Character Animation

COS 426, Fall 2022

PRINCETON UNIVERSITY

Computer Animation

- Describing how 3D objects (& cameras) move over time

Pixar

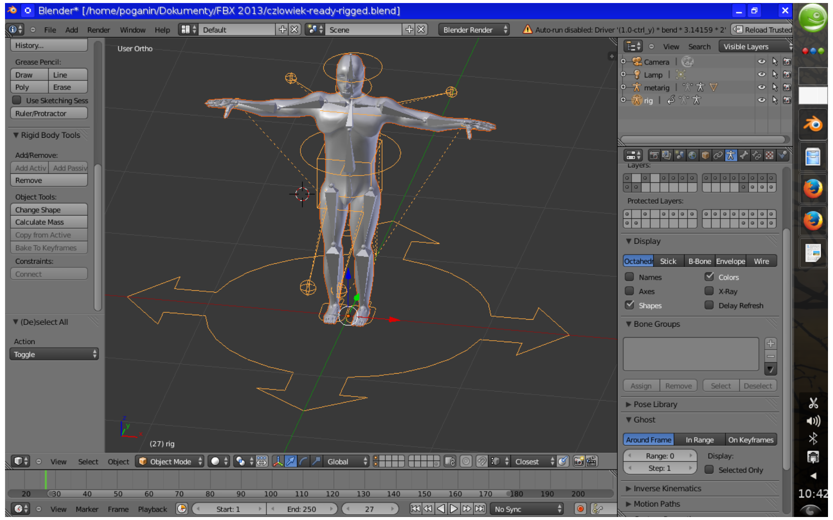
Computer Animation

- Challenge is balancing between …
    - Animator control

  vs.
    - Physical realism

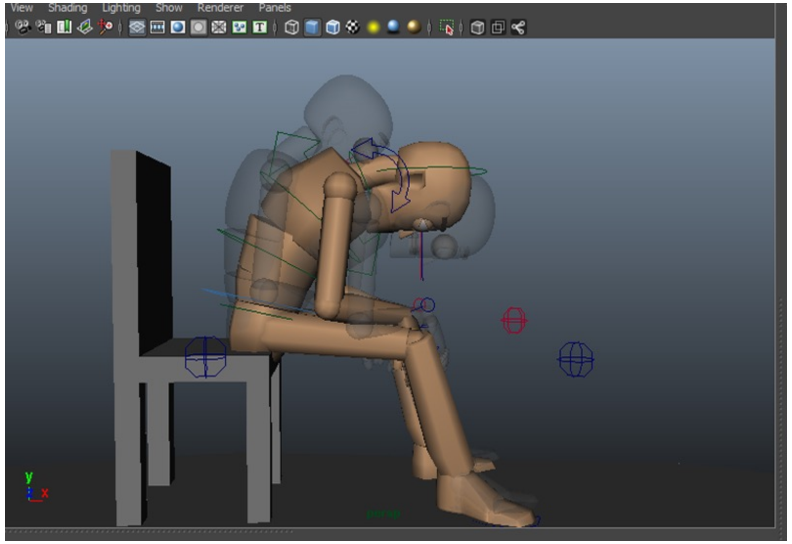
Computer Animation

- Manipulation
  - Posing
  - Effect of pose



https://blenderartists.org/

- Interpolation
  - Keyframes
  - In-betweens

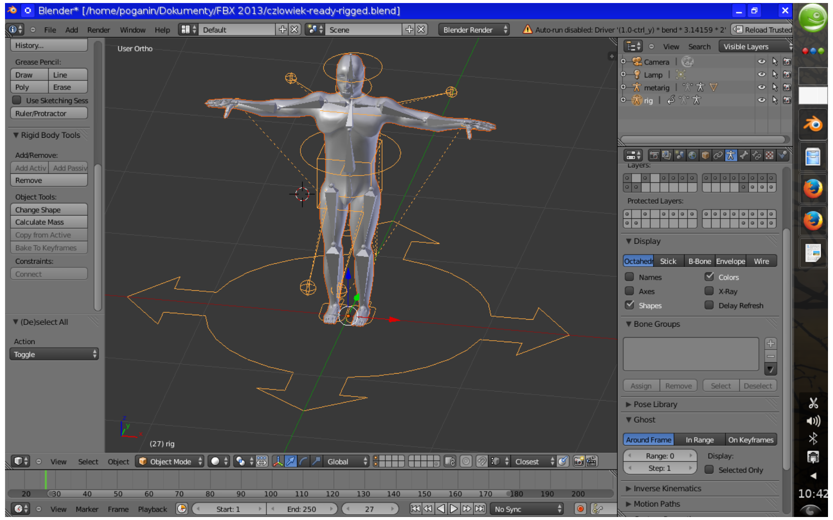


focus.gscept.com

Character Animation Methods

- Modeling (manipulation)
  - Deformation
  - Blendshapes
  - Skeletons

- Interpolation
  - Key-framing
  - Kinematics
  - Motion Capture



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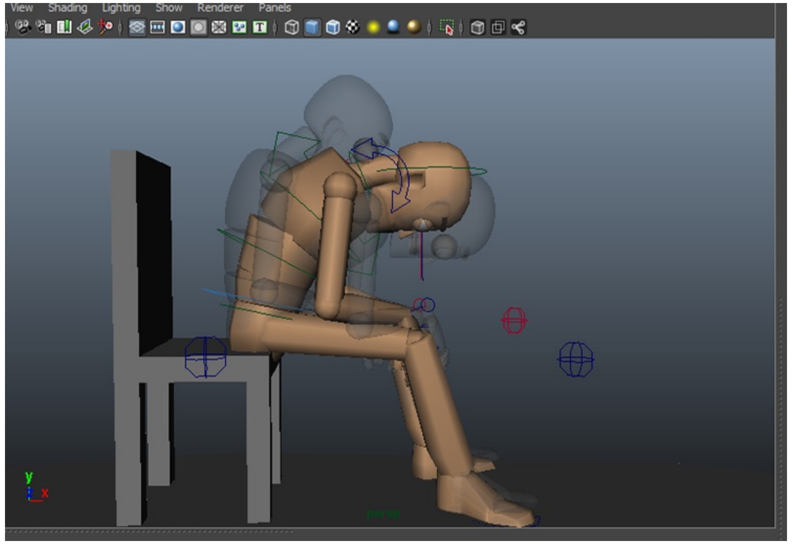

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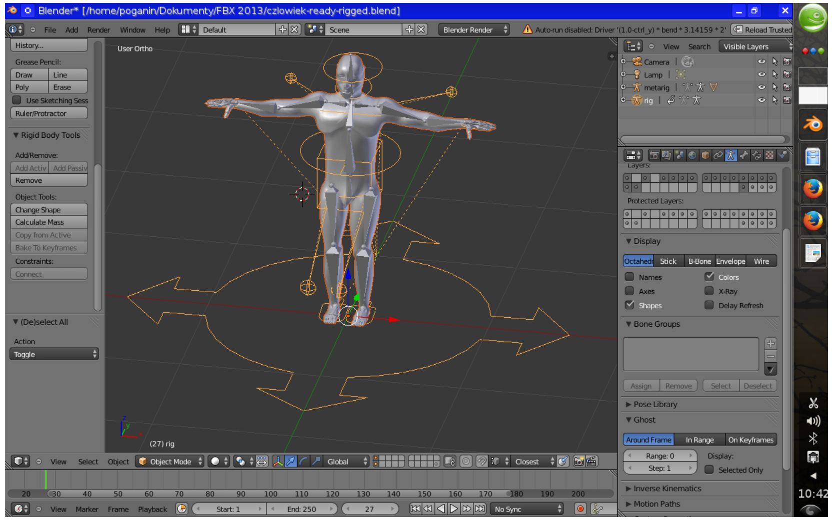

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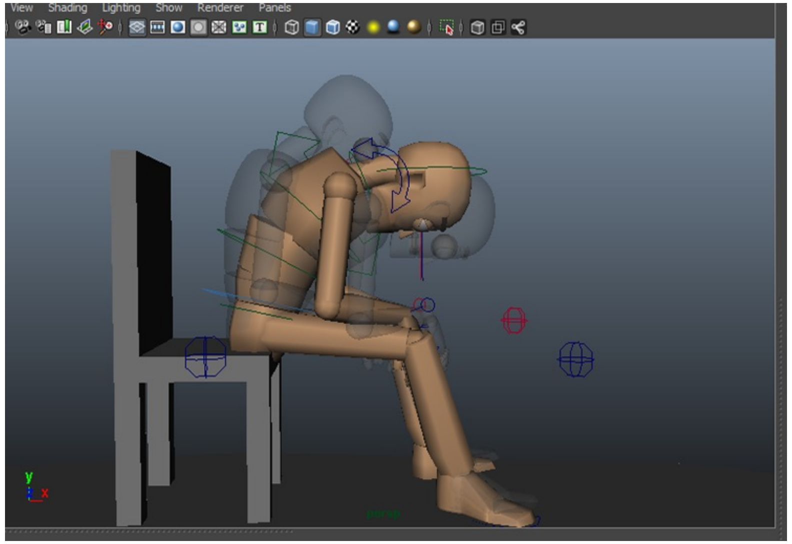

