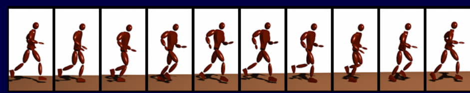
Physically Based Motion Transformation



The Animation Problem

Automatic generation of expressive/realistic motion that achieves a given set of tasks

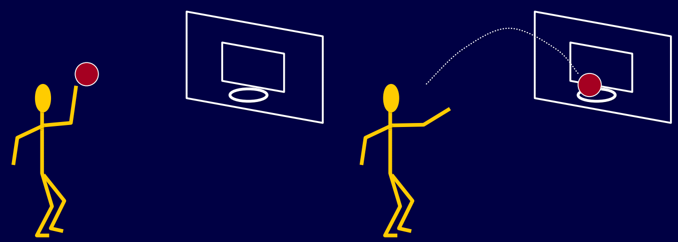
- An open problem
- Realism vs. control tradeoff

Physically-based Methods

- Forward simulation [Baraff]
  - Highly realistic
  - Simulated character very hard to control
- Controllers [Raibert, Hodgins, Ngo, van de Pane]
  - Fast motion generation once controllers are computed
  - No set rules on controller generation

Spacetime Constraints

- Provide both realism and control
- Downside
  - Methods do not scale up
  - Sensitivity to the initial position



Captured Motion

- Sampled DOFs through time gathered from the real world
- Rich and realistic
- Hard to edit

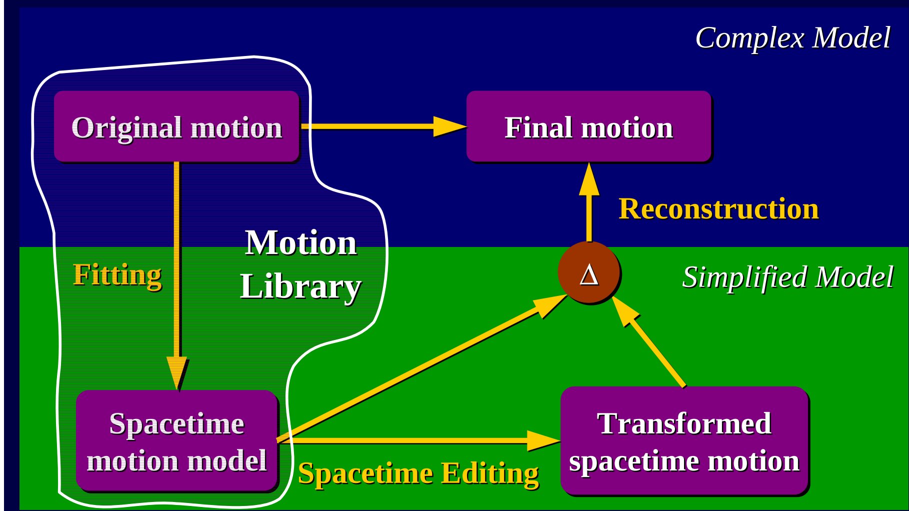
High Level Control

- Get a limp walk by making one leg stiff
- Reduce gravity to get a “moon walk”
- Change the position and timing of foot placements
- Make a “quiet” run by reducing the floor impact forces

The New Approach

- Transform existing motion
- Spacetime constraints formulation
- Simplified character representation
- Get the best of both worlds:
  - Expressiveness of captured data
  - Controllability of the spacetime model

Outline



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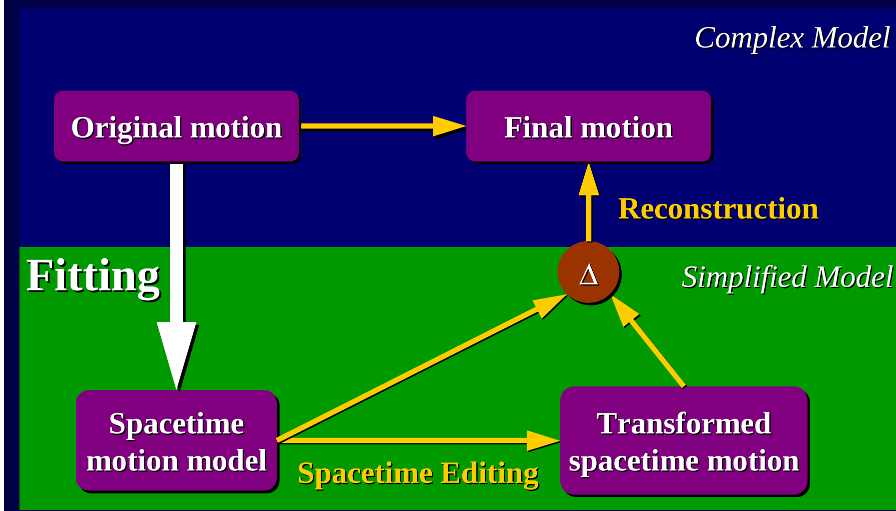
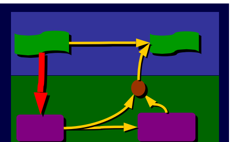


