Physically Based Motion Transformation

Captured Motion

- Sampled DOFs through time gathered from the real world
- Rich and realistic
- Hard to edit [Witkin,Popović, Gleicher, Bruderlin]

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Motion Warping Drawbacks

- Works well only for small deformations
- No high-level editing constructs

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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

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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

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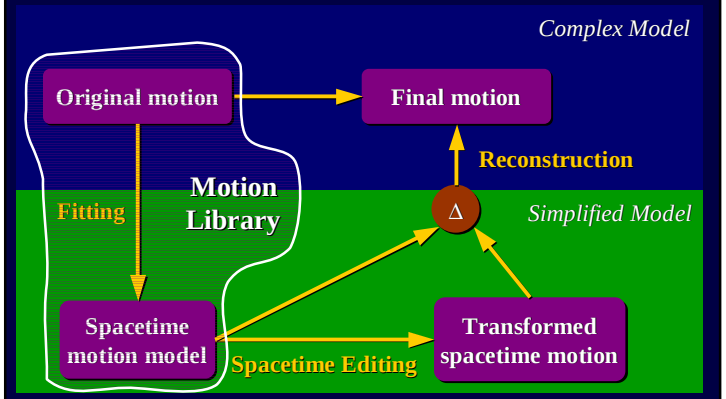
Outline



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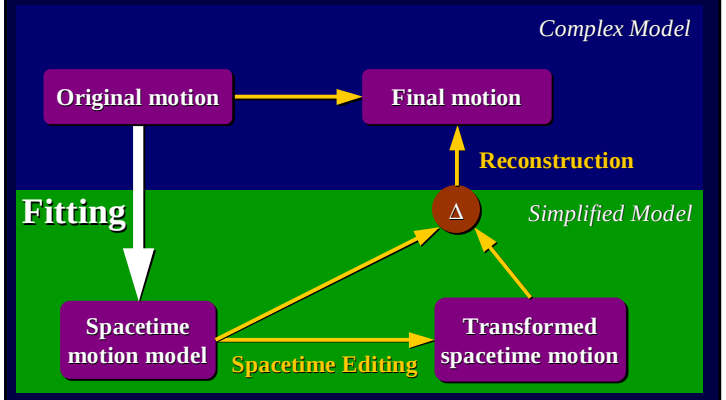
Outline



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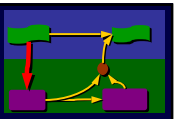
Model Fitting



- Two phases:
  - Simplify character kinematics
  - Use input motion to construct a spacetime motion model

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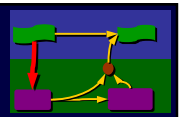
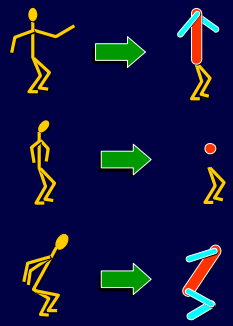
Simplified Kinematics



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



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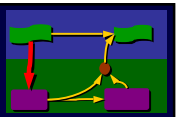
Simplified Kinematics



Human Run

Human Jump

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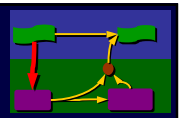
Motion Fitting



- Handle – a property that correlates the original to the simplified model

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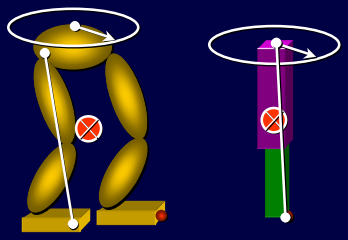
Handle Examples



Original Handle

Distance Handle

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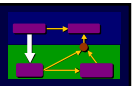
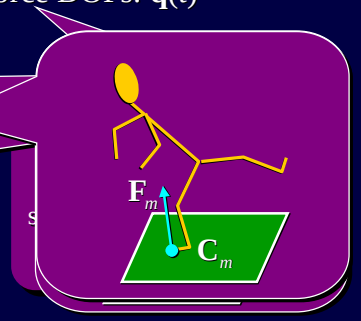
Motion Synthesis As Constrained Optimization



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



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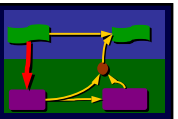
Spacetime Model Fitting



