

15-464/15-664 Technical Animation
April 2, 2013

Physically Based Character Animation



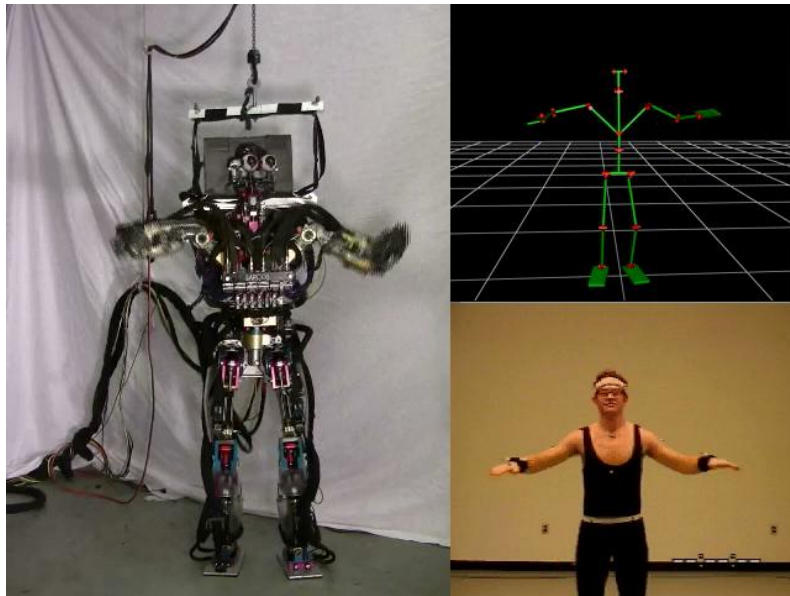
Disney Research
Pittsburgh

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Physically Based Character Animation

Use physics (equation of motion) for animation

- Automatically obtain physically plausible animations
- Critical for physical characters (robots)
- Not always required for virtual characters (CG)



The Incredibles (2004)

[Yamane, Anderson, Hodgins 2010]



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Use for Virtual Characters

Automatically synthesize new motions

Modify physical parameters

React to disturbances



Method Classification

- By source motion
 - With source motion (e.g., motion capture data)
 - Without source motion
- By approach
 - Optimization
 - Simulation



Use Source Motion?

- With source motion
 - Physically plausible and human-like
 - Noise and retargeting issues
- Without source motion
 - Design preferable motion pattern
 - Not guaranteed to be human-like



Optimization Approach

- Cost function with joint torques and/or contact forces
 - Joint torques: minimize power, energy
 - Contact forces: check feasibility
- Easier to control the result
 - Stop optimization somewhere reasonable
 - Results don't have to be strictly optimal
- Large optimization problem



Simulation Approach

- Forward simulation of the motion resulting from a set of controllers
- Can generate responses to unscripted events
 - Environment change
 - Push
- More difficult to control
 - Characters may fall down (and they do)



Methods

	Without source motion	With source motion
Simulation	[Isaacs and Cohen 1987] [Hodgins et al. 1995] [Zordan and Hodgins 1999, 2002] [Yin et al. 2007] [Macchietto et al. 2009] [Coros et al. 2010]	[Yamane and Nakamura 2003] [Treuille et al. 2007] [da Silva et al. 2008] [Muico et al. 2009] [Lee et al. 2010]
Optimization	[Jain et al. 2009] [Liu et al. 2010] [Wang et al. 2010] [Wang et al. 2012] [Witkin and Kass 1988] [Fang and Pollard 2003] + lots of work for humanoid robots	[Sok et al. 2007] [Popovic and Witkin 1999] [Liu and Popovic 2002] [Safonova and Hodgins 2004]



Simulation-Based

How to control simulated characters

Unstable

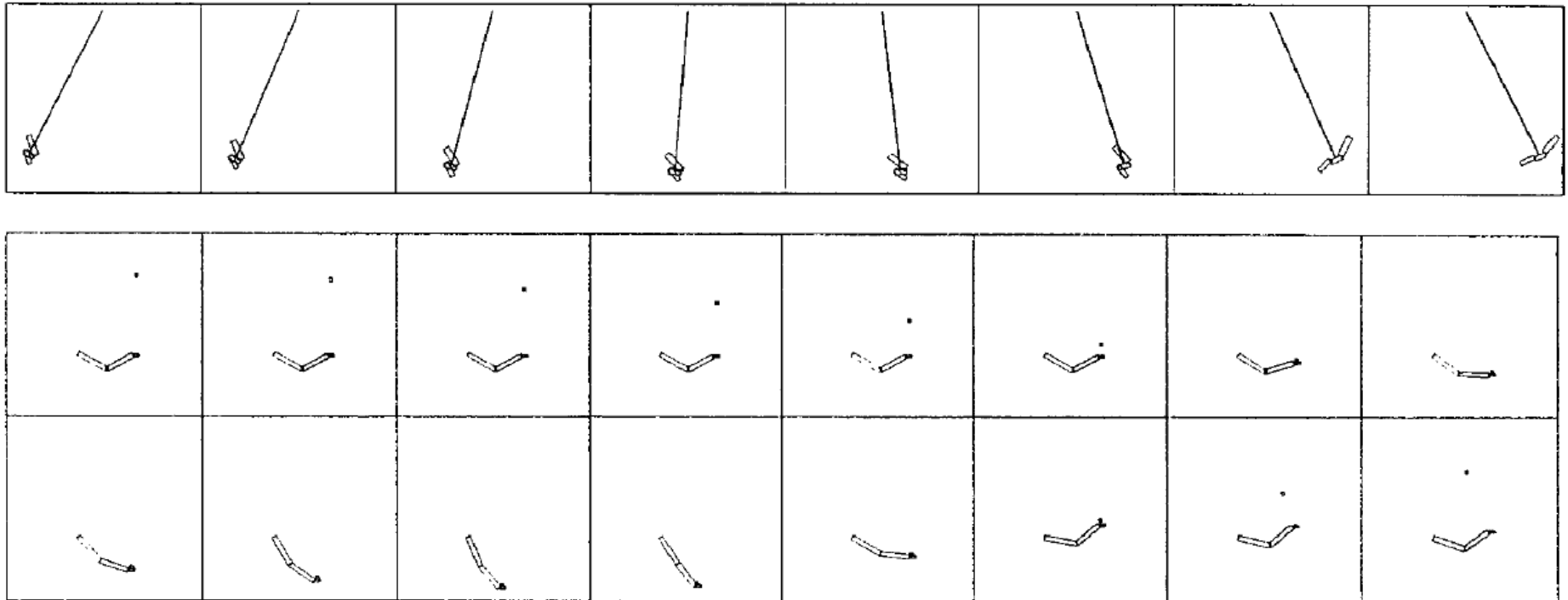
Contact forces are unilateral



Early Simulation Work

[Isaacs and Cohen 1987]

