Structure and Exploration:

Mathematical Concepts in Post-Modern Dance and Dance-Tech

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Introduction

Dance and mathematics are seen by many as diametrically opposed disciplines. One is looked at as physical, the other as cerebral; one is based on movement, while the other might be symbolized by Rodin's "The Thinker." Furthermore, a gendered component tends to be associated with each discipline: there is the expressive, feminine dancer versus the rational, masculine mathematician. Combining the two would appear problematic. However, just as music and math are often thought to be connected in some fundamental way—for example the ancient Greek's hypothesized ratios to be the foundation of both disciplines[1]—so too with dance one can observe the use of mathematics in the basic geometric shapes, fundamental arrangements of numbers in the various groupings of dancers, and perhaps most importantly in the deep patterns and rhythms expressed through movement.

An immediately apparent connection between movement and the quantitative disciplines exists in a rapidly emerging field often referred to as "dance-tech," which encapsulates any sort of collaborative project involving dance and digital technology. But mathematical ideas existed in dance well before computers. Although this relationship can be traced back through much of dance history, from the elaborate geometric spatial patterns produced by the Renaissance court dances to Oskar Schlemmer's Bauhaus dances of the late 1920s, this paper begins with an investigation of Merce Cunningham's work of the 1950s, progressing through time up to present-day dance-tech projects.

The question explored here is twofold. First, how did post-modern dance choreographers between the 1950s and 1980s incorporate mathematical concepts into their choreographic practices, and what were their motivations to do so? Secondly, how did the advent of digital

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[1] Filmer Stuart Cuckow Northrop, "The Mathematical Background and Content of Greek Philosophy," in *Philosophical Essays for Alfred North Whitehead,* ed. Alfred North Whitehead (New York: Russel and Russel, 1936), 4, 37-38.

technologies allow choreographers of the twenty-first century to expand upon these mathematical ideas of their predecessors and make them more tangible?

Sources and Methodology

To address the above research questions, I chose to analyze the work of five choreographers: Merce Cunningham, Trisha Brown, Lucinda Childs, William Forsythe, and Wayne McGregor. The theories and works of Cunningham, Brown, and Childs exemplify the use of mathematical concepts in a more theoretical framework, while the dance and digital technology projects spearheaded by Forsythe and McGregor bring a technical rigor to the abstract theory, forcing these choreographers to make important decisions about the abstraction of movement in order to represent dance on a computer. While I recognize that Cunningham, Brown, and Childs all used technology in their work or choreographic practices at some point, this paper focuses solely on their "pre-tech" pieces[2] in order to juxtapose their conceptual mathematical ideas about dance with those explored in current dance-tech projects.

Insights into Cunningham's choreographic process come from *The Dancer and the Dance*, a book of conversations between French writer Jacqueline Lesschaeve and Merce Cunningham. In the interviews, Cunningham goes into great detail describing the mathematical procedures he used to create many of his dances, including *Torse* (1975), which I cite in a discussion of Cunningham's famous chance procedures. Sally Banes' *Terpsichore and Sneakers* and Susan Leigh Foster's *Reading Dancing* provide examples of the organizing principles and structures inherent in the work of Lucinda Childs and Trisha Brown. As specific examples, I

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[2] With the possible exception of Lucinda Child's *Dance* (1979), which uses video projections during live performance.

reference Brown's *Accumulation* pieces from the early 1970s and *Locus* (1975), as well as one of Childs' most famous works, *Dance* (1979), for which she received a Guggenheim Fellowship.

For the digital technology projects, I examine Wayne McGregor's Choreographic Language Agent, a digital interactive choreographic tool designed to assist dancers in the studio with the development of new movement. Additionally, I analyze William Forsythe's *Synchronous Objects for One Flat Thing, Reproduced,* a series of graphical visualizations that present spatial and temporal features of choreography through new digital mediums. Some of these visualization tools are commonly used in other disciplines, such as the topographical map, whereas others are new developments and seem to be more like artistic experiments than meaningful data visualizations.

Much of the dance literature acknowledges the importance of organizational structures in dance, particularly in the work of post-modern choreographers; however, the analysis of these structures is often surface-level and does not elaborate on the underlying mathematical principles. Furthermore, there is very little written by mathematicians and computer scientists discussing the interplay between their disciplines and dance. Therefore, most of the literature on the subject is written by people who do not have a deep understanding of how the mathematical concepts are used in a traditional setting. Marc Downie, a computer scientist and performance graphic designer, is an exception to this rule.[3] For this reason, I use a section of his thesis proposal on the "computational sensibility"[4] of dance as a starting point for a number of my

[3] Downie was one of the main contributors to McGregor's Choreographic Language Agent. He also worked with Merce Cunningham to create *Loops* (2001-11), a digital depiction of Cunningham's solo dance for hands and fingers.
[4] Marc Downie, "Choreographing the Extended Agent: Performance Graphics for Dance Theater" (PhD diss., Massachusetts Institute of Technology, School of Architecture and Planning, Program in Media Arts and Sciences, 2005), 5.

analyses. Downie's insights will prove helpful for illuminating some of the deep connections between dance and mathematical thinking.

Background

Rather than dividing this paper into sections based on mathematical principles, my discussion occurs in chronological order. We begin with Merce Cunningham, then move to Trisha Brown and Lucinda Childs, and finally consider Wayne McGregor and William Forsythe. Merce Cunningham's avant-garde work of the 1950s paved the way for the post-modern dance movement, which endeavored to make the patterns and sequences of dance the predominant elements of a piece of choreography. He thereby rejected the previous notions of expressionism exemplified by Martha Graham. Lucinda Childs and Trisha Brown—who began presenting their work as part of a larger community of young choreographers at the Judson Memorial Church between 1962 and 1964—are prime examples of post-modern choreographers who relied heavily on the ideas of structure, both of movement in the body and of the overall dance in space and time.

