius in relation to the position of the sun, using some knowledge of angles and trigonometry to do so.\(^7\) In addition, the building of the pyramids proved to incorporate many mathematical concepts dealing with trigonometry and the use of pi and the golden ratio.\(^8\)

Unlike mathematics in Ancient Greece and Ancient Egypt, the development of mathematics in China took another very different route. Chinese mathematics differed from the abstract and philosophical view of Greek mathematics in that it was incredibly concise and problem based. Mathematics in China was motivated by problems of the calendar, trade, land measurement, architecture, government records, and taxes.\(^9\) The Chinese developed the use of counting boards by the fourth century BC in order to effectively calculate using decimal places. It is interesting to

note that the Chinese were the only ones to have used counting boards at this
time.\textsuperscript{10}

Despite the differences in the development of mathematics throughout the
world, it wasn’t until the seventeenth century that the revolution in mathematics
truly began with analytic geometry and differential and integral calculus.\textsuperscript{11} Greek
geometry held an important place in this revolution but their model of “axiomatic
crystallization and systematic deduction” dissolved in the seventeenth and
eighteenth centuries.\textsuperscript{12} New pioneers in mathematical science began to use more
intuitive speculation and persuasive reasoning along with “a blind confidence in the
superhuman power of formal procedure” in order to revolutionize the science of
mathematics throughout the world.

Prior to the revolution in mathematics, Euclidean geometry was what most
philosophers and mathematicians in the Middle East believed was the language of
mathematics. Euclidean geometry, the geometry of the Ancient Greeks, was one of
the only forms of mathematics that developed axiomatically at the time. The Ancient
Greeks were the first to use axiomatic thinking: “knowing this is true, we can prove
that is true.”\textsuperscript{13} In his most famous work \textit{Elements}, Euclid of Alexandria (330 BC? –
275 BC?) proposes a discussion of geometry with a list of undefined terms and

\begin{itemize}
\item \textsuperscript{10} Ibid.
\item \textsuperscript{12} Ibid.
\end{itemize}
definitions followed by a set of axioms and postulates.\textsuperscript{14} These axioms and postulates describe the basic properties of geometry and illustrate the basic relations that exist among the defined and undefined terms. Together, these form the logical framework of Euclidean geometry. In my research, I have found that this logical framework can also be applied to dancers using axioms and postulates to discover new ways to move, improvise, or improve technique. Dancers have all the material they need but require deductive reasoning to discover new approaches to finding material. As Euclid used axioms and postulates to deduce new and nonobvious conclusions, dancers can also use what they already know to reveal unexpected consequences of old axioms and postulates.

In *Elements*, Euclid states his basic terms and definitions, axioms, postulates, and common notions in a series of thirteen books. In Book I, Euclid states “a point is that which has no part, a line is breadthless length, the extremities of a line are points, a straight line is a line which lies evenly with the points on itself, a surface is that which has length and breadth only, the extremities of a surface are lines...”, etc.\textsuperscript{15} Euclid defines that which we know in order to delve deeper into the world of mathematics. His work in the development of mathematics altered geometry from a “purely utilitarian mental device to an abstract mental pursuit, governed by its own

\textsuperscript{14} Ibid.

principles."\textsuperscript{16} Euclidean geometry remained the center of mathematical thought until the last decades of the 19\textsuperscript{th} century.\textsuperscript{17}

Geometry, unlike almost all other branches of mathematics, must be integrated into the laws that govern the universe. As a result, "geometry is a natural law just like the laws of motion of a body."\textsuperscript{18} Almost all geometrical concepts serve as a framework for how we view space. For example, points, distances, directions, lines, surfaces, volumes, etc. influence the way we understand and move through space. We see space as consisting of points and describe all geometrical shapes in terms of points. As a dancer and choreographer, I am drawn to this comparison, noting how I choreograph seeing dancers as points in space. In his work, Euclid determined that a single point cannot be defined in space and is thus an abstract concept.\textsuperscript{19} Since a single point cannot be isolated in space, it is clear to see that space is continuous. Geometric continuity became the basis of Euclidean and modern geometries.

From the birth of geometry, came the origination of several other branches of mathematics, including arithmetic and algebra. Geometry, in its simplest form, requires the addition of arithmetic to points on the plane. Simply put, geometry requires a two-dimensional manifold so that describing the position of any point on

\footnotesize
\begin{itemize}
  \item \textsuperscript{17} Tabak, John. \textit{Beyond Geometry: A New Mathematics of Space and Form}. New York: Facts On File, Inc., 2011, xvii.
  \item \textsuperscript{18} Motz, Lloyd and Jefferson Hane Weaver. \textit{The Story of Mathematics}. New York: Plenum Press, 1993, 7.
  \item \textsuperscript{19} Ibid, 7-8.
\end{itemize}
the plane requires two coordinates.\textsuperscript{20} This aspect of geometry especially pertains to modern dance choreography as we view dancers’ positions in terms of coordinates with respect to the audience, wings, walls, etc. Since geometry grew to depend on numbers and addition of points in space, arithmetic and algebra began to develop as open-ended mathematical tools that were governed by a few rules and definitions but not by a body of axioms.\textsuperscript{21} Arithmetic, initially, only dealt with integers and signified quantity but soon expanded into the “realms of fractions and irrational and complex numbers, and became associated with order, organization, and information.”\textsuperscript{22} Algebra, similar to arithmetic, expanded into algebraic expressions of letters as well as numbers, but it also developed even further in its application to logic and language in a form called “Boolean algebra, after the nineteenth century mathematician George Boole.”\textsuperscript{23} The birth of arithmetic and algebra drove the world of mathematics into an entirely new direction, allowing many others to see the essence of mathematics as “the study of relationships between objects that are only (voluntarily) known and described by some of their properties, precisely those that are put as axioms at the foundations of their theory.”\textsuperscript{24}

With the development of geometry, arithmetic, and algebra came the growth of new and abstract mathematical forms. From there, geometry, together with algebra, gave birth to trigonometry, analytic geometry, calculus, and post-

\textsuperscript{20} Ibid.
\textsuperscript{21} Ibid.
\textsuperscript{22} Ibid.
\textsuperscript{23} Ibid.
Newtonian mathematics. Mathematicians were no longer concerned with numbers exclusively, but rather with objects, properties, values, relationships, and so on. They began to spend most of their time reasoning about abstract things rather than calculating with numbers.

In the earlier part of the twentieth century, mathematical research was driven by two specific demands made on the mathematician: “(1) the need of the mathematician himself to place mathematics on a flawless, logical base and to free it of all inner contradictions and philosophical inconsistencies and (2) the demand of the theoretical physicists for the advanced mathematics they required for the proper development of their physical theories.” With the start of this new-age mathematical evolution, mathematicians began to view the world and universe in mathematical systems.