Computed torque control with kinematic constraints

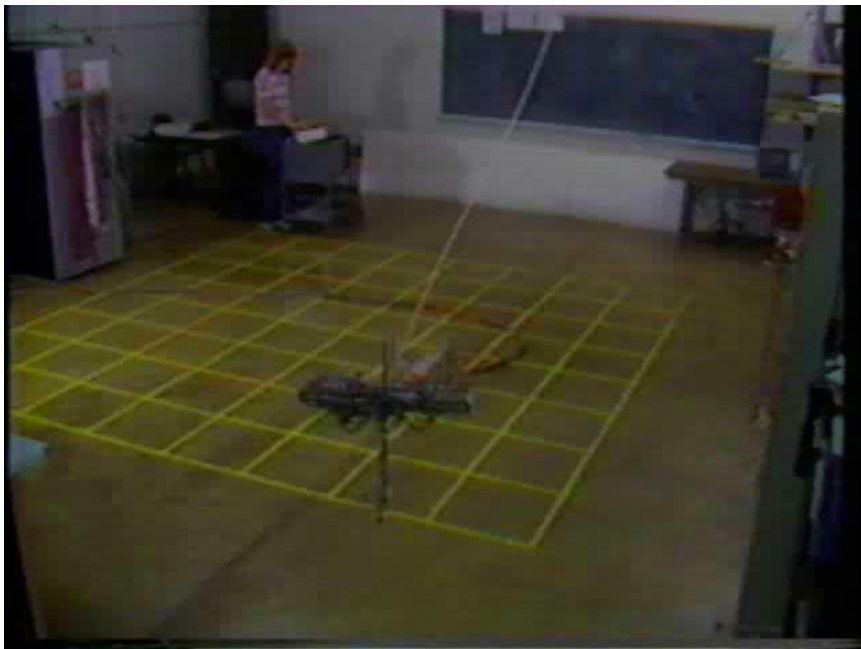


Simulating Complex Motions

[Hodgins et al. 1995]

Finite state machines and PD control

- Represent complex behaviors as state transitions
- Choose reference pose and PD gains for each state



[Hodgins, Koechling, Raibert]

SIMBICON [Yin et al. 2007]

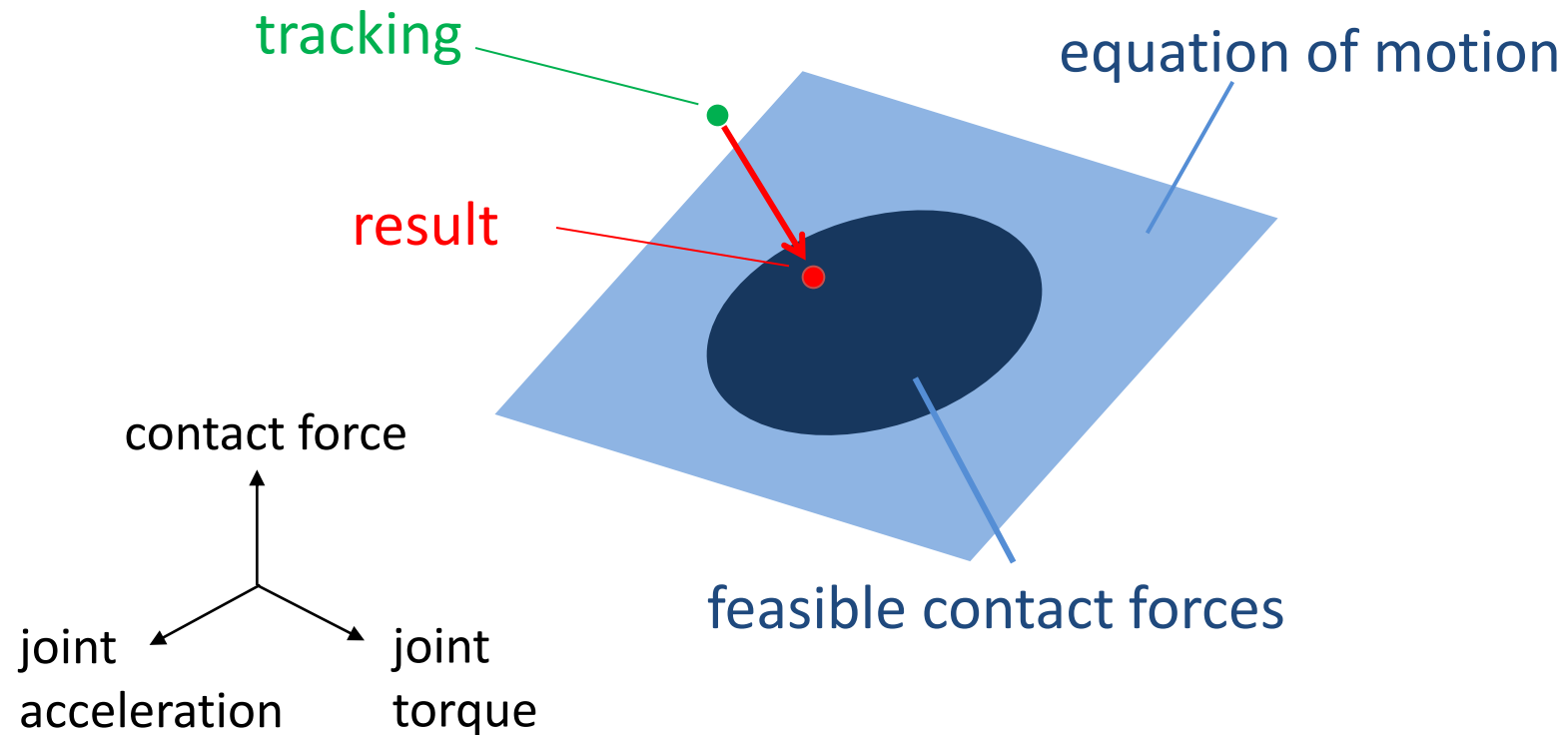
SIMBICON: Simple Biped Locomotion Control



