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An Approach to Improving Informal Mathematics Education Through Aesthetic Computing and Dance-based Representation

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ABSTRACT

Mathematical notation can sometimes be daunting for the K-12 student who to text-based representations. One approach to reduce the student's anxiety is to augment traditional notations with ones that the student may find compelling. In particular, we would like to create a computer-based visualization of simple mathematical algebraic structures by exploring the use of dance and theater as means of representation. The advantage to using dance is that it is engaging, immersive, and highly interactive—normally adjectives not used to describe mathematical notation. The use of "representation" as a means for learning in mathematics forms one of the core areas specified by the National Council of Teachers of Mathematics (NCTM). While representation is often associated with representing items in "solution space," we extend the investigation of representation in the "problem space" – framing the algebraic expressions that, when solved, create solution spaces. We have found that the dance approach provides potential incentive for student learning.

INTRODUCTION

Aesthetic computing (Fishwick 2006, 2007) is the application of the theory and practice of art and design to the field of computing and mathematics. The primary goal of our research is to represent basic mathematical structures (NCTM 2007) in the form of dance and theater. We investigated several approaches to this and created implementations to achieve these representations and a production. This work was done at the University of Florida, primarily in the Computer and Information Science and Engineering Department with consultations with the School of Theatre and Dance.

Our production involves dancers, sound, props, visualization, narrative, and choreography to teach the elements of mathematical structure and behavior of simple algebraic equations. The mathematical equations used are broken down to their basic form, using a "parse tree" representation. This representation is then used as a basis for the choreography through a formal mapping process. Performers interact with each other, mirroring both the static and dynamic relations between variables and operators. A live production is being designed through a collaboration involving University of Florida faculty members Jim Sain from the School of Music, Ric Rose from the School of Theatre and Dance, with Allison Corey and Paul Fishwick from the College of Engineering.

We begin with some background on the fundamental tree structure of simple algebraic equations, and then proceed with the main part of the paper defining our work to date in representation.

REPRESENTING A LINE

The primary goal embedded in the simulated production is to find an alternate method of representing equations. We created an animation using the line equation as the source structure to be represented. The line equation is an artifact in "problem space" that has a "solution space" (i.e., a plot or graphical representation achieved through solving the equation). The primary problem space representation is illustrated in Figure 1.

$$y = mx + b$$

or

$$y = m * x + b.$$

Figure 1. The equation of a line

Figure 1 shows two textual forms of the line equation: an implicit and explicit form. The explicit form shows all operations. Figure 2 shows an alternative problem space representation: a tree created through parsing the second expression in Figure 1. The tree is represented in its infix form, meaning that the root of the tree is the main operator, the equal sign (=), with the children of the root containing each side of the equation. Thus, the parents in the tree are the operators and the children are the constants and variables. The equation for a line can then be represented as seen below. Figure 3 represents the execution of Figure 2: the solution space or plot.

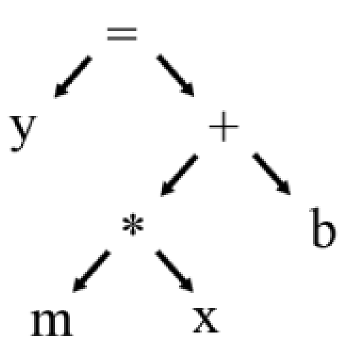


Figure 2. The tree formation of a line.

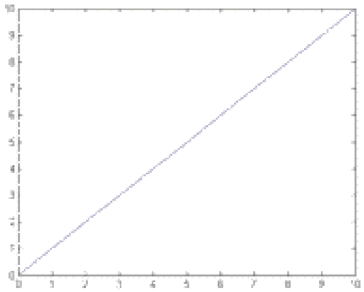


Figure 3. The graphical representation of a straight line.

MAPPING APPROACHES USING THEATRE AND DANCE

In a dance production, one or more of the following can potentially portray these two mathematical representations:

- Formations of Dancers
- Dancer Configuration and Movement
- Costumes
- Sculpture or Stage Props
- Lighting Projection
- Music and Sound

The designed production focuses on dancer formation and costumes, as well as a ground mapping showing the tree form for the equation of a line. This simulation begins with dancers in a tree form, and then moves into the graphical representation of a straight line. Dancers dressed in blue represent the variables of y, m, x, and b, while dancers in red represent the operators =, *, and +.

