Today's Topics

16. Intro to Computer Animation
17. Computational Photography

Exam prep session:

7-9pm Wednesday, Dec 15th
in BA 5256 (seminar room near my office)

Topic 16:

Computer Animation

- Keyframe animation
- Forward kinematics
- Inverse kinematics
- Motion capture
- Physics-based animation (dynamics)

Keyframe Animation

Basic Idea: Define model parameters at key frames and interpolate (often using cubic splines)

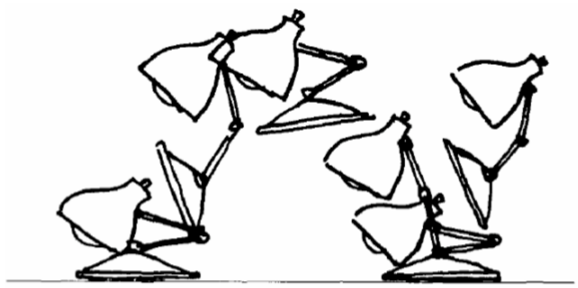

FIGURE 3. Squash & stretch in Luxo Jr.'s hop.

J. Lasseter, "Principles of Traditional Animation Applied to 3D Computer Animation" Proc. SIGGRAPH, pp. 35-44, 1987

Designing Plausible Motions

It is quite easy to end up with a physically impossible motion

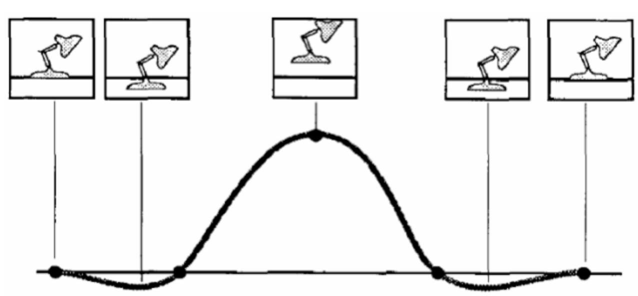

FIGURE 10a. This spline controls the Z (up) translation of Luxo Jr. Dips in the spline cause him to intersect the floor.

Designing Plausible Motions

It is quite easy to end up with a physically impossible motion ⇒ add a sufficient # of keyframes to constrain the motion sufficiently

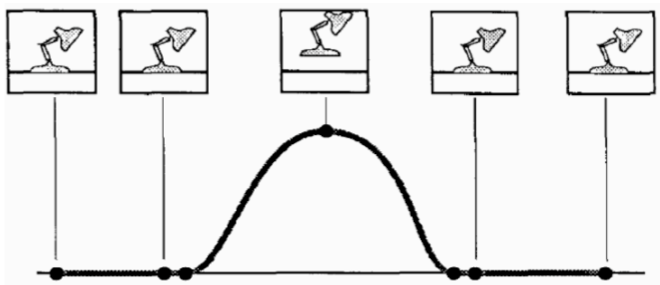

FIGURE 10b. Two extra extremes are added to the spline which removes the dips and prevents Jr. from going into the basement.

Keyframe Animation

"Whether it is generated by hand or by computer, the first goal of the animator is to entertain. [...] Tools, in the sense of hardware & software, are simply not enough."

– John Lasseter, Pixar

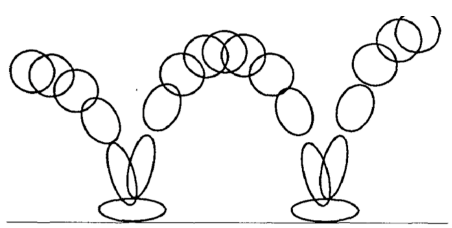

FIGURE 2. Squash & stretch in bouncing ball.

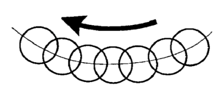

FIGURE 4a. In slow action, an object's position overlaps from frame to frame which gives the action a smooth appearance to the eye.

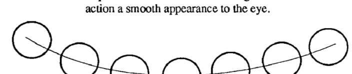

FIGURE 4b. Strobing occurs in a faster action when the object's positions do not overlap and the eye perceives seperate images.

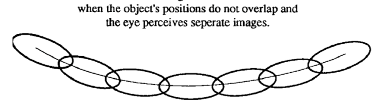

FIGURE 4c. Stretching the object so that it's positions overlap again will relieve the strobing effect.

Keyframe Animation

"Whether it is generated by hand or by computer, the first goal of the animator is to entertain. [...] Tools, in the sense of hardware & software, are simply not enough."

– John Lasseter, Pixar

Luxo Jr.

Keyframe Animation

Pros

- Very expressive
- Animator has full control of animation

Cons

- Very labor intensive
- Difficult to create convincing physical realism (if that is a goal)

Used for practically anything except complex physical simulations (smoke, water, etc)

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Computer Animation

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Specifying & Interpolating Keyframes

- Instead of painstakingly specifying every little motion, specify very few keyframes (or just initial & goal)
- Interpolations done automatically

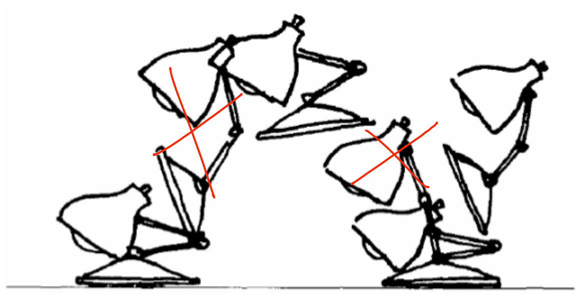


FIGURE 3. Squash & stretch in Luxo Jr.'s hop.