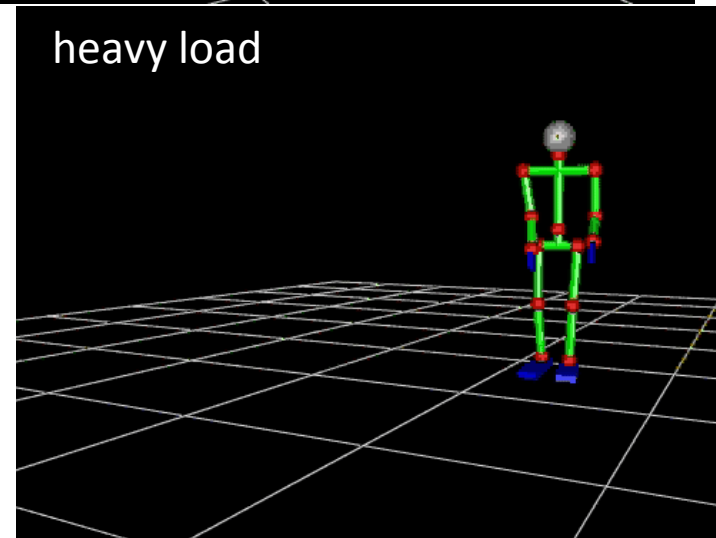
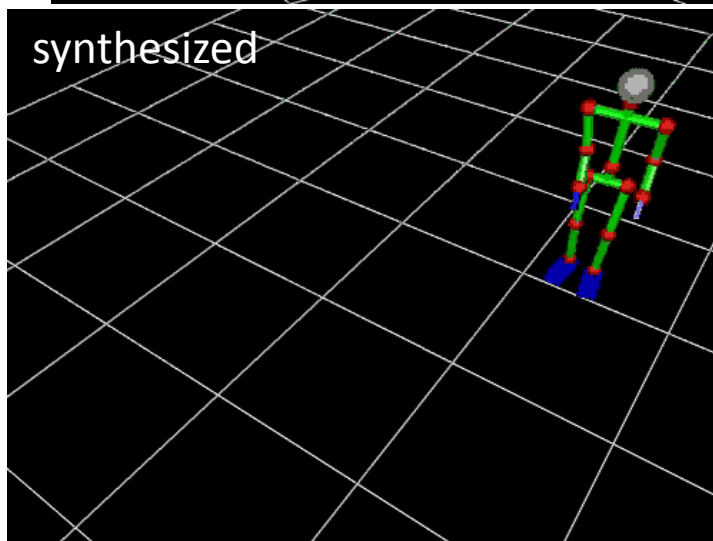
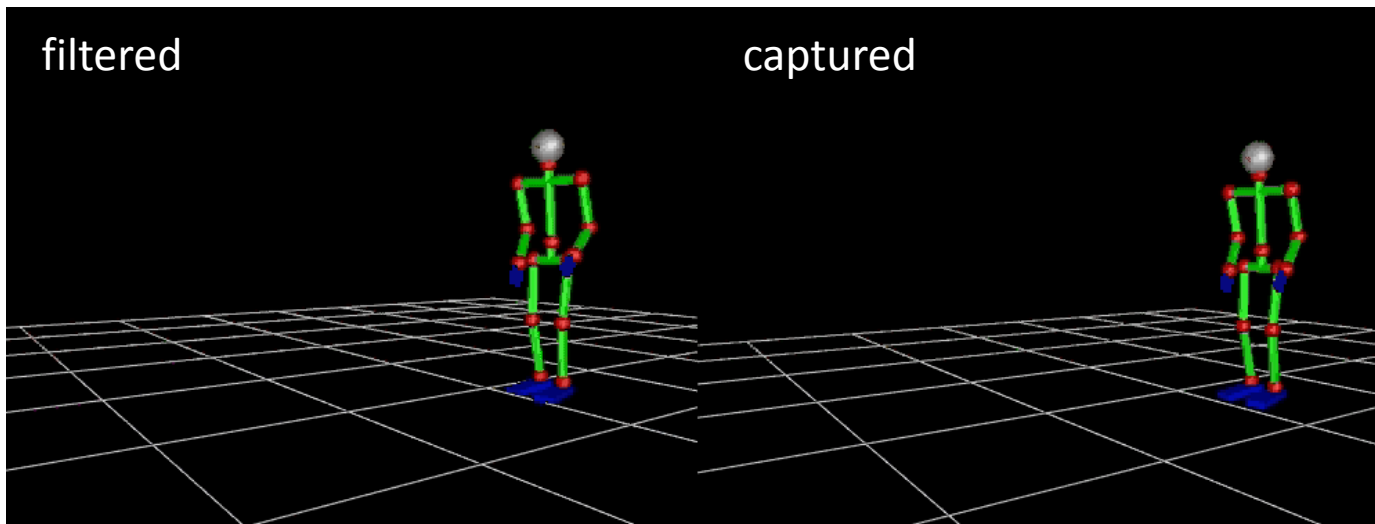
Simulation with Source Motion

[Yamane and Nakamura 2003]