Cunningham, Brown, and Childs were interested in the organizing principles of movement and all relied to some extent on mathematics, algorithms, or chance in their choreography. Their dances did not involve symbolism or deep emotion and they were not concerned with expressing a universal human condition; instead, they focused on concrete movement and the articulate body moving through space in unexpected ways. But the methods devised to generate unexpected movement and patterns varied from choreographer to choreographer and often involved long, complex processes.

Decades later, the field of dance-tech is providing ways to automate these processes, as my discussion of McGregor's Choreographic Language Agent will illustrate. Dance-tech is often thought of as limited merely to the employment of various types of technology to performance. While this is certainly one facet of the field, this paper deals with digital technology projects that exist outside the scope of performance, specifically the use of computers to create and analyze dances.

Many of the mathematical concepts and the motivations behind using them in dance span the choreographers, and significant connections are noted as they come up. Perhaps the most crucial theme is that of structure and exploration: how did these choreographers rely on mathematical ideas to explore new movement possibilities of the body in space and time. In the case of Forsythe, we must also ask: how did statistical analysis lead to the discovery of existing patterns in a pre-choreographed piece?

I will be using a number of mathematical and computer science concepts in my argument, some of which will undoubtedly be familiar while others are more specialized. These include, but are not limited to, generalization, representation, combinatorics, and probability. I believe it will be most useful if I define and explain these terms as they arise in their applicable contexts. No concepts will be defined in formal mathematical notation, thus no prior mathematical background is necessary to follow the argument.

Syntactical principles of choreography: Cunningham, Brown, and Childs

In order to perceive how mathematical concepts play into dance, it is necessary to better understand the elements that make up a piece of choreography, particularly as found in the work of Cunningham, Brown, and Childs. In *Reading Dancing,* Susan Leigh Foster breaks down the syntactical structure of choreography into three main categories: *mimesis, pathos,* and *parataxis*.[5] *Mimesis* pertains to reproduction and imitation, whether it be the repetition of a movement phrase or the physical representation of a musical score or narrative. *Pathos* deals with less tangible elements of movement like feelings and imagery—a popular choreographic element in the work of expressionist choreographers like Martha Graham. Cunningham, Brown, and Childs, however, were most interested in *parataxis,* which Foster describes as a "formulaic approach to the organization of movement." This approach "includes diverse procedures for sequencing movement that range from aleatory techniques to variations on spatial or temporal properties of movement."[6]

One of Merce Cunningham's first realizations about the structure of dance was that the spatial design of ballet and early modern dance was usually constructed with the proscenium stage in mind; therefore, it was frontal and the eye was drawn to the center.[7] But Cunningham decided to reject this traditional notion of where and how dancers should exist in space. He describes his choice to "open up the space" in an interview with Jacqueline Lesschaeve in *The Dancer and the Dance*:

> What if, as in my pieces, you decide to make any point on the stage equally interesting? I used to be told that you see the center of the space as the most important: that was the center of interest. But in many modern paintings this was not the case and the sense of space was different. So I decided to open up the space to consider it equal, and any place, occupied or not, just as important as any other. In such a context you don't have to refer to a precise point in space. And when I happened to read that sentence of Albert

[5] Susan Leigh Foster, *Reading Dancing: Bodies and Subjects in Contemporary American Dance* (Berkeley: University of California Press, 1986), 92.
[6] Ibid., 94.
[7] Merce Cunningham and Jacqueline Lesschaeve, *The Dancer and the Dance* (New York: Marion Boyars, 1985), 17.

> Einstein's: 'There are no fixed points in space', I thought, indeed, if there are no fixed points, then every point *is* equally interesting and equally changing.[8]

Immediately, Cunningham found that his choreography had infinitely more possibilities. Without a central reference point, he had more freedom to experiment with directionality, sequencing, and simultaneous phrase work (i.e. multiple dancers performing different phrases at the same time) because "the space could be constantly fluid, instead of being a fixed space in which movements relate."[9]

Cunningham became enthralled not just by spatial but also temporal possibilities of dance—how can rhythm and tempo be altered and layered to produce even more complicated movement patterns? Many of Cunningham's dances were not choreographed to music. Rather the music and dance were composed separately and then performed side-by-side, thus disassociating the two arts.[10] With the expanded possibilities of time and space, Cunningham was forced to devise methods to choose from the many potential outcomes. Instead of making the choices himself, he turned to "chance" procedures, which soon became a hallmark of his work.

Cunningham, and his lifetime collaborator John Cage, most famously used the *I Ching*—an ancient philosophical Chinese text and divination manual also known as the *Book of Changes*—to determine the outcomes of their respective choreographic and musical scores. The theory behind the text is that sixty-four hexagrams correspond to different circumstances for change in the universe. Numbers generated by chance procedures are mapped to the hexagrams, which are said to provide guidance for moral decision making. A hexagram consists of six

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[8] Ibid., 17-18.
[9] Ibid., 18.
[10] However, Cunningham had strict control over the length of both the music and the dance to ensure they occupied the same amount of time.

stacked lines, each of which can be unified (yin) or broken into two (yang). The two options for each line produce sixty-four (2^6) possible outcomes.