PROCEDURE

Planning a Production

The next objective was to map out the movements of the dancers. Adobe AfterEffects was used in order to create the basic movement animations including the placement of each of the dancers representing the variables and operators. One idea discussed included using ribbon or other fabric to connect the dancers in the graphical and tree forms to solidify the visual image. This idea developed into using a floor mapping of the parse tree form of the equation, which was placed at the feet of the dancers in the beginning of the simulated production.

A Simulated Production

Blender (Roosendaal 2004) and a subcomponent program called MakeHuman were used to model the dancers and stage for the simulated production. MakeHuman is another open-source software program developed by Blender users that models human forms based on various set parameters. The user can change the size of various body muscles as well as the type of human model created by manipulating slide bars. The model can then be exported from MakeHuman and imported into Blender to rig and skin. We created a model for a dancer and created an armature for it, then proceeded to manipulate the vertex groups to minimize deformations.

We then duplicated the dancer model six times so that there were seven total dancers, one for each of the variables and operators in the line equation. The dancers were then skinned and rigged to an armature in Blender and animated. While in the tree form of the equation, the dancers perform choreographed turns. The performers then move into a diagonal line formation where they take on the choreography of a kick line drill team.

We created the stage environment for the production consisting of a wood textured floor or stage and a deep red texture curtain and stage wings and modeled the operators and variables of the equation for a line and created a floor map, which allowed the audience to see what each of the dancers represented. We modeled a simple dress costume for each of the dancers and used the colors of the dresses to distinguish between the dancers representing variables and those representing operators. Variables take a blue color and the operators take a red.

The simulation works as a ‟marching band” where the dancers are in the tree form at the beginning of the production (a representation of Figure 2), and then move into the graphical form of a diagonal line (a representation of Figure 3). It is a ‟marching band” style in that the audience, looking from a bird′s eye view perspective, can clearly see the forms created by the dancers. Time based screenshots of the simulation are shown in Figure 4. Figure 5 shows frame 5 in greater detail.

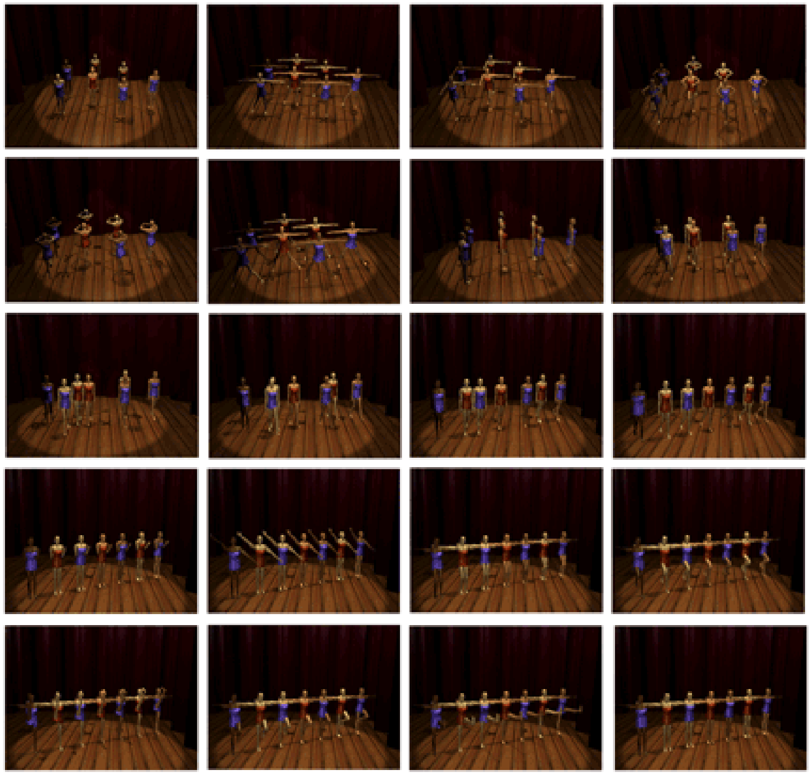


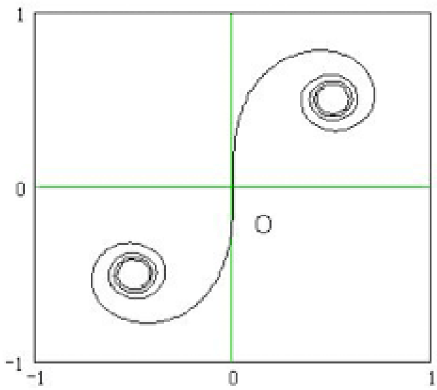
Figure 4. A series of time-stamped screen shots from the produced simulation.

