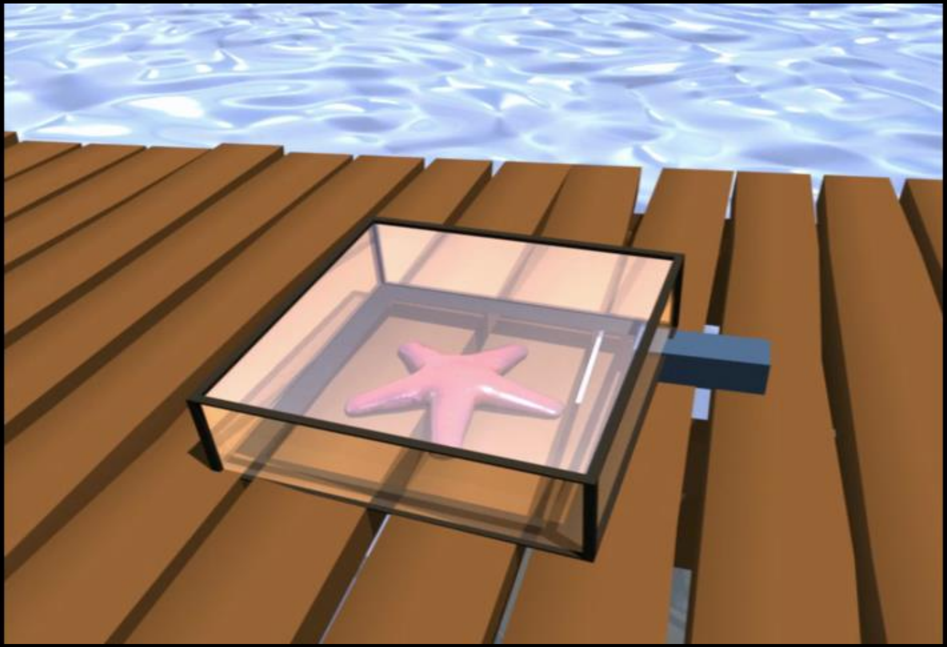
Directing Physically Based Interactions

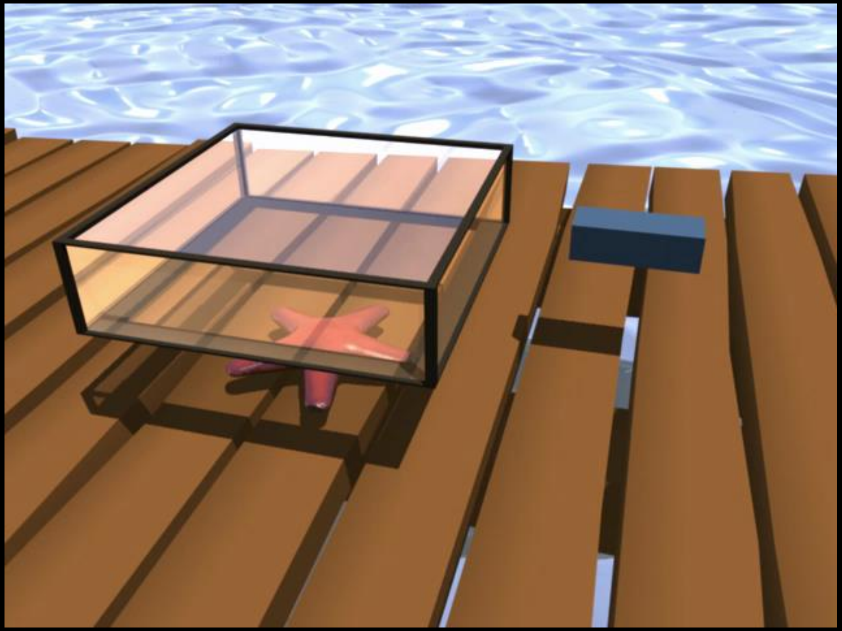
Animating Dexterous Motions

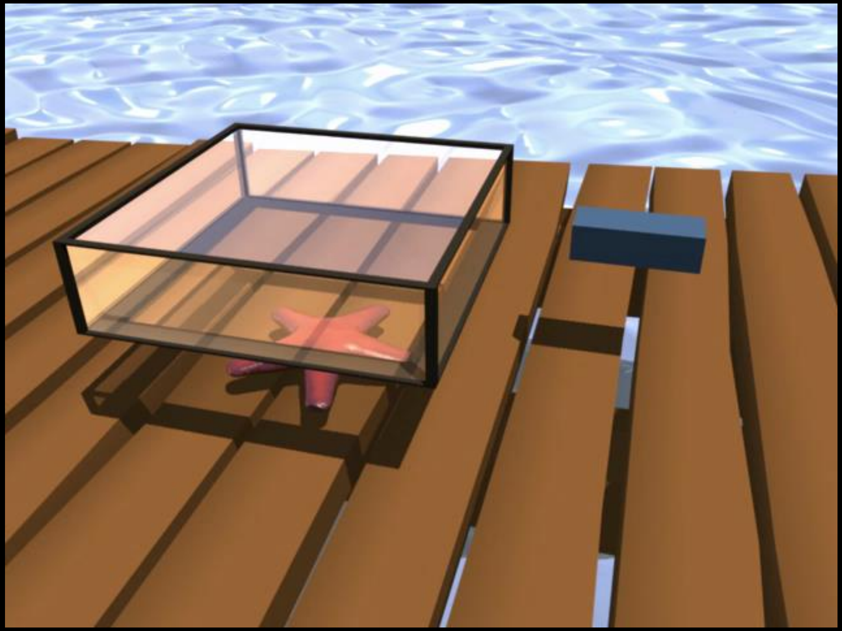


How can we easily animate the starfish’s escape?

