RESEARCH STATEMENT
Joseph J. LaViola Jr.

My research interests lie in human computer interaction, interactive computer graphics, and virtual environments. My work in these areas has also spawned interests in areas such as machine learning and pattern recognition, 2D parsing, and human motion estimation.

Dissertation Research

In my dissertation research, I developed a new approach to creating and exploring dynamic illustrations that can be used by both teachers and students in mathematics and physics courses. This new paradigm, mathematical sketching, lets users write down mathematics, make drawings, and associate the mathematics to them, so they animate based on the mathematical specifications (see Figure 1). Since users make mathematical sketches using a pen-based computer, they are using a familiar pencil-and-paper interface augmented with computational power. There were several important problems I solve in order to bring mathematical sketching to fruition.

![Figure 1. A mathematical sketch showing the motion of two cars, one with constant velocity and the other with constant acceleration.](image)

First, because pencil and paper is so commonly used by teachers and students in mathematics and the sciences, I wanted mathematical sketching to mimic pencil and paper and reduce the amount of mode switching. Thus, users needed to be able to write down and have the system recognize 2D mathematical notation, make drawings, associate mathematics to drawings, and invoke commands without having to switch modes by using buttons or menus. I used compound context-sensitive gestures to avoid conflicts between inking and commands (this also helped reduce the number of gestures users had to learn). Second, the handwritten 2D mathematical expressions must be
recognized by the system so they can be processed and used to gather data for animation. Recognizing handwritten mathematical expressions is a difficult problem that has been explored for many years. To deal with this issue, I developed a hybrid mathematical symbol recognizer, in conjunction with a complete mathematical expression recognizer, that uses pairwise AdaBoost classifiers with the Microsoft Handwriting recognizer as a preprocessing step. This approach was faster than using pairwise AdaBoost classifiers in isolation and showed no statistically significant loss in accuracy. Third, even though users can write down mathematical specifications and associate them to drawings, important information must be inferred from the mathematics and drawings to animate them properly. I thought it was important to reduce users’ cognitive burden by making mathematical sketching as simple as possible. Therefore, users need not directly dimension the animation coordinate system. Instead, drawing dimension analysis is used to infer coordinate dimensions based on the structure of the drawings and any labels associated to them. Finally, during the course of my work, I defined and developed strategies for dealing with drawing rectification problems. Since in mathematical sketching users write precise mathematical specifications and make imprecise drawings, correspondence mismatches are possible; drawing rectification is the process of fixing these mismatches.

As part of my dissertation work, I also ran user evaluations on mathematical sketching; the results indicate it is a powerful, easy-to-use tool for creating dynamic illustrations that beginning physics and mathematics students would use in their class work. More detail on mathematical sketching is given at www.cs.brown.edu/people/jjl/mathpad/.

Other Research

In addition to my dissertation research, I have also done work in human motion estimation and prediction and interactive 3D graphics. Human motion tracking is critical in many virtual and augmented reality applications. The focus of my work in this area is developing and analyzing motion estimation algorithms and developing models that characterize the behavior of motion tracking algorithms under different parameters, such as sampling rate, noise variance, and motion type (e.g., hand, head). My work thus far has produced a predictive motion tracking algorithm testing suite that lets researchers analyze these algorithms for their own tracking needs. The suite has been used by several different research groups around the world. In addition, I used the testing suite to compare a double exponential smoothing-based predictor with a more traditional Kalman filter-based predictor, and showed empirically that the former runs over 100 times faster than the latter with no loss of accuracy.

In interactive 3D graphics, my focus has been on developing new 3D user interaction techniques and new input devices for virtual environments. I have worked on a variety of techniques for improving navigation through 3D worlds, including hands-free navigation and nonisomorphic rotation. In addition, I have also developed strategies for combining hand gestures and speech input in multimodal interfaces.
Future Research

Although I have worked in a variety of areas in user interfaces and interactive computer graphics, the dominant theme in all my research has been improving the user experience. I have focused on using innovative technology beyond traditional desktop interaction and leveraging insights in how users perform different tasks in an attempt to automate them and reduce the user’s cognitive load. This approach has allowed me to explore how work from other disciplines including, pattern recognition, machine learning, time series analysis and signal processing, can be used in human computer interfaces. I plan to continue with this approach in my future research.

Since mathematical sketching is a new area of human-computer interaction, a significant amount of research is left to do. One of the areas I will focus on will be improving mathematical sketching (a comprehensive research agenda can be found in Chapter 11 of my dissertation). For example, I will continue to work on developing better mathematical expression recognition algorithms as well as extending the power of mathematical sketching to support richer and more complex dynamic illustrations. These extensions will present significant challenges in user interface design and intelligent inferencing.

Accurate tracking in virtual and augmented reality is still an unsolved problem and robust and powerful motion estimation algorithms will continue to play a significant role in making human motion tracking more transparent to the user. I plan to continue to explore improving human motion tracking by finding better and more robust algorithms that meet the demands and nuances of human motion.

Research in 3D user interfaces is still ripe for new and innovative results and I plan to return to this area with a slightly different spin. Over the last few years, as the video game industry has grown in leaps and bounds, games research laboratories have sprouted up in universities around the world. However, few of these labs focus specifically on research in 3D user interfaces for games. With each generation of game hardware, graphics and sound continues to improve but game user interface innovation seems to remain constant. I believe there is a great opportunity here to do interesting research in improving game play and the overall user experience with video games. Thus, I plan to leverage my work in 3D user interfaces to start an interactive entertainment usability and interface lab where these issues can be explored. It is my hope that the work done in this lab will not only improve video games, but can also be extended to other areas of interactive computer graphics.