

Research Statement for Lucas Kovar

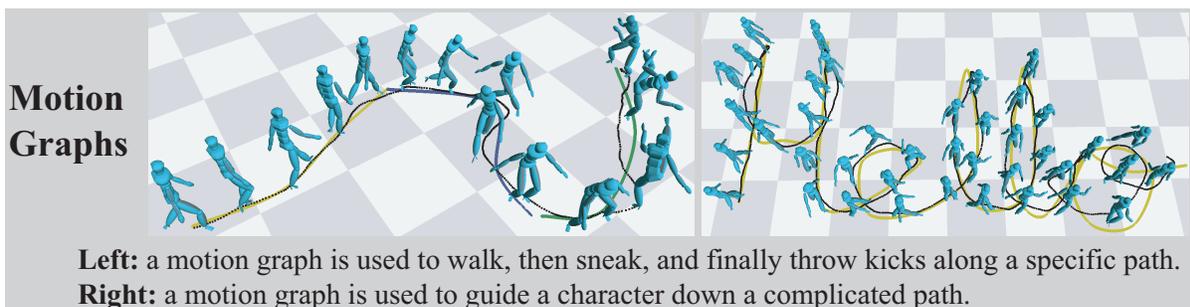
1 Introduction

My research interests have revolved around creating realistic animated humans. Animated humans are important to a variety of applications, including: entertainment, where they appear as characters in games and as special effects in movies; training simulations, which are used by the military to prepare soldiers and by industry to instruct workers in using equipment; and visualization aids, such as for medical analysis (studying an injured person's gait) and equipment design (determining if controls can be comfortably accessed). My thesis work focused specifically on animating realistic human motion; that is, having characters *move* correctly, regardless of how (for example) their skin and clothing looks. This is a challenging problem for two reasons. First, human motion is intrinsically complicated. The human body is an intricate structure containing hundreds of individual bones and muscles, and it is capable of both subtle movements (such as shrugging shoulders) and highly dynamic motions (such as a back flip). Second, people are natural experts on human motion. Having seen other people move our entire lives, we are highly attuned to the subtleties of human movement, and casual viewers can readily identify even minor inaccuracies in animated motion.

A popular way of animating realistic motion is to use a technology called *motion capture*, which obtains accurate 3D recordings of the movement of a live performer. However, by itself motion capture offers no control over what a character does; much like a video, it can only be used to play back the original performance. **My thesis shows how to use motion capture data to build generative models that provide high-level control over a character's actions, while preserving the realism of the original data.** For example, an artist might ask a character to walk down a path and open a door, and the model would handle the details of constructing appropriate walking and door-opening motions. **The single most important contribution of my existing research is the development of automated methods that make it feasible to work with large data sets.** This is crucial because data-driven models can only reliably produce motion "near" the original examples, and hence expressive models require large amounts of data. My thesis work provides a comprehensive set of techniques that span multiple levels of focus, from enforcing low-level kinematic properties during motion synthesis, to building models that can synthesize entire motions at once, to providing intuitive high-level interfaces for creating motions with specific properties.