- Appearance of intelligent motion
- Believable physical interaction with the glass box
- Dynamic, fun actions
- Animation tools accessible to anyone

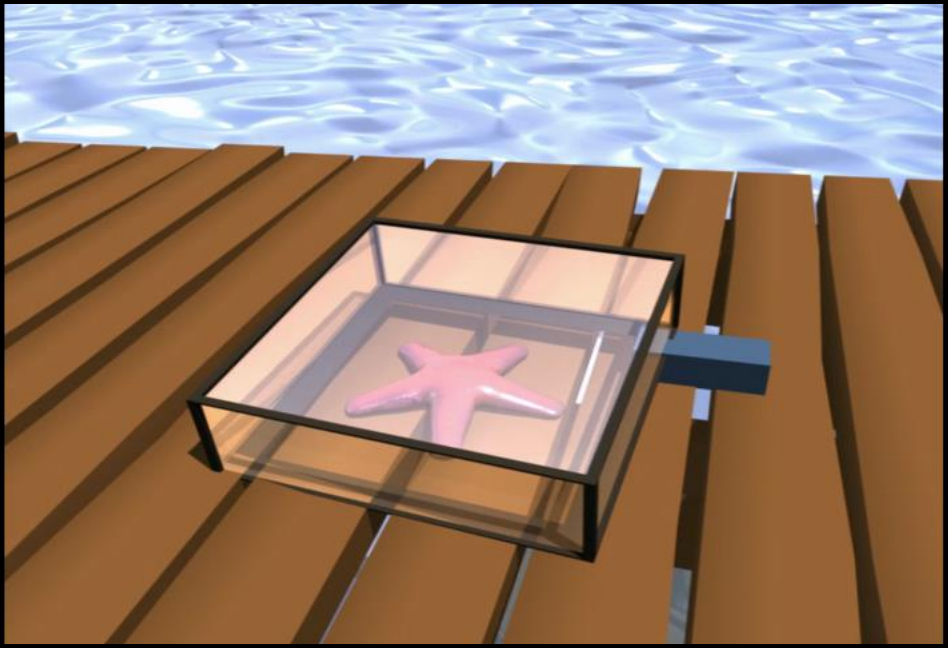
Animating Dexterous Motions



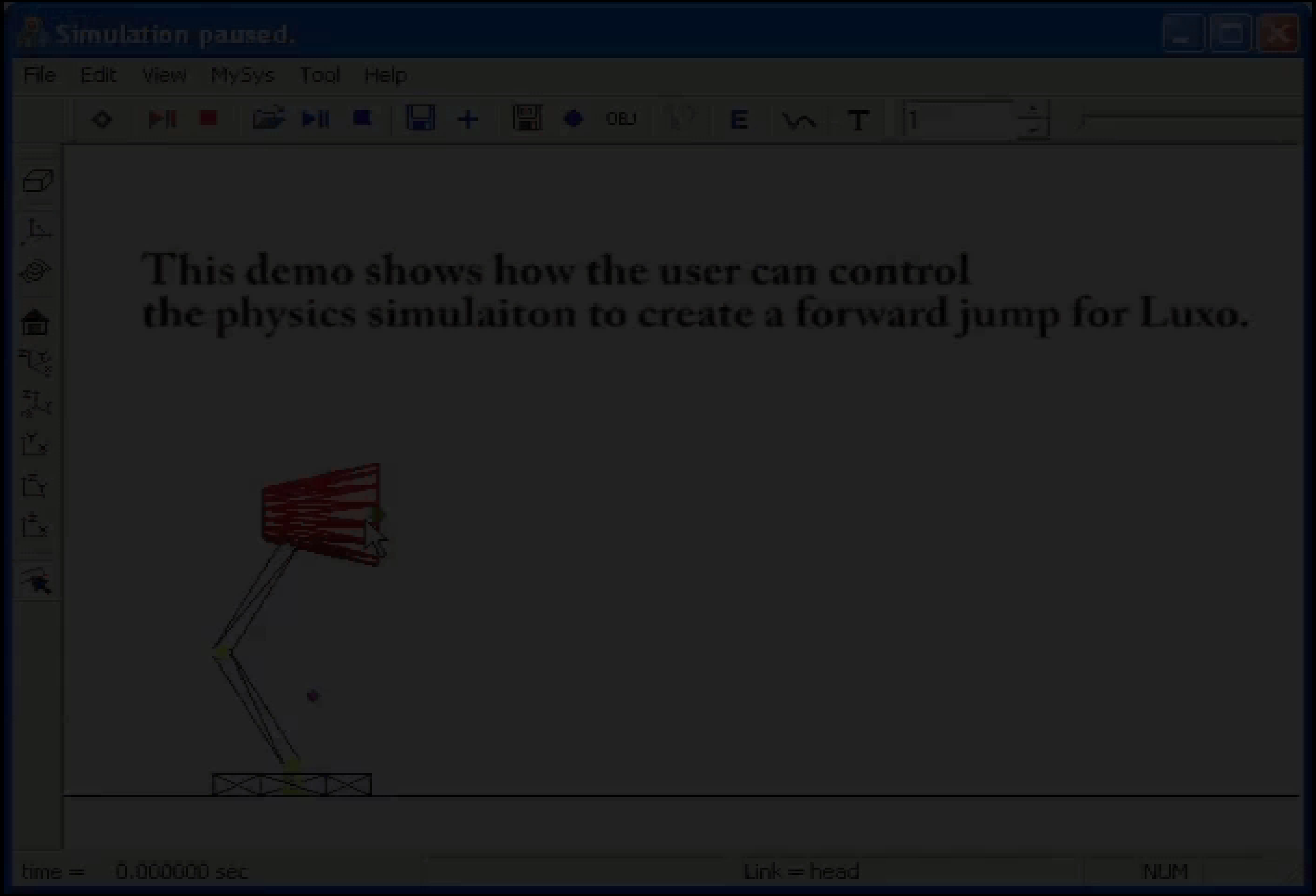


Videos created by two novice users using our system.

What Control Modes are Intuitive?



User Interface Example



This demo shows how the user can control the physics simulaiton to create a forward jump for Luxo.