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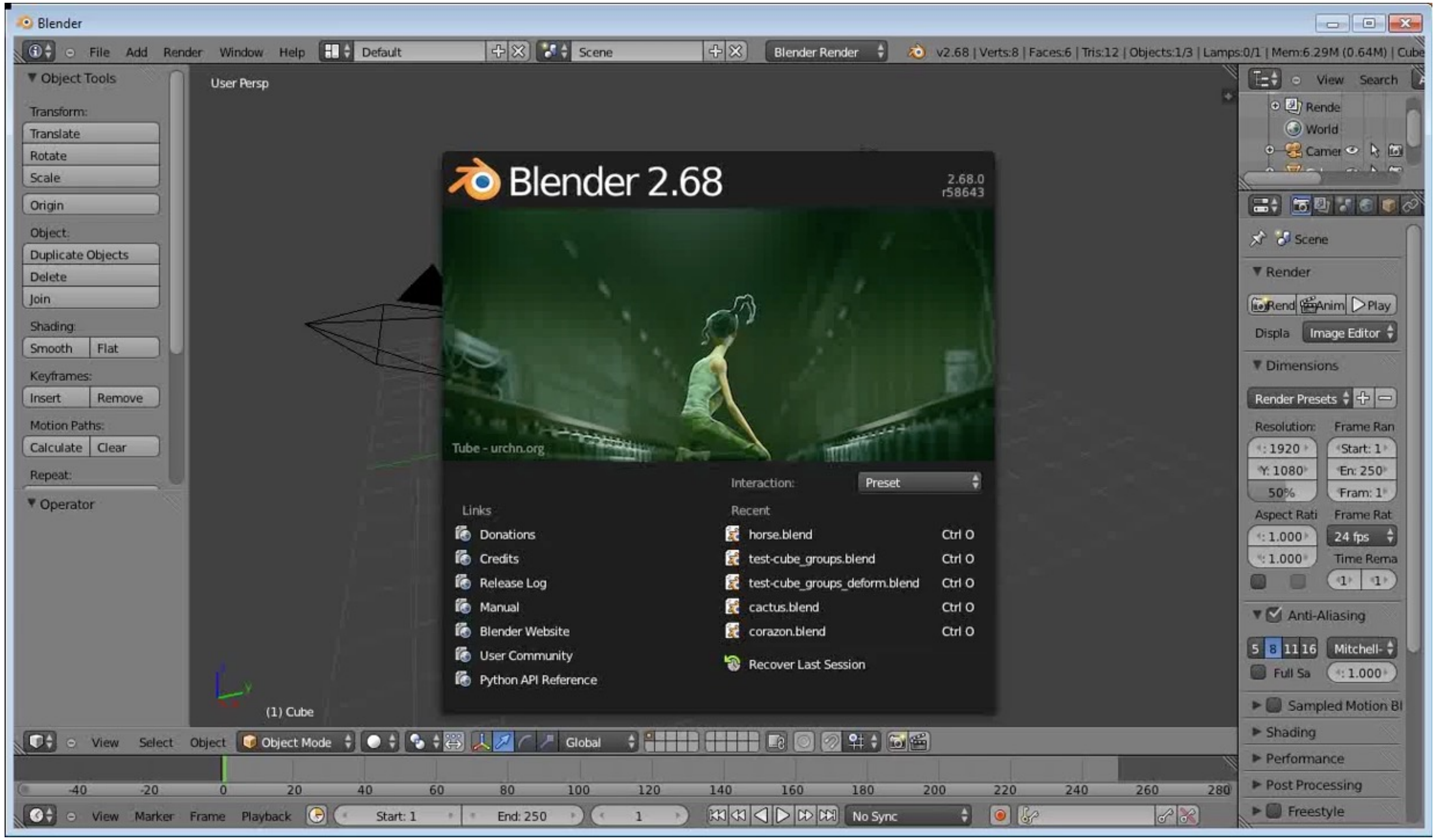
Deformation

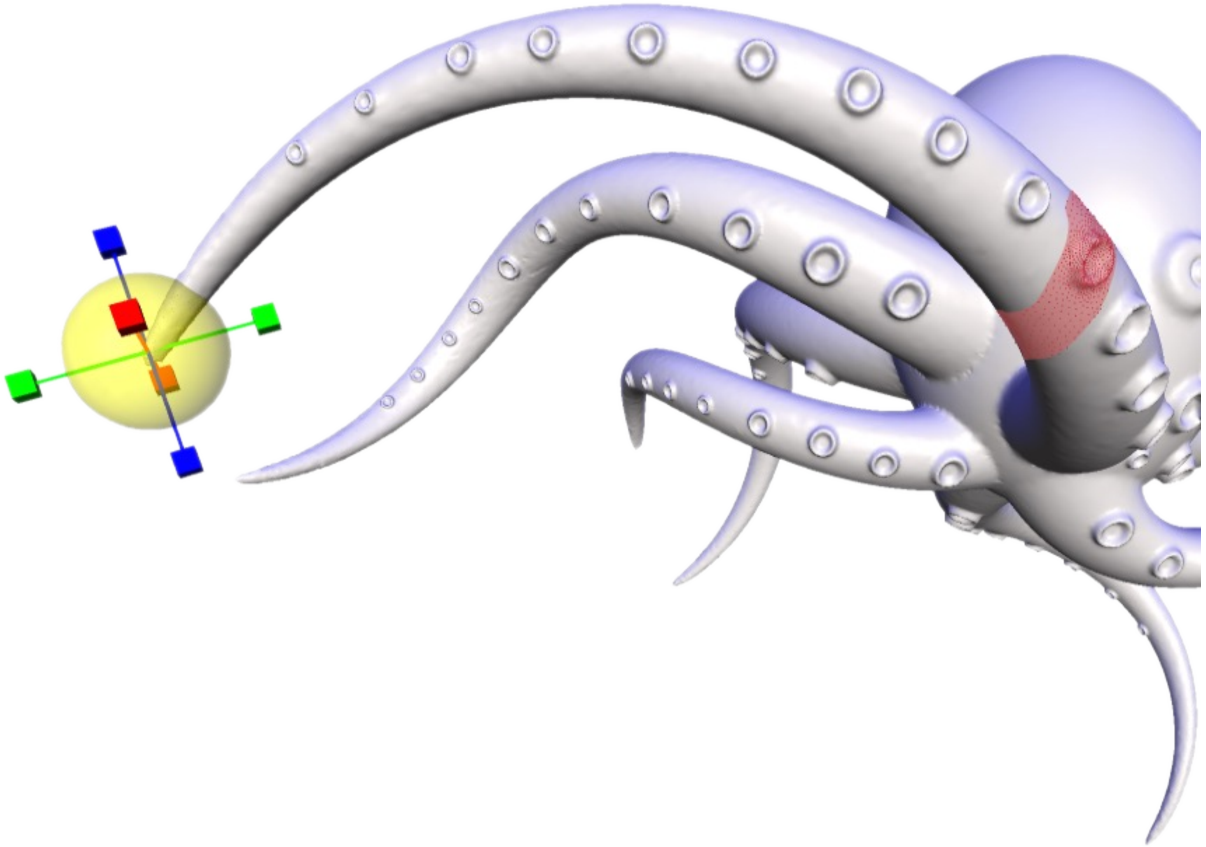
- How to change a character's pose?
  - Every vertex directly
  - Intuitive computation

https://www.youtube.com/watch?v=oxkf_N-QCNI



Deformation

- A HUGE variety of methods
  - Laplacian mesh editing
  - ARAP
  - CAGE Base
  - Barycentric coordinates
  - Heat diffusion
  - Variational
  - …