Animating Articulated Structures

1. Forward kinematics

   specify how joints should move

2. Inverse kinematics

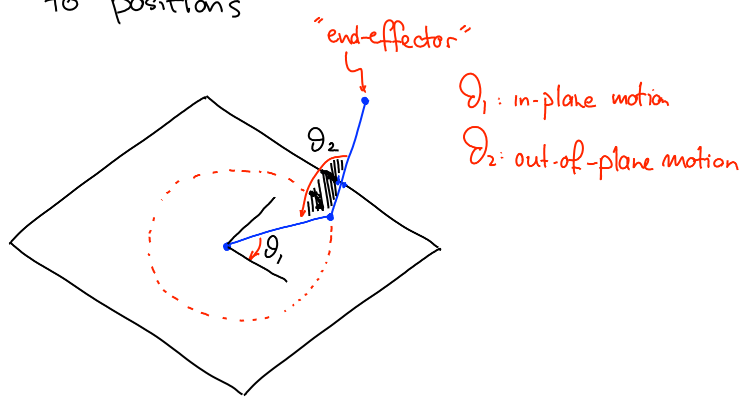
   specify where character should go, then deduce joint motion

3. Motion capture

   record motions of real people/objects, then transfer to digital characters

Forward Kinematics

Goals:
- determine space of possible motions
- parameterize it
- establish a mapping from joint angles to positions



Forward Kinematics

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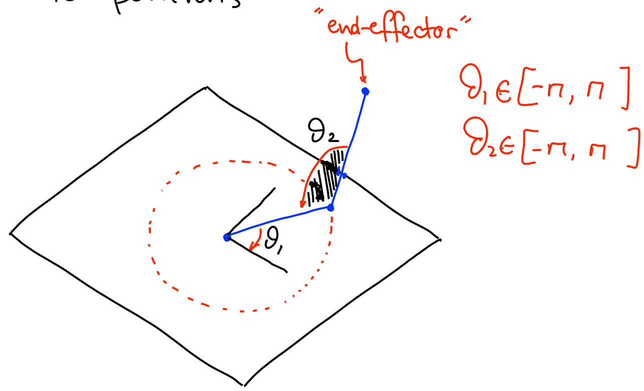
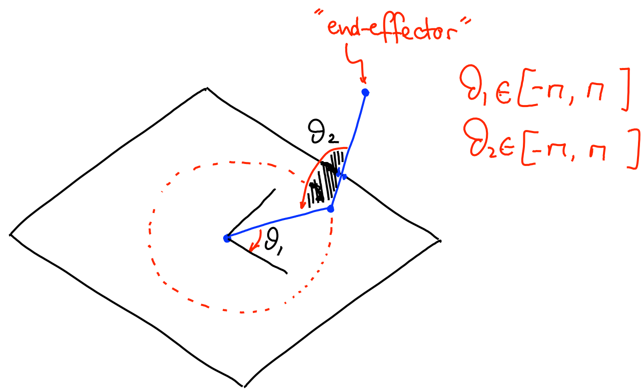


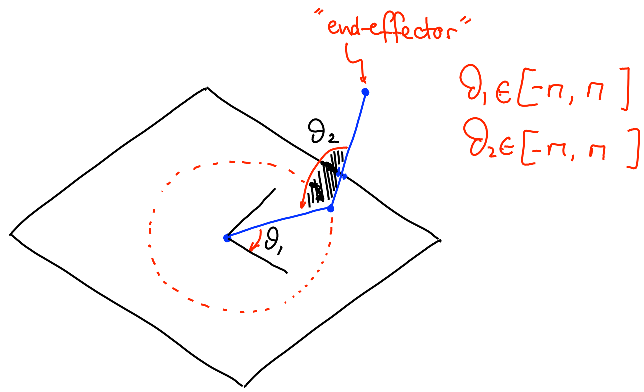
End-Effector Space (aka "Configuration Space")

What is the set of points that are "reachable" by this 2-axis structure?

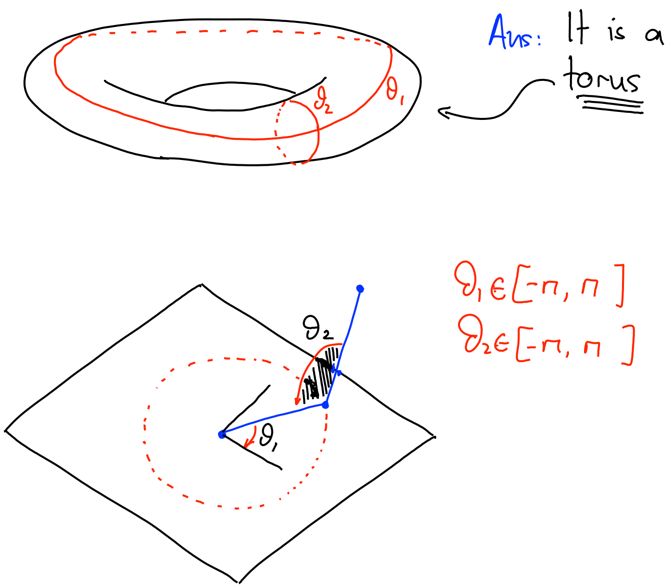


End-Effector Space (aka "Configuration Space")

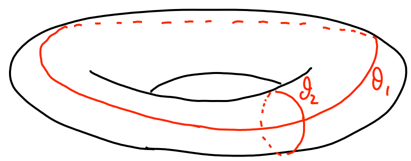
What is the set of points "traced" by the end-effector as θ_1, θ_2 go through all angles?