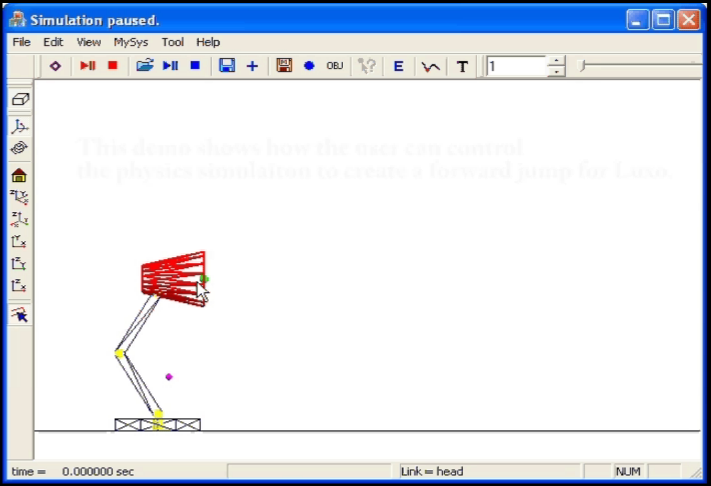
time = 0.000000 sec

Link = head

Interface Modes

Manipulate Bones

- Drag a bone to control its motion
  - direct control of head position



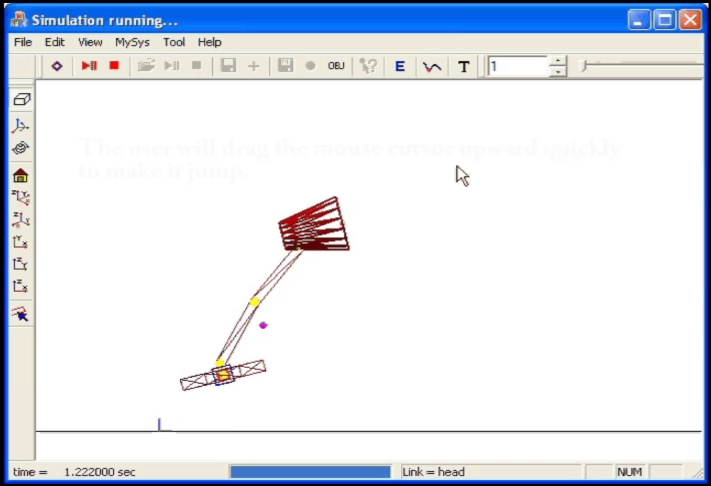
This demo shows how the user can control the physics simulaiton to create a forward jump for Luxo.

time = 0.000000 sec

Link = head

NUM

- Constrain a bone to a fixed position / orientation
  - constrain base to orientation shown



The user will drag the mouse cursor upward quickly to make it jump.

time = 1.222000 sec

Link = head

NUM

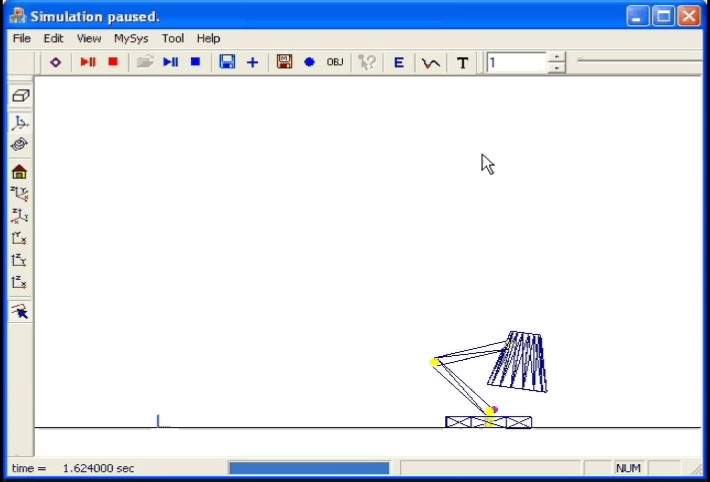
Interface Modes

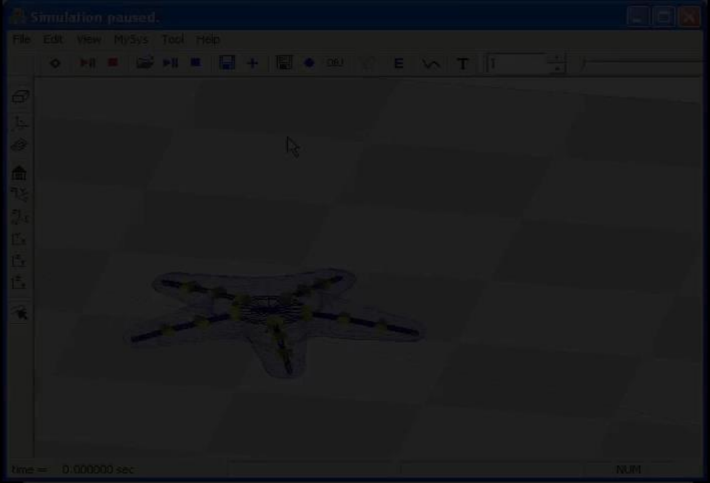
Manipulate Center of Gravity

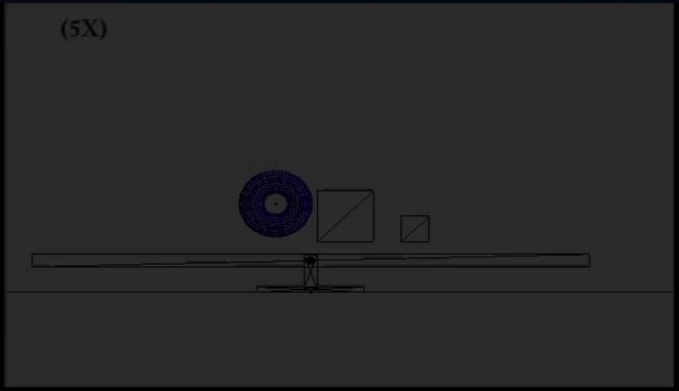
- Drag the CG of the lamp in a tightly controlled manner to keep it balanced