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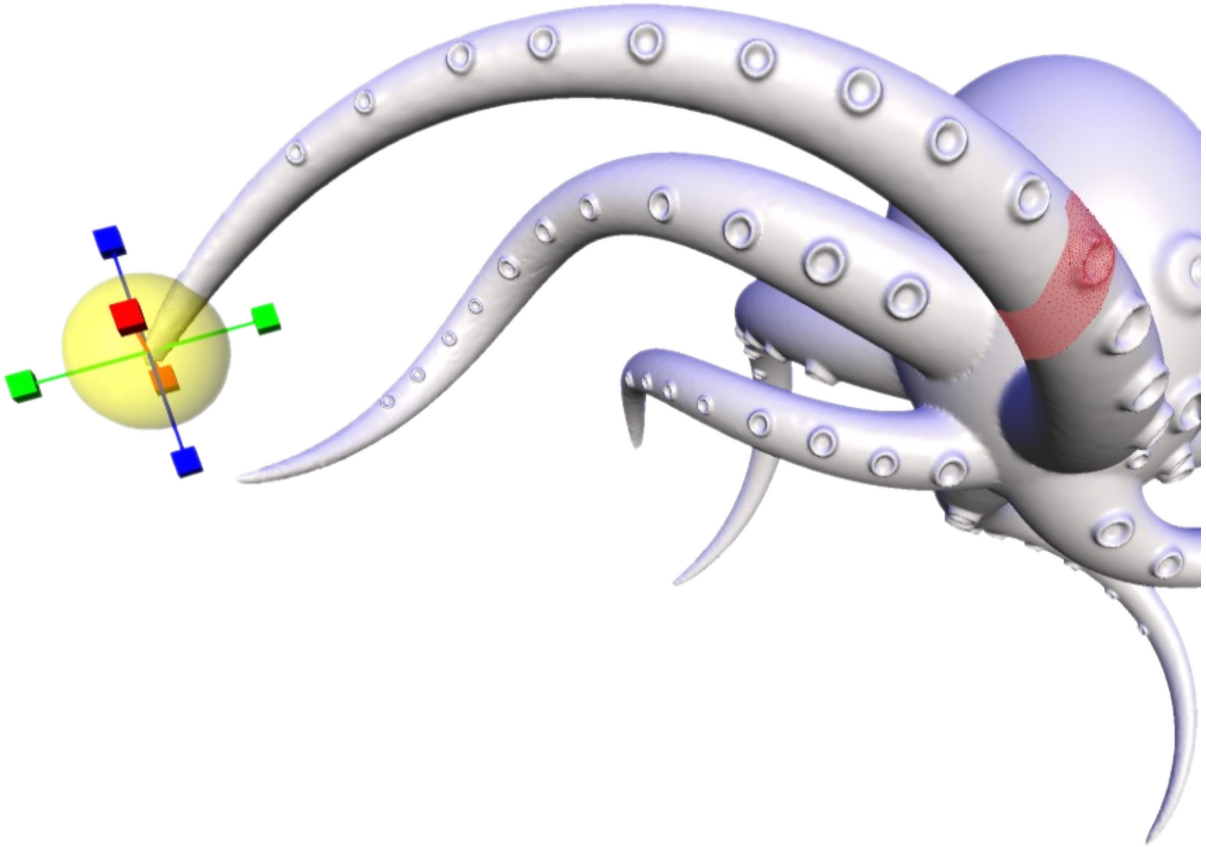

Overall framework

1. Compute differential representation

$$\delta_i = L(v_i) = v_i - \frac{1}{d_i}\Sigma_{j\in \mathrm{N}(i)} v_j$$

2. Pose modeling constraints

$$v_i' = u_i, \qquad i \in \boldsymbol{C}$$

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3. Reconstruct the surface – in least-squares sense

$$\begin{pmatrix} L \\ L_c \end{pmatrix} \boldsymbol{V} = \begin{pmatrix} \boldsymbol{\delta} \\ \boldsymbol{U} \end{pmatrix}$$

Example

Laplacian Mesh Editing

A short editing session
with the *Octopus*

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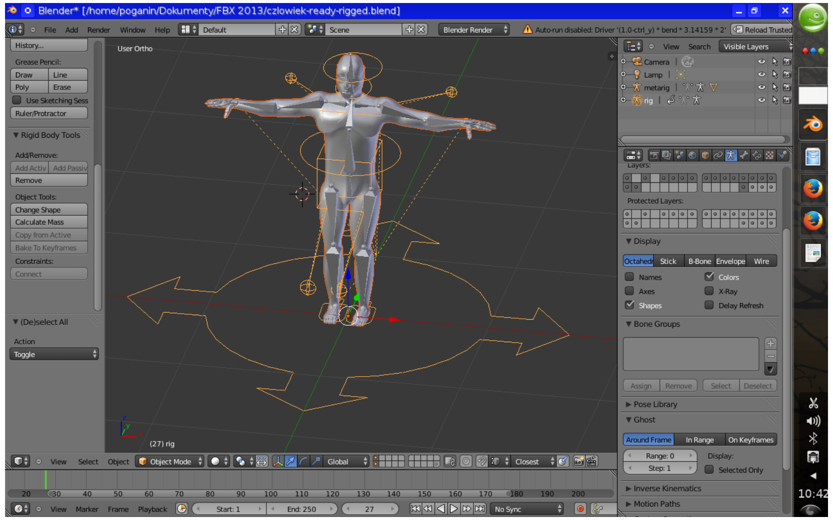

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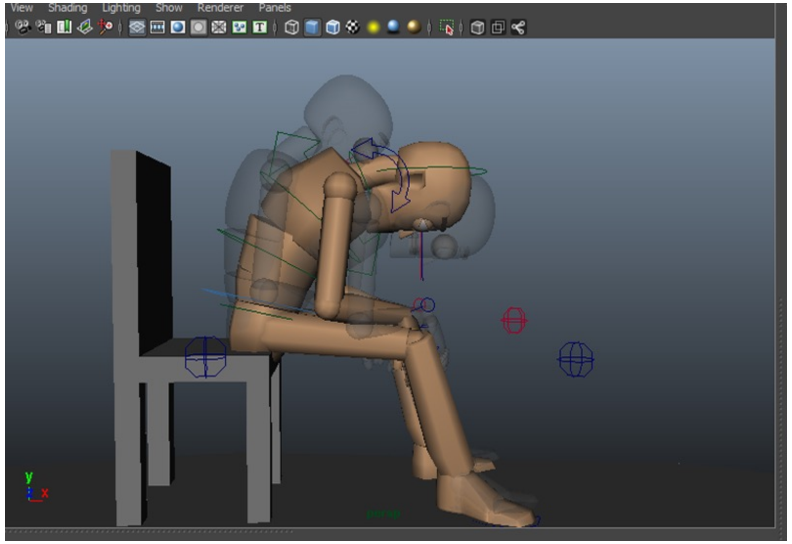