End-Effector Space (aka "Configuration Space")

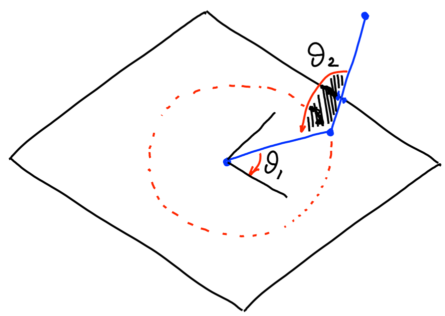


End-Effector Space (aka "Configuration Space")



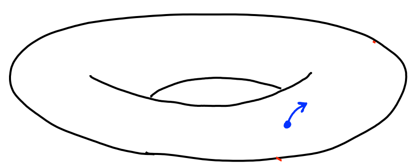
Q: How can we parameterize the torus?

Hint: it is a surface of revolution!

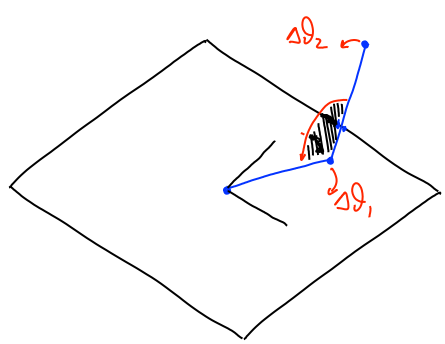


$\theta_1 \in [-\pi, \pi]$
$\theta_2 \in [-\pi, \pi]$

Motion in Joint Space vs. Configuration Space



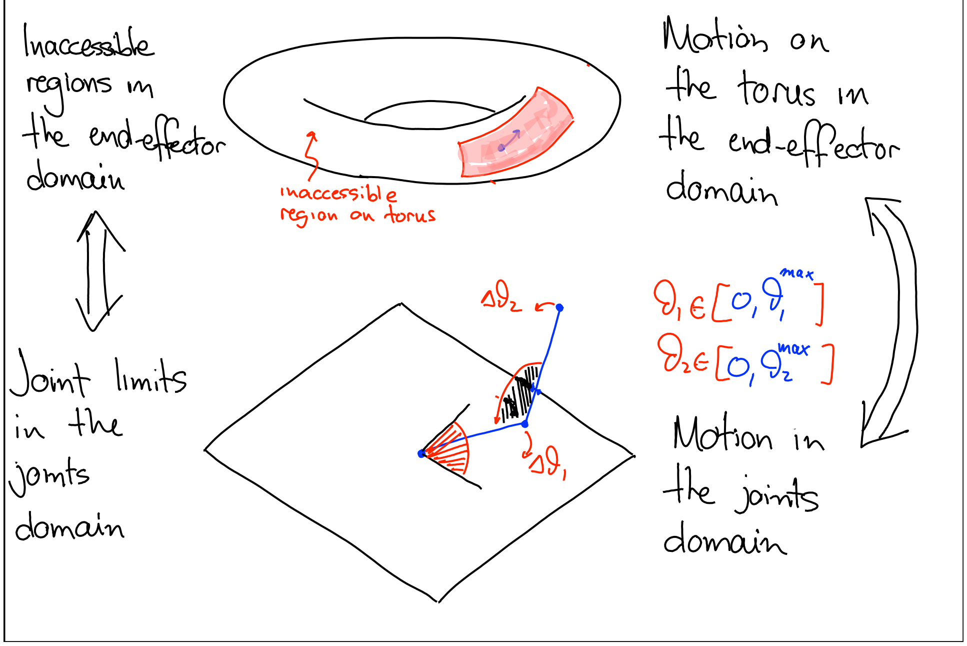
Motion on the torus in the end-effector domain



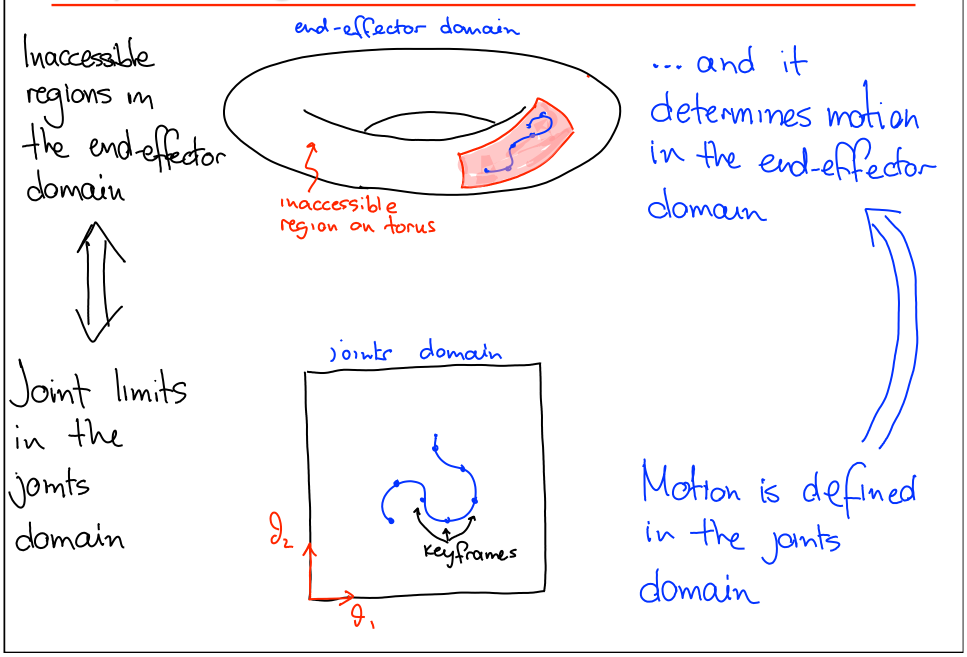
$\theta_1 \in [-\pi, \pi]$
$\theta_2 \in [-\pi, \pi]$