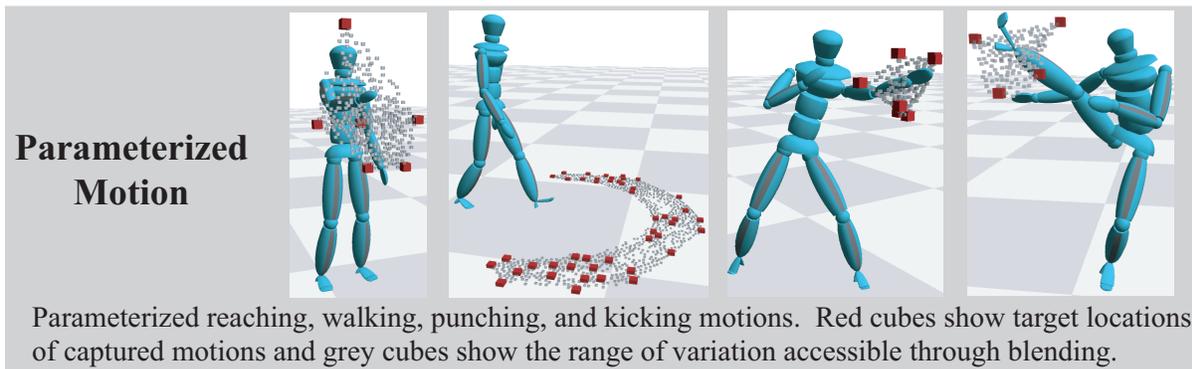
2 Summary of Previous and Ongoing Work

Please visit <http://www.cs.wisc.edu/~kovar/projects.html> for associated papers and videos.



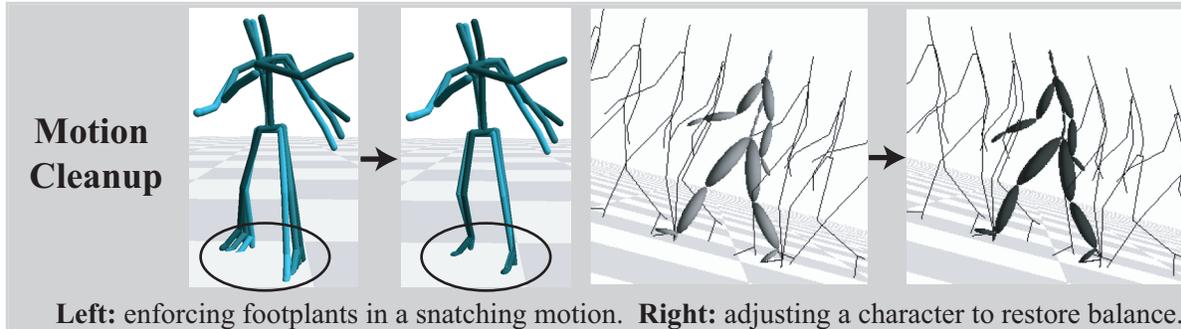
Motion capture data consists of static motions of finite duration. A single data file, for example, might contain someone walking a few steps or picking up a glass. However, applications like games

require characters to adapt their actions to changing circumstances and to be animated for unknown (and lengthy) periods of time. Along with two other research groups which independently performed similar work [1, 7], I developed [5] the first practical method for automatically constructing indefinitely long motions tailored to user-specified requirements. My work showed how to automatically detect places where captured motions are locally similar and then construct special transition motions that seamlessly join these different segments of data. The result is a *motion graph*, which is a directed graph where edges represent clips of motion and nodes indicate places where different clips can connect; new motions can be created simply by traversing the graph. To control motion synthesis, a user specifies high-level constraints and a branch-and-bound technique is used to search the graph for a motion that best satisfies those constraints. For example, a user might draw a path on the ground and ask for a motion that follows this path. An extension of this work [2] allows one to construct graphs with simple internal structures (a few “hub” nodes with many outgoing edges), making it simpler and more efficient to control a character’s motion. Motion graphs provide a highly automated alternative to the labor-intensive methods that are currently used in practice [8].



Motion graphs create new motions by rearranging and attaching existing actions, but they cannot create fundamentally new actions. For example, if a data set has seven motions of someone reaching to different places, then the character will only be able to reach to these seven locations. This can be remedied by *blending* captured motions to create new ones, where blending intuitively amounts to computing a weighted average. A mapping can then be built between blend weights and high-level motion features, creating a *parameterized motion* that can be controlled intuitively. For instance, a parameterized reach might allow one to animate specific reaches simply providing the location of the target object.

Existing methods for building parameterized motions [9, 11] require considerable manual labor and are designed for small, contrived data sets consisting exactly of example motions that evenly sample a predefined range of variation. In practice, a data set will contain many different kinds of motions, each of which span an unknown range of variation. My research has provided several automated techniques that greatly simplify the construction of parameterized motions from these larger, more general data sets. To help users collect example motions, I have introduced a novel database search algorithm for identifying segments of motion data that represent variations of the same underlying action [4]. I have developed a fully automatic blending algorithm that can handle a wider range of input motions than existing manual algorithms [3]. Finally, I have introduced a strategy for building accurate and efficient parameterizations that explicitly avoid undue extrapolation from the available data [4]. Ongoing research is aimed at combining these methods with graph-based motion synthesis.