- Drag the CG of the starfish abruptly to create a jump

- Drag the CG of the donut in a free form manner to create the desired animation



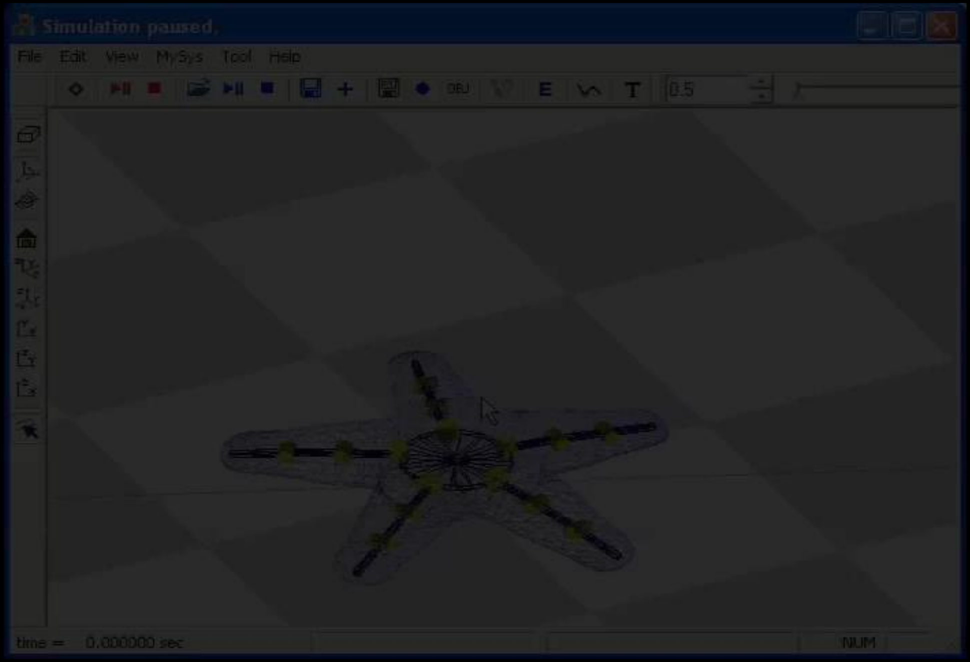




Interface Modes

Manipulate Character Root Orientation

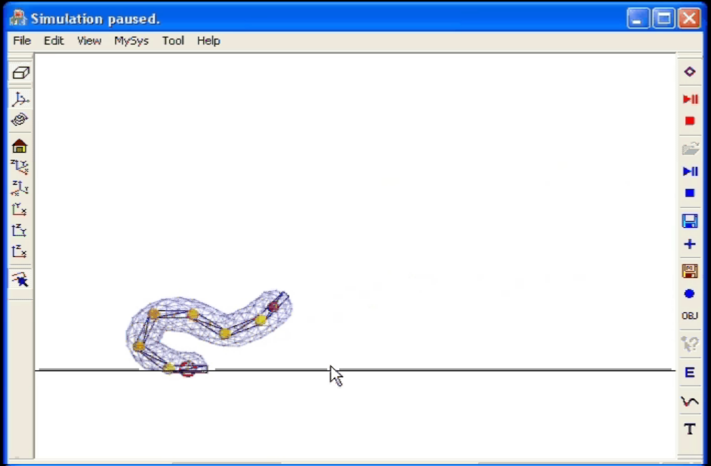
- Drag a special rotation widget for 3D rotational motions

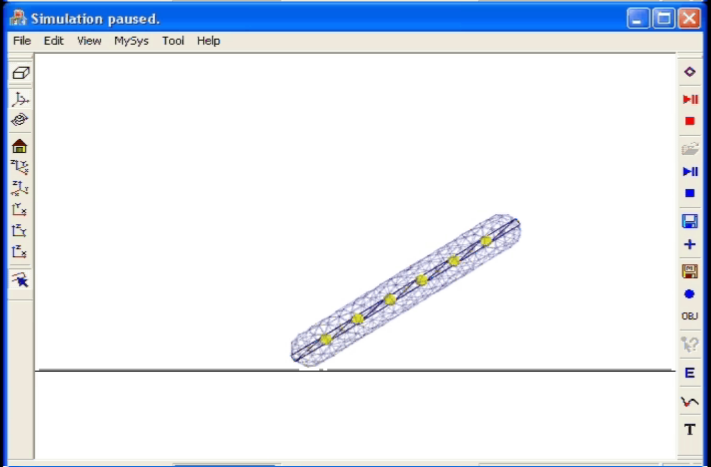


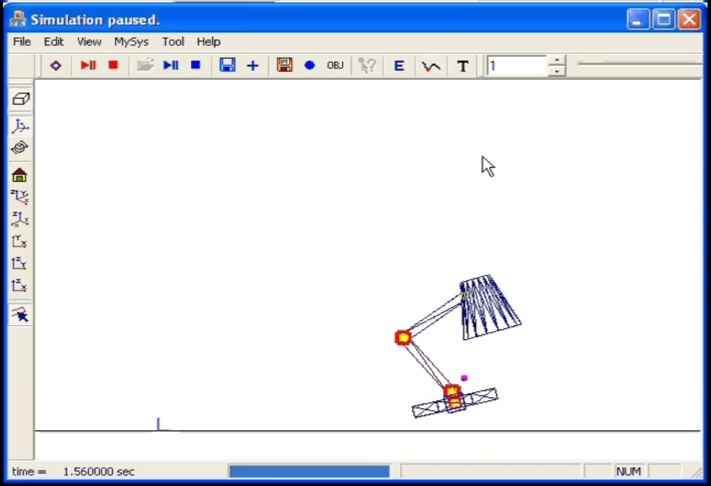
Interface Modes

Manipulate Joints

- Keyframe a leaping action for the worm
- Set and maintain joint limits
- Run a passive controller for a soft landing
  - How? Set a single desired configuration and low stiffness