Motion in the joints domain

Motion in Joint Space vs. Configuration Space



Key-Framing with Forward Kinematics



Key-Framing with Forward Kinematics

Pros

Very easy to specify & implement

Cons

- Often we care more about where the character should go, not how to get there
- Very hard to know how to move joints of a complicated figure in order to get the desired pose (esp. in presence of obstacles)

Key-Framing with Forward Kinematics

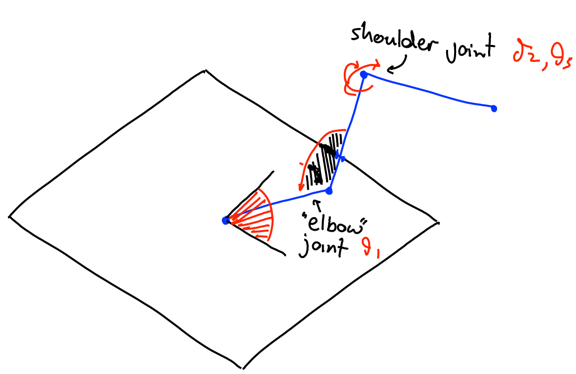
End-effector spaces quickly become very complicated!

Example: What is the end-effector space of an arm?

Ans A 3-torus embedded in $\mathbb{R}^3$ ...

$$(\vartheta_1, \vartheta_2, \vartheta_3) \longrightarrow \mathbb{R}^3$$

joint angles → end-effector



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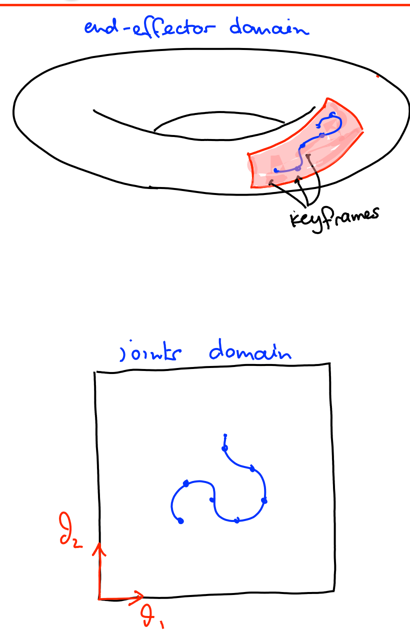
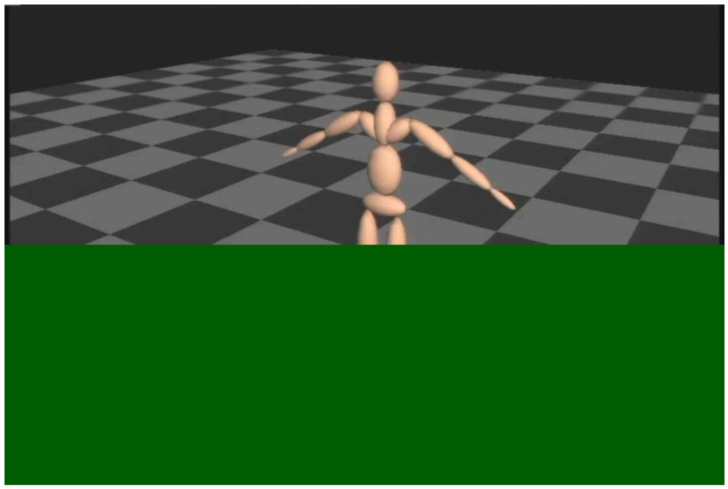
Key-Framing with Inverse Kinematics



We specify where the end-effector should move in the domain

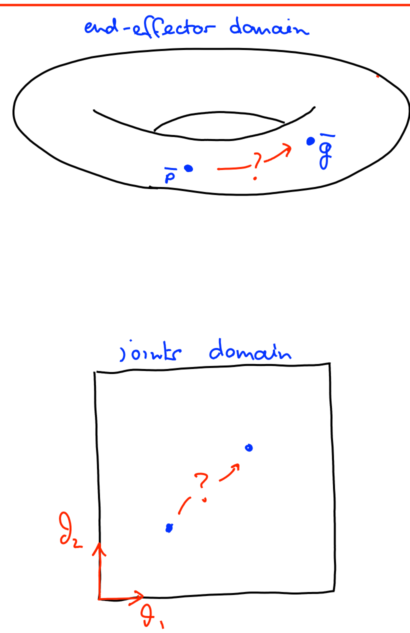
The joint motion to achieve this is computed automatically.