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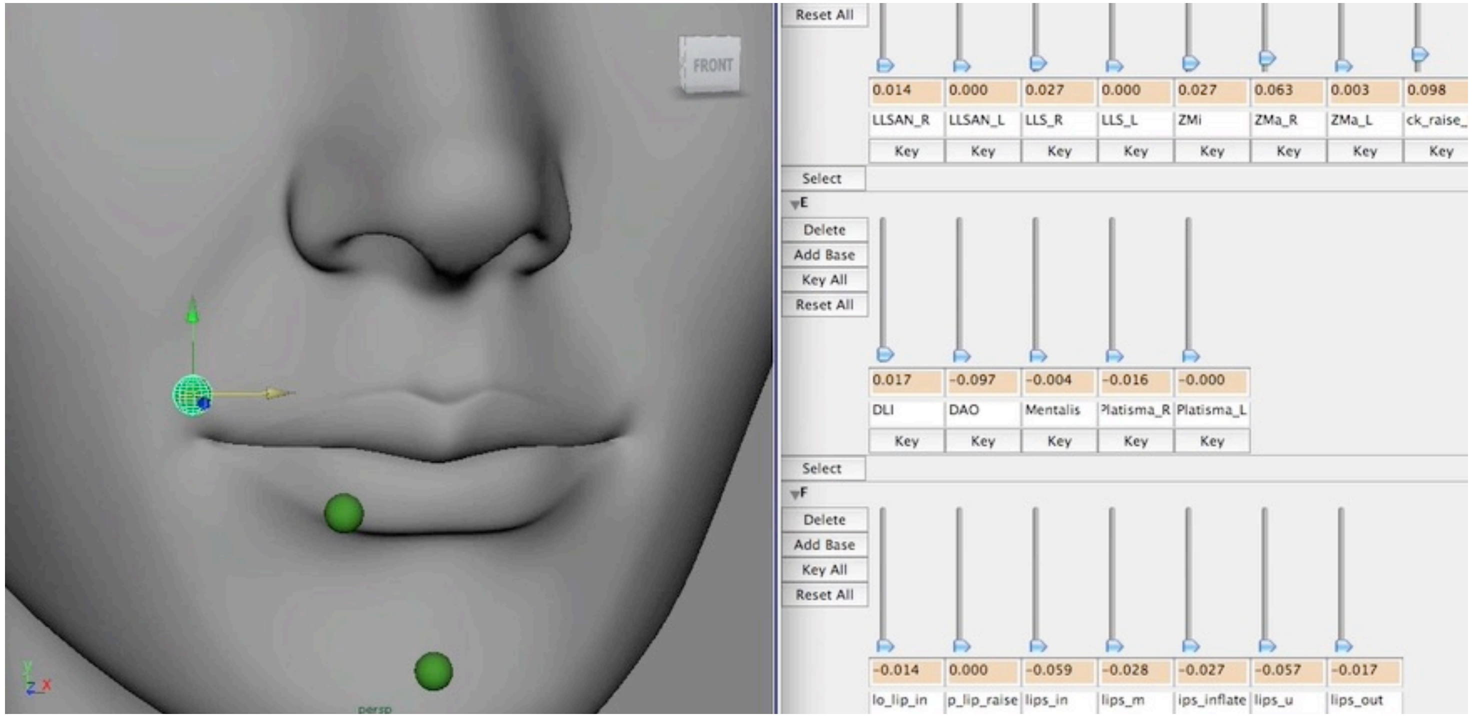
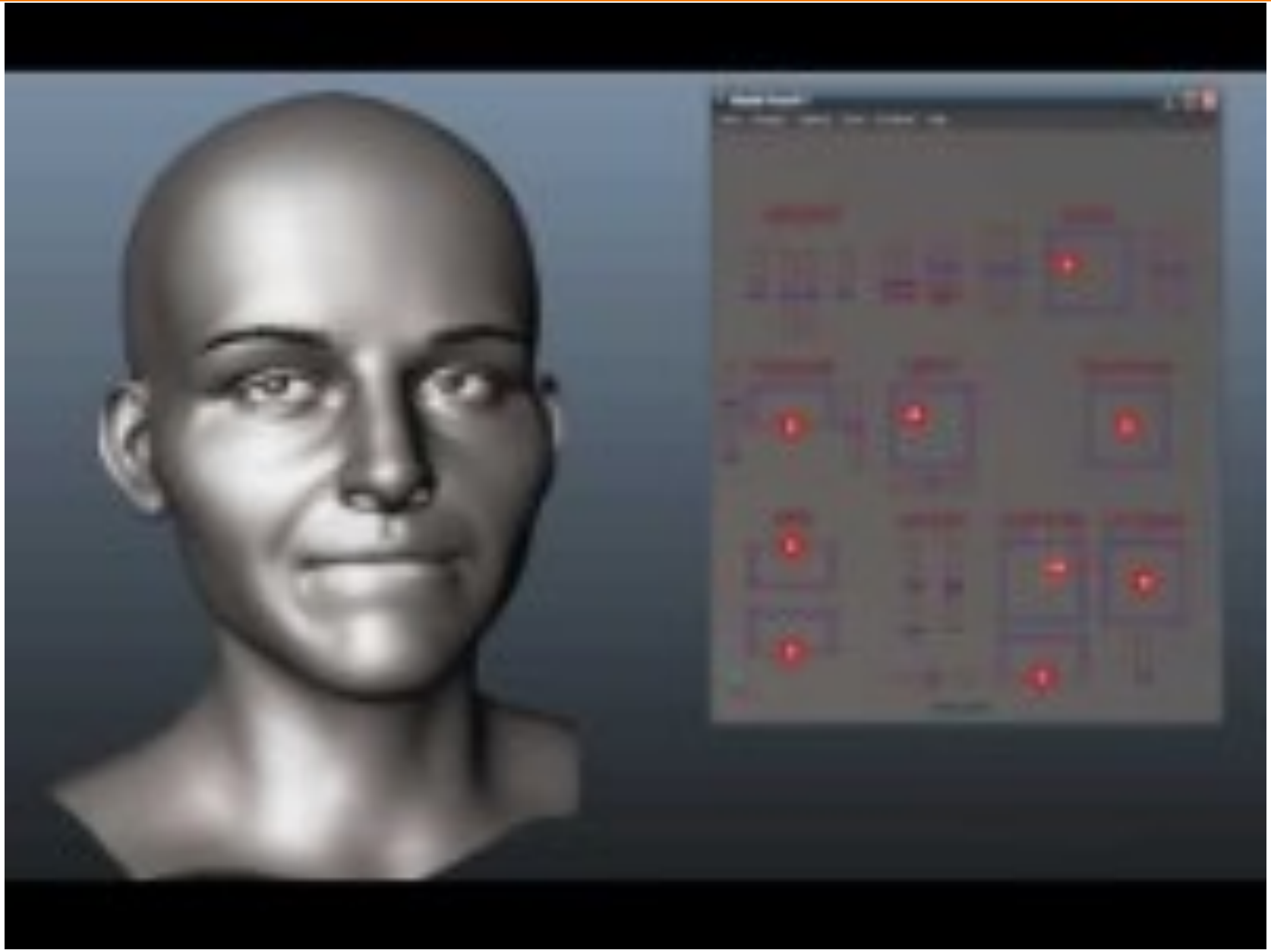
Blendshapes

- Blendshapes are an approximate semantic parameterization

- Linear blend of predefined poses



Blendshapes



https://www.youtube.com/watch?v=KPDfMpuK2fQ

Blendshapes

- Usually used for difficult to pose complex deformations
  - Such faces
- Given:
  - A mesh $M = (V, E)$ with m vertices
  - n configurations of the same mesh, $M_b = (V_b, E), b = 1 \dots n$

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  - $M' = (\Sigma_{b=1\dots n} \mathrm{w_b V_b, E})$
- Delta formulation:
  - $M' = (\Sigma_{b=1\dots n} V_0 + \mathrm{w_b(V_b - V_0), E})$
  - A bit more convenient
- M_0 - the rest pose, w_b blend weights

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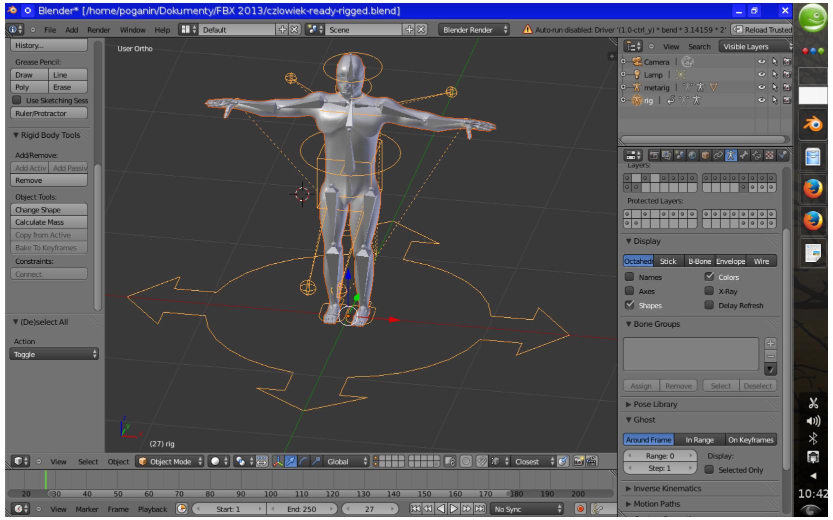

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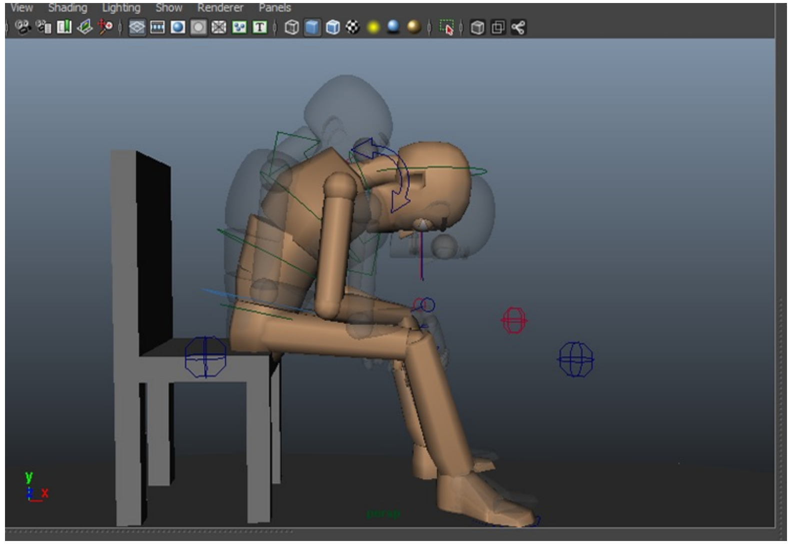

