Robot Controllers in Animation

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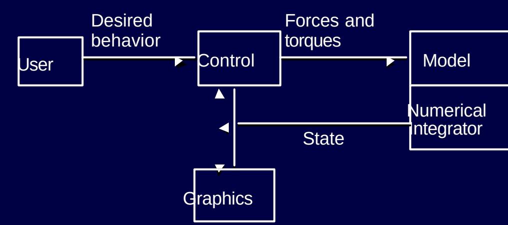
Control Systems



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Where do the control laws come from?

- Observation
- Biomechanical literature
- Optimization
- Intuition

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Hierarchy of control laws

1. State machine
2. Control actions
3. Low level control

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Hierarchy of control laws

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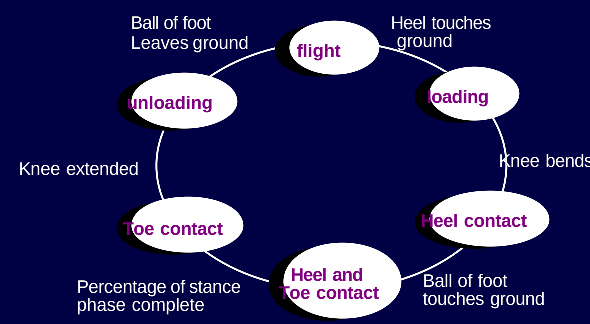
Running state machine



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Hierarchy of control laws

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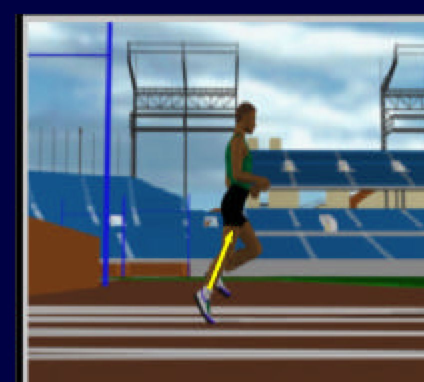
Flight duration



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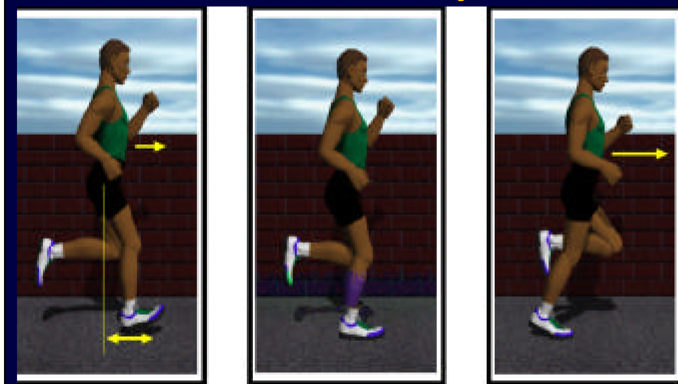
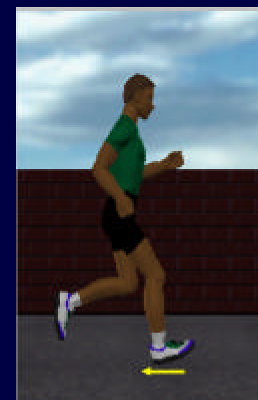
Forward Velocity

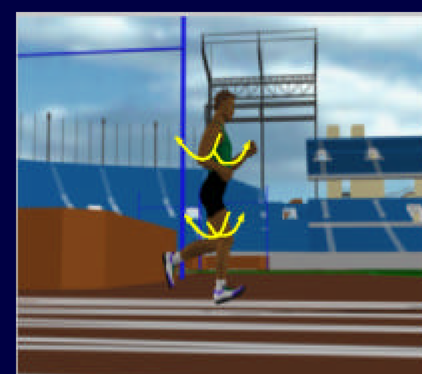


Ground speed matching



Balance: roll, pitch, yaw

Mirroring: hips and shoulders



Control laws for all states

Neck: turn in desired facing direction
Shoulder: mirror hip angle
Elbow: mirror magnitude of shoulder
Wrist: constant angle
Waist: keep body upright

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Hierarchy of control laws

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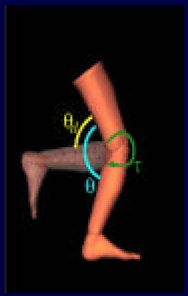
Low level control

$$t = k(q_d - q) + k_v(\dot{q}_d - \dot{q})$$



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Difference between walking and running

- Walking: double support
- Running: flight phase
- Energy transfer patterns
  - Inverted pendulum
  - Pogostick

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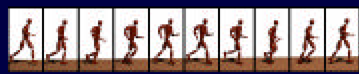
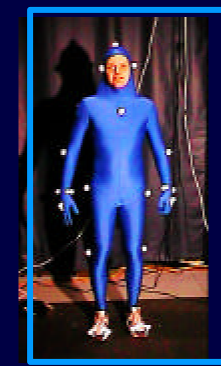
Physically Based Motion Transformation