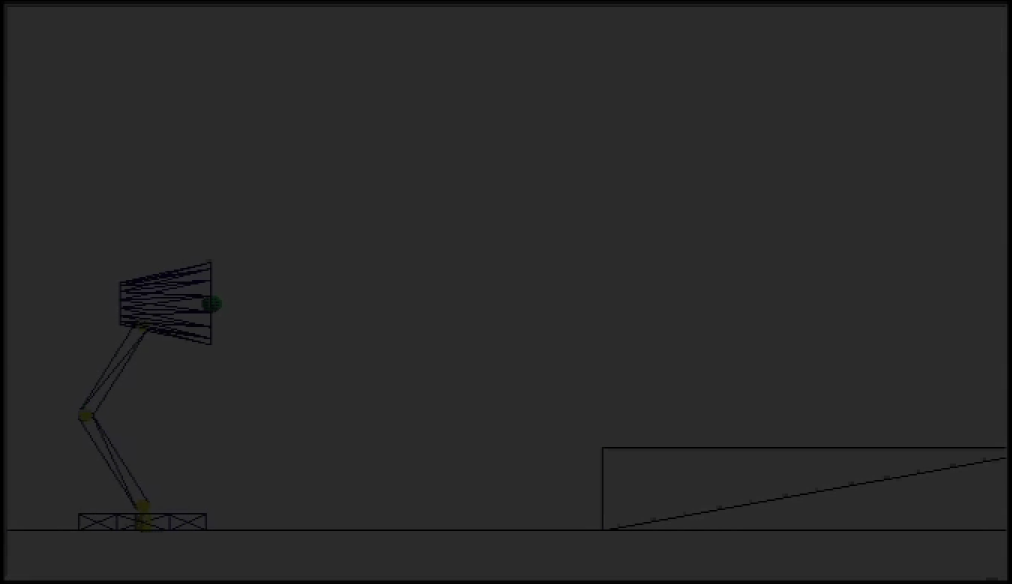




Interface Modes

Previewing

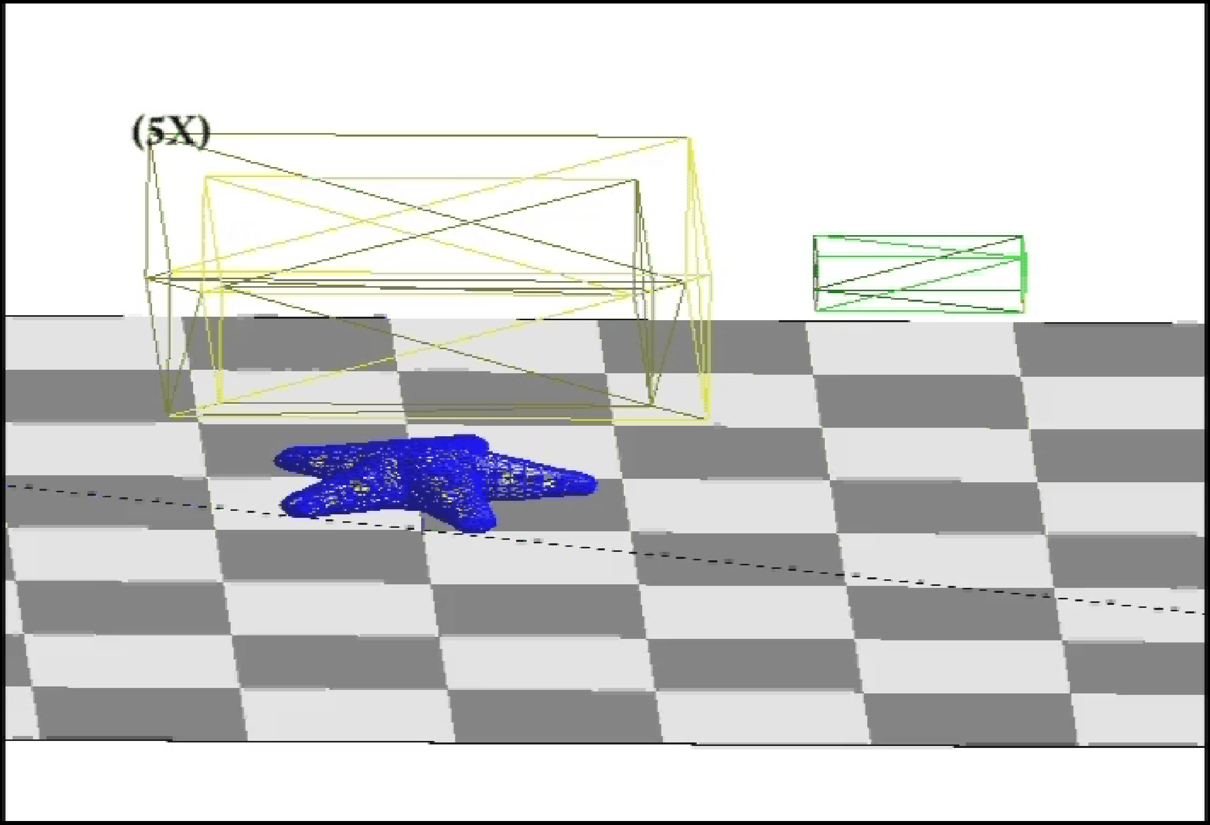
- Observe the effect of maintaining current command for a given period of time



Interface Modes

Speed up, slow down, advance, back up the simulation

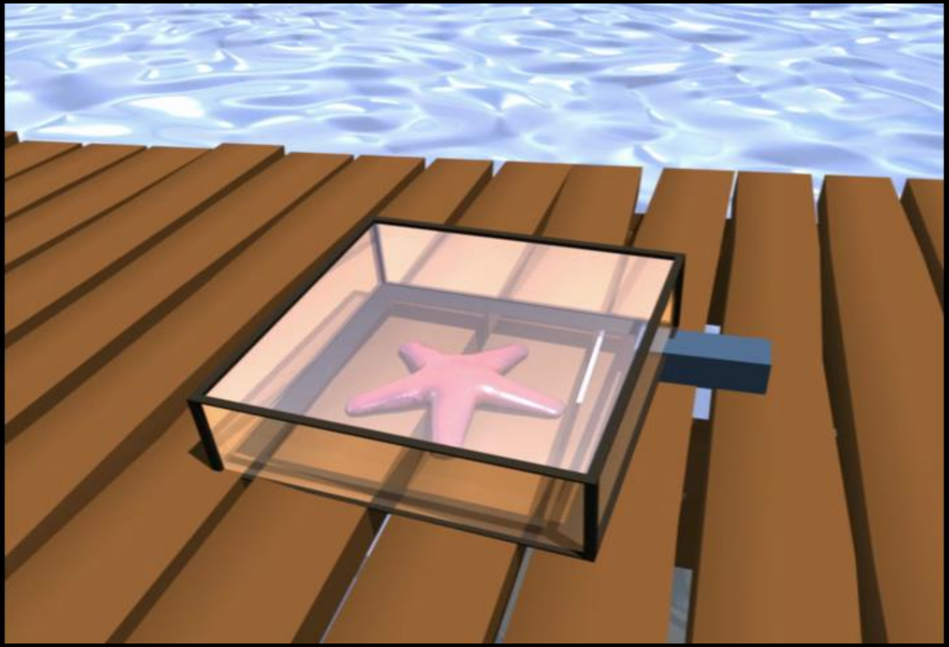
- Trial and error to learn the character dynamics and achieve desired result