Cunningham would flip coins in order to determine whether each line of the hexagram was yin or yang. After six coin flips, the resulting hexagram would be mapped to a box in an eight-by-eight square grid—sixty-four boxes for the sixty-four possible hexagrams. Cunningham devised these grids for many elements of his dances including movement phrases, space, and time. His first piece with the *I Ching* was fittingly called *Suite By Chance* (1953). The dance consisted of four parts: "The first movement was *andante,* the second movement was very slow; the third movement a little faster; the last movement was very fast. Apart from that, I subjected every single thing to chance."[11] Cunningham's decision to leave nearly all of the elements of his piece to random coin flips was radical. Not only was he relying on chance, but the probability of any of the sixty-four events happening was equally likely. In statistical terms, this means that they followed a uniform distribution. Thus, Cunningham quite literally had no idea what would happen next, at least within the parameters of the sixty-four possibilities. Following *Suite by Chance*, aleatory procedures involving the *I Ching* continued to be integral part of Cunningham's process.

In *Torse* (1975), which was created over twenty years later, the sixty-four movement phrases corresponded to weight changes, with phrase one consisting of a single weight change and phrase sixty-four consisting of sixty-four weight changes. Furthermore, the speed of the phrase was correlated to the number of weight shifts, with each phrase becoming progressively faster. In *Torse,* Cunningham used the *I Ching* to determine everything from what phrases were performed, to who performed them, where the dancers existed in space, and how the dancers entered and exited the stage. According to Cunningham, "what it amounted to was a *continual*

[11] Cunningham and Lesschaeve, 90.

change,"[12] a statement that reflects both the philosophy of the *Book of Changes* and Cunningham's ideas about the lack of stationary points in space.

Perhaps it is also worth mentioning that Gottfried Leibniz, the German philosopher and mathematician, also drew inspiration from the *I Ching* to create his binary number system—the zeroes and ones that form the basis of computer systems. Thus, the digital technologies used by William Forsythe and Wayne McGregor to choreograph and analyze dances have a history that can be traced back to the *I Ching*.

Aside from a clear interest in the philosophy behind this ancient Chinese text, Cunningham was fascinated by the ideas of combinatorics—the field of mathematics involving the combination, permutation, and enumeration of finite sets of elements—despite having no formal training in mathematics. His description of a simple finite sum is so excruciatingly detailed that it's almost painful to read:

> I decided to number the entrances and exits one, three, five, and two, four, six, and to link them by all the possible trajectories. You can go one to one, one to two, one to three, one to four, one to five, one to six…that's six, then if you go to two, you can go to one – that's just the reverse – so you go two to three, two to four, two to five, two to six – so that's five. From three – one, two and three are taken care of, so you go three to three, three to four, three to five, three to six – that's four. Four is taken care of except for four – and five and six then five to five, and to six, then six to six – and it comes out to twenty-one altogether: 6+5+4+3+2+1 = 21 space possibilities.[13]

[12] Ibid., 22.
[13] Ibid., 84.

While the exhaustive description of this simple mathematical phenomenon is not entirely necessary, it reflects Cunningham's sheer enthusiasm for combinatorics and the possibilities it creates for choreography.

Merce Cunningham once boasted that the element that set his work apart from traditional choreographies was the "enlargement of possibilities,"[14] much of which can be attributed to his rejection of traditional ideas about space, music, and structure. But instead of leaving these possibilities to the imagination, Cunningham meticulously mapped out all of his options, defining new structures in which to explore movement. As he explains it, the "paperwork" had to be done before he entered the studio or else nothing would be accomplished.[15] The relationship between structure and exploration was a core motivating factor for the use mathematical principles in his dances, and as we will see, it is a common theme in the work of Brown, Childs, McGregor, and Forsythe.

Computer scientist Mark Downie notes another important attribute of Cunningham's choreographic process that is inherent in many quantitative disciplines: representation. Just as dancers and choreographers have struggled for centuries to establish a universal notation system to represent the complexities of dance through numbers, symbols, and diagrams, computer scientists grapple with representing objects in even more abstracted terms, namely the digital bits that underlie all computer programs. Downie explains that computer scientists must figure out how to best represent objects "to enable their *manipulation* and *reinterpretation,* and reconnection with new things."[16] He also points out that "much of [Cunningham's] quest for new compositional strategies could be re-read as a quest for useful representations that support useful

[14] Ibid., 18.
[15] Ibid., 21.
[16] Downie, "Choreographing the Extended Agent," 7.

compositional actions."[17] Thus, Cunningham's detailed charts of possible outcomes were a way of representing different choreographic elements so that they could be "manipulated" and "reconnected" with other elements of the dance, resulting in pieces with new and unexpected organizational systems. Determining how best to represent the real world in an abstracted form is also a key feature of mathematics and likewise one of the central questions behind Forsythe and McGregor's investigations into digital technologies and dance.

Moreover, computer science and mathematics are often concerned with generalizing concepts so that they can be applied to a number of situations. Marc Downie gives a widely applicable definition of generalization in computer science: "A recasting of an established formal system in new, more flexible terms, that immediately produces a range of new systems."[18] Similarly, Cunningham was interested in expanding what constituted the dance vocabulary to include movements outside of the traditional ballet and modern dance lexicons. In *The Dancer and the Dance,* he states straightforwardly, "I started with the idea that first of all any kind of movement could be dancing."[19] He found particularly interesting the types of movement that didn't seem to work because they were unknown: "Now when you find something you don't know about or don't know how to do, you have to find a way to do it, like a child stumbling and trying to walk, or a little colt getting up…Then something would come which I would think lively."[20] Cunningham reveled in finding ways to explore the unknown and make the seemingly impossible possible, an idea adopted by McGregor in his search for new movement with the Choreographic Language Agent.