For the purpose of this research, I will focus on one aspect of the evolution of modern mathematics, specifically the study of chaos. In later chapters, I will explain what the study of chaos is as well as how it developed from observations of dynamical systems, such as binary stars or planetary systems.

Mathematics is a language, a compositional one, where its semantics are precisely defined and unambiguous. Its complete lack of ambiguity enables exact reasoning. However, despite the concrete nature of mathematical language, the structure itself allows for us to understand more complex and abstract systems.

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Mathematics allows us to understand relationships in time and space and gives us the proper framework to apply these structures elsewhere.
CHAPTER TWO

An Introduction to Modern Dance in America

In the previous chapter, I explored the development of mathematics as a compositional language. In this chapter, I will explore the development of another language: the embodied language of dance. Languages develop over time and continue to change phonetically, morphologically, semantically, syntactically, etc. Just as any language can acquire an influx of new words, change spelling, pronunciation, and meaning of words, so too can dance. Twentieth century modern dance, specifically, is one leading example of dance as an embodied language.

John Martin, a renowned dance critic of The New York Times, stated in 1933 “the modern dance was a point of view.”26 In other words, he believed that modern dance externalized, projected, and communicated a personal, authentic experience. In America, modern dance was conceived and rooted by three prominent figures: Loïe Fuller, Isadora Duncan, and Ruth St. Denis. All three of these women had been attracted to a style of dance that allowed a freedom of expression not found in contemporary ballet.27 They objected to the rigid structure of ballet, the artificiality of the classic technique, the superficiality of the themes, and the frivolity of its current aims.28 With their curiosity and perseverance, these women became the early predecessors of modern dance in America.

27 Ibid, 5.
28 Ibid, 5.
Loïe Fuller, a pioneer of modern dance and theatrical lighting techniques, was born in Fullersburg, Illinois on January 22, 1862. Having had no formal dance experience, Fuller gained her movement experience as an actress, playwright, singer, dancer, and producer from 1865 to 1891. In 1891, Fuller created one of her most famous works titled The Serpentine Dance, a solo piece whose effects were influenced by long trains of a silk skirt. Fuller then visited Paris in 1892 where she became a huge success from the night of her debut at the Folies-Bergère. Fuller continued making dances and using special effects where voluminous folds of silk costume were viewed from colored theatrical lighting. Her work was revolutionary not only in the field of dance, but also in the field of dramatic lighting. At the time, only scientists had begun studying light refraction and electric lighting had just come into use in theaters. Loïe Fuller invented new pieces of theatrical lighting equipment and always traveled with a large group of technicians. She constantly toured abroad as well as in the United States and was embraced as a fellow revolutionary by Impressionists, Symbolists, and Art Nouveau movements. Around the turn of the twentieth century, Fuller turned from solo pieces to group works and, in 1908, founded a school of dance. Although neither her works nor school lasted that long, Fuller’s impact on the dance world was profound. Loïe Fuller

revolutionized the way lighting and costume were used in dance and theater and her contributions to the arts opened up new doors for dance in America.

Isadora Duncan was born on May 26, 1877 in San Francisco, California. As a child, Duncan studied ballet, Delsarte technique and burlesque forms like skirt dancing. Her professional career began in Chicago in 1896 where she joined the troupe of Agustin Daly as an actress. In 1897, her family relocated to London where she studied ancient Greek art and danced as a solo performer at a number of society functions. In 1898, Duncan returned to New York City where she began dancing solo works at the homes of wealthy patrons and in art galleries. Her first professional appearance came in 1903 at the Theatre Sarah Bernhardt in Paris. The next year, Duncan toured Russia where she came into contact with Michel Fokine and is rumored to have influenced his own choreographic innovations.

In 1905, Isadora and her sister Elizabeth opened up a school for 40 children in Grünewald, near Berlin, which was then moved to Paris in 1908. Duncan left most of the teaching to others, but supported the school’s finances with her personal performance income. Duncan created a variety of works dealing with fierce libertarian beliefs and influenced by the passions and tragedies of her own life. In 1913, Duncan tragically lost her two children in a drowning accident and created two well-known pieces of this period titled Marseillaise (1915) and the Marche Slave.

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33 A technique derived from French theoretician François Delsarte who reasoned linking of the body’s postures and gestures, the heart’s emotions, and the mind’s thoughts to help dancers dignify the body and make it a vehicle for complex expression


35 Ibid.
(1916), both of which portrayed the resilience of the human spirit in the face of adversity.\textsuperscript{36} Isadora Duncan died in Nice September 14, 1927.

Beginning her life of dance having only taken ballet classes, Duncan felt restricted by the rigid structure and did not believe the human body was meant to move in such unnatural and constricting ways. Duncan created her own movement vocabulary inspired by the movements of trees and waves, ancient Greek sculpture, and the writings of Nietzsche and Havelock Ellis.\textsuperscript{37} Her simple, flowing movements represented the rhythms of nature and the greater emotions of man.\textsuperscript{38} Duncan freely expressed herself through movement by focusing on the source of all movements, i.e. the solar plexus, and, unlike ballet, she moved in a way that acknowledged the body’s weight and gravity. She often danced barefoot and barelegged, wearing loose, filmy tunics, and paired her dances with classical music, something that seemed highly inappropriate at the time.

Isadora Duncan’s “free movement” works continued revamping the art of dance even after her death with the help of her many followers. The “Isadorables” (six of Duncan’s pupils who staged Duncan-style performances) continued to teach her ideas and movement even after her death. Her legacy continues to live on through current modern dance works and at the Isadora Duncan International Institute and Isadora Duncan Dance Foundation. Her work in dance was extremely instrumental in planting the seeds for the modern dance movement by creating a

\textsuperscript{36} Ibid.
\textsuperscript{38} Ibid.
form of movement that allowed freedom of expression not found in contemporary ballet.

Along with Isadora Duncan, another influential member of the free movement era was Ruth St. Denis. Born in Somerville, New Jersey January 20, 1879, Ruth St. Dennis was an American dancer, teacher, and choreographer who is considered to be one of the pioneers in American modern dance. Her dance career began in the music hall, studying mime, social dance, and recitation with her mother. What inspired her most, however, was the Orient, where the religious view of dance gave her room to further develop her own spiritual values of the art. While the ethnic authenticity of her works was always suspicious, it was expressive of themes perceived by St. Denis in Oriental culture and proved entertaining to its audience members. St. Denis made a variety of exotic dances from a ‘Hindu’ ballet titled *Radha* (1906) to an Egyptian-inspired dance titled *Egypta* (1910). Despite her commercial appeal, St. Denis aspired to a more profound moral significance in her work and insisted on the ability of dance to deal with thoughtful ideas and emotions. Her solo works often centered on “the drama of spiritual awakening or the beauty of the inner life.”