- 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 muscle forces

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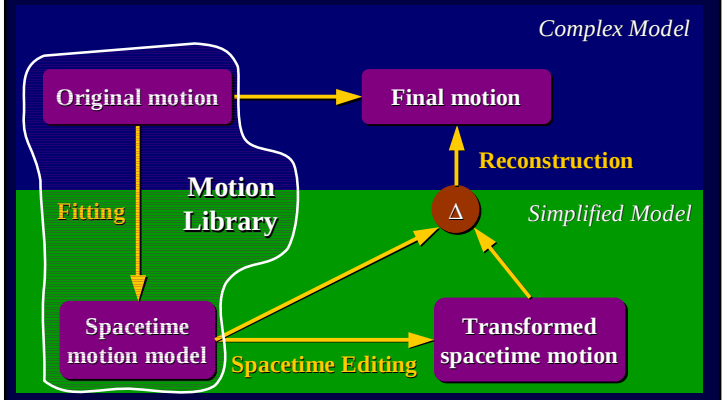
Outline



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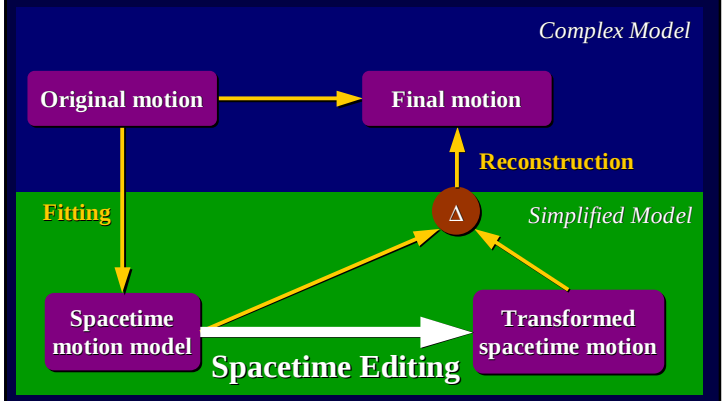
Outline



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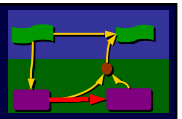
Spacetime Editing



- 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

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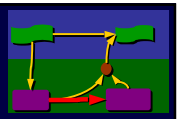
Spacetime Editing



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

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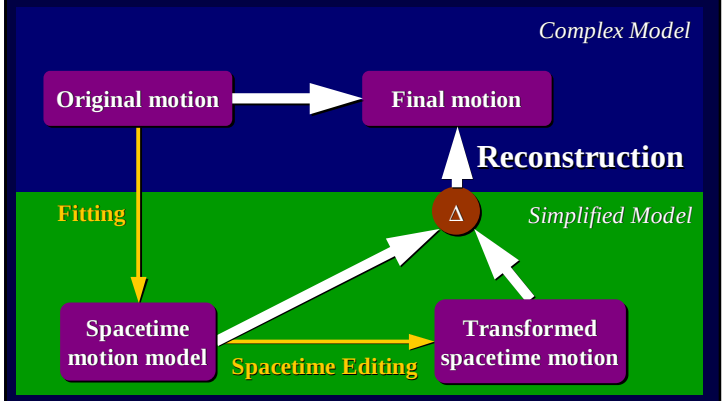
Outline



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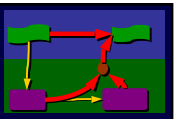
Motion Reconstruction



- Three different handle sets
  - Original motion handles
  - Spacetime fit handles $\mathbf{h}(\mathbf{q}_s)$
  - Transformed spacetime handles $\mathbf{h}(\mathbf{q}_t)$
- Compute final motion handles

$$\mathbf{h}(\mathbf{q}_f) = \mathbf{h}(\mathbf{q}_o) + (\mathbf{h}(\mathbf{q}_t) - \mathbf{h}(\mathbf{q}_s))$$

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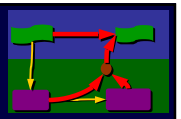
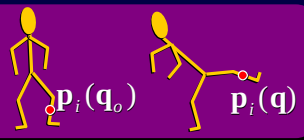
Minimum Displaced Mass Objective



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



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

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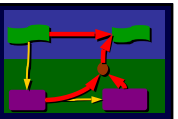
Reconstruction Algorithm



- For each time t solve

$$\underset{\mathbf{q}_f}{\text{minimize}} \quad E_{dm}(\mathbf{q}_o, \mathbf{q}_f)$$
$$\text{subject to} \quad \mathbf{h}(\mathbf{q}_f) = \mathbf{h}(\mathbf{q}_o) + (\mathbf{h}(\mathbf{q}_t) - \mathbf{h}(\mathbf{q}_s))$$

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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

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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

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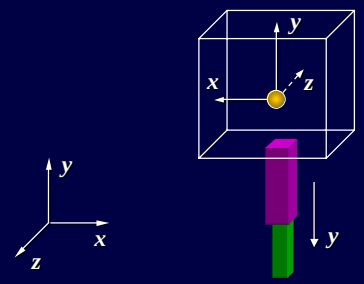
Hopper



Prismatic Joint

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