Optimization-based Interactive Motion Synthesis for Virtual Characters

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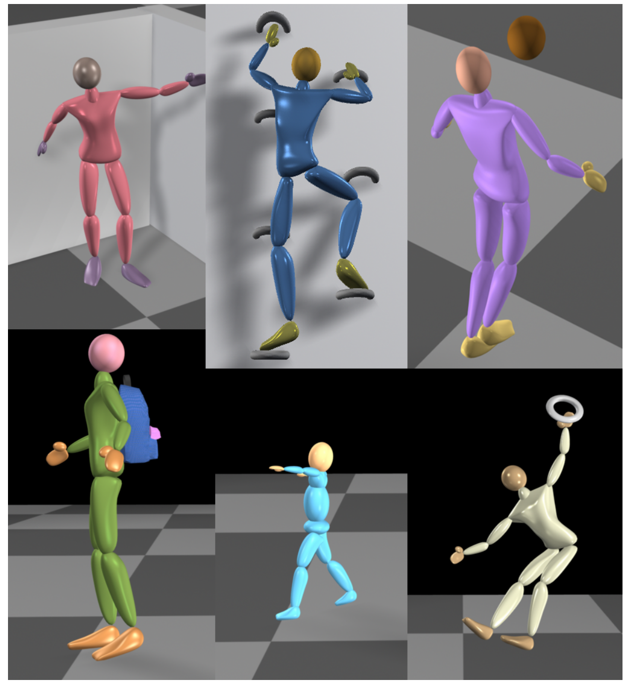
1 Introduction

Modeling the reactions of human characters to a dynamic environment is crucial for achieving perceptual immersion in applications such as video games, training simulations and movies. Virtual characters in these applications need to *realistically* react to environmental events and *precisely* follow high-level user commands. Most existing physics engines for computer animation facilitate synthesis of passive motion, but remain unsuccessful in generating motion that requires active control, such as character animation. We present an optimization-based approach to synthesizing active motion for articulated characters, emphasizing both physical realism and user controllability. At each time step, we optimize the motion based on a set of goals specified by higher-level decision makers, subject to the Lagrangian dynamics and the physical limitations of the character. Our framework represents each decision maker as a controller.

Optimization-based approach also provides a generic framework for designing intuitive and yet versatile controllers. In this framework, a controller is a set of high-level commands and preferences formulated into constraints and objective functions. Because the optimizer directly solves for joint configuration instead of joint torques, the controllers can enforce intuitive kinematic constraints and objective functions that produce the desired motion. We demonstrate that our framework can easily adapt to different characters and different environment. Furthermore, our approach unifies high-level motion planning and low-level motion synthesis into a single optimization. The character is able to make intelligent decisions based on her dynamic state and environment conditions.



2 Motion Synthesis

The heart of our algorithm is an optimization that computes the character's joint configuration, $\mathbf{q}^{t+1}$ $(\equiv \{q_1^{t+1},\ldots,q_n^{t+1}\})$, for the next time step, as well as the external force, λ, associated with each mechanical constraint, $\mathbf{C}_m(\mathbf{q}^{t+1})$. A mechanical constraint enforces a specific geometric relation in generalized coordinates by applying appropriate amount of mechanical force. By setting boundaries on λ, we can ensure that mechanical forces are limited to the physically realistic friction model.

To ensure the physical realism of the movement, we apply augmented Lagrange's equations of motion, $L_j(\mathbf{q}^{t+1},\lambda)=0$ for each generalized coordinate, q_j. Because the root translation and rotation do not have any actuators to generate internal torques, Lagrange's equation of motion must be satisfied exactly at root coordinates. We do not enforce Lagrange's equation of motion directly on other joints because they are implicitly equipped with actuators that can generate arbitrary internal torques to satisfy the equation. Instead, the realism of joint movements depends on kinematic constraints, $\mathbf{C}_k(\mathbf{q}^{t+1})$, and objective functions, $E(\mathbf{q}^{t+1},\lambda)$, defined by the controllers. Lagrangian dynamics on the global motion and the joint torque limits also play important roles in regulating the joint movement.

3 Controller Design

To demonstrate the generality of our framework, we designed a balance controller, a dodge controller, and a climb controller that define different sets of objectives and constraints in the optimization.

The balance controller incorporates multiple strategies for maintaining and recovering balance, including supporting the center of mass (COM), stabilizing the upper body, adjusting joint angles and velocities, taking steps and using environment features, such as walls, for support when recovering balance against large external perturbations.

The user can directly encode high-level control strategies into objective functions. As an example, objective functions corresponding to strategies "Keep the joint velocities low" and "Reach the desired position" can be simply written as $E_1(\mathbf{q}^{t+1}) = \sum_j \left(\frac{q_j^{t+1}-q_j^t}{\Delta t}\right)^2$, and $E_2(\mathbf{q}^{t+1}) = \|\mathbf{p}_b(\mathbf{q}^{t+1})-\mathbf{p}_0\|^2$, where $\mathbf{p}_b(\mathbf{q}^{t+1})$ is the position of a point on body node b in world coordinates, and $\mathbf{p}_0$ is the desired position.

To demonstrate seamless integration of high-level intentions into an optimization problem in our framework, we design a dodge controller by coupling intentional behaviors with the balance controller. When the character perceives an incoming object, the controller will add a dodging objective to keep the character a minimal distance away from the object. Since the two conflicting goals, balancing and dodging, are optimized simultaneously, the character is able to make the optimal move based on knowledge of both her current dynamic state and her environment.

Finally, we design a rock climb controller that requires complex coordination of the body. This seemingly difficult motion only requires a simple controller and one canonical pose generated using inverse kinematics.