Modeling Humans & Animals
Simulation Model

Joint Hierarchy
Virtual Actuators
Proxy Geometry
Visualization Mesh
Physics-based Animation

Controller

\[ \tau \]

Physics Engine

\[ q, \dot{q} \]
Under actuated
Inherently unstable
\[
\begin{bmatrix}
F^d_v \\
T^d_v
\end{bmatrix}_b = k_p(q^d_b - q_b) + k_d(\dot{q}^d_b - \dot{q}_b) + k_{ff}
\]

\[
\begin{bmatrix}
I \\
r_0 \times \\
r_1 \times \\
\vdots \\
r_m \times \\
I
\end{bmatrix}
\begin{bmatrix}
F_0 \\
F_1 \\
\vdots \\
F_m \\
x
\end{bmatrix} = \begin{bmatrix}
F_B \\
T_B
\end{bmatrix}
\]

\[
\min (Ax - b)^T(Ax - b)
\]
subject to \(F_i^m \geq F_{\text{min}}^m\)

\(-\mu F_i^m \leq F_i^t \leq \mu F_i^m\)
\[ \tau = J^T F \]
Walking

• Described **temporally** in terms of stride duration and its two components per leg, swing time and stance time
Walking

• Described **temporally** in terms of stride duration and its two components per leg, swing time and stance time, and **spatially** in terms of foot placement locations
Foot Placement Control

\[ d = d_f(v_d) + (v - v_d) \sqrt{\frac{h}{g}} \]
Foot Placement Control
Towards Increasingly Complex Motor Skills
## Quadrupedal Gaits

### Trot

<table>
<thead>
<tr>
<th></th>
<th>RR</th>
<th>FR</th>
<th>FL</th>
<th>RL</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Canter

<table>
<thead>
<tr>
<th></th>
<th>RR</th>
<th>FR</th>
<th>FL</th>
<th>RL</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Controller Parameterization

\[ h(t) \]

\[ F \]

\[ d_f \]
Motion Data
After Learning

walk
Locomotion Control for Legged Robots
Locomotion Control for Legged Robots
Towards increasingly accurate biomechanical models

Flexible Muscle-Based Locomotion for Bipedal Creatures

SIGGRAPH ASIA 2013

Thomas Geijtenbeek
Michiel van de Panne
Frank van der Stappen
Towards increasingly accurate biomechanical models

Realistic Biomechanical Simulation and Control of Human Swimming

Weiguang Si*  Sung-Hee Lee†  Eftychios Sifakis‡  Demetri Terzopoulos*

*University of California, Los Angeles
†Korea Advanced Institute of Science and Technology
‡University of Wisconsin, Madison
Questions?