Model Reduction for Human and Animal Locomotion

Jovan Popović

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1 Motivation

Modeling human and animal motion is a fundamental scientific objective, with important applications in computer graphics, robotics, and medicine. Applications in graphics include education, training, and visualization, as well as animation in art, film, and entertainment; in robotics, robot design and the design of controllers for locomotion; in medicine, the diagnosis of medical problems and the design of prosthetic devices. The necessary step in all these applications is to develop a predictive mathematical model of locomotion. In entertainment, this model of locomotion is optimized to create motions that match artistic intentions and satisfy constraints that reflect the desired story. Similarly, in robot design and medicine, locomotion models are optimized to develop and revise motion controllers and prosthetic devices.

In each application, the success of a resulting method is contingent on the quality of the mathematical model of locomotion: models of great complexity are difficult to simulate, analyze, and optimize. The dynamics of locomotion, in particular, presents an immense computational challenge:

- the equations of motion are highly nonlinear;
- the joint-angle representation of a skeleton is high-dimensional and redundant (i.e., the same hand motion can be described by many different shoulder and elbow motions);
- locomotion is a hybrid dynamic system controlled by continuous actuators (muscles) and discrete events (collisions with the ground).

Ideally, the simplest predictive model should be used for each application, but so far most methods are applied to standard formulations of Lagrangian dynamics for jointed rigid bodies. As the most basic method of model reduction, joints with minimal effect on the observed behavior are frequently removed to reduce the dimensionality of the model. In a standard computer graphics practice, human skeletons are frequently reduced to jointed rigid-body structures of approximately fifty degrees of freedom. More recent methods reduce the dimensionality even further by manually simplifying skeletons for each class of motions: broad jump, running and others.

2 Proposed Research

I propose to develop a general framework for constructing simple, low-dimensional models of locomotion. This framework will formalize and automate the standard practice of joint removal. However, the main research objective is to construct more convenient representations of jointed rigid-body structures and to develop approximating models for new representations consistent with the geometric structure underlying the mechanics. In short, model reduction will not only eliminate insignificant joints, but also discover alternative representations and controllably approximate the dynamics equations.

The resulting models will not assume joint-angle representations of rigid-body structures. Some evidence already suggests that alternative representations are numerically more convenient for different applications. For example, a representation of human walk with sagittal-elevation angles is less sensitive to variations in height and weight as well as the walking speed and terrain. For new representations of rigid-body structures, the new model-reduction framework will also formulate simpler mathematical models of locomotion. The simpler models will approximate the dynamics of locomotion, but be simpler to work with analytically and computationally. This model-reduction framework will be developed from empirical analysis of simulated and motion-captured data of human and animal locomotion. The general approach will apply statistical methods such as principal component analysis to the state space and use a projection to construct the model in the reduced space.

An immediate application of the proposed research is motion re-targeting for computer animation. Reduced models would yield a common representation for mapping the human motion onto an animal or vice versa. For example, a human in a motion-capture studio could control an animated animal character by acting out the desired behavior. Further applications include motion synthesis with multigrid methods, design of robot controllers, and medical analysis of healthy gaits.

3 Tentative Agenda

2001–2002 In the first half of the year, we will build the infrastructure for analyzing simulated and motion-captured data. The motion-capture studio, funded by EECS startup funds, should be installed by January 2002. In the second half of the year, we will begin statistical analysis of simulated and real data.

2002–2003 By January 2002, we will develop the model reduction framework and investigate the immediate application to motion re-targeting. In the second half, we will investigate applications in motion synthesis and robot control.