Key-Framing with Inverse Kinematics



Grochow et al, SIGGRAPH'04

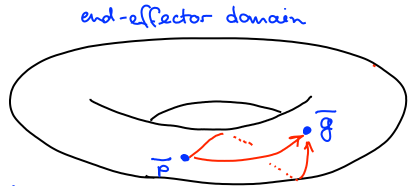
Inverse Kinematics



We specify where the end-effector should move in the domain

The joint motion to achieve this is computed automatically.

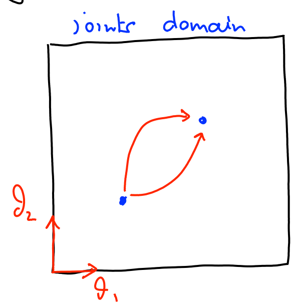
Inverse Kinematics: Difficulties



We specify where the end-effector should move in the domain

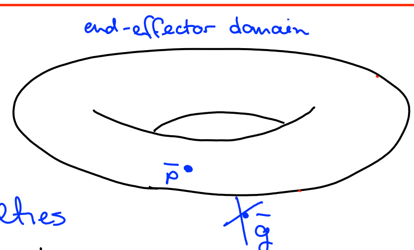
Major difficulties

- many ways to go from $\bar{p}$ to $\bar{g}$ (solution not unique!)



The joint motion to achieve this is computed automatically.

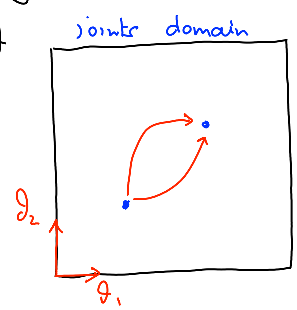
Inverse Kinematics: Difficulties



We specify where the end-effector should move in the domain

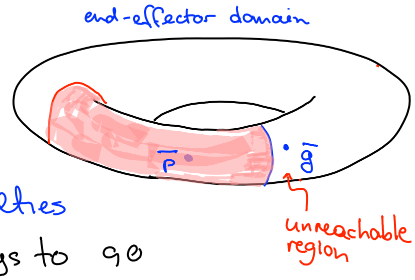
Major difficulties

- many ways to go from $\bar{p}$ to $\bar{g}$
- position may not be reachable!



The joint motion to achieve this is computed automatically.

Inverse Kinematics: Difficulties

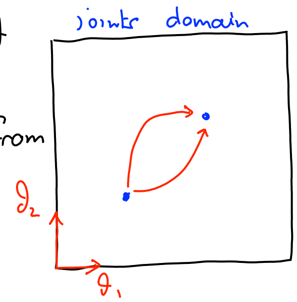


We specify where the end-effector should move in the domain

The joint motion to achieve this is computed automatically.

Major difficulties

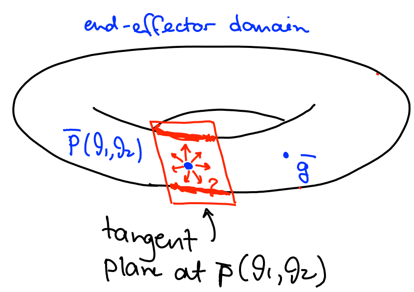
- many ways to go from $\bar{p}$ to $\bar{g}$
- position may not be reachable!
- mapping to/from joint space is highly non-linear!



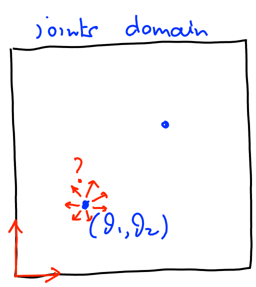
Numerical Inverse Kinematics

Linearization

Given current position $\bar{p}(\theta_1, \theta_2)$ take a small step toward goal position



Q: How should we move joints differentially to make positive progress toward goal?

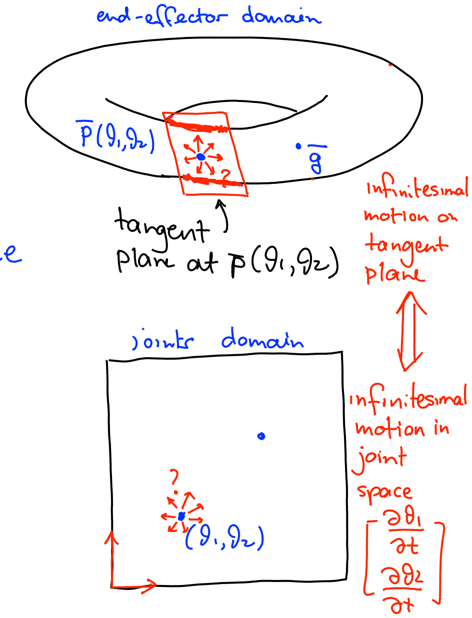


Numerical Inverse Kinematics

Linearization

Given current position $\bar{p}(\theta_1, \theta_2)$ take a small step toward goal position

how do we move on tangent plane to minimize distance to goal?