In 1914, Ruth St. Denis married Ted Shawn, a distinguished dancer, teacher and choreographer at the time, and in 1915, the two opened up the Denishawn

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39 Ibid, 390.
42 Ibid.
Dance School in Los Angeles, California. At Denishawn, dancers learned various styles of dance including oriental, primitive, and German modern dance, and put on major productions including *A Dance Pageant of Egypt, Greece and India* (1916) and Gluck's *Orpheus and Eurydice* in 1918. Denishawn disbanded after St. Denis and Shawn separated in 1931, but the company gave birth to the careers of many early modern dance pioneers including Jack Cole, Doris Humphrey, Martha Graham, and Charles Weidman.

Like Fuller, Duncan, and St. Denis, Doris Humphrey, Martha Graham, and Charles Weidman each yearned to externalize personal, authentic experience; however, unlike their predecessors, the second generation of modern dance was more concerned about contemporary ideas and issues than past civilizations and beauty. Whereas Isadora Duncan and Ruth St. Denis took a sweet and light approach to rejecting contemporary ballet and finding their own freedom of expression, this second coming of modern dancers in America was more harsh in their tactics and hoped to portray not only the good in man, but also the depths of terror, hostility, guilt, anguish, and remorse.

Doris Humphrey, born in Oak Park, Illinois on October 17, 1895, began studying dance at the Francis W. Parker School in Chicago and was teaching ballroom dance by 1913. By 1917, Humphrey became a member of the Denishawn Dance School in Los Angeles and was taken into the company where she danced

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43 Ibid, 390-391.
until 1928. When she left Denishawn in 1928, Humphrey had already begun to
explore a new style and had developed a fundamental theory of movement that
soon became the foundation of her technique. Along with Charles Weidman,
another Denishawn dancer who left around the same time, Humphrey founded the
Humphrey-Weidman Dance Company in New York. Both dancers taught,
choreographed, and performed together for the next sixteen years. After suffering
from severe arthritis, Humphrey retired in 1944 but continued to work as a teacher,
choreographer, and artistic director for José Limón’s dance company. In addition to
her work for her own company and for José Limón’s, Humphrey joined the staff of
Bennington School of Dance and continued to teach there and at the Julliard School
until her death in 1958. Humphrey was the author of The Art of Making Dances and
‘New Dance’, both of which set forth her choreographic methods and were
published shortly after her death.

After leaving Denishawn in 1928, Doris Humphrey was able to expand her
own movement vocabulary and style to better fit the nature of the late 1920s.
Humphrey wished to find a vehicle of expression for contemporary ideas and
remarked that “the dancer should not be ‘concerned entirely with the graceful line
and the fine, animal ease’ that technical study provided; ‘he should also be
concerned with his existence as a human being played upon by life, bursting with

44 Ibid, 222-223.
45 Brown, Jean Morrison, Naomi Mindlin, and Charles H. Woodford, eds. The Vision Of Modern
opinions and compulsions to express them.”  
Humphrey looked toward the basic sources of movement to best portray the feeling of the mid-1900s. She viewed the body in relation to space, an idea that will later on lead into our connection of mathematics with dance. Humphrey saw movement as the body’s way of contrasting the pull of gravity and developed a technique of fall and recovery. She believed that dance “existed in ‘the arc between two deaths’,,” between static positions of standing and that of lying still and focused on the conflict of man with his environment. Humphrey created a variety of works both at Denishawn and in her own company that were both abstract and dramatic, dealing with present issues and communities. Some of her most famous works include Drama of Motion (1930), Water Study (1928), Life of the Bee (1929), The Shakers (1931), and the trilogy New Dance (1935-6). Humphrey’s contribution to modern dance in America was immeasurable and her work expanded this present revolution in dance.

Like other pioneers in modern dance, Charles Weidman, born in Lincoln, Nebraska in 1901, began dancing and choreographing at a time of great change in America. Weidman began his career in dance in 1921 when he joined the Denishawn Dance School. As a member of the company, Weidman frequently performed as Martha Graham’s partner, but his most lasting collaboration occurred with Doris Humphrey. After the two left Denishawn and formed their own school and company in 1928, Weidman began choreographing a variety of works best know for their

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satirical and whimsical comedies.\textsuperscript{49} Wanting to create a form of dance that was more unique to America, Weidman worked with Humphrey to choreograph an assortment of pieces that dealt with American social themes. Some of Weidman’s works include \textit{And Daddy Was a Fireman Too} (1943), \textit{New Dance} (1935), \textit{A House Divided} (about Lincoln, 1945), \textit{Fables for Our Time} (after Thurber, 1947), and \textit{Is Sex Necessary?} (1959).\textsuperscript{50} In addition to his work for the Humphrey-Weidman Dance Company, Weidman also choreographed for several Broadway shows, the New York City Center Opera, and for his own company. In 1960 he founded the Expression of Two Arts Theater in New York with the sculptor Mikhail Santaro where he kept alive his old works and choreographed new ones for his pupils, including José Limón and Bob Fosse.\textsuperscript{51} Weidman’s dedication to developing a form of dance more unique to America laid the foundation of modern dance in America and influenced many young, especially male, dancers to do the same.

While Doris Humphrey and Charles Weidman were viewed as two of the main pioneers in modern dance in America, the most far-reaching of them all was Martha Graham. Born in Allegheny, Pennsylvania in 1894 and raised in Santa Barbara, California, Martha Graham had a remarkably strong mother who encouraged her to become a dancer. Graham began studying at the Denishawn school in 1916 and by age 22, she joined the Denishawn company. At Denishawn,
Graham worked closely as a performer with Ted Shawn after receiving little attention from St. Denis. In 1923, Graham left the Denishawn company to join the Greenwich Village Follies from 1923 to 1925. She also began teaching at the Eastman School of Music in Rochester, New York. On April 18, 1926, Graham gave her first independent concert where she had eighteen dances on the program, performed by three other women and her. A year later she founded the Martha Graham School of Contemporary Dance, which became the leading school of its kind. The technique taught at the school was Graham’s unique style of movement, consisting of movement generated by the lower back and pelvis and focused on the importance of breath. From this technique, Graham developed her main method of movement known as contraction and release. Graham’s revolutionary choreography was inspired by strong, dynamic women of history and literature and often featured earthbound dynamic and angular shaping. 

