Guest Editors’ Introduction

Physics-Based Characters

Aaron Hertzmann • University of Toronto

Victor Zordan • University of California, Riverside

To outsiders, it might seem natural—obvious, even—that you could use physics to make animated characters move in games and movies. The surprising fact is that physics-based characters have never been very successful in production. However, over the last few years, physics-based character animation has been experiencing tremendous growth and a great deal of attention in computer graphics research. Why has physics fared so poorly until this recent resurgence, and will it ever play a significant role in commercial character animation?

Physics-Based Animation’s Growth and Decline

In the ’80s, a small vanguard of animation researchers explored physics-based character animation with the same enthusiasm others applied toward rendering and other areas. Just as radiometry provided a solid theoretical foundation for rendering, physical principles of dynamics and control were applied to character animation. Fundamental concepts of Newtonian mechanics, optimal control, and simulated biology would seem to provide both the theoretical basis for animation and a natural framework for managing the complexity of coordinated movement.

Unfortunately, despite decades of research, these methods haven’t yet fulfilled their promise. Until recently, the eager programmer attempting to create physics-based characters would quickly encounter a range of seemingly insurmountable problems. Hand-tuned characters usually look stiff and artificial, or else could fall down at the touch of a feather. Behavior optimization can run for hours or days and still never produce a good-looking result.

On the other hand, physical methods have become mainstream in the animation of other objects, such as cloth, hair, water, and smoke. The key factor is that these simulations are passive: they require simulating physics equations but don’t require sophisticated control to make them appear natural. Such simulations have been wildly successful in animation largely because they provide rich detail and complexity where hand animation or data capture is difficult.

In contrast, character animation is active: it requires descriptions not only for the body’s physics but also for behavior control. Whereas character animation in games frequently uses passive dynamics, better known as “ragdoll physics,” games usually only employ physics after the character has died and no longer exerts any active muscle forces.

In the most general setting, creating good control requires answering this question: how does the brain create muscle forces at each instant? This question crosses fields as diverse as sensorimotor neuroscience, robotics, and artificial intelligence, and no one yet knows the answer. Whereas, for example, Claude-Louis Navier and George Gabriel Stokes introduced equations for describing fluid dynamics in the early 1800s, no such equivalent yet exists for movement control. Because of physics-based character animation’s many difficulties, for many years it was a largely dormant topic, with few publications annually.

The Rise of Data-Driven Animation

With the growth of motion capture databases, data-driven animation became popular. Motion databases made creating high-quality motion quick and easy. It seemed that physics had become obsolete: why simulate something when you can just copy or learn it from the data?

Yet the limitations of data-driven methods eventually became apparent: if all you have is data, then you can only create motions like the data. For interactive settings (especially games), you might want a vast range of motions that don’t repeat yet behave naturally in real time. Capturing all the
data you might ever need for the game is simply impossible. So, considerable research focused on methods for generalizing and reusing data. But ultimately, many of the most obvious and trickiest of data-driven methods’ failures—such as poor ground contact (including footskate), object interpenetration, and implausible ballistic motion—are violations of basic physical laws. At the least, physics could help correct these errors.

**Physics-Based Animation’s Rebirth**

Beyond the limitations of data-driven methods, new types of real-time animation are emerging that demand more flexible ways to create motion. With user-generated characters and avatars, as in the game Spore, characters can’t be pre-animated or captured because they must be able to move naturally the moment the user creates them. Also, richer, more continuous-input devices such as the Nintendo Wii and Xbox Kinect provide ways for users to produce high-dimensional, kinematic control that doesn’t easily map to pre-scripted animation.

Recently, the ever-growing need to create more flexible motion has focused more interest on physics. In part, the widespread availability of human-motion data has led to much related research, analysis, and experimentation. This effort has included techniques that incorporate physics and the integration of motion data into control systems, which is making the distinction between physics-driven characters and data-driven characters less clear.

Also, whereas animation research had largely abandoned physics-based characters for some time, other fields didn’t have the luxury of ignoring physics. In particular, diverse fields such as biomechanics, robotics, optimal control, and optimization have made great strides in understanding movement. And, although none of these fields focus on precisely the same problems that interest animation, a wide range of developments has made physics-based characters more feasible. Furthermore, with modern processors’ ample computational power, the practical use of various techniques, optimization, and modern control approaches for real-time or near-real-time animation has become a reality.

From a combination of seemingly disparate components, a new generation of physics-based animation approaches are emerging that are robust and maintain a standard of visual quality approaching data-driven synthesis. And even with the holy grail of control principles that describe human motion still a mystery, the animation research community continues to forge its own path. We’ve learned that we don’t need to solve the problem of biological control, nor do we need to throw out the advantages of animator control and motion capture. Instead, current research aims to find the best of all worlds, judiciously combining physics with human-motion examples, animator input, or both. This special issue brings together four examples of the innovations in this exploding area.

**In This Issue**

In “Simulating 2D Gaits with a Phase-Indexed Tracking Controller,” Yeuhi Abe and Jovan Popović introduce a flexible solution for robust synthesis of timing-based control for locomotion with a physical simulation. In “Stable Proportional-Derivative Controllers,” Jie Tan, Karen Liu, and Greg Turk investigate a method that allows arbitrarily high stiffness, even at large time steps, while maintaining stability. In “Practical Character Physics for Animators,” Ari Shapiro and Sung-Hee Lee present a practical set of tools usable in a commercial pipeline that correct physical parameters associated with keyframe data. Such tools let animators retain control while objectively judging the generated motion’s plausibility. Finally, in “Direct Control of Simulated Nonhuman Characters,” Junggon Kim and Nancy Pollard offer an intuitive method for controlling self-propelled characters with unique morphologies.

The results of the research presented here and the related recent research in various venues show that physics-based character animation is indeed a promising and increasingly exciting domain. With this explosion of work, it is safe to say the concept is finally “proven,” but, for the most part, it is not yet practical and has not yet made its way to production. Nonetheless, the indications make it clear that physics will play an important role in the animation of characters for the foreseeable future.

**Aaron Hertzmann** is an associate professor in the University of Toronto’s Department of Computer Science. His research interests are computer graphics, computer vision, and the application of machine learning to both. Hertzmann has a PhD in computer science from New York University. Contact him at hertzman@dgp.toronto.edu.

**Victor Zordan** is an associate professor in the Computer Science and Engineering Department at the University of California, Riverside. His research interests are physical simulation; motion capture; algorithms for creating believable (and unbelievable) motion; and novel uses for animation in electronic games, medical and training applications, and 3D virtual worlds. Zordan has a PhD from Georgia Tech. Contact him at vbz@cs.ucr.edu.