Discovery of Complex Behaviors through Contact-Invariant Optimization

Igor Mordatch, Emanuel Todorov and Zoran Popović
University of Washington
{*mordatch,todorov,zoran*}*@cs.washington.edu*

1 Introduction

We present a recent motion behavior synthesis framework capable of producing a wide variety of important human behaviours, including locomotion, getting up, crawling, climbing, carrying objects, acrobatics (handstands in particular), and various cooperative actions involving two characters and their manipulation with environment. Our framework is not specific to humans, but applies to characters of arbitrary morphology. It is fully automatic and does not require domain knowledge specific to each behavior, or pre-existing examples such as motion capture data.

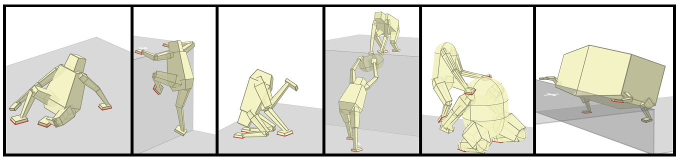

Figure 1: Selection of motions generated by our framework

2 State of the Art

Previous approaches to motion planning have been successful by restricting themselves to a specific regime and exploiting domain-specific knowledge. For locomotion, this includes using reduced models based on inverted pendulum dynamics and assuming a fixed pattern of foot-ground contact phases or stances (e.g., [3, 2]). However, these approaches cannot generalize to motions outside of their stereotypical regimes. More general approaches have applied discrete planning ([1]), but involve solving difficult search problems.

3 Proposed Solution

We pose motion planning as a continuous optimization problem, where the motion is broken up into a sequence of phases. For each phase, we optimize spline trajectories of features on the character (in our case, position and orientation of torso and limb end effectors). Additionally, we optimize a novel continuous contact variable for each limb and phase that smoothly controls whether or not the limb's end effector is in contact with the environment. When a contact variable is active, the limb's contact surface is free to generate ground reaction forces, but the contact surface must actually be touching the ground. Thus, the decision of when to make footplants/handholds are made explicit in the optimization process.

The character's joint angles can be recovered from features using inverse kinematics and forces recovered using inverse dynamics (which due to using contact variables is a smooth function). Trajectory is optimized such that joints, features, forces and contact variables are all consistent with each other, and that high-level motion goals are accomplished. The resulting objective function is smooth and can be successfully optimized with standard gradient-based methods.

4 Open questions

While our initial results are very encouraging, a number of important questions remain. Contact is only one type of high-level control attached to trajectories. Can there be other high-level decision variables that when optimized jointly with the trajectory make the problem easier? We have also performed our optimization over a simplified character and dynamics model. Is this necessary, or can a full model be used instead? Lastly, can this approach be applied to motion planning for other tasks such as hand manipulation or other difficult domains where constraint-driven phases bifurcate the optimization space? If so, can this bridge the gap between trajectory optimization and discrete planning?

Video of sample results may be viewed at:

www.cs.washington.edu/homes/mordatch/dw2012.mov

References

[1] Chestnutt, J., "Navigation Planning for Legged Robots," PhD thesis, Carnegie Mellon University, 2007.

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[3] Srinivasan, M., and Ruina, A., "Computer optimization of a minimal biped model discovers walking and running," Nature, 2006.