Martha Graham expressed that the function of dance is to make apparent again the hidden realities behind accepted symbols. In order to do this, an art must make new symbols that allow us to see the truth behind present symbols. Although they may be intimidating and strange at first, these new structures allow us to find truth and reality in previously accepted notions. In her works, Graham created new structures to break what was previously accepted. Her company, which was born out of her school, was an all-women ensemble until 1944. Their first performance

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52 Ibid, 196.
53 Ibid, 196.
was in 1929 and they toured internationally from the 1950s. Graham’s predominantly female troupe portrayed strength and determination in the variety of works she choreographed, including *Primitive Mysteries* (1931), *Appalachian Spring* (1944), *Cave of the Heart* (1946), and *Steps in the Street* (1989). Graham’s choreography ranged from narrative, dramatic works that intensely explored interior worlds of their characters to humorous, lighthearted works that explored comedy and unusual lyricism. Overall, Graham choreographed a total of 181 works. She taught, and later danced with, an incredible cast of dancers and choreographers, including Bertram Ross, Eric Hawkins, Paul Taylor, and, most crucial to this research specifically, Merce Cunningham. She worked closely with musician Louis Horst and collaborated with many artists including Isamu Noguchi, Margot Fonteyn, Rudolf Nureyev and fashion designer Halston.\(^{55}\) Graham continued performing and choreographing until her late 70s and her works continue to live on in her company and in the works of several major ballet companies, including the Dutch National Ballet and American Ballet Theatre.

As one of the towering figures in twentieth century American modern dance, Martha Graham generated fearless choreography and technique that was groundbreaking at the time. She opened up new doors and endless possibilities for artists and dancers in the mid-1900s. Graham’s incredibly long career contributed to and established the idea of modern dance as a valid, independent art form and her

school and company provided the starting point for many of the major modern
dance choreographers who followed.
CHAPTER THREE

An Application of Mathematical Structures in Modern Dance

“...art changes because science changes – that is, changes in science give artists different understandings of how nature works.”

(Cage, 194)

Mathematics and modern dance, both uniquely defined languages and creative forms of communication, create a comprehensive understanding of physical space and our relationships to time, space, and energy. Their deep-rooted histories and specific trajectories give them the foundation needed in order to develop new ideas and enable perceptions of spatial relationships to evolve. As a compositional language, mathematics uses terms and definitions to serve as building blocks for abstract theorems and systems. Mathematics analyzes shapes and patterns in space with the use of symbols, values, variables, functions, and expressions. Modern dance, an embodied language, infuses these shapes and patterns in space within our bodies using various movement vocabularies, energies, and relations to space and one another. The two languages, though conceived, rooted, and expanded in drastically different ways, overlap in many. There is a deeper connection between the two fields that exists beyond the superficial links, such as counting beats and
steps or noticing clear patterns and shapes. This connection can be seen in the way mathematical concepts influence, inspire, and decipher modern dance.

To begin, I would like to analyze the ways in which mathematics and modern dance connect on a structural level. The language of mathematics, as discussed in Chapter 1, stemmed from Euclid’s *Elements*, which proposed a list of undefined terms and definitions followed by a set of axioms and postulates. Euclid’s use of definitions, in this case, implied more than a dictionary definition because it included operations as well. Spoken languages, more often than not, grow with the addition of new words, which must then be defined in terms of known words. Mathematics and modern dance, however, introduce as few definitions as possible so that new concepts emerge as the products of pure reasoning and logic.⁵⁶ In Euclid’s *Elements*, we are given precise definitions of a point, a line, a straight line, a surface, a plane surface, a plane angle, etc. From these definitions, we are able to build axioms, postulates, and theorems that form the foundation of a logical structure, such as geometry. Euclid’s introduction to axioms and their use “as a basis for the construction of a vast intellectual edifice such as geometry are among the greatest achievements of the human mind because they permit an infinitude of deductions or theorems.”⁵⁷

In modern dance, choreographers often use exploration to generate new movement vocabulary or technique. Martha Graham, for example, took a well-

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⁵⁶ Ibid, 9.
known term, “breath”, and used deductive reasoning and exploration to develop her own technique of contraction and release. Looking back at the origins of modern dance, we see that one reason it emerged as an art form was because it strayed away from classical forms, such as ballet. Ballet, which defined as many terms as possible and left little room for deductive reasoning, became stagnant in the eyes of many modern dancers. José Limón, a pupil of Charles Weidman, stated “It is dangerous for an art, however ‘classical,’ to become so rigid, so fossilized, as to lose the freshness, resiliency, and vigor of its original impulse.”

Euclid’s introduction to axioms and postulates served as a standard for logical reasoning and allowed many fields to develop using this framework. In many ways, modern dancers reveal unexpected consequences and deduce new and nonobvious conclusions by building off of previously defined terms and techniques to develop their own strategies for making movement.

**Integrating Geometry**

Using the language and structure of mathematics, we can further explore other mathematical concepts in order to understand how mathematics influences, inspires, and deciphers modern dance choreography. Geometry, unlike most creative art forms, is concrete by its very nature because it deals with the nature of mathematical space. As discussed earlier and in previous chapters, Euclidean geometry defined points in space, lines, angles, planes, distances, directions, shapes,

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etc. It gave meaning to the way we view and define space. In her book titled *The Art of Making Dances*, Doris Humphrey states “Every movement made by a human being, and far back of that, in the animal kingdom, too, has a design in space; a relationship to other objects in both time and space; an energy flow, which we will call dynamics; and a rhythm.” Humphrey clearly states that movement, specifically modern dance movement, has a design in space and a relationship to other objects in both time and space. The natural laws of geometry govern the way we view and utilize space.

Trisha Brown, for example, is a well-known modern and post-modern choreographer whose dances “are shaped by dreams of levitation, by geometry, enigma, physics, by memory, mathematics and geography, by language.” Born in rural Aberdeen, Washington in 1936, Brown immersed herself in wilderness environment, in dance, and in athletics. She attended Mills College in California where she studied modern dance technique and composition derived from the teachings of Graham and her musician, Louis Horst. Trisha Brown spent a lot of time experimenting and exploring with Anna Halprin, Simone Forti, Yvonne Rainer, Robert Whitman, Robert Rauschenberg and Merce Cunningham. She was a founding member of the Judson Church Dance Theater in 1962 and also of the improvisational company, Grand Union, in 1970.

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60 Ibid.
Brown’s choreography is famous for its ability to transcend physical limits and blur the line between intellect and instinct, present and past, abstract form and mythic form, and visibility and invisibility. In her choreography and experimentation, Brown reduced movement to its purest form and context. She choreographed a set of works from 1971 to 1975 that dealt with this simplicity and breakdown of movement. *Accumulation* (1971), *Group Primary Accumulation* (1973), *Accumulation with Talking* (1973), and *Group Primary Accumulation: Raft Version* (1974) each slice movement down to sparse gestures played out sequentially, following mathematical principles. Brown focused on the idea of sequencing in choreography and how accumulation, or addition, of specific gestures can create an entire movement phrase.