Dynamics Filter

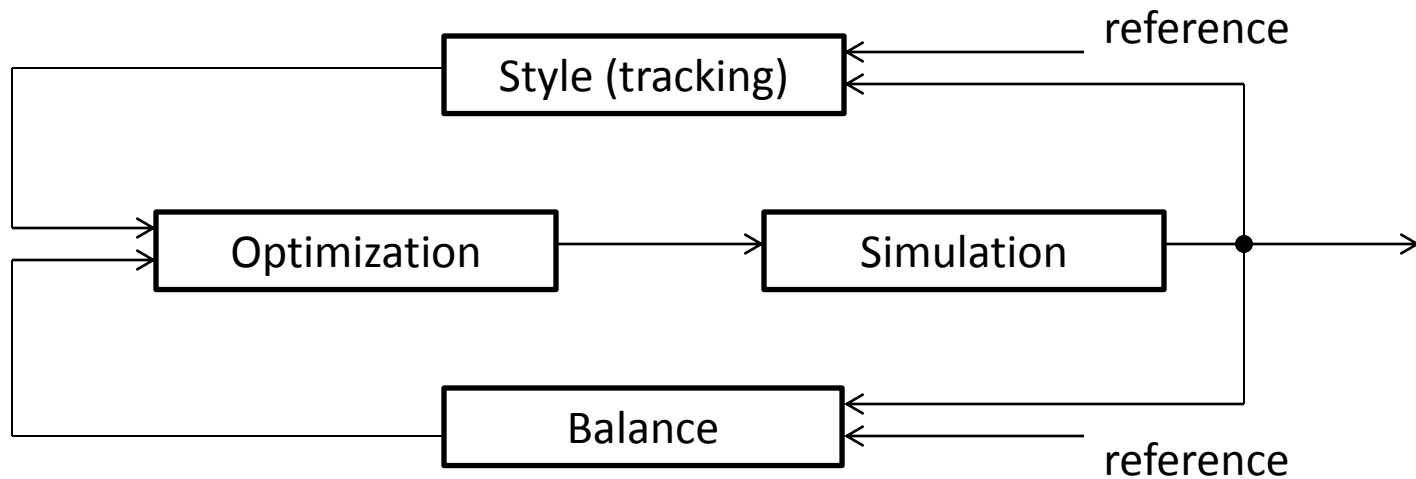


Simulation with Source Motion



Tracking and Balancing

[da Silva et al. 2008]



Simulation with Source Motion

SIMBICON-style realtime modification [Lee, Kim, Lee 2010]

Data-Driven Biped Control

Yoonsang Lee

Sungeun Kim

Jehee Lee



Optimization-Based

How to formulate a tractable optimization problem

Huge search space
Expressive motions



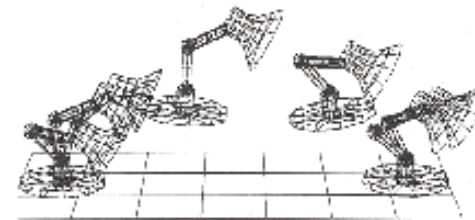
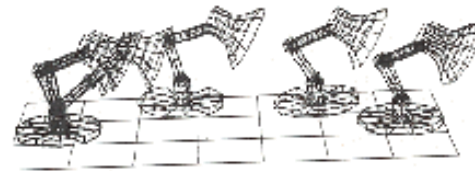
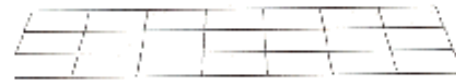
Spacetime Constraint

[Witkin and Kass 1988]

Minimize actuator power

Subject to

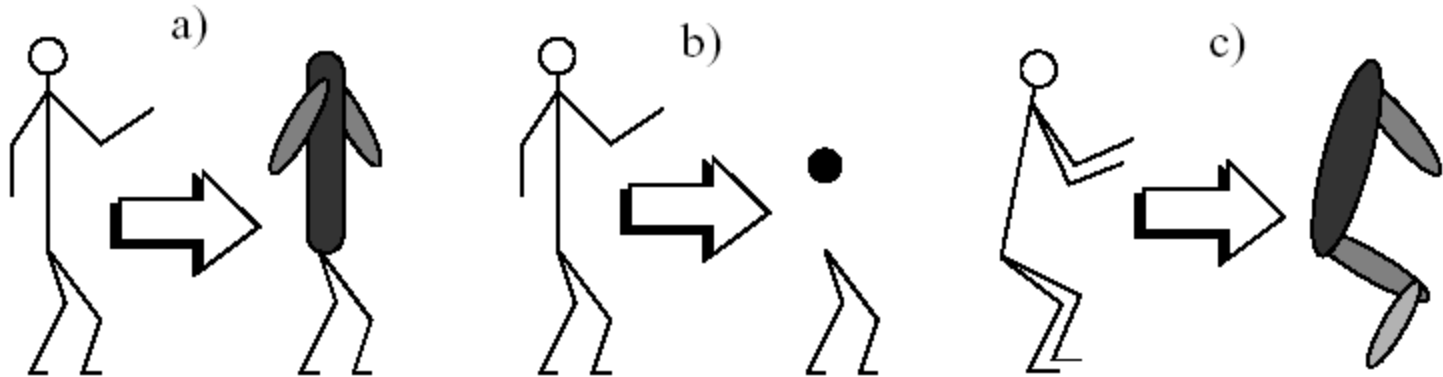
- Start and goal positions
- Contact constraints



More Spacetime Constraints

[Popović and Witkin 1999]

Using simplified models



Objective function

- Difference from the original motion
- Smoothness of joint torques

More Spacetime Constraints

[Popovic and Witkin 1999]