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[17] Ibid., 8.
[18] Downie, "Choreographing the Extended Agent," 6.
[19] Cunningham and Lesschaeve, 39.
[20] Ibid., 39-40.

While Cunningham's ideas are very clearly explored in dance-tech projects, his influence on the dance world was apparent well before computers and the endeavor to create movement algorithmically and to analyze it statistically. The Judson choreographers of the early 1960s immediately implemented and expanded upon Cunningham's ideas of patterned movement and structural formulations, though most of them did not use aleatory procedures in the same way that Cunningham did. Trisha Brown and Lucinda Childs, specifically, mastered the use of what Susan Leigh Foster refers to as "logico-mathematical structures,"[21] which continued to be a defining characteristic of their work well after Judson. Furthermore, their theories about choreography have many similarities to concepts in computer science, as well as Forsythe and McGregor's dance-tech projects.

In *Terpsichore in Sneakers,* Sally Banes notes that Trisha Brown's "major concern has always been to find the schemes and structures that organize movement, rather than the invention of movement per se."[22] Notably, one of Forsythe's central goals of the *Synchronous Objects* project was to make the organizing principles of movement visually persistent, clearly drawing from ideas of the early post-modern choreographers like Trisha Brown.

Some of the first and more straightforward structures that Brown experimented with were equations of accumulation. She created several pieces in the early 1970s solely focused on this concept, entitled *Accumulation* (1971), *Primary Accumulation* (1972), *Group Primary Accumulation* (1973), and *Split Solo* (1974). The basic idea was to repeat certain gestures several times. After an adequate number of repetitions, about seven or eight, the dancer would add another gesture and repeat the two in succession, gradually adding more movements. In *Primary Accumulation*, the final phrase reached thirty gestures. Brown would then throw in caveats and

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[21] Foster, 176.
[22] Sally Banes, *Terpsichore in Sneakers: Post-Modern Dance* (Middletown: Wesleyan University Press, 2011), 90.

obstacles, like changing the angle of the body in space (*Primary Accumulation*), adding other dancers to the space to purposely disrupt the people performing the accumulation phrase (*Group Primary Accumulation*), or splitting the body in half so that one dancer performed the movements of the left side of the body and the other the right (*Split Solo*).

In a section on Trisha Brown, the documentary *Making Dances: Seven Postmodern Choreographers* presents excerpts of a later solo version of *Accumulation*, which is merged with another piece called *Water Motor.*[23] In addition to splicing back and forth between the two pieces, Brown simultaneously tells two stories, choosing at random when to switch narratives and movement phrases. She must keep track of where she is in each of the four units of movement/speech in order to pick up at the precise place she left off when she returns to the unit.

The movements of *Accumulation* are very recognizable due to their seemingly infinite repetitions. Brown's gestures are subtle and nonchalant, yet highly precise. With hands in loose fists and thumbs extended out, she rotates her forearms and swings her arms in all directions with a controlled ease. Sometimes the two halves of the body find symmetry in moments of synchrony, but more often they form slightly different complementary positions. The arm gestures are accompanied by a gentle tread of the feet and the intermittent lift of a knee or turn of the head. The clear angles and lines present comprehendible geometric shapes, though they are in constant transition and motion. It is obvious when Brown switches to *Water Motor* because she bursts into sudden motion, kicking, jumping, and twisting her body in all directions. But her body's intricate convolutions, while mesmerizing, make it challenging to grasp or categorize any particular movement or shape. The juxtaposition of these two qualities of movement reinforces the impact of simplistic, repetitive gestures. Sally Banes explains that in dance, "so many

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[23] *Making Dances: Seven Post-Modern Choreographers,* produced by Michael Blackwood. (1980; New York: Michael Blackwood Productions, 2014), DVD.

physical features of an action are forgotten because there are no concepts with which to categorize and perceive them. Repetition fills this gap, ingraining gestures in the mind through systematic contrast and comparison."[24] The concept of categorizing and describing "physical features of an action" arises again in the discussion of Forsythe's dance-tech work.

Locus (1975), created just after the series of accumulation pieces, was an eighteen-minute piece performed by four dancers in silence. Compared to *Accumulation*, the piece involved much more complex procedures to create movement and structure, moving beyond simple gestures.[25] By using an imaginary cube to delineate twenty-seven points in space, Brown established a domain for the dancers to express variations of her mathematical-linguistic system. The twenty-seven points corresponded to letters in the alphabet with the 27th indicating a "space" that was located in the center of the cube. Each dancer's movements were correlated with a biographical statement from a program whose letters had been transposed into numbers corresponding to their cube points. The dancers were then required to interact in some way with each of the twenty-seven imaginary points in order to generate movement.

Mark Downie eloquently describes how the computer science topic of representation is inherent in *Locus*:

> A *transformation* of the dancer's kinesphere into boxes, the *representation* of these boxes by letters of the alphabet, the *manipulation* of the temporal sequencing of boxes by the creation of words and messages and the *retransformation* of these messages into movement yields a dance — a complex semaphore often intersecting with the representation's mirror —the spoken word.[26]

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[24] Banes, *Terpsichore*, 126.
[25] The following illustration of Brown's choreographic process for *Locus* is based on Sally Banes description in *Terpsichore in Sneakers* (Banes, 90).
[26] Downie, "Choreographing the Extended Agent," 8-9.

