Movement Skills for Physics-based Characters: A Roadmap

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Past  →  Future

methods
lessons

"Can you fly that thing?"
“Not yet ...”
The Control Problem

- online optimization
- predefined control laws

$q, \dot{q} \rightarrow \tau \rightarrow \text{Controller} \rightarrow \text{physics-based simulation} \rightarrow \dot{M}{\ddot{q}} = Q - C$

Online Optimization

QP problem at each time step

unknowns: $\tau, \dot{q}, F_c$

objectives:
- joint motion
- COM motion
- angular momentum
- minimum torque

equality constraints: $M\ddot{q} = Q - C$

inequality constraints:
- contact force limits
- joint limits
- torque limits
Online Optimization ++

- model predictive control

current timestep | finite horizon | entire motion

Predefined Control Laws

\[ q, \dot{q}, \tau, x \rightarrow F \rightarrow u \rightarrow \text{motion} \]

\[ \text{Controller} \]

\[ \tau \rightarrow \text{physical-based simulation} \]

Linear Feedback law: \[ u = Fx \]
Predefined Control Laws

[Raibert & Hodgins, 1991]  
[SIMBICON, 2007]  
+ many others
Predefined Control Laws

[Generalized Biped Walking Control, 2010]
Similarities and Differences

- similarities
  - model-based
  - tracking mocap data
  - foot placement models
  - model abstraction
  - various skills

- differences
  - knowledge of full EOM
  - role of optimization

Lessons Learned
2D is an excellent starting point
“massively addictive and frustrating”
“this is the most incredible thing, ever. i think i will just play ravine jump and hut jump for the rest of my life, trying to kill my little man in more amusing ways. this is ... he .. he flops about so wondefully! and the voice acting is hilarious.”
“Since everyone at my school plays that instead of doing any work done. we plan on putting our money together and getting a license collectively. Yessire, we are cheap.”
Shared Tools Matter

• dynamics simulators
  – SD/FAST, ODE, OpenSim, Webots, Vortex, PhysX, Bullet, Vortex, RTQL8/Dart, Gazebo, Box2D

PBCA, Robotics, and Biomechanics: we’re all interested in the same things

Optimizing Locomotion Controllers Using Biologically-Based Actuators and Objectives

Control of Dynamic Gaits for a Quadrupedal Robot
Locomotion is Manipulation

Learn State and Action Abstractions

Learning abstractions, e.g., COM?
Output feedback with full matrix

\[
\begin{bmatrix}
\delta a
\end{bmatrix} = \begin{bmatrix}
M_x
\end{bmatrix} \begin{bmatrix}
\delta s
\end{bmatrix}
\]

\[
\delta s = s - s_0
\]
\[
\delta a = a - a_0
\]
• Reduced Order Form

\[
\begin{pmatrix}
\delta a \\
\delta s
\end{pmatrix} = \begin{pmatrix}
M_{ap} \\
M_{ps}
\end{pmatrix} \begin{pmatrix}
\delta s
\end{pmatrix}
\]
Terrain Runner: Control, Parameterization, Composition, and Planning for Highly Dynamic Motions

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Abstraction over time

- **Task goal**: 10 steps
- **Control Policy**: steps
- **Balance-aware Controllers**: 50 ms
- **PD Controller targets**: 5 ms
- **Joint torques**
Robust Task-based Control Policies for Physics-based Characters

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SIGGRAPH ASIA 2009

Progressive Learning of Skills

STEPUP
Locomotion Skills for Simulated Quadrupeds

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Transfer of Skills

Positions and Forces both matter!

\[ M\ddot{q} = Q - C \]
The killer app has yet to arrive

Looking Forward

• shared tools, shared vocabulary: crowdsourcing
• more skills, integration, hybrid models
• gaze, gestures, emotions, ...
• more robotics, manipulation, 3D printing
• future inflection point in usage
• learning abstractions: “what matters when”
Thanks to many

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Petros Faloutsos  Dana Sharon

NSERC Discovery
GRAND NCE
Canada Research Chairs

In memory of Joe Laszlo

Limit Cycle Control, SIGGRAPH 1996

Interactive Control, SIGGRAPH 2000
• Thanks for listening
• Questions and Discussion?
\[ F_V \]

\[ J_V = \frac{\partial P_{COM}}{\partial \theta} \]

\[ \tau_V = J_V^T F_V \]

\[ F_{\text{gc}}^i \]

\[ J_{\text{gc}}^i = \frac{\partial P_{COM}^i}{\partial \theta} \]

\[ \tau_{\text{gc}}^i = J_{\text{gc}}^T F_{\text{gc}}^i \]