Captured Motion

- 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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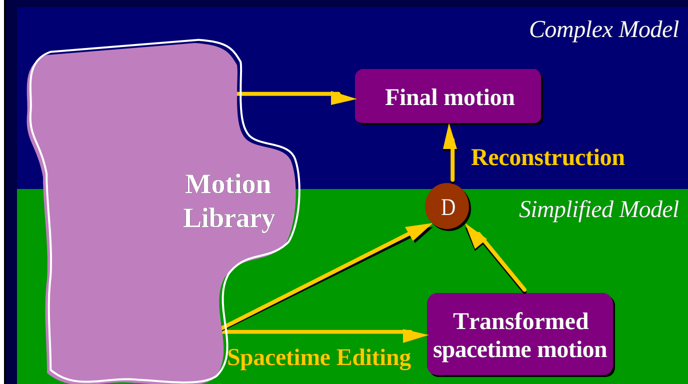
Outline



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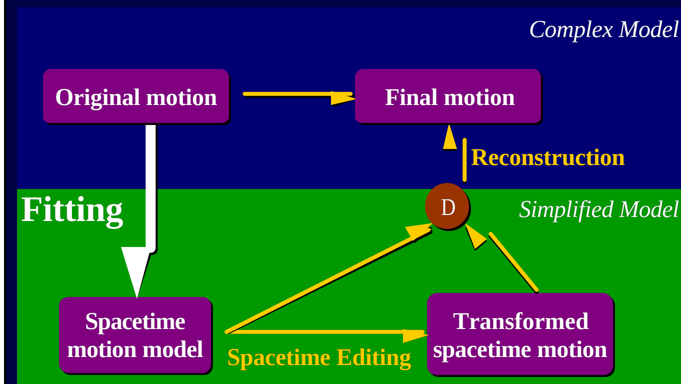
Outline



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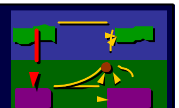
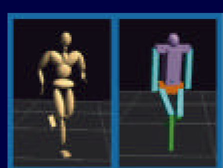
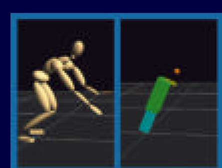
Simplified Kinematics





Human Run



Human Jump

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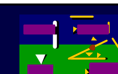
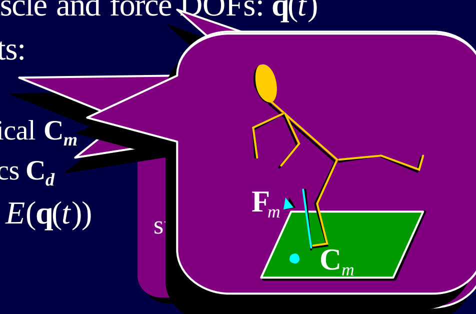
Motion Synthesis As Constrained Optimization



- 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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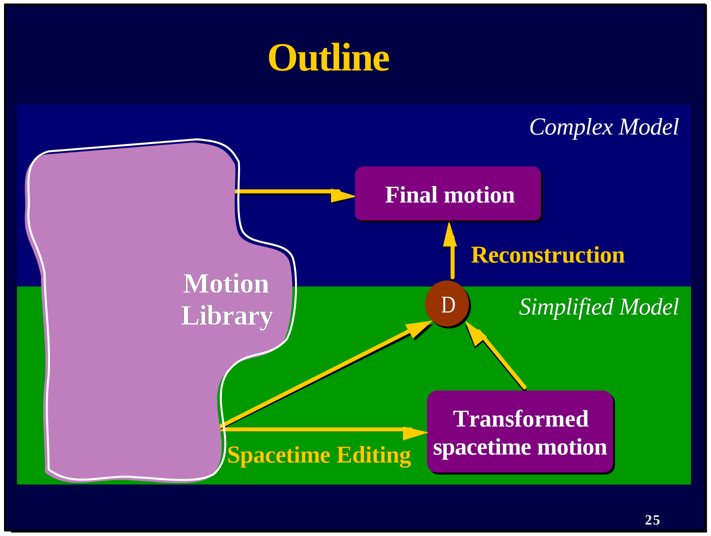
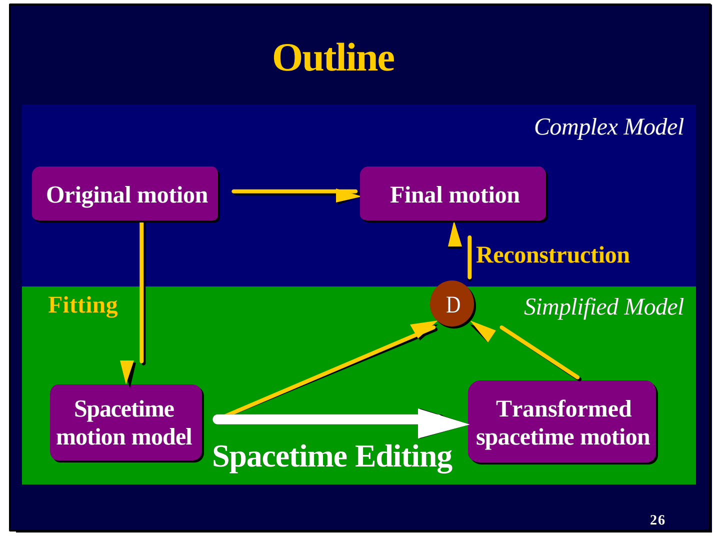
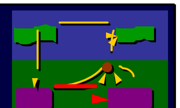


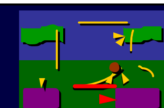


Spacetime Editing



- 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

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

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