Furthermore, probability plays an important role in what points of the "cube" are visited. Brown justifies her choice to use a mundane piece of writing in her movement generating system by saying "all I wanted was a sequence of numbers."[27] Thus, the mapping of arbitrary words to numbers can be seen as a type of chance procedure, although it differs from Cunningham's coin flipping in that the probability of ending up with each of the numbers is not equal; clearly the letters "e" and "a" will be used far more frequently than "x" and "z." Brown traverses from meaningful (though arbitrary) human language to a more or less random numerical system in order to generate movements that create meaning again through an entirely different communicative medium: dance.

While Brown and Cunningham experimented with complicated structures both of the dance in space and time and of the body (i.e. discovering simultaneous patterns of motions in different body parts), Lucinda Childs' interest lay mostly in the organization of the dance as a whole. Thus, Childs' movement vocabulary was far simpler than that of Trisha Brown or Merce Cunningham largely consisting of pedestrian movements like skips, hops, walks, and spins. Yet, structural complexities required highly trained dancers to perform her work. Childs, like Brown, experimented with accumulation and repetition, but her work emphasized the overall patterning of movement through space.

One of Lucinda Childs' signature works, *Dance* (1979), exemplifies this focus on geometric patterns.[28] The piece is a collaborative masterpiece between Childs, Phillip Glass, and Sol Lewitt, in which life-sized videos, and sometimes much larger avatars, of the dancers are projected onto a sheer screen in front of the live performers. The dancers on the stage move in

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[27] Trisha Brown quoted in Amanda Jane Graham, "Space Travel: Trisha Brown's *Locus*," *Art Journal* 75, no. 2 (2016), 33.
[28] The following description of *Dance* is based on a restaging of the original work, performed by the Lucinda Childs Dance Company at the Joyce Theater on December 8, 2016.

near-perfect synchrony with their video counterparts, the replication acting as another sort of repetition. The piece is divided into three sections, each of which manages the space quite differently.

In the opening section, the dancers move in pairs laterally across the stage, rarely deviating from the straight lines that connect the wings. The movement is a unique blend of playful pedestrian and balletic motions that emphasize linearity and amplify the horizontal lines produced by the dancers' trajectories through space. Just when the viewer's eyes become tired of following the dancers left to right and then right to left across the stage, the section comes to an end, and after a short blackout, a huge projection of Lucinda Childs herself is displayed on the screen. Her eyes move about ever so slightly, almost as if to mimic the viewer's gaze while watching the performance.

Then, the video dissipates and a dancer emerges from the center of the top of the stage. She moves in a direct path downstage, cutting the space in two in the direction perpendicular to the paths of the dancers from the previous section. After this initial strict division of the space, she proceeds to explore diagonals and curves for the first time through walks, hops, and pivots with loose swinging arms, as well as more technically challenging turns and leaps. In the third section, these shapes and pathways through the space are further explored by larger groups of dancers. With more people on the stage, there is a greater emphasis on symmetry; at almost every moment, there is a dancer in the direct opposite part of the space as another, forming a visually harmonious geometric whole. Moreover, the dancers in the video perform the piece on a floor consisting of square grids, almost as if they are tracing through a large piece of graph paper. At times, the film angle points diagonally downward to highlight the dancers' paths through this grid.

Undeniably, the mathematical ideas of sequencing and patterning are central to *Dance*, as they are to most of Childs' other works; however, due to the ephemerality of movement, the geometry of a certain spatial configuration is visible for a moment but quickly morphs into something new. It is therefore quite challenging to comprehend the spatial patterns of the entire piece at once. As we will see, some of Forsythe's choreographic objects provide a remedy to better comprehend the structure of choreography by displaying the dance in a non-transient form.

Merce Cunningham, Trisha Brown, and Lucinda Childs were not mathematicians, and the computational techniques they used were quite rudimentary from a technical point of view—although as the above examples show, a simple mathematical concept can translate into a highly complicated task for the body. Still, their ideas were inspired by the philosophy of mathematics and reflect many of its themes, including structure, abstraction, and representation. Wayne McGregor and William Forsythe also embraced these themes, but not just theoretically; the next sections will explore how the use of computers forced McGregor and Forsythe to make important decisions about abstraction of movement in order to represent dance through digital mediums.

Wayne McGregor: Choreographic Language Agent

A British choreographer and the artistic director of Random Dance, Wayne McGregor began working with a team of computer scientists and digital artists in 2009 to create a user-friendly software environment "for exploring variations in choreographic instruction."[29] The Choreographic Language Agent, or CLA, is designed to take movement descriptions in language familiar to the dancers as input in order to create a visual manifestation of the user's commands

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[29] Marc Downie, "Open Ended Group: Choreographic Language Agent," accessed November 20, 2016, http://openendedgroup.com/artworks/cla.html.

in the form of a three-dimensional geometric figure. Unlike traditional programming languages that produce a final product, the geometric renderings of the CLA are simply an intermediate step of the choreographic process; the dancers must re-interpret the output to create movement in their own bodies, or reject the output altogether.

Rather than creating a realistic, anatomically correct digital representation of the human body, the creators of the Choreographic Language Agent used a “minimalist point-line vocabulary” in order to “rapidly sketch movement explorations at all levels (limb, body, stage-space).”[30] In the software environment, the dancer’s kinesphere is represented by a cube and the geometric figure corresponding to the dancer’s body is made up of a network of nodes and edges that can be warped by sentences consisting of action verbs and spatial specifications (e.g. rotate all points about center). As the figure performs the actions, it leaves a trace of points through space in order to visualize the trajectory. The “phrase language”[31] is broken down into three categories: transformation (the action), points (what the action is being applied to), and conjunction (how the action relates to the other phrases in time). It is then possible to alter the temporal and sequential structure of the phrase by stretching or squashing phrases on the screen and rearranging them.