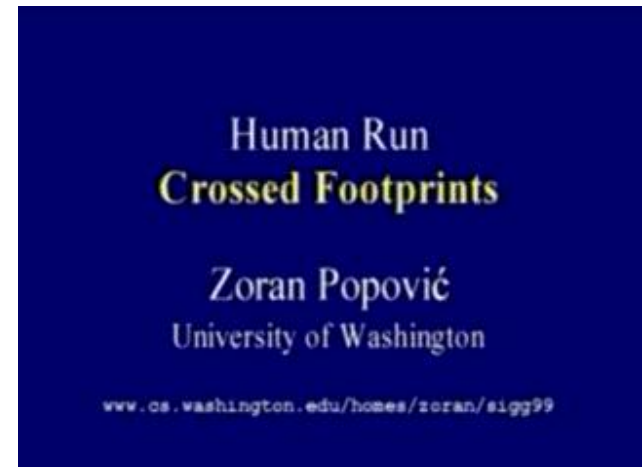
1) Original



2) Simplified



3) New constraints



4) New motion



More Spacetime Constraints

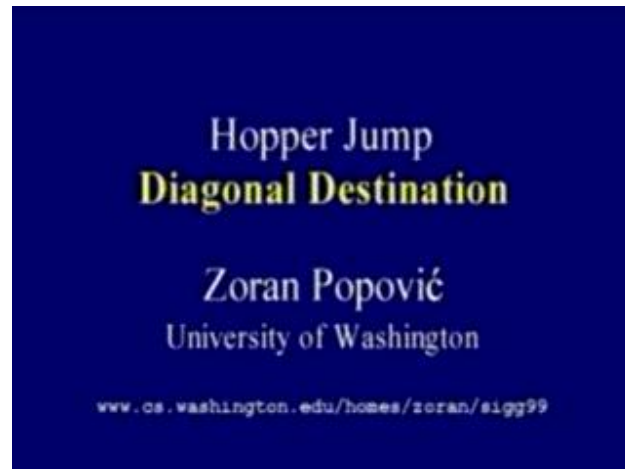
[Popovic and Witkin 1999]



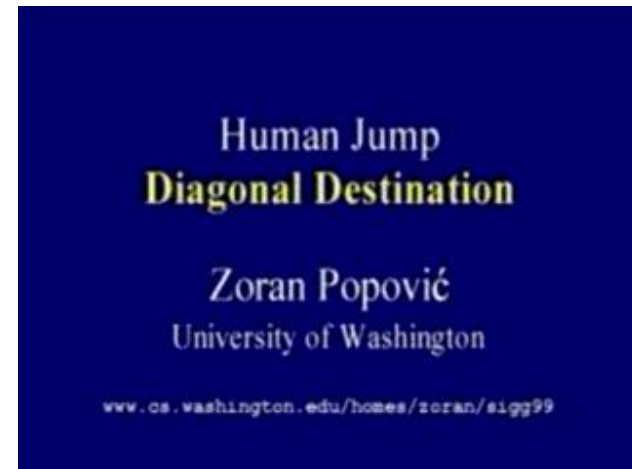
1) Original



2) Simplified



3) New constraints

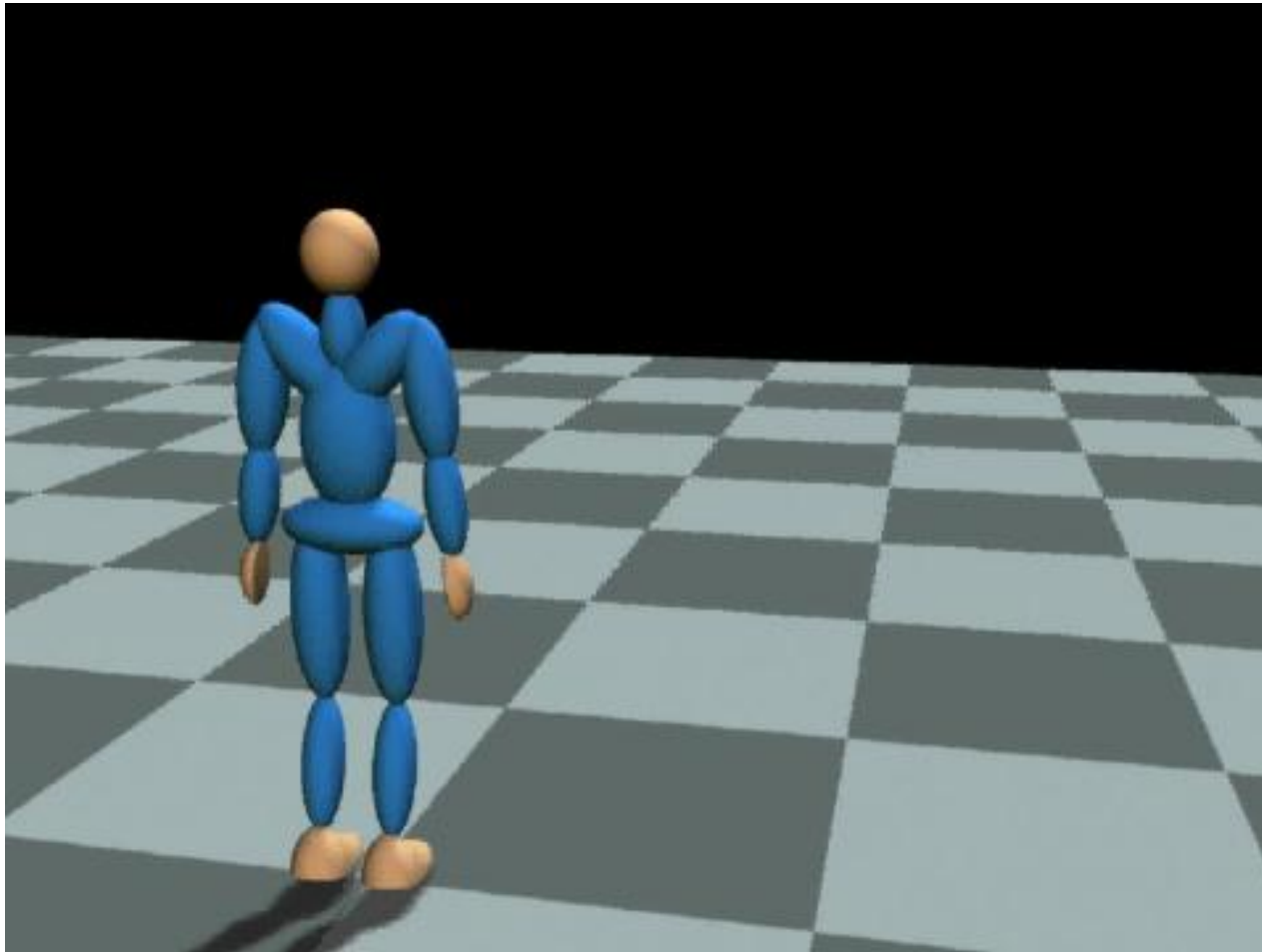


4) New motion



Optimize from Simple Animation

[Liu and Popovic 2002]