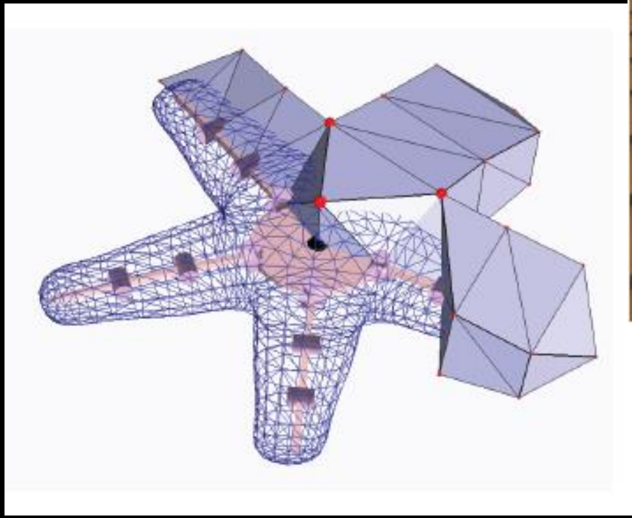
Animating Dexterous Motions

Our observation: Different control modes are needed at different times to create animations sophisticated enough to tell a story

Our solution: Put a variety of control modes into the animators hands and make them as intuitive as possible



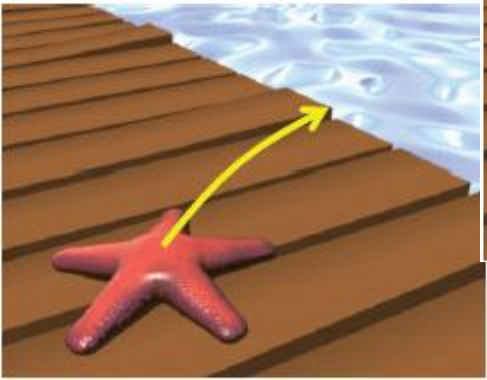
Overview of Our System



Character model:

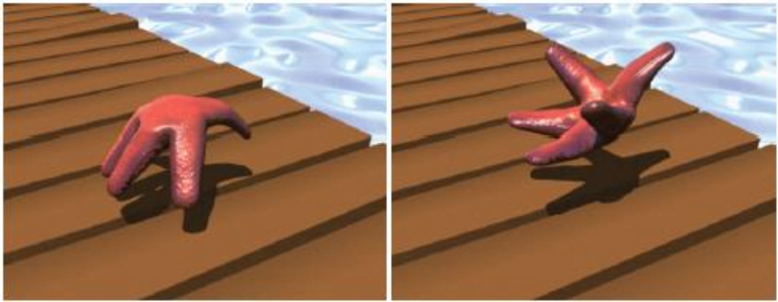
Coarse volumetric model -> fast simulation

Fine surface detail for appearance, contacts and collision



User Interface:

Real-time, trial and error (e.g., Jump like this!)



Results:

Compute muscle forces for the character to best achieve the user’s goals

Junggon Kim and Nancy S. Pollard, “Direct Control of Simulated Non-Human Characters,” IEEE CG&A, 2011

Interface Modes Under the Hood

The user is placing a variety of constraints on the character’s motion

How do we determine how the character should behave, in a physically realistic manner, to best meet th straints??

Our only “lever” is acc ations or torques tha st be applied at the character’s joints to e the simulation