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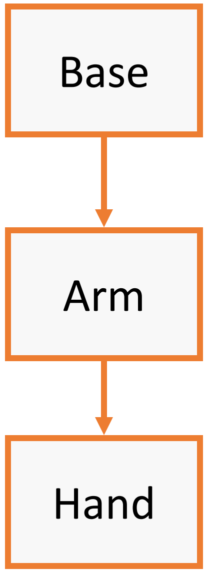
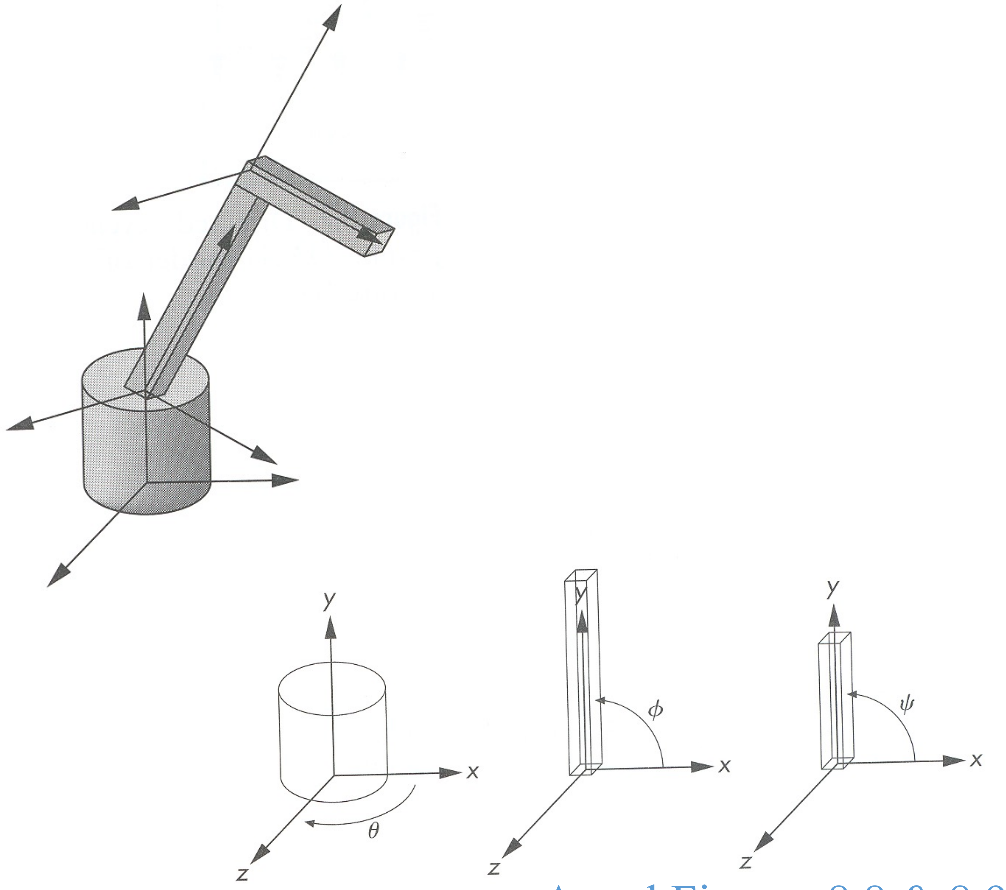
Articulated Figures

- Character poses described by set of rigid bodies connected by “joints”



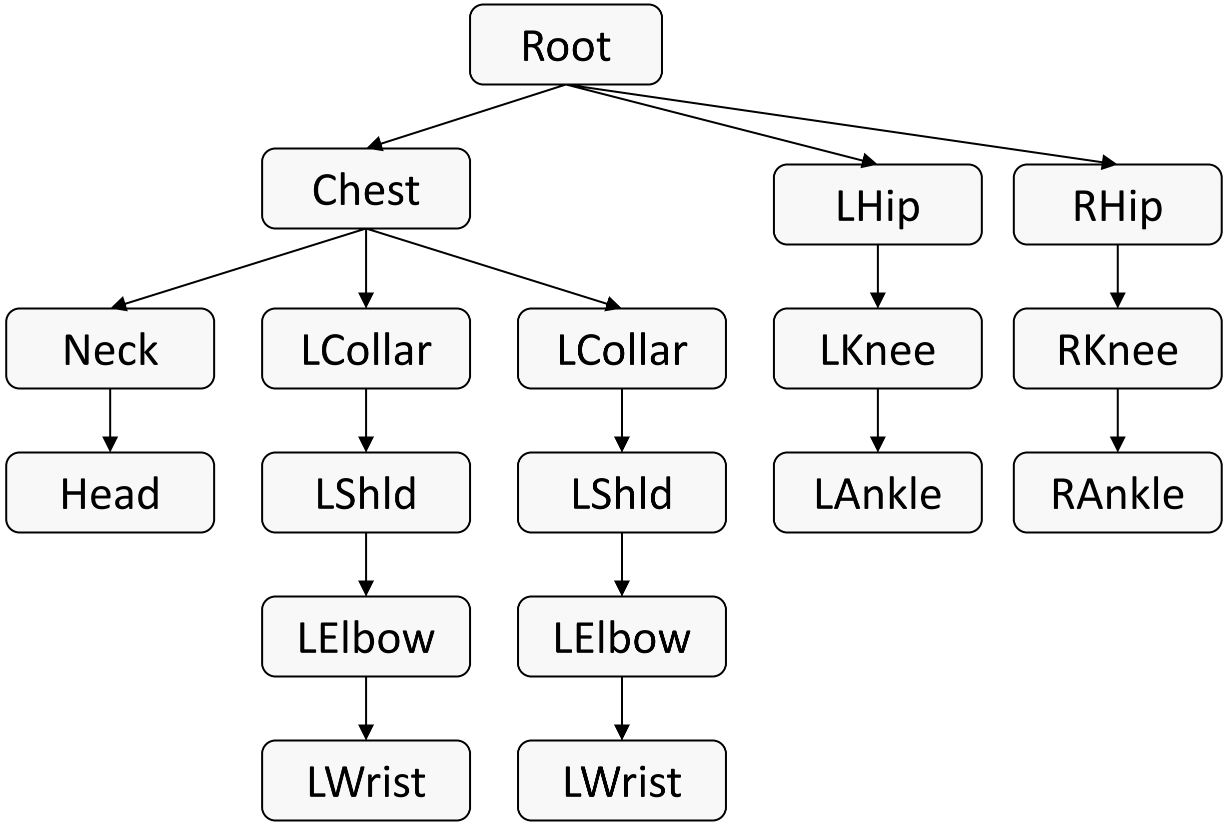
Scene Graph

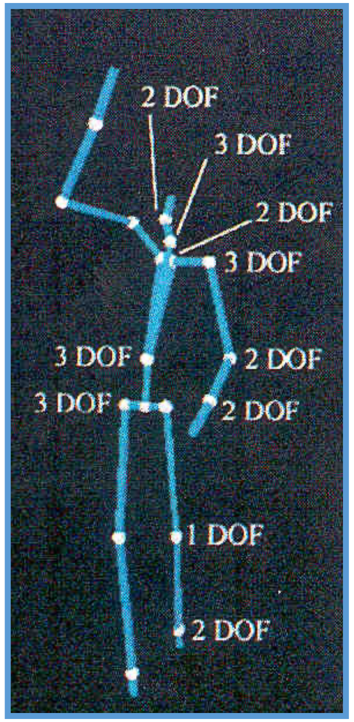


Angel Figures 8.8 & 8.9

Articulated Figures

- Well-suited for humanoid characters





Rose et al. `96

- Animation focuses on joint angles, or general transformations

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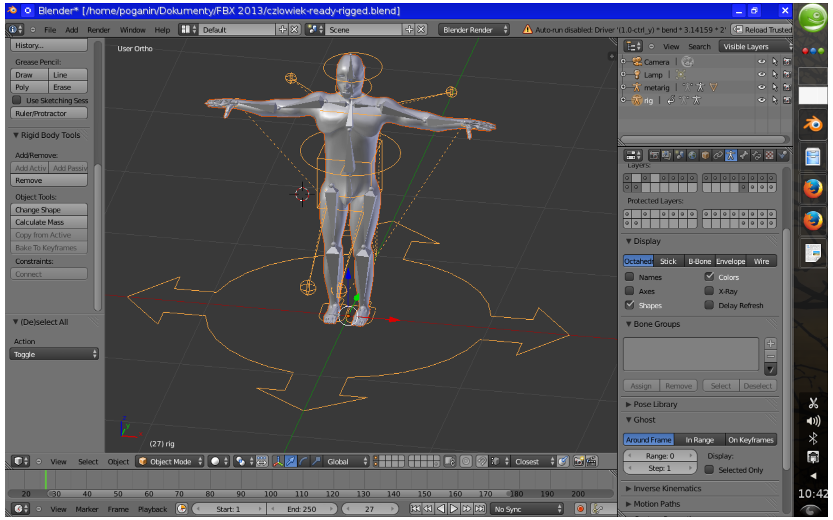