Q: How should we move joints differentially to make positive progress toward goal?

translation to goal:

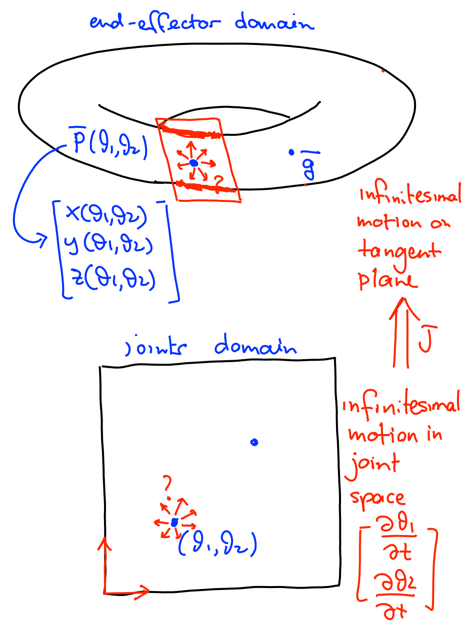
$\bar{g} - \bar{p}(\theta_1, \theta_2)$

Inverse Kinematics & the Jacobian

Linearization

$$\begin{bmatrix} \frac{\partial x}{\partial t} \\ \frac{\partial y}{\partial t} \\ \frac{\partial z}{\partial t} \end{bmatrix} = \begin{bmatrix} \frac{\partial x}{\partial \theta_1} & \frac{\partial x}{\partial \theta_2} \\ \frac{\partial y}{\partial \theta_1} & \frac{\partial y}{\partial \theta_2} \\ \frac{\partial z}{\partial \theta_1} & \frac{\partial z}{\partial \theta_2} \end{bmatrix} \begin{bmatrix} \frac{\partial \theta_1}{\partial t} \\ \frac{\partial \theta_2}{\partial t} \end{bmatrix}$$

end-effector motion; Jacobian J; joint motion



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translation to goal:

$\bar{g} - \bar{p}(\theta_1, \theta_2)$

Inverse Kinematics & the Jacobian

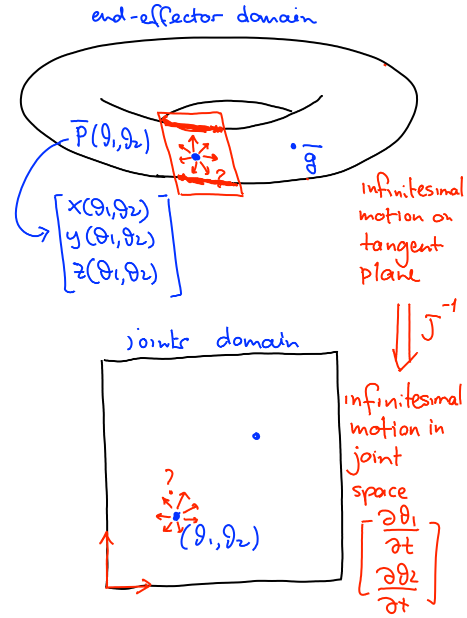
Linearization

end-effector motion → $\frac{d\bar{p}}{dt} = J \frac{d\bar{\theta}}{dt}$ ← joint motion (J: Jacobian) $\Longrightarrow$

$$\frac{d\bar{\theta}}{dt} = J^{-1} \frac{d\bar{p}}{dt}$$

Q: How should we move joints differentially to make positive progress toward goal?

translation to goal:
$\bar{g} - \bar{p}(\theta_1, \theta_2)$



Inverse Kinematics Using the Jacobian

Linearization

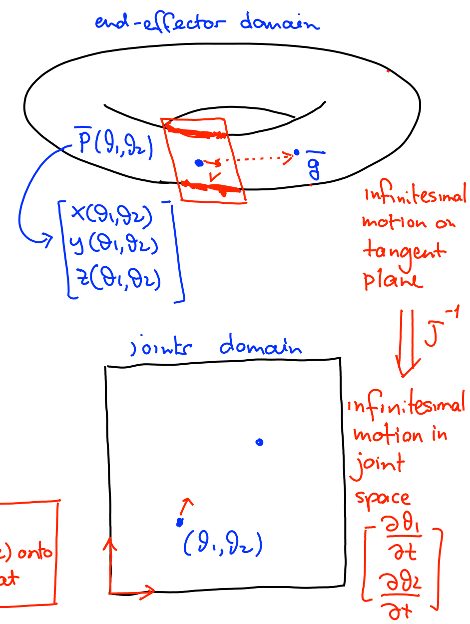
end-effector motion → $\frac{d\bar{p}}{dt} = J \frac{d\bar{\theta}}{dt}$ ← joint motion (J: Jacobian) $\Longrightarrow$

$$\frac{d\bar{\theta}}{dt} = J^{-1} \frac{d\bar{p}}{dt}$$

Q: How should we move joints differentially to make positive progress toward goal?

$$\frac{d\bar{\theta}}{dt} = \alpha J^{-1} \vec{V}$$

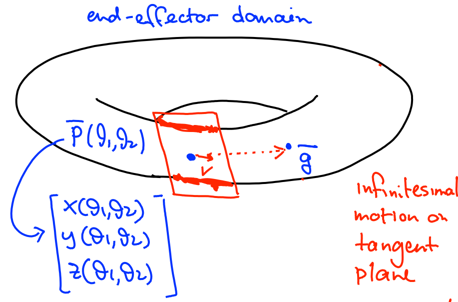
α: small step length; $\vec{V}$: projection of $\bar{g} - p(\theta_1,\theta_2)$ onto tangent plane at $p(\theta_1,\theta_2)$