Optimize from Simple Animation

[Liu and Popovic 2002]

Optimization setup

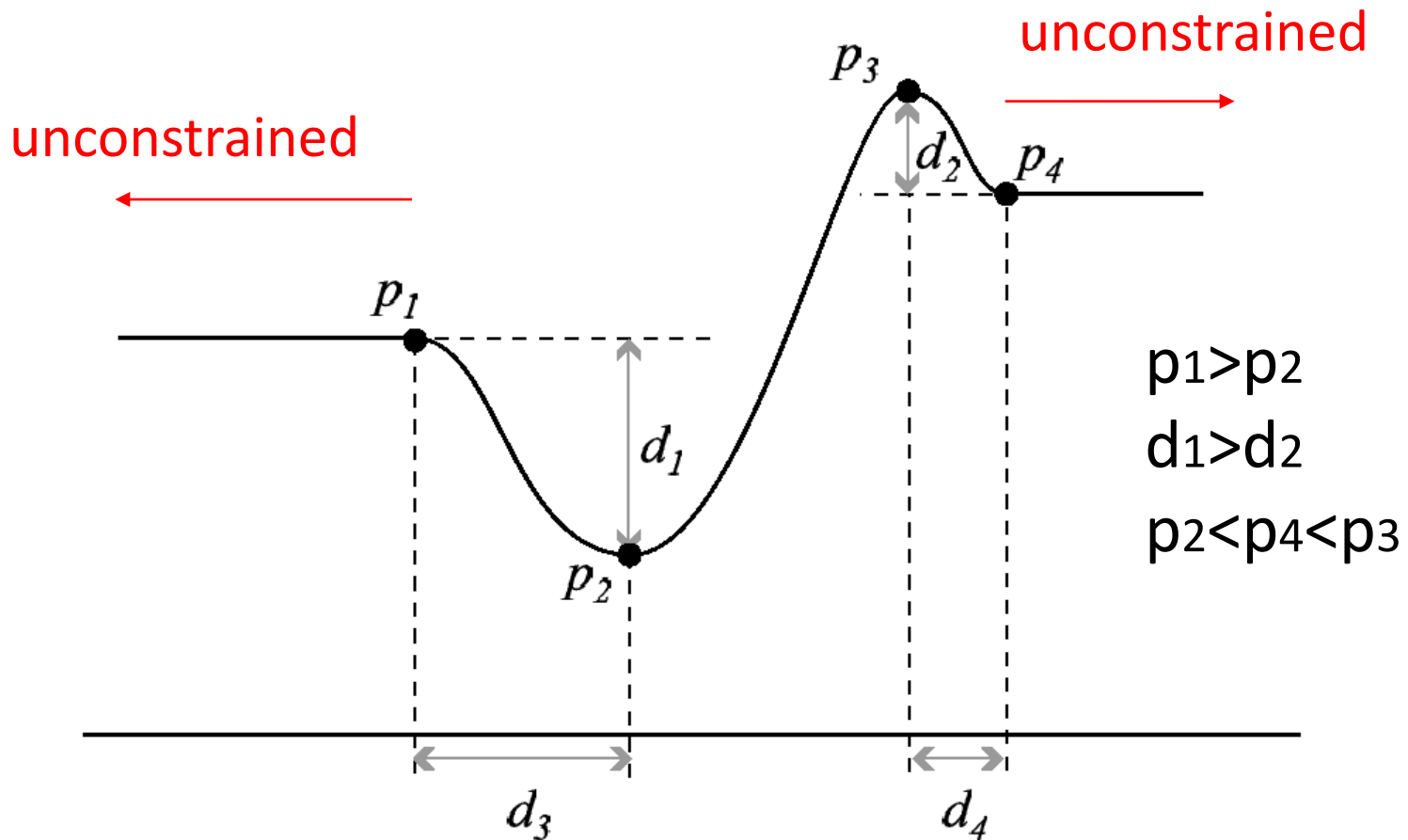
- unknowns: joint angles at all frames
- constraints
 - contacts
 - transition pose
 - **momentum**
- objective function
 - mass displacement
 - smooth joint angles
 - static balance