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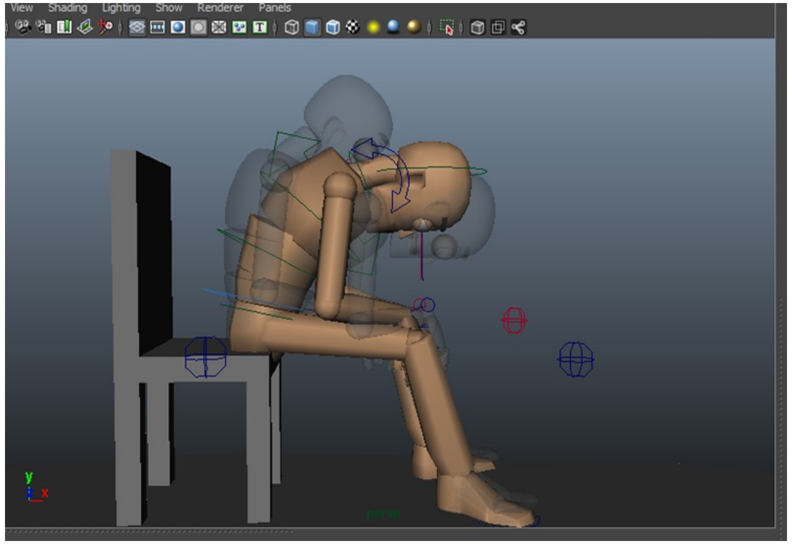

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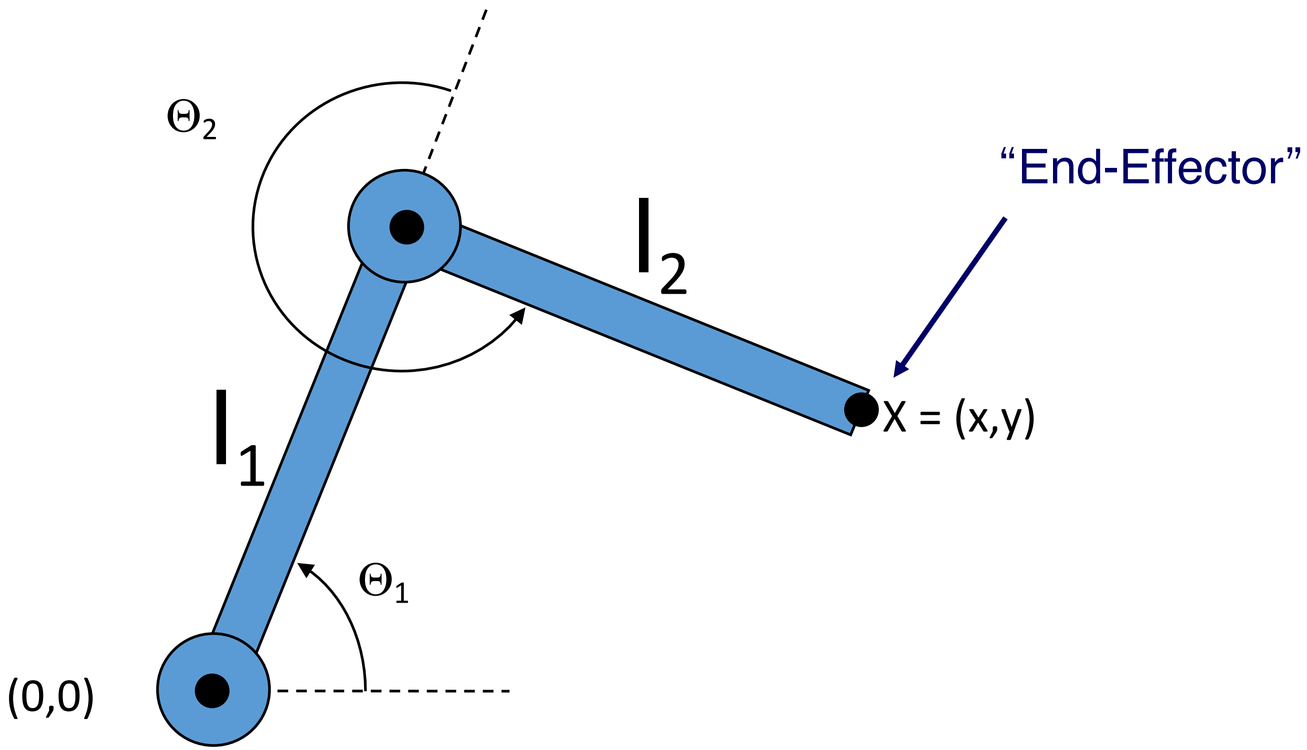
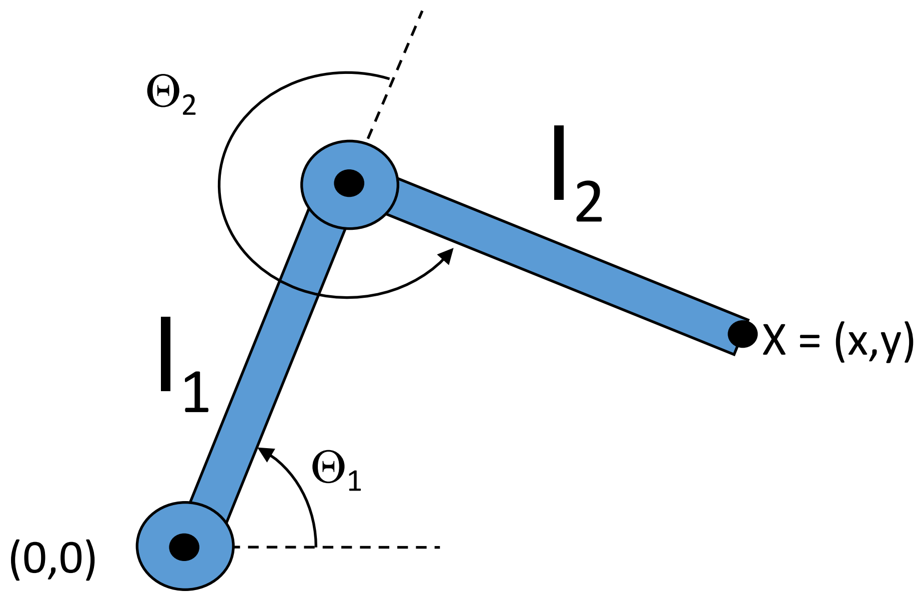
Forward Kinematics

- Describe motion of articulated character



Forward Kinematics

- Animator specifies joint angles: Θ_1 and Θ_2
- Computer finds positions of end-effector: X