Inverse Kinematics Using the Jacobian

Linearization

- J is different at each (θ_1, θ_2) ⇒ must recompute after each step
- J may not be invertible ⇒ take pseudoinverse



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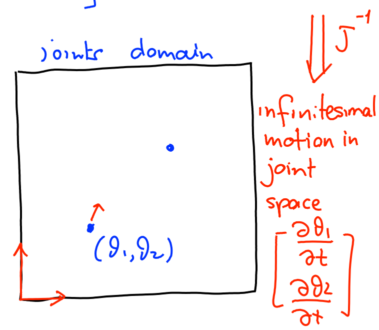

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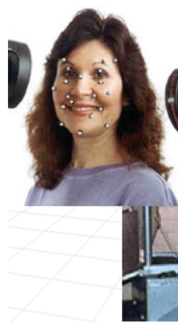
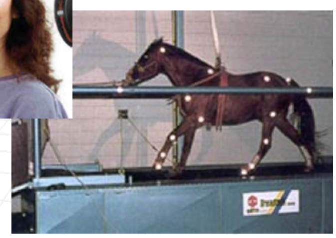
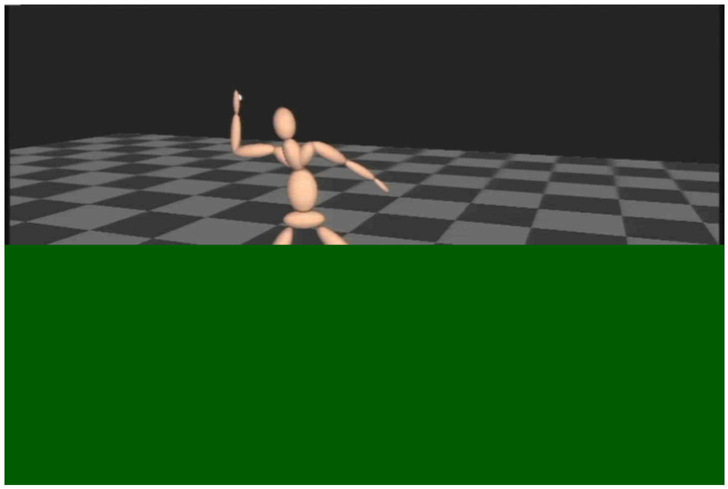
Marker-Based Motion Capture





What the Camera Sees ...

Manipulating & Re-Targeting MoCap Data...



Grochow et al, SIGGRAPH'04

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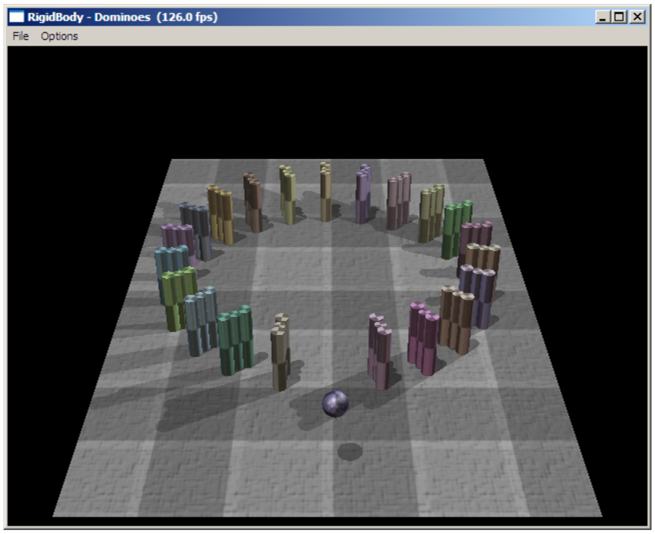
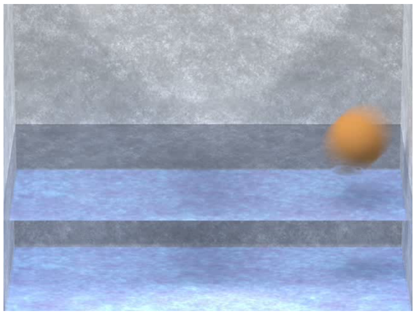
Simulating Rigid-Body Physics



Simulating Physics of Fluids & Rigid Bodies



Simulating Physics of Fluids & Rigid Bodies

Topic 17:

Computational Photography

- Keyframe animation
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- Motion capture
- Physics-based animation (dynamics)

Three Converging Trends

digital cameras

Three Converging Trends

digital cameras + computation

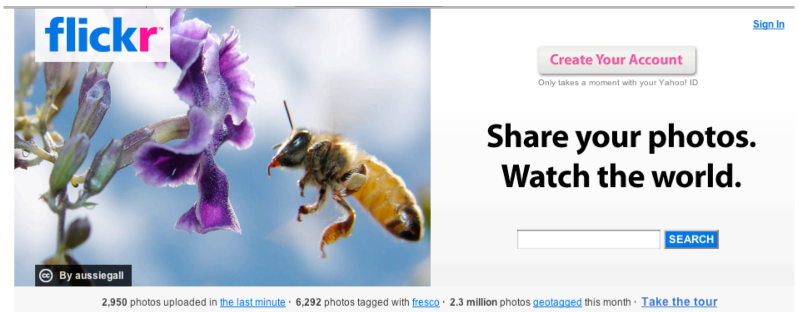
Canon's first wide angle Digital IXUS includes DIGIC III and Face Detection

Amstelveen, The Netherlands, 14 September, 2006: Canon today debuts its latest offering for the style-conscious photo enthusiast – the Digital IXUS 850 IS. The 7.1 Megapixel camera introduces wide-angle zoom capability to the Digital IXUS range for the first time with an optical Image Stabilizer and 28mm (35mm equivalent) 3.8x optical zoom lens.