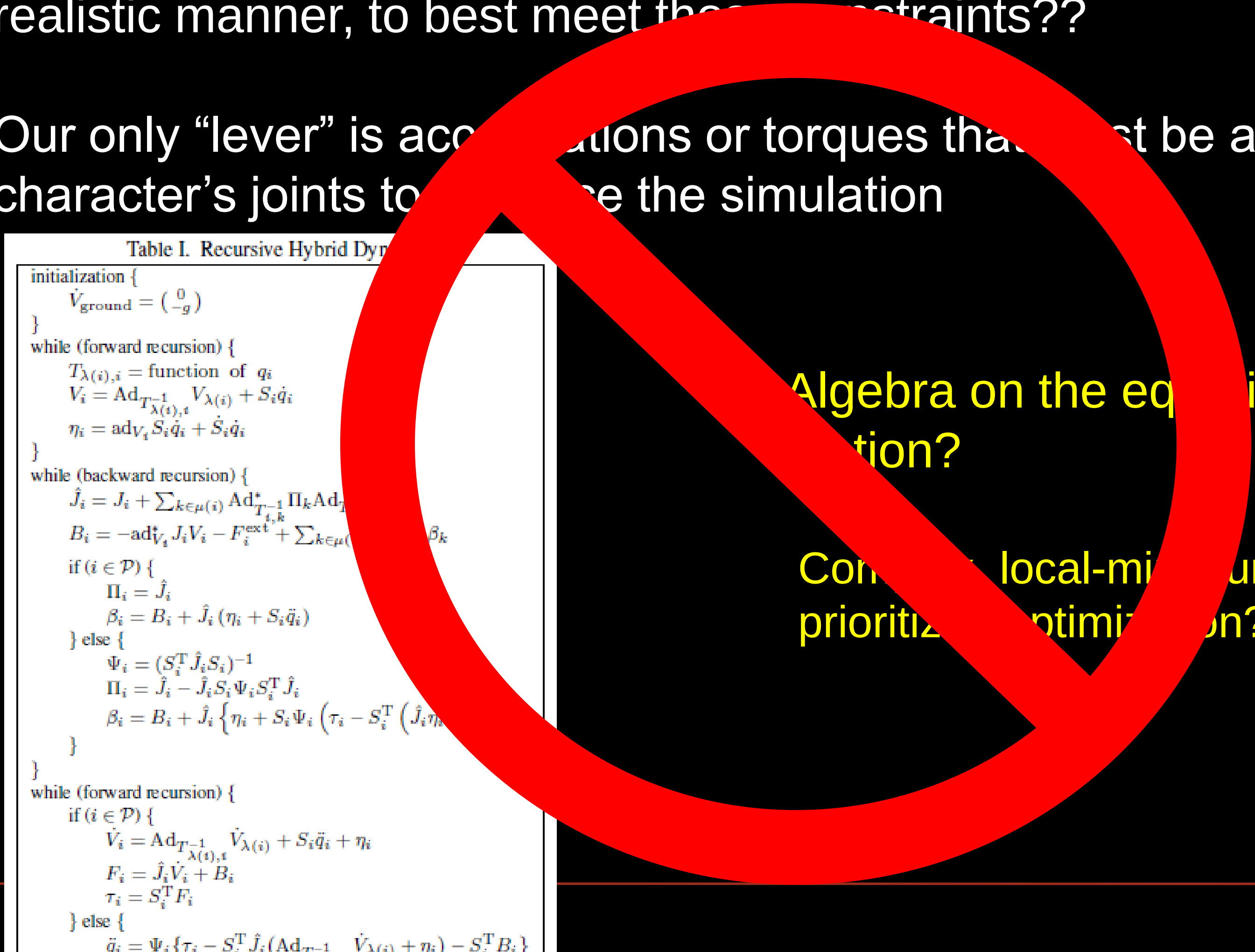


Table I. Recursive Hybrid Dyn

```
initialization {
    $\dot{V}_{\mathrm{ground}} = \binom{0}{-g}$
}
while (forward recursion) {
    $T_{\lambda(i),i} = \text{function of } q_i$
    $V_i = \mathrm{Ad}_{T^{-1}_{\lambda(i),i}} V_{\lambda(i)} + S_i \dot{q}_i$
    $\eta_i = \mathrm{ad}_{V_i} S_i \dot{q}_i + \dot{S}_i \dot{q}_i$
}
while (backward recursion) {
    $\hat{J}_i = J_i + \sum_{k \in \mu(i)} \mathrm{Ad}^*_{T^{-1}_{i,k}} \Pi_k \mathrm{Ad}_{T}$
    $B_i = -\mathrm{ad}^*_{V_i} J_i V_i - F^{\mathrm{ext}}_i + \sum_{k \in \mu(}$   $\beta_k$
    if ($i \in \mathcal{P}$) {
        $\Pi_i = \hat{J}_i$
        $\beta_i = B_i + \hat{J}_i (\eta_i + S_i \ddot{q}_i)$
    } else {
        $\Psi_i = (S_i^{\mathrm{T}} \hat{J}_i S_i)^{-1}$
        $\Pi_i = \hat{J}_i - \hat{J}_i S_i \Psi_i S_i^{\mathrm{T}} \hat{J}_i$
        $\beta_i = B_i + \hat{J}_i \{ \eta_i + S_i \Psi_i ( \tau_i - S_i^{\mathrm{T}} ( \hat{J}_i \eta_i$
    }
}
while (forward recursion) {
    if ($i \in \mathcal{P}$) {
        $\dot{V}_i = \mathrm{Ad}_{T^{-1}_{\lambda(i),i}} \dot{V}_{\lambda(i)} + S_i \ddot{q}_i + \eta_i$
        $F_i = \hat{J}_i \dot{V}_i + B_i$
        $\tau_i = S_i^{\mathrm{T}} F_i$
    } else {
        $\ddot{q}_i = \Psi_i \{ \tau_i - S_i^{\mathrm{T}} \hat{J}_i ( \mathrm{Ad}_{T^{-1}} \dot{V}_{\lambda(i)} + \eta_i ) - S_i^{\mathrm{T}} B_i \}$
```

Algebra on the eq ions of tion?

Con local-mi um prone, prioriti ptimi n??

Interface Modes Under the Hood

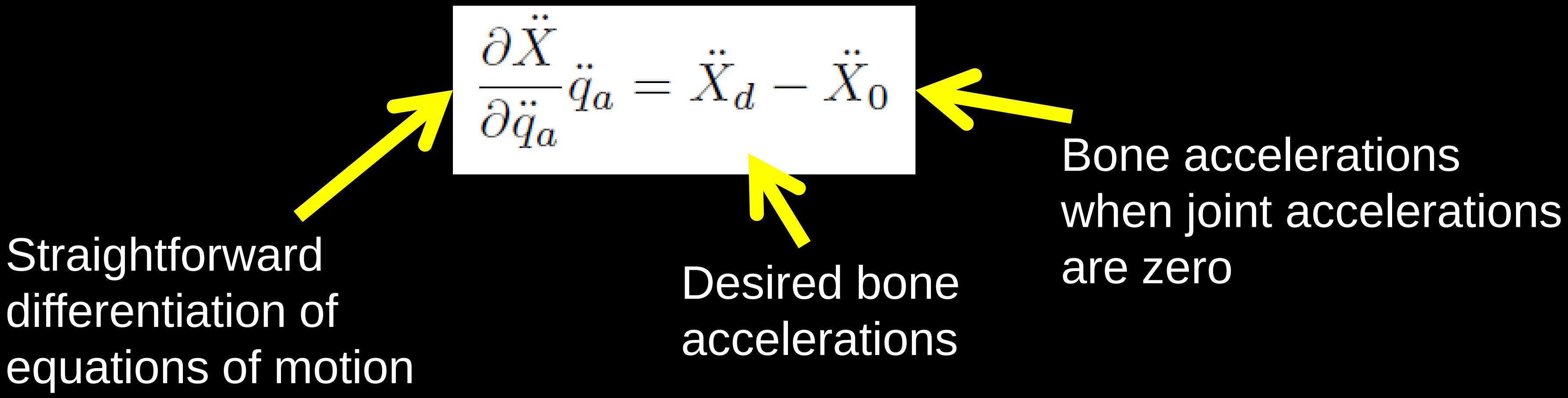
Most quantities we care to measure or control have a locally linear relationship to joint accelerations and joint torques

$$A\ddot{q}_a = b \quad \text{and} \quad C\ddot{q}_a \leq d$$

Evangelos Kokkevis,
Practical Physics for Articulated Characters,
Game Developer's Conference 2004.