Although a majority of her work focused on stripping movement down to its purest form, Trisha Brown’s most prominent work in the field developed as a result of geometric, formal structures. In what some have even referred to as the “structural seventies,” Trisha Brown utilized conceptual and mathematical systems as the foundation for her choreography. From 1973 to 1976, Brown created a group of works titled *Structured Pieces*, including *Sticks*, *Solo Olos*, and *Figure 8*. These works, focusing on pure movement without narrative or emotional content, used formal mathematical structures and objects to portray geometric lines, sequencing and metric time. In *Sticks*, five women slide out from under long white

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poles held lengthwise, step over them, and slide back under them, all the while keeping the poles in contact with the heads or feet of the women. In Figure 8, five women use the ticks of a metronome to move along in unison through a long arrhythmic sequence of touching alternate hands to their heads. In her piece titled Solo Olos, the dancers learn three movement sequences that are then altered as one of the dancers calls out “reverse,” “spill,” or “branch.” Brown’s Structured Pieces present an overall formal consideration of geometric concepts with anatomical and spatial intention.

In 1983, Brown created what would become one of her most famous works: Set and Reset. As described on the Trisha Brown Dance Company website, “the seductively fluid quality of the movement in this Trisha Brown masterpiece, juxtaposed with the unpredictable geometric style has become the hallmark of Ms. Brown’s work.” Set and Reset explores improvisation within a set structure as dancers use a specific movement sequence to play with. Dancers were told to “act on instinct”, meet, interlock for an instant, pass on, guide by cueing, or line up. Timing, though flexible, plays an important role in the piece as bodies move on and off stage, weaving through one another, avoiding collisions and grasping split-second unisons. Using formal mathematical and geometrical structure, Brown successfully employs raw material, or movement, in a functional and objective way.

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Set and Reset “is a dance whose currents you feel kinesthetically as you watch; you feel it on your very skin, like running water.”

Brown created many works “looking at architecture... because that’s what’s there. That’s the environment. Not the stage. Not the studio.” Her dancer-objects became part of the architectural features of the piece, evoking a tangible connection between person and place. In her piece titled Locus (1975), Brown created a virtual room of an imaginary cube with its faces subdivided into 26 points for each letter of the alphabet. In the piece, dancers would gesture to each point with mechanical motions of the joints such as hinging, rotating, or leaning. The body in space created an anatomical structure of line and volume as the skeletal system articulated angles of 45, 90, and 180 degrees. Brown let go of the personal, internal qualities of her dancers and rather allowed for the structural language and space of grids, angles, and semaphore-like moves to animate the dance. Brown’s works placed movements and dancers as objects in time and space, filling her pieces with story and metaphor as well as clear signs of geometrics. In almost all of Trisha Brown’s works, dancers represent exactly what they are: objects in space.

In order to further understand this concept of objects in space, it is important to reflect on the specific notion of points in space, discussed in Chapter 1.

Geometry, as a natural law, describes points, lines, surfaces, volumes, directions,

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distances, etc. in space. We tend to view space as consisting of points and describe all geometrical shapes and configurations in terms of points in space. For example, plotting four points in space, all equidistant from one another, can form a square. In modern dance, we view dancers as points in space, whether as points on the stage, in the studio, or in an unconventional site. Regardless of the location of the piece, spatial arrangements are almost always taken into consideration and dancers are given a very specific starting point or end point. In Elements, Euclid determines that a single point cannot be defined in space and is, thus, an abstract concept. He reasons that because a single point cannot be isolated in space, space must be continuous. Many modern dance choreographers have explored this concept and experimented with the continuity of space and isolation of a single point in space.

Merce Cunningham, for instance, recognized as a defining twentieth century modern dance choreographer, initiated a controversial and eye-opening reinvestigation of time, space and compositional procedures. Born in Centralia, Washington in 1919, Cunningham studied tap, folk, and ballroom dancing followed by training in modern dance at the Cornish School of Fine Arts in Seattle, at Mills College, Oakland, California, and at the Bennington Summer School of Dance. In 1939 Cunningham joined the Martha Graham company where he danced for the next six years of his life. During his time in the company, Cunningham built close relationships with the musician John Cage. In 1944 he and Cage staged a joint concert at the Humphrey-Weidman Studio Theater in New York. Dance critic Edwin Denby, after attending the performance, noted that he had “never seen a first recital
that combined such taste, such technical finish, such originality of dance material, and so sure a manner of presentation." The concert’s ingenuity and creative collaboration was well received by its audience members and set the tone for one of dance and music’s most dynamic partnerships to come. By 1945 Cunningham left Graham’s company but continued working with Cage as his musical collaborator and adviser. In the following years, Cunningham gained followers and became an independent choreographer developing his own, unique style: one that combined lower-body aspects of ballet with free, mobile torso movements.

As Cunningham’s ensemble grew in numbers, his methods for choreography developed as well with a strong emphasis on dancer relationships to both space and to the audience. Throughout his career, Cunningham experimented with new creative methods and used technology to further enhance his choreographic goals. He was one of the first choreographers to use computer software to generate movement sequences on screen, which, in turn, assisted in increasing the complexity of action and stage pattering in his pieces. In his piece titled Trackers (1991), Cunningham created movement with the assistance of LifeForms, a computer choreographic software tool developed at Simon Fraser University.

69 Ibid, 72.
Cunningham continued to explore different facets of technology as sources for inspiration. In the latter part of his career, Cunningham choreographed works especially for the camera, exploring and expanding the possibilities of dance on screen. In his work titled Points in Space (video, dir. Elliott Caplan and Cunningham; mus. Cage, 1986), Cunningham plays with the audience’s view of center stage and alters the way we view continuity of a dance. Inspired by Albert Einstein’s assertion that “there are no fixed points in space,” Cunningham’s work challenged the way we view the stage space. Cunningham viewed space as an open field and, through his choreographic works, aimed to disrupt the convention of central focus on the stage. Realizing that space is continuous, as a single point cannot be defined in space, Cunningham began to view every point in the space as equally interesting and appealing to the audience. He choreographed Points in Space with the intention of changing the way we view “front” in modern dance. For Cunningham, the stage had four fronts, remaining open on all sides. Each dancer’s placement and positioning was as important as the next dancer’s and their bodies formed precise angles at varying heights. Having the dance on film allowed Cunningham to highlight these precise angles and differences in facing and spatial arrangements within the space.

In an interview with Jacqueline Lesschaeve, Cunningham states that by acknowledging Einstein’s assertion, he was able to open up “an enormous range of possibilities.” Instead of viewing dancers and movement sequences as concrete

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objects in space, Cunningham began to view movement as continuous throughout space and imagined numerous transformations. During his interview, Cunningham proclaims, “the space could be constantly fluid, instead of being a fixed space in which movements relate.”74 By acknowledging the dancers and their movements as continuous throughout space, Cunningham was able to create an original aesthetic, unlike that which was previously seen in modern dance. Points in Space successfully portrays this continuity of movement as dancers weave in and out of the camera’s view, allowing the viewer to feel as though space and time are continuous.