Geared to satisfy serious photographers, the ultra-compact Digital IXUS 850 IS stays true to its design heritage with a smoothly sculpted curvature design and all-metal finish. Enhanced performance and image quality are assured through Canon's latest DIGIC III image processor, which also enables low-noise ISO 1600 shooting and new Face Detection AF/AE – a Canon technology that detects up to nine faces in a frame and automatically optimises the focus and exposure for great people shots.
The Digital IXUS 850 IS will be available from early October.

Three Converging Trends

digital cameras + computation + web



Digital post-processing

Photoshop

- replacing traditional darkroom techniques
- also replacing exposure compensation, color filtering, and other specialized shooting techniques

second generation tools

- warping images, stitching panoramas
- will eventually replace the view and panoramic camera

around the bend

- high-X imaging (resolution, dynamic range, focus, etc.)
- techniques based on multiple images

Slide by Marc Levoy

SIGGRAPH Videos

Nishino & Nayar, "Eyes for Relighting," Proc. SIGGRAPH 2004

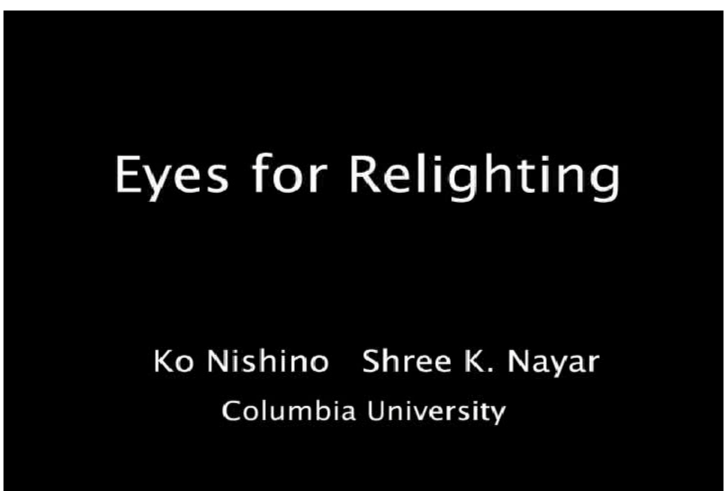
Bitouk et al, "Face swapping: Automatically replacing faces in photographs," Proc. SIGGRAPH 2008

Ballan et al, "Unstructured Video-based Rendering: Interactive Exploration of Casually-Captured Videos," Proc. SIGGRAPH 2010

Liu et al, "Content-preserving warps for 3D video stabilization," Proc. SIGGRAPH 2009

Yuan et al, "Image deblurring from blurred/noisy image

Eyes for Relighting



Face swapping

Face Swapping:
Automatic Face Replacement
in Photographs

Dmitri Bitouk, Neeraj Kumar, Samreen Dhillon,
Peter N. Belhumeur, Shree K. Nayar

Columbia University

Unstructured Video-based Rendering

**Unstructured Video-Based Rendering:
Interactive Exploration
of Casually Captured Videos**

L. Ballan	G. J. Brostow	J. Puwein	M. Pollefeys
ETHZ	UCL	ETHZ	ETHZ

SIGGRAPH 2010

3D Video Stabilization

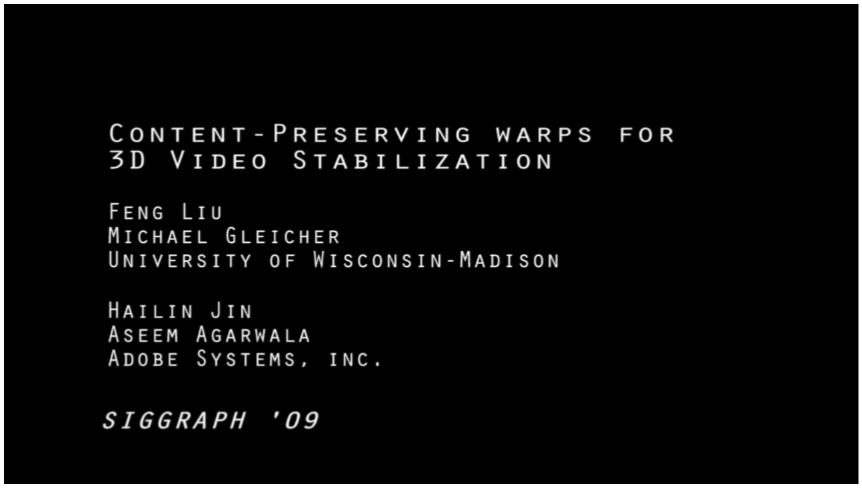


Image deblurring

What Comes Next...

Computer Graphics

2521 Human Motion Modeling

2522 Advanced Image Synthesis

2529 Facial Animation

2530 Computational Photography

HCI

318 Design of Interactive Computational Media

Computer Vision

320 Introduction to Visual Computing

487 Foundations of Computational Vision