While the program itself is deterministic—meaning that it will produce the same output on every run given the same input parameters—each dancer’s physical realization of the output will be quite different because the dancers are not mimicking a virtual human body. Thus, the dancers are given great autonomy, while still allowing the choreographic tool to inform their creative processes. After working through how to interpret the CLA’s output through physical

[30] Ibid.
[31] Luke Church, Nick Rothwell, Marc Downie, Scott DeLahunta, and Alan F. Blackwell, “Sketching by programming in the Choreographic Language Agent” (paper presented at the annual conference for the Psychology of Programming Interest Group, London Metropolitan University, 2012), 5.

problem solving, the dancers can return to the CLA and alter the input by changing the descriptive sentences, sequence of events, timing, etc. Furthermore, different sentences can overlap in order to produce simultaneous actions (e.g., rotate rightmost points about center while simultaneously moving the leftmost points through center).

Unlike Merce Cunningham, McGregor and his dancers do not explicitly use chance procedures to produce movement; however, they do not necessarily know how their language inputs will translate into the "body" of the CLA or their own bodies, leaving much room for uncertainty and exploration. Of course, it might be easy to imagine what a straightforward input sentence might look like—at least in the digital output of the CLA—but as sentences of actions are layered, the output becomes much harder to visualize, leaving both the intermediate and final products (the CLA outputs and the physical dances) up to chance in a sense. The programmers are currently working on an additional feature of the software that will allow the user to input conditions. The CLA will then "react" to these conditions, giving the tool greater autonomy and taking more decision-making power away from the dancers.[32]

The creators of the CLA recognized that the choreographic process is full of trial-and-error, so they built a version control system into the tool.[33] Each time a change is made to a phrase, a new node in a branching tree is created. The user can return to that node at any point if he/she does not like the subsequent changes and begin making new changes, which adds a branch to the tree starting at that point. In this system, all versions of the phrase are easily accessible, highlighting the importance of exploration in the process. Unsurprisingly, version control is also a key feature of software development, illustrating another parallel between computer science and choreography.

[32] Marc Downie, "Open Ended Group: Choreographic Language Agent."
[33] Sketching by Programming in the Choreographic Language Agent, 5.

The CLA project raises interesting ideas about the relationship between abstraction and specification. Oftentimes in a choreographic or improvisatory exercise, dancers use imagery and abstract language that can be interpreted in a number of ways. The CLA challenges this standard practice by forcing McGregor and the dancers to define specific language. What does it really mean to hang or to fold? In order to produce these qualities in the "body" of the CLA, each word must be mapped to a mathematical meaning, a geometric operation. The mapping process requires the dancers to come to a consensus about exactly how these action verbs will affect the resulting geometric figure. The interpretation comes during the next step of the process when the dancers are forced to translate the digital figure into their bodies. In choreography, a practice that is almost exclusively dominated by language, physical bodies, and sometimes music and other auditory cues, adding another sensory input variable can be a valuable technique in breaking one's traditional habits. Again, strict structure paradoxically leads to creativity.

While the CLA requires a specification of language, it is also an abstraction of movement. As previously mentioned, the geometric figure of the CLA is intentionally simplistic; therefore, it is a form of generalization, such that each dancer's interpretation of the abstract figure is a specific instance of the geometric "object." Analogously, instantiation in computer science is defined as follows:

> Instantiation is the realization of a predefined object. For instance, in object-oriented programming (OOP), a class of object may be defined with certain properties (associated variables), accessories (ways to access those variables), and methods (characteristic functions).[34]

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[34] "Instantiation," Computer Hope, accessed November 20, 2016, http://www.computerhope.com/jargon/i/instantiation.htm.

The figure that the Choreographic Language Agent produces can be viewed as a general object. The dancer then decides on the “properties” and “methods” of the object. Do the points of the figure correspond to particular joints of the body? How exactly does the body replicate or reflect the motion of the points across the screen?

There are many challenges to working with a software program in a dance studio, one of the most obvious being the logistical issues of walking back and forth from a desk with a computer to the open studio space. However, the Choreographic Language Agent introduces exciting ideas into the practice of choreography and further develops several theoretical concepts that the Cunningham, Brown, and Childs had worked with: altering the syntactical structures of dance, detaching dance from feeling evoked by language, and establishing a formal system from which to explore. Additionally, the CLA has many similarities to universal computer science concepts, such as version control and instantiation.

William Forsythe’s Synchronous Objects

American ex-pat and former artistic director of Ballet Frankfurt, William Forsythe also sought to bridge the gap between quantitative disciplines and dance. While McGregor’s work with the Choreographic Language Agent was primarily concerned with incorporating technology into the choreographic process, William Forsythe spearheaded a project that considered the statistical analysis of a piece that had already been finalized. In 2006, he began working on *Synchronous Objects,* which was the pilot study for Motion Bank, a digital collection of choreographic works. A team of collaborators from a variety of disciplines, including dance, computer science, statistics, graphic design, geography, and architecture, collected spatial and “attribute” data from Forsythe’s *One Flat Thing, Reproduced* (2000), a piece for seventeen dancers, which was inspired by the notion of musical counterpoint. The attribute data came from the dancers' firsthand accounts of the piece, which provided information about cues, improvisation, moments of "sync-up", and recurring movement themes within the work. The *Synchronous Objects* website allows the user to watch a full-length video of the fifteen-and-a-half-minute piece, while simultaneously viewing a visual timeline of the above attributes in order to give the viewer a better sense of the "flow of the dance."[35]

The spatial information was obtained by extracting motion data from video recordings using computer vision techniques that break down video into frames of infinitesimally small increments. Computer vision offers the possibility to analyze at the granular level the structural and temporal elements of a dance, the same organizing principles that Cunningham, Brown, and Childs sought out to explore. But huge quantities of data are unintelligible on their own; hundreds of thousands of data points do not offer any insights about a choreographic work or dance in general. Thus, further levels of abstraction, analysis, and creation must take place in order to render the information meaningful.