Figure 5. Detail of frame 5.

The next step was to create choreography for the dancers. We created the animation strictly using key framing. In the first form (the tree form), the dancers complete a simple turn sequence signifying the simplicity of the tree representation of an equation. The dancers then walk to the graphical form (the straight line). In this formation, the dancers move as a basic kick line. Kick line choreography is often incorporated into dance routines when the dancers are placed into one or more straight lines. Also, kick line routines more often than not consist of lines of dancers being connected by the arms, an addition which reinforces the diagonal graph representation. The final touch on the simulation was to create lighting effects, particularly the spotlight look that would be incorporated in a real life performance that pinpoints the dancers and holds the attention of the audience.

An Extension into More Complex Equation Sets

We are now going to discuss a slightly more complex set of equations to represent. The Spiral of Cornu is a structure of a family of curves known as *polynomial curves*. This idea of aesthetically representing mathematical equations through performance-based arts can further be applied to any mathematical equation and representation. The graphical representation and equations of the Spiral of Cornu are shown below in Figure 6.



$$x(t) = a\int_0^t \sin(u^2)du$$

$$y(t) = a\int_0^t \cos(u^2)du$$

Figure 6. The equations and graph of the Spiral of Cornu.

Planning a Production

A still shot of the AfterEffects animation shown below in Figure 7 represents the $x(t)$ half of the Spiral of Cornu. Each square represents a dancer after all dancers have moved into the graphical representation formation.

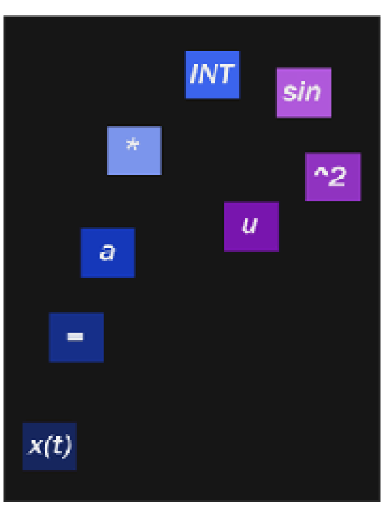


Figure 7. A possible mapping of dancer formations for a Spiral of Cornu representation.

Another idea that was discussed that could be incorporated into a performance included an "alphabet representation" where two dancers could pose their bodies in such a way as to represent the tree form of the equation as seen in Figure 8.

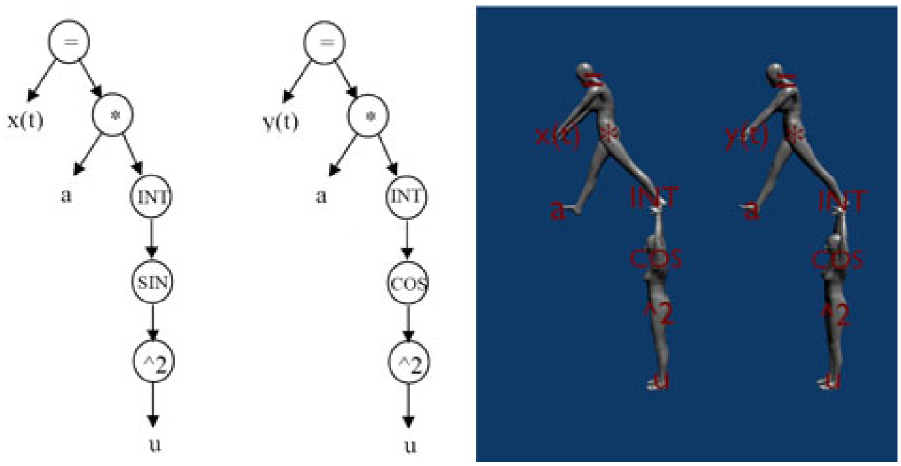


Figure 8. The "alphabet representation" displaying the tree form of the Spiral of Cornu equations on the left, and its corresponding mapping to a human form on the right.