Optimize from Simple Animation

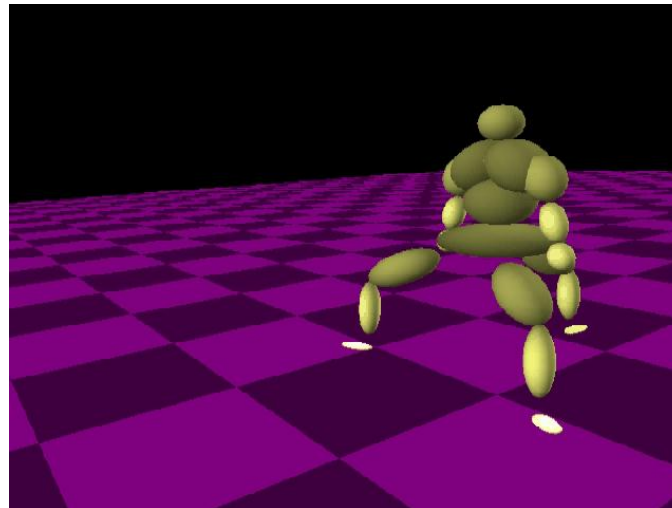
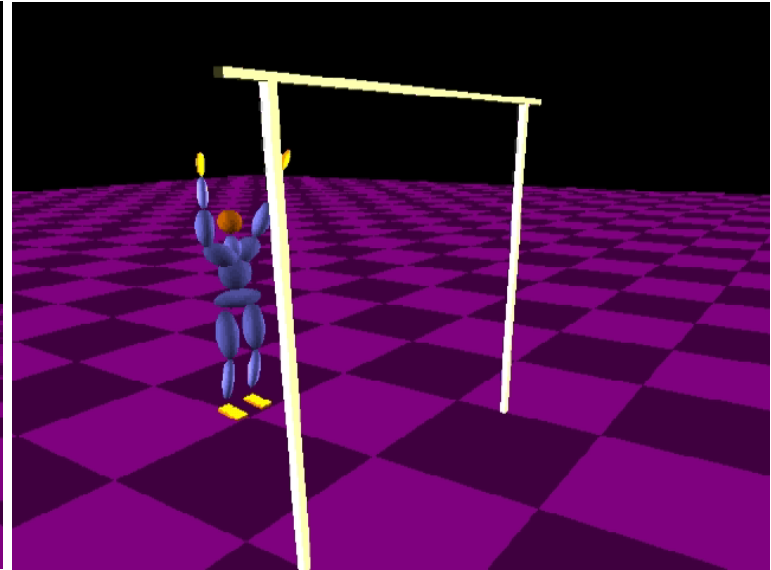
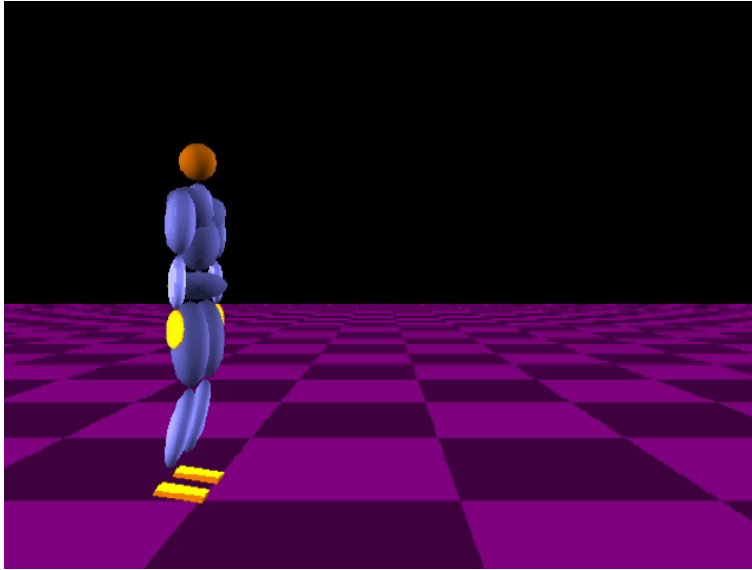
[Liu and Popovic 2002]