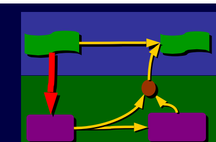
Model Fitting



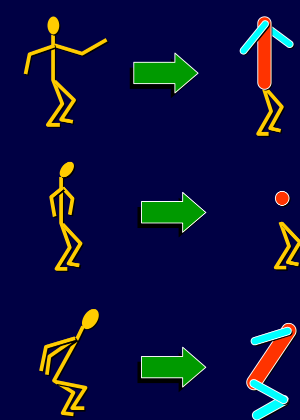
Two phases:

1. Simplify character kinematics
2. Use input motion to construct a spacetime motion model

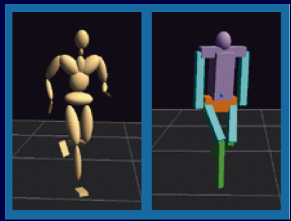
Simplified Kinematics



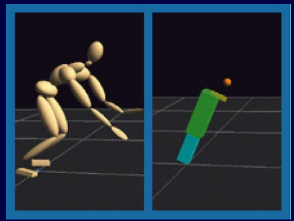
- Remove irrelevant DOFs
- Reduce ***passive*** body structure to mass points
- Exploit symmetric movement of limbs



Simplified Kinematics



Human Run

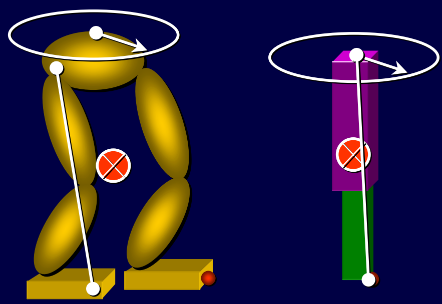


Human Jump

Motion Fitting

- Handle – a property that correlates the original and simplified model
- Must have enough handles to fully determine simplified model configuration

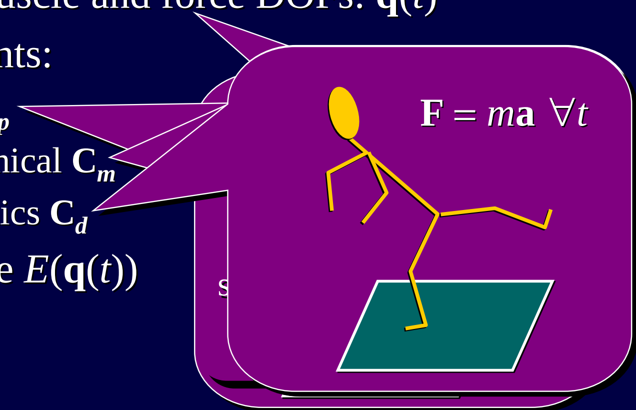
Handle Examples



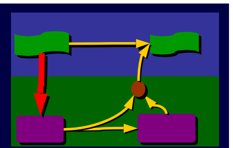
Distance Handle

Motion Synthesis As Constrained Optimization

- Body, muscle and force DOFs: $\mathbf{q}(t)$
- Constraints:
  - Pose $\mathbf{C}_p$
  - Mechanical $\mathbf{C}_m$
  - Dynamics $\mathbf{C}_d$
- Objective $E(\mathbf{q}(t))$