Creating a Plot

The University of Florida School of Theatre and Dance utilized some of the themes of our simulation in the Shadow Dance Theatre summer production of "Raven Lake" (Rose 2006). "Raven Lake" is an interpretive piece regarding the evolution of ideals and love over the passage of time. The production deals with searching for perfection in love and the fact that it is nonexistent. It introduces concepts of math and science, an unrequited love, the passage of time with a writer and an old man, the contrast between black and white, and two simultaneously occurring seasons, as well as a dancing master leading the ravens, shadows of past ballerinas, and the struggle with one ballerina to give up the ideals of the past.

One instance in the production that correlates to the mathematical concepts of the simulation deals with the Spiral of Cornu. "Two equations to form one," as said by one of the performers in the production, relates the dual mathematical equation to love and relationships. Other comparisons of motion equations and potential and kinetic energy equations are more interpretive. These concepts are presented and left for the audience to interpret. For educational purposes, we wanted the simulated performance to be less interpretive and more representational. The audience should take away the knowledge of the equation representation and the visual graph representation while the dance and performance act as the link between the two.

The Possibility of Incorporating Motion Capture

One technique that we tried was importing an open source motion capture file, or a BVH file (biovision hierarchical motion), of a ballet dancer into Blender. We then created an armature by running a found Python script and rigged and skinned the dancer model to the armature, and tried to minimize character deformation. However, we ran into trouble creating a smooth animation due to unknown reasons. After correcting all vertex groups, the BVH movements did not run properly, and we are investigating solutions to this anomaly.

The Orthopaedics and Sports Medicine Institute at the University of Florida controls its own biomechanics and motion analysis lab and software. The Institute has done work such as analyzing a golf swing and our quarterback's arm, as well as helping to discover new treatments for amputees. The facility contains a motion capture system that allows for the evaluation of musculoskeletal performance in athletes and patients. We had the opportunity to run a few test trials using the lab. One of us (Corey) wore markers that kept track of motion and ran several trials of a variety of basic dance movements. A screen shot of the footage is shown below in Figure 9.

We took the coordinate points for each of the markers and created a BVH file for the points and imported them into blender. However, we did run into glitches and were not successful in creating the full range of motion, so this technique did not work for the models in the final simulation.

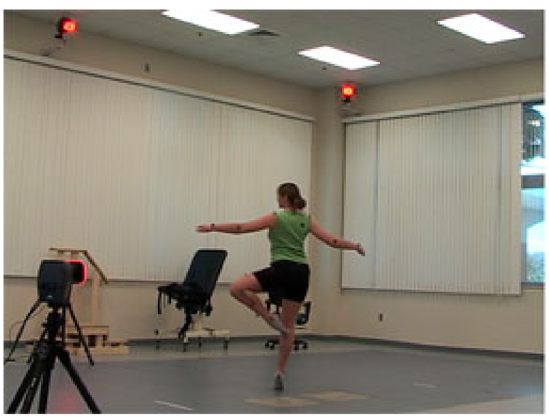


Figure 9. A screen shot from the motion capture video footage.

CONCLUSIONS AND FUTURE WORK

The purpose of this project was to create an effective method of representing the structure and behavior of various equations through dance-based performance. Using dance as an alternative to traditional text-based representations, students who would otherwise struggle and become frustrated by the mathematics discipline, can become engaged in the representation and behavior in a physical time-based manner. A simulation of a sample production was created to show relationships between dance movement (both individual and formation-wise) and equation representation. The production proved to be a successful step towards improving informal mathematics education. The basis of the study can further be extended into other virtual programs.

We also considered other programs during the course of this research. Alice (Dann et al. 2005) is a program developed by the Stage3 Research Group at Carnegie Mellon University. This program serves as an introduction to programming for students beginning in middle school and continuing through upper levels of education. The goal is to expose these students to and spark an interest in the area of computer science. Because this program has a primarily educational goal, it would be a suitable candidate for the creation of future productions with a similar theme. Second Life (Rymaszeweski et al. 2006) is a 3D online digital world imagined, created and owned by its residents. The open source interactive environment has over two and a half million registrants. The program allows users to buy and sell Linden dollars, own virtual land and communicate with other users. The basis of this program lies in BVH motion capture files, and would be an excellent extension of the created simulation.

Our plan is to continue this work by strengthening the connection between the available motion capture data and one of the 3D programs that we have employed, and work closely on a live production of theater and dance. We hypothesize that by employing dance and theater in the representation, not only of mathematics solution spaces (i.e. curves and algorithmic executions), but also of problem spaces (i.e., the structure of algebra), we may assist students by motivating them to study mathematics and, later, more complex structures found in computer science.

ACKNOWLEDGMENTS

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