From the collected data, the researchers of *Synchronous Objects* at Ohio State University created a series of twenty "choreographic objects," each representing a particular aspect of the dance—cues, spatial patterns, etc.—through another medium. Synchronous, meaning "happening, moving, or existing at the same time,"[36] is the perfect adjective to describe these objects that deconstruct the dance into its simultaneously occurring parts. As a result, one can get a better sense of how different structures contribute to the overall progression and design of the piece.

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[35] William Forsythe and Norah Zuniga Shaw, "Synchronous Objects for One Flat Thing, Reproduced: Dance, Data, Objects Essays" accessed September 17, 2016, http://synchronousobjects.osu.edu/content.html.
[36] *Merriam-Webster Dictionary, s.v.* "synchronous," accessed November 20, 2016, https://www.merriam-webster.com/dictionary/synchronous.

Many of the choreographic objects are solely based on the attribute data, specifically the network of over two hundred cues. The Cue Annotation tool displays animated lines that extend from one dancer and shoot across the stage to another in order to visualize the transfer of physical information. For clarity, a circle also encompasses the dancer who is giving the cue just before the line(s) appear in order to emphasize the directionality of each cue (who is giving it and who is receiving it). The annotations can be played with or without the corresponding video of the piece, so the user can experiment with context. While the animation without the dance gives a more abstracted perspective of the piece's structure, the version with the dance could be valuable in understanding the causality of actions if, for example, a group of new dancers were to try to learn the piece off of the video. Oftentimes, videos and written notations are used in combination to restage a work. The direct annotation of a video presents a well-integrated mechanism for learning and better comprehending repertoire pieces without the hindrance of referencing two distinct sources.

The Cue Score object presents the same cues but through a graphical representation, making it easier to grasp the overall trends in the network since the cues do not disappear from the screen as the dance progresses. Each of the seventeen dancers is given a line on a staff, and the cues are plotted over time. At a point in time when a cue is exchanged, nodes appear on the lines corresponding to the dancers involved and an arc connects them. The dancers are organized on the staff by their total involvement in the cueing system, with those handling the most responsibility at the bottom. In an interview, Forsythe excitedly remarked that this quantification of cues reflected the personalities of the dancers and the leadership roles they generally take on.[37]

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[37] "William Forsythe discusses Synchronous Objects," YouTube video, 6:08, posted by "ACCAD at Ohio State University," April 6, 2012 (filmed 2009), accessed September 17, 2016, https://www.youtube.com/watch?v=uQdZBOVYLdI.

The choreographic objects that pertain to the elaborate cueing system in *One Flat Thing, Reproduced* echo Merce Cunningham's ideas about constant change and fluidity. Cunningham once likened the essence of dance to water, which some might find surprising given his emphasis on intense structure.

> It's difficult to talk about dance. It's not so much intangible as evanescent. I compare ideas on dance, and dance itself, to water. Surely, describing a book is certainly easier than describing water. Well, maybe…Everyone knows what water is or what dance is, but this very fluidity makes them intangible. I'm not talking about the quality of dance, but about its nature.[38]

The visual manifestations of the cueing system emphasize the connection between dancers, highlighting what Cunningham referred to as the constant fluidity of space. Furthermore, the objects' persistence through time makes the cue structure more tangible and conducive to both quantitate and qualitative analysis.

Another choreographic object called Alignment Annotations illustrates "short instances of synchronization between dancers in which their actions share some, but not necessarily all, attributes."[39] These characteristics include trajectory, direction, and angularity. For example, the tool leaves animated trace forms in space when multiple dancers simultaneously create arcs, sharp acute angles, or clear lines with their bodies, regardless of whether or not they are performing an identical movement phrase. The tool provides a solution to Sally Banes' realization that there are few ways to categorize and describe physical features of an action. Thus, movement motifs may become more apparent to the observer after viewing them with the accompanying annotations.

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[38]Cunningham and Lesschaeve, *The Dancer and the Dance*, 27.
[39] Ohio State University, "Synchronous Objects: Alignment Annotations / Object Explanations," http://synchronousobjects.osu.edu/content.html#/AlignmentAnnotations.

In addition to this attribute data, motion tracking data allowed Forsythe to explore his dynamic use of space and time in *One Flat Thing, Reproduced*. The Movement Density object resulted from measuring the proportion of time that the dancers spent in each part of the space during the piece (i.e., the "density patterns"). The map produced hot spots, the most frequently visited areas of the space, and also highlighted neglected regions. The results were displayed in a topographical map and indicated that while dancers occupied most points in space on at least a few occasions, the majority of the activity happened in the center. Cunningham's observation/criticism that concert dance tends to treat the center of the stage as the most important area is supported by the empirical evidence provided by this tool. Along with a density map for all of the dancers, separate surfaces were created for each individual to detect differences in their patterns. Some were more isolated to a single area, whereas others spanned the space more evenly. Interestingly, the movements of individual dancers tended to be less concentrated to the center of the space compared to the overall group. A movement density analysis of one of Cunningham's pieces would show whether or not he succeeded in "mak[ing] any point [in space] equally interesting"[40] and equally visited.