In addition to the basic foundation of geometry, one can also view geometric symmetry as a way of understanding modern dance choreography. According to the Merriam-Webster Dictionary, “symmetry” is defined as “balanced proportions; also: beauty of form arising from balanced proportions.” Additionally, symmetry can be defined as “a rigid motion of a geometric figure that determines a one-to-one mapping onto itself.” In other words, suppose you have a set A and a set B, both containing a set number of elements. In mathematics, one-to-one mapping means that no matter which element of set A you choose, it will always match up to one element of set B and only one. No two elements in set A can share the same element in set B. Additionally, a one-to-one mapping onto itself means that all elements in set A must match up to all elements in set B and no two elements in set A can share the same element in set B. While this may seem highly complex and

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wordy, all it really means is that symmetry takes an image and creates an image that is identical to the original.

Mathematical symmetry, specifically geometric symmetry, can be observed through geometric transformations but also with respect to the passage of time, as a spatial relationship, and as an aspect of abstract objects, theoretic models, language, music and knowledge itself. Dr. István Hargittai, author and professor of chemistry at the Budapest University of Technology and Economics, published a two-volume issue of the international journal *Computers and Mathematics with Applications: Symmetry: Unifying Human Understanding* in which he states that symmetry is not only “one of the fundamental concepts in science, but it is also possibly the best bridging idea crossing various branches of sciences, the arts, and many other human activities.”\(^7\) Hargittai’s assertion is based on the current practice of extending symmetry to the mathematical concept of isometrics. Within this framework, symmetry can be viewed as four transformations of a geometric figure that keep a one-to-one mapping onto itself: translations, rotations, reflections and glide reflections.\(^7\)

In modern dance, one employs symmetry in order to alter a movement phrase or spatial arrangement of a piece. Translations, the first kind of geometric transformation, slide an object in space by some variable \(t\), for which \(T_t(x) = x + t\). In

other words, given a point x in the space A, you can translate the image t-spaces by adding t to x.

![Translation of an image A](image)

**Figure 1. Translation of an image A**

Rotational symmetry, the second geometric transformation, is self-explanatory for the most part; it is symmetry with respect to some or all rotations in m-dimensional Euclidean space. For example, if we were to rotate the image below (Fig. 2) 120 degrees clockwise, we would wind up with an identical image.

![Rotational symmetry of 120 degrees](image)

**Figure 2. Rotational symmetry of 120 degrees**

Reflection symmetry, also known as mirror symmetry, mirror-image symmetry, or bilateral symmetry, is symmetry with respect to reflection about an axis. For example, looking at the two images below (Fig. 3), one can see that a reflection
about the y-axis (the vertical line) will allow the image to overlap. The overlapping of the butterfly’s wings proves that the butterfly is symmetrical along the y-axis.

![Butterfly Image](image)

**Figure 3.** Reflection symmetry of a butterfly about the y-axis

The final geometric transformation that concerns modern dance choreography in this research is a glide reflection. A glide reflection is a type of opposite isometry\(^77\) of the Euclidean plane that combines a reflection over a line with a translation along that line. In Figure 4 below, the triangle ABC is first reflected over the line \(\ell\) and then translated along the line \(v\) to form the new image \(A'B'C'\).

![Glide Reflection Diagram](image)

**Figure 4.** Glide reflection of triangle ABC along lines \(\ell\) and \(v\)

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\(^{76}\) Isometry is a transformation that is invariant with respect to distance; i.e. the distance between two points in the pre-image must be the same as the distance between the two points after the transformation of the image.
Using these four symmetries – translation, rotation, reflection, and glide reflection – one can create what is called the Klein four-group \((Z_2 \times Z_2)\) by combining all symmetries. For example, if a dancer were to start off with a mirror reflection and then a rotation of 180 degrees, they would end up in the same position as if they had simply applied a glide reflection to their original position. Combining any of these four symmetries will result in at least one of the original symmetries. Recognizing the existence of this Klein four-group is surprisingly relevant to modern dance choreography in that it allows a choreographer to envision where a dancer may end up given specific transformations. It also allows a choreographer to list all the different possible transformations a dancer could encounter given specific instructions. While dancers may not use this terminology in rehearsals, it is important to practice performing symmetries to see the various outputs of combinations. When a choreographer says, for example, “now do the same thing but on the other side,” or “reverse it,” or “face another way,” or “start two steps behind”, etc. a dancer will understand how their transformation will affect their overall position at the start and end of the phrase.

In their research on the ways in which dance and math intermingle, Sarah-Marie Belcastro and Karl Schaffer, both mathematicians and both dancers, explore

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77 The Klein four-group is the direct product of two copies of the cyclic group of order 2 and is the smallest non-cyclic group. In 2D, it is the symmetry group of a rhombus and of a rectangle (identity, vertical reflection, horizontal reflection, and a 180 degree rotation). In 3D, there are three different symmetry groups: one with three perpendicular 2-fold rotation axes, one with a 2-fold rotation axis and a perpendicular plane of reflection, and one with a 2-fold rotation axis in a plane of reflection.

symmetry as an access point for modern dance choreography. Symmetry can have both local scale and global scale implications, from symmetry within an individual body to symmetries between groups of people moving.

While these four symmetries can be exceptionally useful in creating modern dance choreography, they can also hinder creative choreography if not used correctly. In her book *The Art of Making Dances*, Doris Humphrey proclaims, “symmetry is lifeless.” In her opinion, “symmetrical design always suggests stability, repose, a passionless state, the condition before will and desire have begun to operate, or after these have subsided.” For Humphrey, symmetry can be used as a tool for modern dance choreography but should not be the main choreographic method used. Humphrey very boldly suggests “overuse of symmetry is not only naïve and unimaginative, but also very dull.”

One modern dance choreographer who would have shared Humphrey’s distaste for symmetry is Yvonne Rainer. Yvonne Rainer, born in San Francisco, California in 1934, began her career in dance studying with Graham, Cunningham, and Anna Halprin. In 1962, she became a founding member of the Judson Dance Theater along with Lucinda Childs, Steve Paxton, David Gordon, and Trisha Brown. Rainer became an influential member of New York’s post-modern school as she expressed a need to reduce dance to its essential elements and say “No to spectacle,

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80 Ibid.
no to virtuosity, no to transformations and magic and make-believe” in her “NO Manifesto.”

In 1966 Yvonne Rainer created the piece titled Trio A, part of the larger work called The Mind is a Muscle. In this piece, Rainer strived to portray movement-as-task or movement-as-object above all. In the four-and-a-half-minute movement series (performed simultaneously by three people), there was never a pause between phrases, limbs were never fixed still and were stretched to their fullest extension only in transit. No one part of the series was made any more important than any other, allowing the piece to remain detached from story telling. The execution of each movement remained at an equal level of energy throughout the piece, conveying a sense of “unhurried control.” Mimetic movements were not employed for this piece and the “problem of performance” was dealt with by never allowing the dancers to confront the audience, either by averting gaze or by constantly engaging the head in movement. Variation and consistent consecutive repetition were not principle methods of development in Trio A as Rainer strived to make each movement purely individual with respect to its nature.