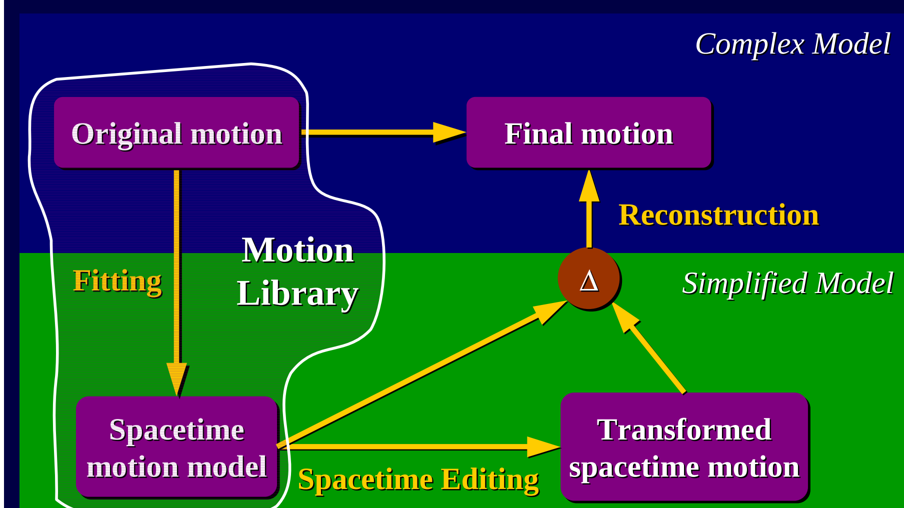
Spacetime Model Fitting



- Biological data: mass distribution, muscles
- Use ***handles*** to create “best-guess” motion
- Specify constraints essential for given motion (e.g. foot placements)
- Use simple objective: smooth muscles

$$E(\mathbf{q}) = \ddot{\mathbf{q}}^2$$

Outline



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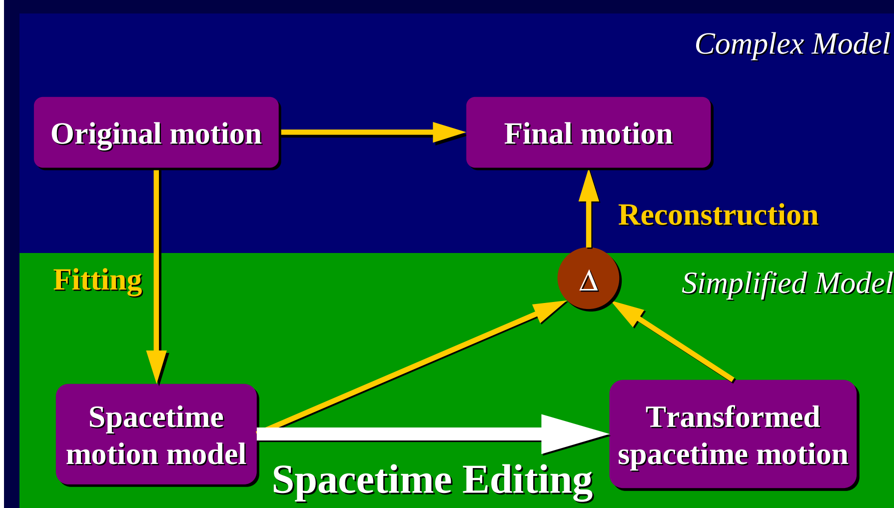
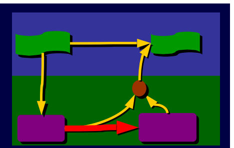
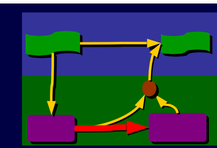


Spacetime Editing



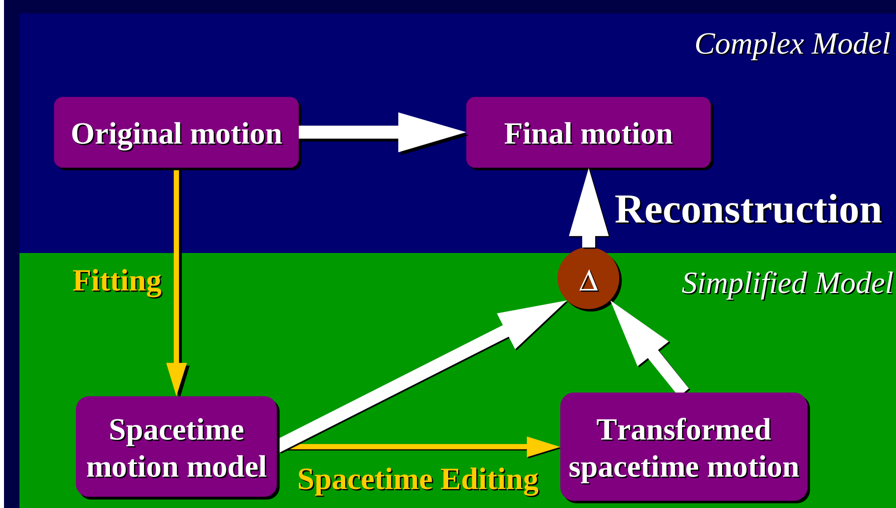
- Change pose and environment constraints
  - Foot placement and timing
  - Introduce a new obstacle
- Change the objective function
  - Minimize floor impact forces
  - Make dynamic balance more important

Spacetime Editing



- Change explicit character parameters
  - Short leg
  - Redistribute mass
  - Modify muscle characteristic
  - Gravity