Real human motion often contains interactions between end effectors (hands and feet) and parts of the environment, and each of these interactions corresponds to a kinematic constraint that requires the relevant end effector and object to be in contact. For example, one of the most common kinematic constraints is a *footplant*, which requires a foot to remain stationary on the ground; footplants typically occur whenever a leg bears weight. Kinematic constraints can be violated in synthesized motion, causing disturbing artifacts — for instance, a violated footplant results in a character that unnaturally slides or skates on the floor. Previous methods for enforcing kinematic constraints have relied on expensive optimization procedures that are unstable when the character is in near-singular configurations. I developed an efficient algorithm [6] that only involves closed form computations and handles singularities robustly. The speed and reliability of this algorithm makes it uniquely suited for automated contexts, allowing motions to be “cleaned up” without user intervention.

In addition to kinematic constraints, synthesized motions may violate physical laws. My colleagues and I have made an investigation [10] into enforcing physical laws in an efficient and controllable manner.

3 Future Research

My future research plans revolve around the development of usable, high-fidelity models of humans. The extraordinary complexity of humans makes this a rich topic with many possible avenues of investigation. In particular, my agenda is not limited to building more accurate and controllable motion models (although this certainly remains a challenge), but encompasses several other problems, including: modelling shape and deformation of the body, hair, and clothing; modelling reflectance properties of skin and hair; and applying my models to domains outside of computer graphics, including computer vision, robotics, and biomechanics. I anticipate that the applications of this research will be numerous and diverse, for the simple reason that accurate modelling of humans has immediate relevance to anything that involves telling stories, facilitating communication, and simulating or analyzing real-world events. The remainder of this section briefly describes some specific potential research projects.

1. **Incorporating physics.** One strategy for synthesizing motion is to use physical simulation to compute a sequence of joint motions that obeys physical laws while performing some action of interest. However, real human movement contains properties like “personality” that are not described by the laws of physics, and a motion that is physically possible may nonetheless appear stiff, unnatural, and robotic. Ideally, an animated motion will both be physically plausible and within the realm of natural-looking movement. In light of this, I plan to robustly incorporate physical laws into data-driven synthesis models, which will have the effect of expanding the range of realistic motion that these models can produce.
2. **Modelling body shape and deformation.** In computer graphics, modelling of human motion has been largely decoupled from modelling of human shape (i.e., the geometry of the body). However,

motion and shape influence each other: people move differently according to size, weight, and musculature, and movement can in some circumstances be tightly constrained by the shape of the body (for example, squeezing through a narrow passage or bumping into a fellow pedestrian). I am interested in developing automated methods for high-fidelity adaptation of motion to different body shapes and sizes. I am also interested in modelling human body deformations, both in general and in the particular (and more challenging) case where there are large interactions between multiple bodies or bodies and the environment.

3. **Motion from video.** Recovering 3D motion from a video (that is, a single camera perspective) is in general an underconstrained problem, but several researchers in the computer vision community have exploited knowledge about the human body (e.g, joint limits) to generate approximate reconstructions of human movement. Unfortunately, these methods tend to be quite fragile, and even in the best of circumstances they yield motion far from animation-level quality. I believe the strong 3D models developed in my work could be adapted to provide robust motion reconstruction and recognition directly from video, with applications to surveillance and gesture-based user interfaces. Moreover, I believe that higher-fidelity 3D models that incorporate hand and facial movement could be developed to recognize and transcribe sign language.
4. **Biomechanical analysis.** Large motion capture databases have been collected by the biomechanics community for many years, but there is general lack of tools for organizing and manipulating this data. I am interested in working with biomechanics researchers to improve the utility of these data sets, with specific possibilities including improved methods for classifying movement and simplification of data organization and processing.

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