Trio A is a prime example of how symmetry can be used as an anti-choreographic tool. In other words, Rainer used symmetry as a starting point for what she hoped to avoid in her piece altogether. Each movement was meant to be

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83 Ibid, 163-164.
pure and individual with respect to its nature. She avoided variation altogether to prove that dance can be just as much of a task for an audience member as it is for a dancer. Because movements never repeated, translated, reflected, rotated, etc., the audience was forced to play closer attention to the material being presented. They could not rely on repetition to catch a movement they might have missed. Rainer avoided using symmetry altogether to further implicate the direction of movement-as-task or movement-as-object. Despite her attempts to avoid symmetry, Rainer still consciously acknowledged the structure as a choreographic method, illustrating the ways in which symmetry intrinsically affects modern dance choreography.

**Integrating Algebra**

Using geometry as a way of understanding space and relationships, we can now look at other mathematical structures to understand time and its purpose in modern dance choreography. As stated in Chapter 1, from the development of geometry came the birth of arithmetic and algebra, both open-ended mathematical tools governed by a few rules and definitions. Algebra, specifically, was the body of knowledge from which all other abstract mathematics emerged. It began as an abstract discipline with no initial history or reality. In the beginning, algebra consisted only of a set of rules defining addition, subtraction, multiplication, division,

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raising a power, and taking root of a quantity.\textsuperscript{86} Over time, however, algebra began to involve letters as well as numbers, forcing mathematicians to redefine relationships between numbers as well as our interpretations of addition, subtraction, multiplication, and division. Mathematicians needed to be incredibly specific about their inclusion of certain numbers, or letters, in their calculations. As time passed, the notion of functions in mathematics was introduced, leading to what is now one of the largest and most fully developed branches of algebra: the concept of the algebraic equation.\textsuperscript{87}

While this is all interesting to note in terms of the history and development of modern day mathematics, how does it, if at all, inform modern dance choreography in America? To begin, one must look at the use of time in modern dance. One way to do this is to look at rhythm. In the preface to \textit{The Vision of Modern Dance}, Jean Morrison Brown explains the aesthetics of modern dance as “abstractions and exaggerations of movement to create an illusion in time-space through the use of force.” Brown also goes on to describe rhythmic design as “achieved by time-force interactions in space, creating dynamics.”\textsuperscript{88} Rhythm, so heavily reliant on time, permeates space, dancers, and audience members in a way one cannot describe. It moves us from deep within and is one of the most persuasive and most powerful elements in dance choreography. Despite this fact, many forms

\begin{flushright}
\textsuperscript{85} Ibid, 59. \\
\textsuperscript{86} Ibid, 64. \\
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of dance, specifically modern and ballet, stress other factors much more, such as
technique, creativity, purity, personality, etc. Rhythm is one of the least used and
least appreciated tools in modern dance.

In *The Art of Making Dances*, Doris Humphrey expresses the importance of
rhythm and its ability to hold an individual together. She describes the four sources
of rhythmical organization in a dancer as follows:

First, the breathing-singing-speaking apparatus which leads to
phrasing, and phrase rhythm. Then the partly unconscious rhythms of
function: the heartbeat, peristalsis, contraction and relaxation of
muscles, waves of sensation through the nerve ends. Another, is the
propelling mechanism, the legs, which man discovered would support
him, one after the other, while moving in space, and which provided
also a conscious joy in beat as the weight changed. Lastly, there is
emotional rhythm: surges and ebbs of feeling, with accents which not
only supply strong rhythmical patterns but are a measure for judging
emotional rhythms in others.89

Knowing these sources of rhythm within the dancer, one can acknowledge the fact
that rhythm is rather intangible. We cannot grasp rhythm the way we can grasp
space and relationships to others in space. Without a clear sense of rhythm, how
then can we understand the mathematics of it all?

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One specific modern dance choreographer, whether intentionally or not, used many algebraic sequences to alter the rhythm of her steps and elucidate the sense of rhythm from within. Lucinda Childs, born in New York in 1940, graduated as a dance major from Sarah Lawrence College in 1962 and went on to study at the Cunningham studio, becoming a member of the Judson collective in 1963. In 1973, she formed the Lucinda Childs Dance Company where she built her name as one of America’s leading modern dance choreographers. Childs’s choreography consists of stripped-down movement vocabulary performed along “geometric floor plans, in rigorous structures that repeat or mutate minutely and precisely over time.” Whether she knew it or not, Childs employed algebraic structures to her pieces in her attempt to objectify movement.

Unlike the many other Judson-era choreographers of the 1960s and 1970s, Lucinda Childs’s minimalism was not a democratic statement. Much of her movement portrayed balletic roots, like that of Cunningham’s. Dancers in her company were often technically trained and exhibited the sophisticated, unclutter, open-body characteristic of Cunningham. Despite her somewhat balletic background, Childs worked with a fundamentally basic vocabulary, consisting of walking, turning, small skips, and leaps. Over time, her vocabulary branched out to include quite a few ballet-derived steps, but only for the purpose of geometric structure and visual lucidity.

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As Childs’s vocabulary developed and her dancers’ abilities changed, one feature of her work remained remarkably constant: the dynamic with which her choreography was performed. Dancers in her company were always either completely still or in motion. There was no in between. No transition steps. In the 1970s, Childs’s dances were organized spatially, along clear geometric floor paths and, temporally, through rudimentary units of simple movement that repeated or changed slightly. Given this framework, Childs explored the importance of seeing movement clearly. Her works of the 1960s and 1970s pushed the limits of simplicity in a dance, while still eluding the viewer’s complete perception.

In the mid-1970s, director Robert Wilson and composer Philip Glass approached Childs to choreograph for their pioneering minimalist opera titled *Einstein on the Beach* (1976). The show lasted an overall five hours, with every gesture and word timed to an exact beat. The production, having no discernible plot or characters, altered everyone’s perceptions of opera at the time. Audience members were left to figure out why Einstein appeared as an ecstatic violinist and dancer, as the action moved between a train station and a space ship.91 Childs noted Wilson’s ability to “transform that space into the classical lines and, in some surrealistic way, also plays against those existing architectural values.”92 In many ways, *Einstein on the Beach* opened up new structural principles for her, spatially, in the enlarged architecture and concentrated geometries of the proscenium stage.

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All of this, however, is building up to Childs work with rhythmic approaches. In *Einstein on the Beach*, Childs involvement suggested a new form of temporal structure in the form of music. Most of Childs dances in the early 1970s were performed in silence and organized by elaborate counts. Inspired by Wilson’s collaboration with Philip Glass, Childs began to structure her dances around and against the duration, tempo, and rhythms of minimalist compositions “whose precise, repetitive, gradually shifting structures paralleled her own choreographic concerns.” In 1979, Childs choreographed *Dance* in collaboration with Glass. The shifting rhythms and cascading arpeggios of Glass’s music were reiterated in Childs’s movement of geometric configurations and minutely cadenced phrases. In her interview with Childs, Judith Mackrell illustrates the piece’s “trancelike meditation on space, pattern and time” as it built “to a kind of ecstatic abstract harmony.”