Example: Bone Constraints

Express bone constraint as a linear function of joint accelerations:



$$\frac{\partial \ddot{X}}{\partial \ddot{q}_a}\ddot{q}_a = \ddot{X}_d - \ddot{X}_0$$

Straightforward differentiation of equations of motion

Desired bone accelerations

Bone accelerations when joint accelerations are zero

Obtaining desired bone accelerations:

$$\ddot{x}_d = k_p(x_d - x) - k_v \dot{x}$$
$$\dot{w}_d = k'_p \; R \; \log((R)^T R_d) - k'_v w$$

Interface Modes Under the Hood

(1) Express all constraints as a linear function of joint accelerations:

$$A\ddot{q}_a = b \quad \text{and} \quad C\ddot{q}_a \leq d$$

(2) Solve a Quadratic Program to obtain joint accelerations:

$$\min_{\ddot{q}_a} ||A\ddot{q}_a - b||^2 + \alpha||\ddot{q}_a||^2 \quad \text{s.t.} \;\; C\ddot{q}_a \leq d$$

(3) Use these accelerations for the next timestep to advance the simulation

Final Demos

Direct Control of
Simulated Non-human Characters

Results
(animations)

(No audio)

Realistic Physical Behavior?

GoQBot I-III

Replicating the Ballistic Rolling and More

Tufts Biomimetic Devices Laboratory

Roboticist: *Huai-Ti Lin* (*Ph.D candidate*)

http://morphingmorphology.blogspot.com

http://www.youtube.com/watch?v=a-1AiExU3Vk

Huai-Ti Lin, Tufts Biomimetic Devices Laboratory

Notes

Constraint priorities: Mouse drags are satisfied after everything else

Contact modeling: “hallucinate” constraints to account for pushoff forces

Objective functions: minimize joint accelerations, torques, or velocities

Speed: Simulations are real-time or better; users preferred 3X-8X slower

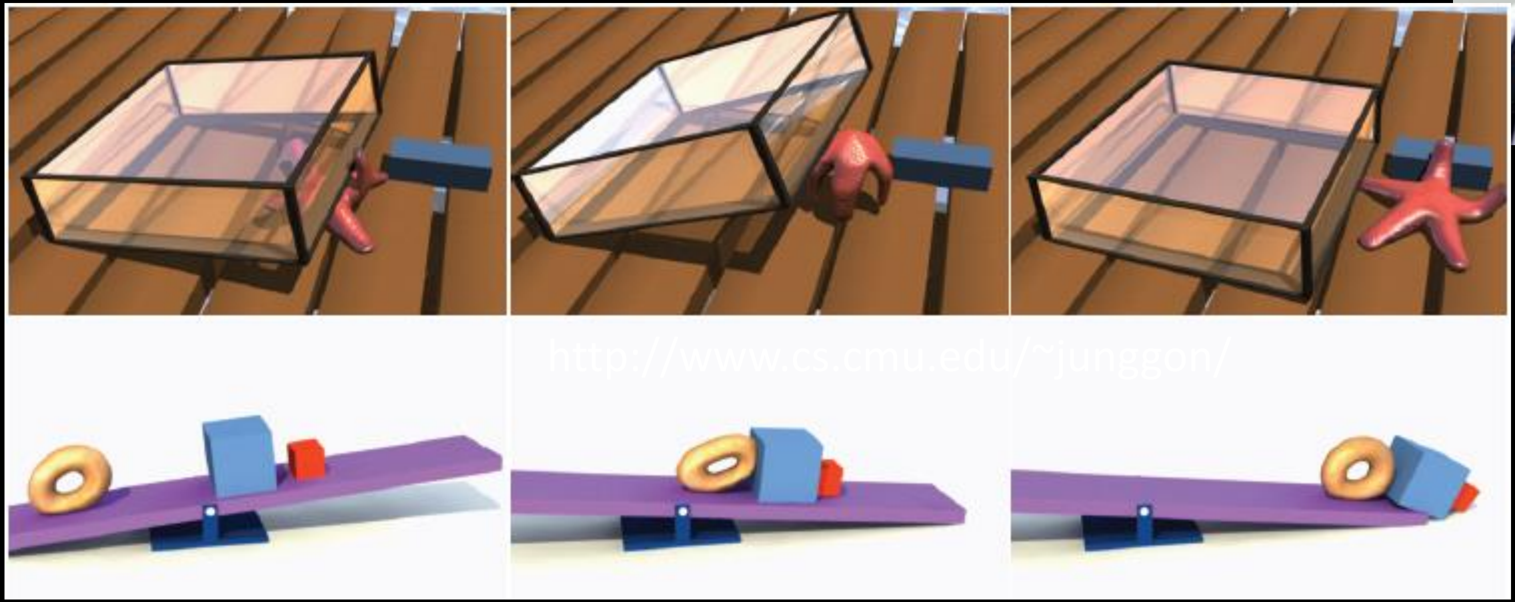
Ease of use: Starfish escape animations created by novices in minutes

What Control Modes are Intuitive?

Fast Simulation of Skeleton-driven
Deformable Body Characters

Junggon Kim and Nancy S. Pollard

References



Junggon Kim and Nancy S. Pollard, "Direct Control of Simulated Non-Human Characters," IEEE CG&A, 2011

Junggon Kim and Nancy S. Pollard, "Fast Simulation of Skeleton-Driven Deformable Body Characters," ACM ToG, 2011

http://www.cs.cmu.edu/~junggon/