Outline



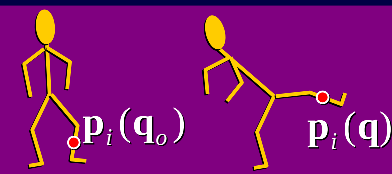
Motion Reconstruction

- Three different handle sets
  - Original motion handles $\mathbf{h(q_o)}$
  - Spacetime fit handles $\mathbf{h(q_s)}$
  - Transformed spacetime handles $\mathbf{h(q_t)}$
- Compute final motion handles

$$\mathbf{h(q_f)} = \mathbf{h(q_o)} + \left(\mathbf{h(q_t)} - \mathbf{h(q_s)}\right)$$

Minimum Displaced Mass Objective

- $E_{dm}(\mathbf{q}_o, \mathbf{q})$ evaluates ***total displaced mass*** when moving a character from pose $\mathbf{q}_o$ to pose $\mathbf{q}$



$$E_{dm} = \underset{i}{\iiint} \mu_i \left(\mathbf{p}_i(\mathbf{q}_o) - \mathbf{p}_i(\mathbf{q})\right)^2 dx\,dy\,dz$$

Reconstruction Algorithm

- For each time *t* solve

$$\begin{aligned} &\underset{\mathbf{q}_f}{\text{minimize}} && E_{dm}(\mathbf{q}_o, \mathbf{q}_f) \\ &\text{subject to} && \mathbf{h}(\mathbf{q}_f) = \mathbf{h}(\mathbf{q}_o) + \left(\mathbf{h}(\mathbf{q}_t) - \mathbf{h}(\mathbf{q}_s)\right) \end{aligned}$$

Alternative Reconstruction Algorithm

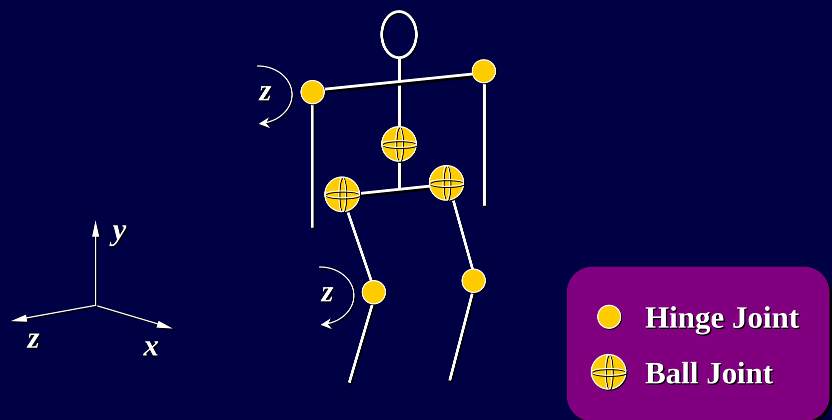
- For each time *t* solve

$$\underset{\mathbf{q}_f}{\text{minimize}} \quad \begin{array}{c} w_{dm} E_{dm}(\mathbf{q}_o, \mathbf{q}_f) + \\ w_h\left[\left(\mathbf{h}(\mathbf{q}_f) - \mathbf{h}(\mathbf{q}_o)\right) - \left(\mathbf{h}(\mathbf{q}_t) - \mathbf{h}(\mathbf{q}_s)\right)\right]^2 \end{array}$$

Example: Human Run

- Original model has 59 DOFs
- Simplified model has ***19*** DOFs
- Optimizations are done on one gait cycle
- Each optimization completes within 2 minutes

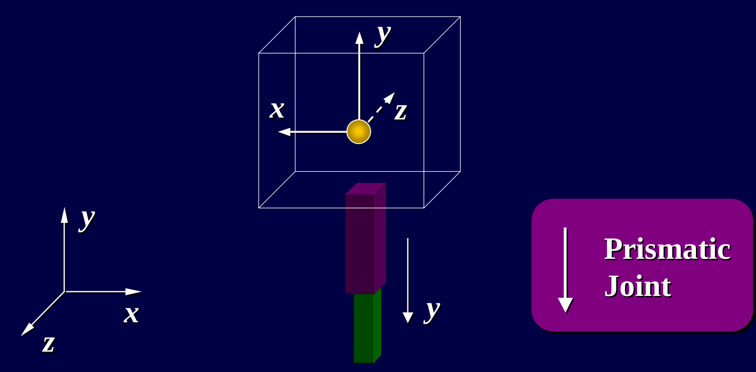
Biped



Example: Human Broad Jump

- Original model has 59 DOFs
- Simplified model has ***11*** DOFs
- Entire upper body reduced to a mass point
- No joint angle DOFs

Hopper



Future Work

- Optimal robots
- Extracting style
- Motion retargeting
- Building motion libraries
- Digital actors