Whether intentional or not, Lucinda Childs employed algebraic sequences of rhythm in her choreography. Her elaborate counts and use of duration, tempo, and rhythms of minimalist compositions derived from algebraic concepts of addition, subtraction, multiplication, division, raising a power, and taking root of a quantity. In addition, her focus on minimalism allowed her to take a single movement phrase

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92 Ibid, 60-61.
93 Ibid, 60-61.
94 An arpeggio is a musical technique where notes in a chord are played or sung in sequence, one after the other, rather than ringing out simultaneously.
and repeat it over and over again, but in different ways. The act of repeating these
movement phrases in different ways each time is an idea stemming from algebraic
concepts of altering a function. Looking at a single movement phrase, one can alter
it by applying a function to the phrase. Whether it was written down mathematically
or not, Childs applied various functions to her movement phrases to alter the
tempo, duration, and rhythm of the piece. By subconsciously employing the concept
of the algebraic equation, Lucinda Childs was able to incorporate the four sources of
rhythmical organization in her modern dance choreography.
CHAPTER FOUR

Structured Chaos in Dance Improvisation

“God has put a secret art into the forces of Nature so as to enable it to fashion itself
out of chaos into a perfect world system.”

-Immanuel Kant

As previously stated in Chapter One, with the start of the new-age mathematical evolution, mathematicians began to view the world and universe in mathematical systems. Geometry, arithmetic, algebra, and developing mathematical structures, such as calculus, topology, etc., all came together to form the concept of mathematical systems. In particular, the study of chaos arose from observations of dynamical systems, which can most simply be defined as a system whose fixed rule or function describes the time dependence of a point in a geometrical space. Dynamical systems are governed by precise laws and under certain conditions, behave in unpredictable ways. What defines a system as chaotic is not whether it is predictable or not, but whether there exist instabilities.

The word chaos can have a variety of different meanings due to its very nature. The Merriam-Webster dictionary defines chaos as “obsolete; a state of things in which chance is supreme; the confused unorganized state of primordial matter before the creation of distinct forms; the inherent unpredictability in the
behavior of a complex natural system; a state of utter confusion.” In their book Coincidences, Chaos, and All That Math Jazz, Edward B. Burger and Michael Starbird defines chaos in the actual world as,

... the phenomenon in which a slight change in the situation at one moment has only a small effect at first but is then magnified with each subsequent step in the process. The eventual effect is a vast, but theoretically predictable, influence on the future. In other words, the butterfly does not cause random weather, it causes different weather. The phrase associated with this idea is ‘sensitivity to initial conditions.’³⁹⁷

The concept of chaos alone overlaps in many ways with many modern and post-modern dance techniques. Choreographers often give a set of instructions to their dancers without necessarily knowing what the end goal may be.

For the purpose of this research, however, it is important to define chaos in terms of mathematics. Burger and Starbird define mathematical chaos as,

... an extrapolation of the real-world butterfly effect. It is not the same as chaos in ordinary English, because it possesses neither randomness nor uncertainty. Instead, a mathematical process that exhibits chaos, although completely accurate and deterministic,

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diverges very quickly from the results obtained with even slightly different initial starting points.\textsuperscript{98}

In general, the chaos theory can be used to describe the behavior of dynamical systems, where the future behavior of the system is fully determined by their initial conditions.

In modern dance, we define improvisation as a practice of responding in and to the moment and to internal and external awareness. Improvisation requires dancers to listen on multiple levels. Because the dancer cannot predict what will come next, they must be fully present in their bodies, in the space, and in their minds. Improvisation in dance requires less thinking and more seeing and doing. An important aspect of dance improvisation to note is that it requires an alert awareness to time, space, and others.

Contact improvisation, as well, is a predominant improvisation structure in modern and post-modern dance. It is the term given to a system of improvised movement, which is based on the relationship between two moving bodies and the effect that the laws of gravity, momentum, friction, and inertia have on their movement. Steve Paxton, one of the founding members of the Judson Dance Theater, devised this structure of improvisation in New York in 1972.

Both improvisation and contact improvisation can be viewed through the lens of mathematical chaos. Since improvisation is a form that is ever changing, it did not seem fitting for me to analyze a specific choreographer’s works in order to find

\textsuperscript{97} Ibid.
chaos theory in their movement. Rather, I took on a physical research of my own, exploring improvisation in Susan Lourie’s Improvisational Forms class. In her class, we participated in a variety of improvisational exercises, ranging from 1-minute dances, to movement based on sound, to sloughing, sliding, and surfing over one another.

What I found as a participant in these improvisational exercises was exactly what chaos theory explains. As initial conditions changed depending on the number of dancers in the group, the framework for which we were given, or the amount of time allotted for each exercise, the final behavior of the “system”, or of the dance, was altered as well. I could not go into any framework with a final concept of what would happen, knowing that the initial conditions could change and therefore alter the rest of the piece. Understanding this concept ahead of time is helpful in terms of allowing oneself to see the endless possibilities that may lie ahead.
CONCLUSION

In my personal research with this subject, I have created two semester-long works titled *Dynamical Systems* and *Stochastic Elements*.

*Dynamical Systems (Fall 2012)*

*Stochastic Elements (Spring 2013)*
These works developed with the process of exploring dance choreography through a mathematical lens. Each semester I took my dancers as well as audience members on a journey through Euclid’s *Elements* to modern day mathematics, observing how geometry, algebra, and mathematical chaos affect our understanding of time, space and energy. My dancers and I engaged in conversation about order and chaos throughout the semester, attempting to understand how we order our lives and bodies in such a chaotic world. Through conversation and exploration of our bodies, we investigated what it is we know and how we know what we know. One of my dancers stated “I know something in the moment that I know it.” Mathematics, a compositional language, builds off of concepts we know in order to understand the world around us. Modern dance uses what we know to explore our bodies in space and time.

With the conclusion of my research, I feel as though given more time, I could further understand how the world of mathematics and the world of modern dance collide. While many others have begun research like this, there is still much to explore in order to bridge the gap between the world of dance and the world of mathematics.
Appendix

Figure 1. From public domain

Figure 2. From public domain

Figure 3. From
https://encrypted-tbn0.gstatic.com/images?q=tbn:And9GcSBzMv669KivAN_xiqBT5O6DY6sgBgCM-GWX1u6ki9j2hrLLbPX

Figure 4. From www.regentsprep.org
http://www.regentsprep.org/Regents/math/geometry/GT6/glidepict.gif
Works Cited

Arnheim, Rudolf. "Symmetry and the Organization of Form: A Review Article."