Angular momentum pattern from biomechanical data



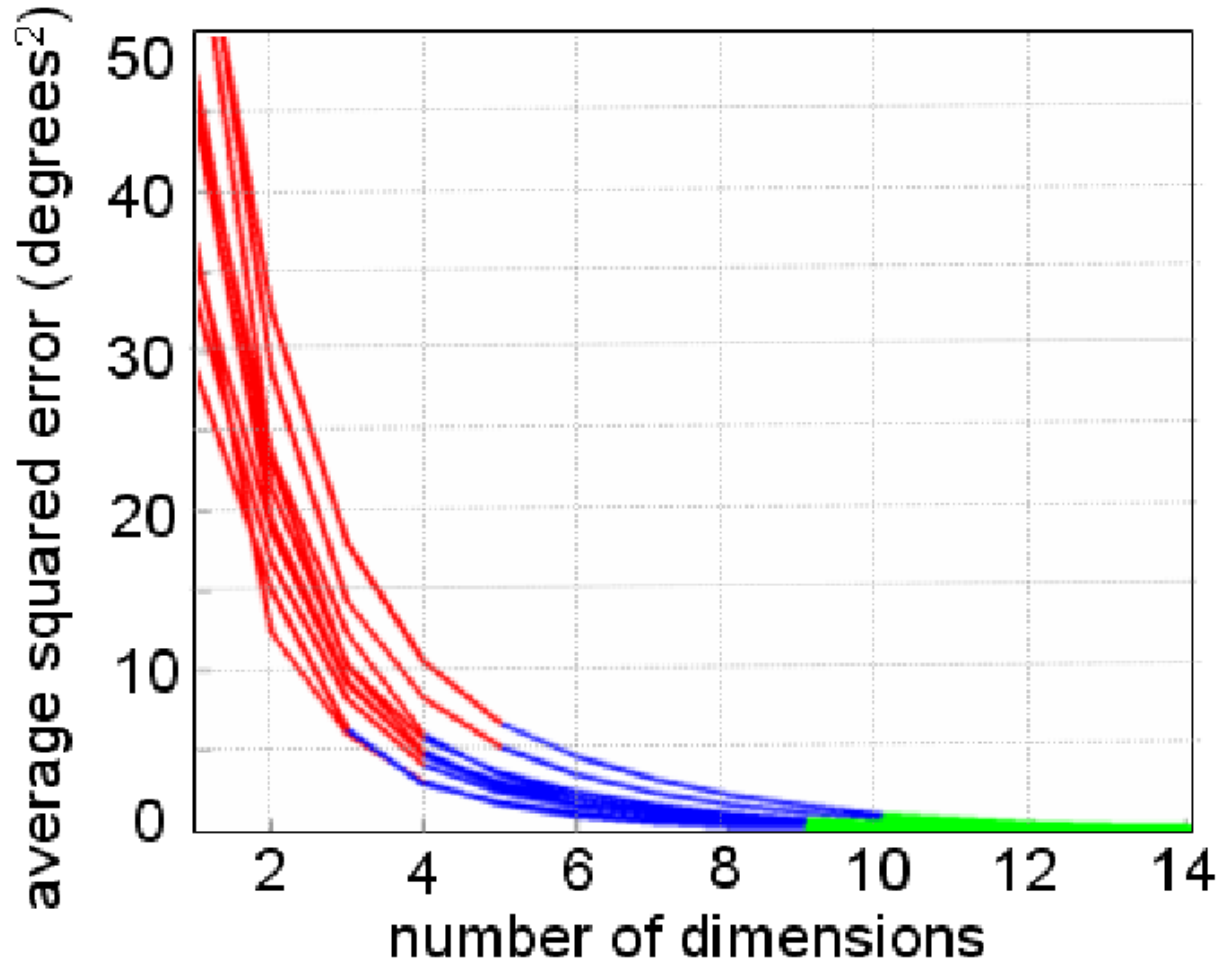
Optimize from Simple Animation

[Liu and Popovic 2002]



Optimize in Low-Dimensional Space

[Safonova, Hodgins, Pollard 2004]



Optimize in Low-Dimensional Space

[Safonova, Hodgins, Pollard 2004]

Optimization setup

- Unknowns: weights for the principal components
- Objective function: torque, acceleration, distribution
- Constraints: user-specified, physics



Optimize in Low-Dimensional Space

[Safonova, Hodgins, Pollard 2004]

Synthesizing
Physically Realistic Human Motion
in Low-Dimensional,
Behavior-Specific Spaces

Alla Safonova
Jessica Hodgins
Nancy Pollard



Hybrid Methods

- 1) Optimization as pre-processing
- 2) Run simulation for reactions

Formulate an optimization problem
that can be solved in real time



Optimization + Reaction

[Sok, Kim, Lee 2007]

Motion rectification and PD control

Simulating Biped Behaviors from Human Motion Data

Kwang Won Sok
Manmyung Kim
Jehee Lee

SEOUL NATIONAL UNIVERSITY



Disney Research, Pittsburgh

Sampling-Based Optimization

[Liu et al. 2010]



Sampling-based Contact-rich Motion Control

Libin Liu* KangKang Yin* Michiel van de Panne‡

Tianjia Shao* Weiwei Xu*

* Tsinghua University + Microsoft Research Asia

‡ University of British Columbia



Disney Research, Pittsburgh

Fast Optimization

[Jain et al. 2009]

- Find the *joint angles* at next step (instead of joint torques)
- Discretized equation of motion: linear to the joint angles at next step
- Minimize joint torque change



Fast Optimization

[Jain et al. 2009]

Optimization-based Interactive Motion Synthesis

Sumit Jain
Yuting Ye
C. Karen Liu

Georgia Institute of Technology



Optimize Robustness

[Wang, Fleet, Hertzmann 2010]

Optimizing Walking Controllers for
Uncertain Inputs and Environments

Jack M. Wang
David J. Fleet
Aaron Hertzmann

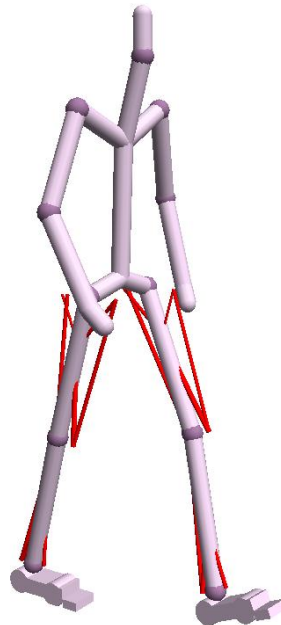
University of Toronto



Physiology-Based Optimization

[Wang et al. 2012]

- 8 muscles for each leg
- Controllers and cost function inspired by physiology
- Produce muscle force patterns close to humans



Biomechanical Model

[Wang et al. 2012]

Optimizing Locomotion Controllers Using Biologically-Based Actuators and Objectives

**Jack M. Wang
Samuel R. Hamner
Scott L. Delp
Vladlen Koltun**

Stanford University



Use in Production

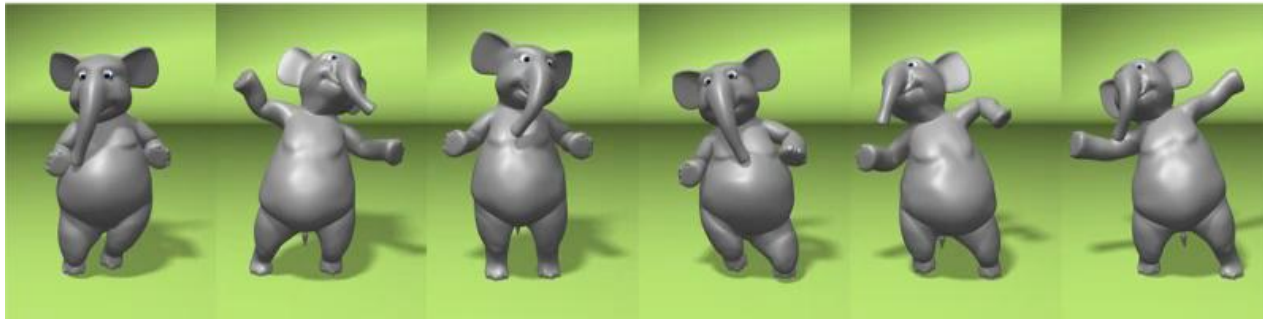
- Not quite yet...
 - Animators want full control of motion
 - Characters don't always have to be physically correct
 - Still too much computation for games
- Production-friendly methods?
 - Only simulate the parts that are difficult to animate



Rig-Space Physics

Rig-Space Physics

Fabian Hahn, Sebastian Martin,
Bernhard Thomaszewski, Robert Sumner,
Stelian Coros, Markus Gross



Future Directions

- Art-directable simulation
 - Popular in cloth/liquid simulation
- Exaggerated physics
 - Interface?

Example 1
Double Kick

[Sok et al. 2010]