The aforementioned examples of analysis tools illuminate some of William Forsythe's goals of the study, on which he elaborates in his essay *Choreographic Objects*. First and foremost, he hopes to reveal through other mediums the various structural elements and hidden patterns of a dance obscured by layers of complexity. Like the post-modern choreographers, Forsythe points out problems of expressionist dance, and he notes that dance is "still subtly relegated to the domain of raw sense" due to its relationship with the body. [41] He argues that

[40] Cunningham and Lesschaeve, *The Dancer and the Dance*, 17.
[41] William Forsythe, "Choreographic Objects," in *William Forsythe and the Practice of Choreography: It Starts From Any Point* (New York: Routledge, 2011 [2009]): 91.

choreographic thinking may provide a means to "circumnavigate this misconception"[42] and asks the reader to consider how this type of thinking might exist in other forms outside of the body.

The idea of exploration was central to the study. The architects, graphic designers, computer scientists, and other collaborators were not merely interested in mining data and analyzing the results; they became highly invested in the creative aspects of the project, becoming choreographers in their own mediums. In their various ways, they attempted to overcome the fleeting nature of dance through various avenues of expression. As a result, *Synchronous Objects* calls into question the motif of ephemerality so often used in descriptions of dance. Forsythe recognizes that the transience of the act is often its source of highest praise but also its ultimate downfall. He states:

> As poignant as the ephemerality of the act might be, its transient nature does not allow for sustained examination or even the possibility of objective, distinct readings from the position that language offers the sciences and other branches of arts that leave up synchronic artifacts for detailed inspection. This lack of persistence through time, like the body itself, is natural and suspect at the same time. The irretrievability of the choreographic enactment, though possibly engendering a nostalgic thrill perhaps also reminds the viewer of the morbid foundations of that same sentiment.[43]

Choreographic objects are ultimately Forsythe's remedy to "the irretrievability of the choreographic enactment," and they are proving to be powerful tools for studying the structural elements of dance and their mathematical underpinnings. The objects can provide quantitative evidence for a choreographer's intuition, such as how a dance occupies the space. At the same time, they can display patterns completely unbeknownst to the dancers and choreographer, which

[42] Ibid.
[43] Ibid.

may call attention to certain habits. When revisiting the work, or creating a new piece, the choreographer then has a more complete idea of his tendencies and can consciously adhere to or rebel against them.

Conclusion

In this paper, I have provided a variety of examples of how dance-tech and post-modern choreographic works incorporated mathematical notions, thereby disproving the common misconception that dance and mathematics are fundamentally disparate disciplines. Although these mathematical inclinations can be seen as a continuation of the inherent tendency for dance to display pattern, number, and repetition, they have taken on a more conscious and explicit emphasis over the last seventy or so years. General themes common to mathematics and computer science, including representation, abstraction, generalization, structure, and patterning, are found in the works of Merce Cunningham, Trisha Brown, Lucinda Childs, Wayne McGregor, and William Forsythe as well. One might wonder about the underlying motivation behind applying a cerebral discipline like mathematics to the physical art form of dance.[44] While it would be easy to read this as some hidden desire to transcend the body, the primary aim would appear to be to broaden and expand the universe of dance by understanding and exposing its beauties and complexities in new ways.

One of the central questions of this paper asked how the advent of digital technologies allowed choreographers of the twenty-first century to expand upon the mathematical ideas of their predecessors and make them more tangible. One clear example is in the concept of representation. Just as mathematicians and computer scientists must figure out how to best represent objects in order to manipulate and reimagine their potential modes of interaction with

[44] Although most dancers, including myself, would argue that dance is also highly cerebral.

the world, the artists examined here sought to represent the movement of the body and other choreographic elements through mathematical structures. For example, Cunningham represented possible outcomes of his dances using an eight-by-eight square grid, while Trisha Brown represented words (or letters) with numbers and translated these into dance. Dance-tech makes the mathematical idea of representation more concrete, since the choreographers must explicitly represent movement in order to code it into a computer. Wayne McGregor's Choreographic Language Agent serves as an intermediary form between dance and language and is used as a representation of both: the body is represented by a cube and the actions applied to the cube are dependent upon linguistic modulations. Finally, all twenty of Forsythe's choreographic objects, which resulted from transforming vast amounts of "dance data" into meaningful visualizations, quite clearly serve as representations of various dance elements.

In addition to exploring common mathematical themes, the five choreographers share similar motivations. Interestingly, the body plays a paradoxical role in many of their choreographic practices. Dance, of course, cannot exist without the body moving through space, but these choreographers sought or seek to break away from the dancing body's natural tendencies by turning to other methods of creation. In the pre-tech choreographic processes discussed here, these methods included using chance procedures and experimenting with patterns of accumulation. Bringing in elements of dance-tech, McGregor's work with a digital interactive choreographic tool liberated him and his dancers from their bodies' habits, allowing them to create unconventional movement phrases. Forsythe's choreographic objects, on the other hand, elucidated patterns of a set work and helped him become aware of his tendencies, which in turn informed future creations.

Although dance-tech outside of performance may seem beyond the interest of general audiences, some of these innovations can help shed light on aspects of dance not readily apparent to the casual observer. In fact, by revealing structures and patterns normally only appreciated by the adept, many of these techniques may be of the most benefit to the uninitiated. Needless to say, some dance-tech projects remain the sole province of the specialist for now. However, in the future, these techniques may also beget new developments that will influence the wider practice of dance and continue to expose the underlying similarities between mathematics and dance.

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