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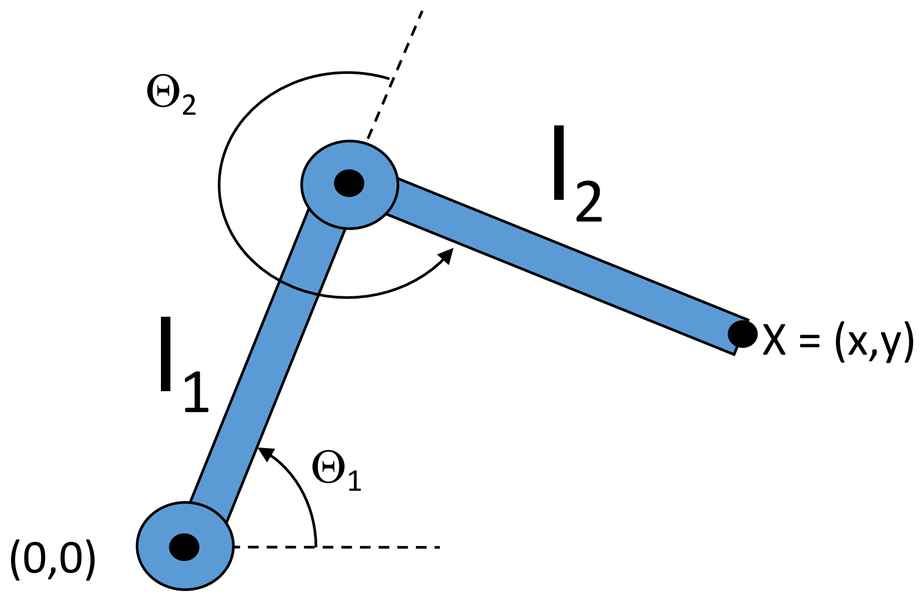
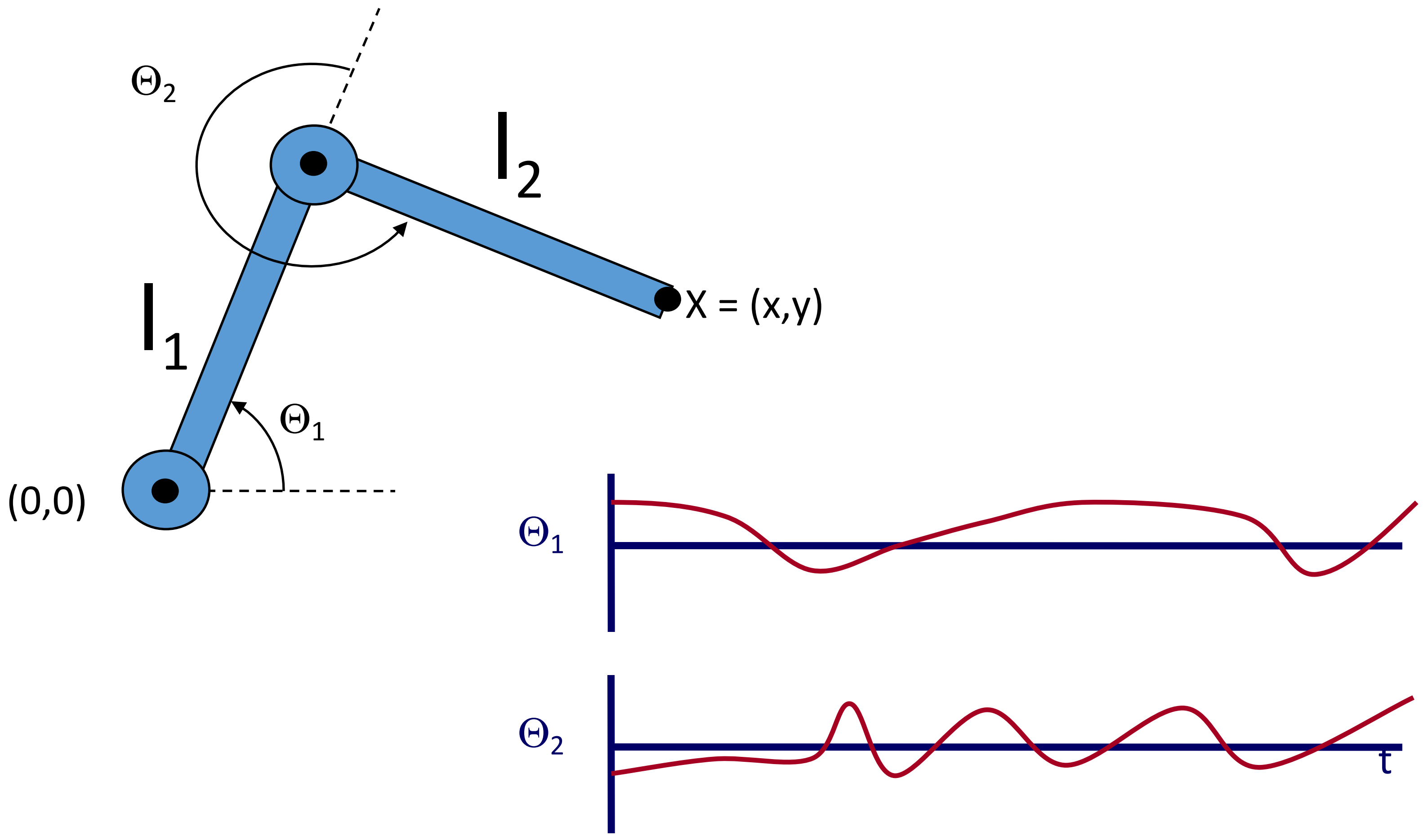


$$X = (l_1 \cos\Theta_1 + l_2 \cos(\Theta_1 + \Theta_2), l_1 \sin\Theta_1 + l_2 \sin(\Theta_1 + \Theta_2))$$

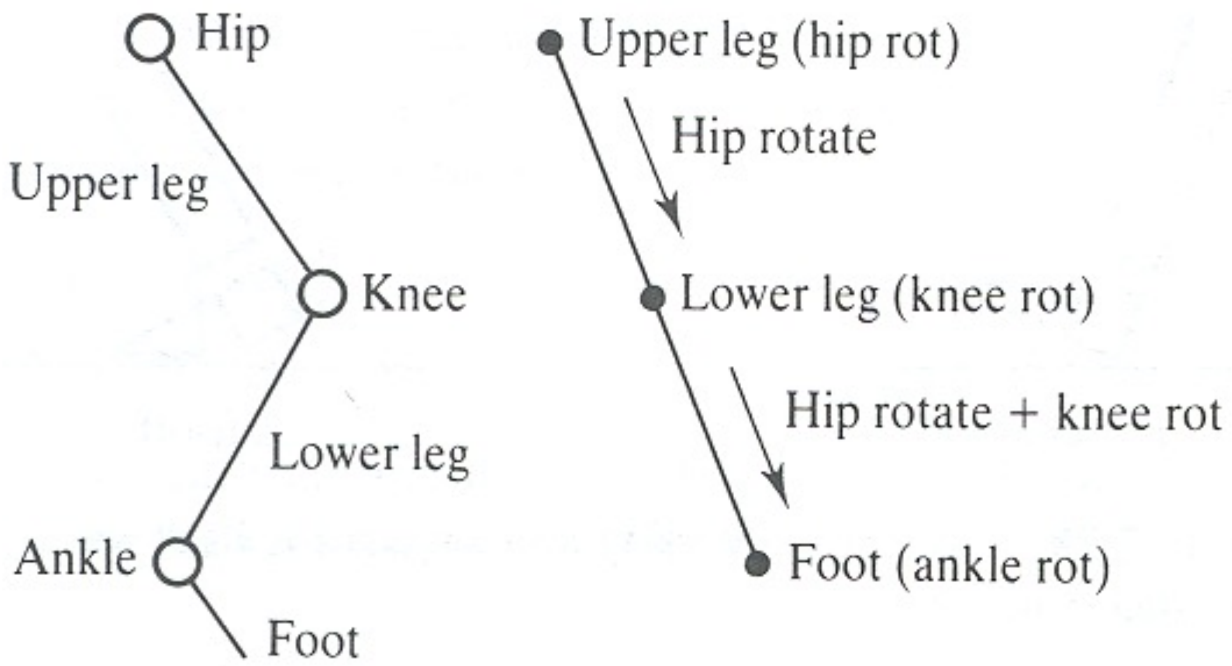
Forward Kinematics Parameterization

- Joint motions specified e.g. by spline curves



Example: Walk Cycle

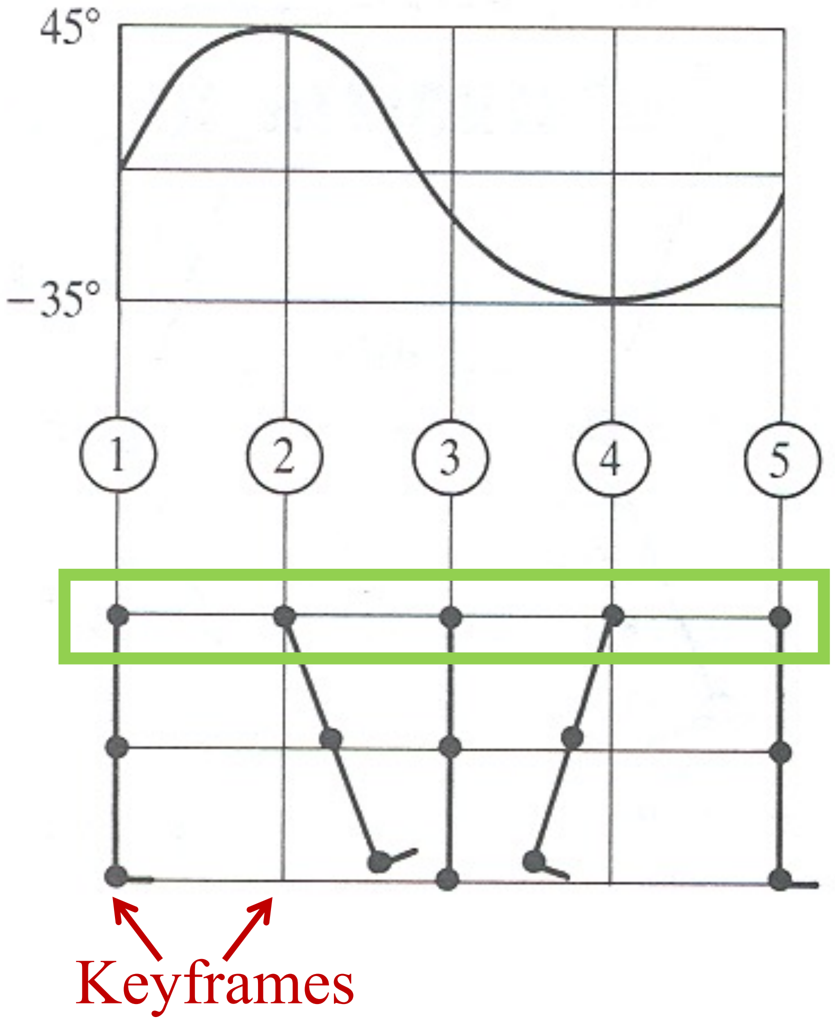
- Articulated figure:



Watt & Watt

Example: Walk Cycle

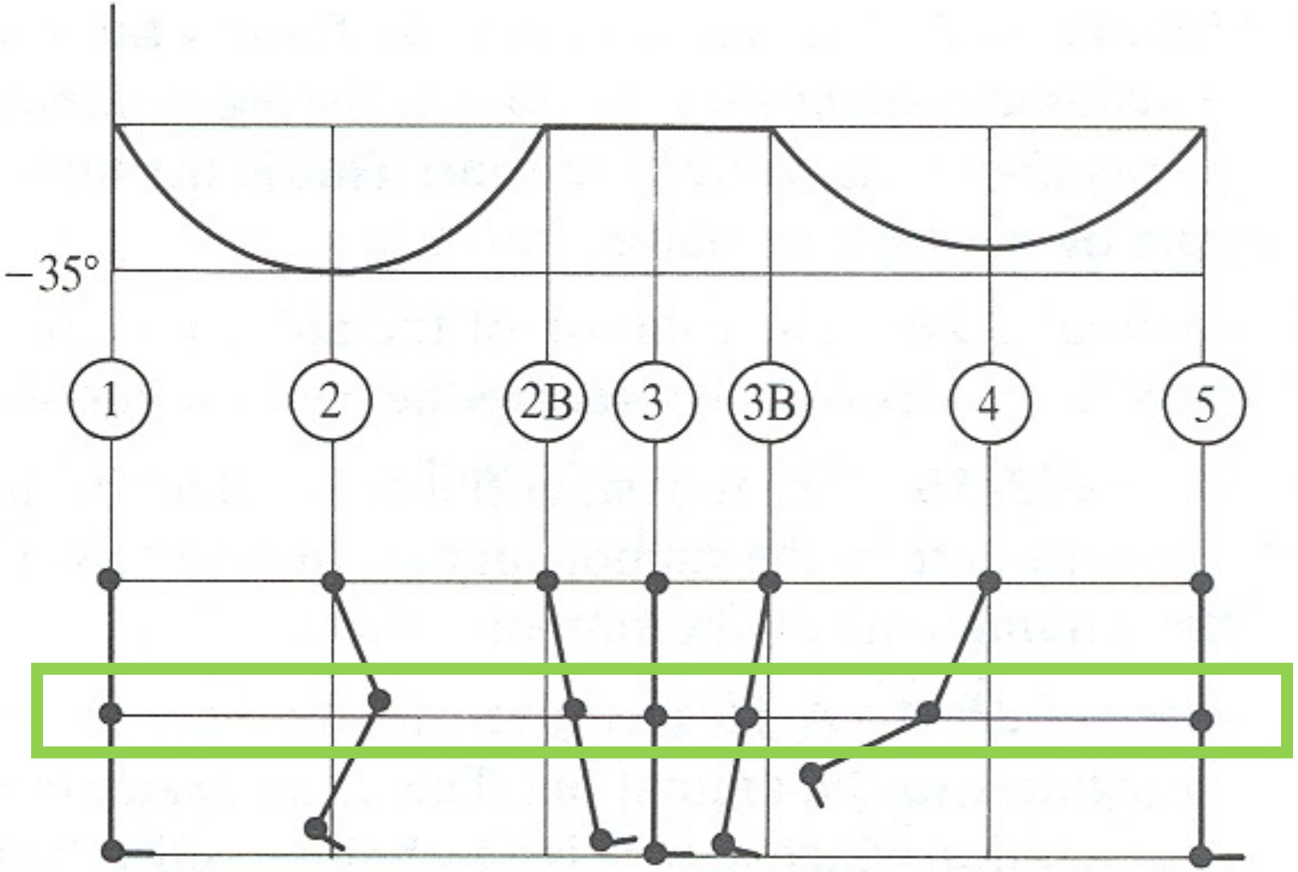
- Hip joint orientation:



Watt & Watt

Example: Walk Cycle

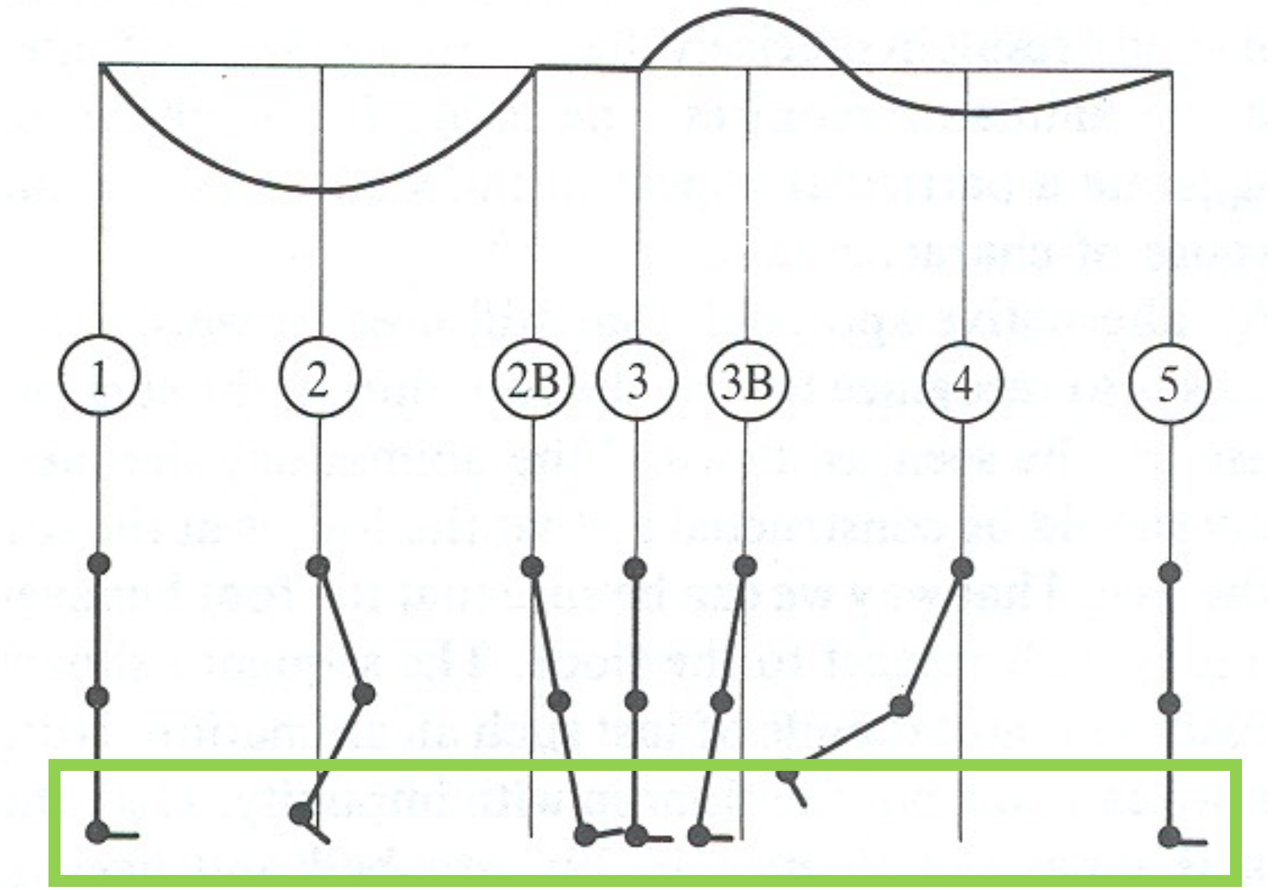
- Knee joint orientation:



Watt & Watt

Example: Walk Cycle

- Ankle joint orientation:



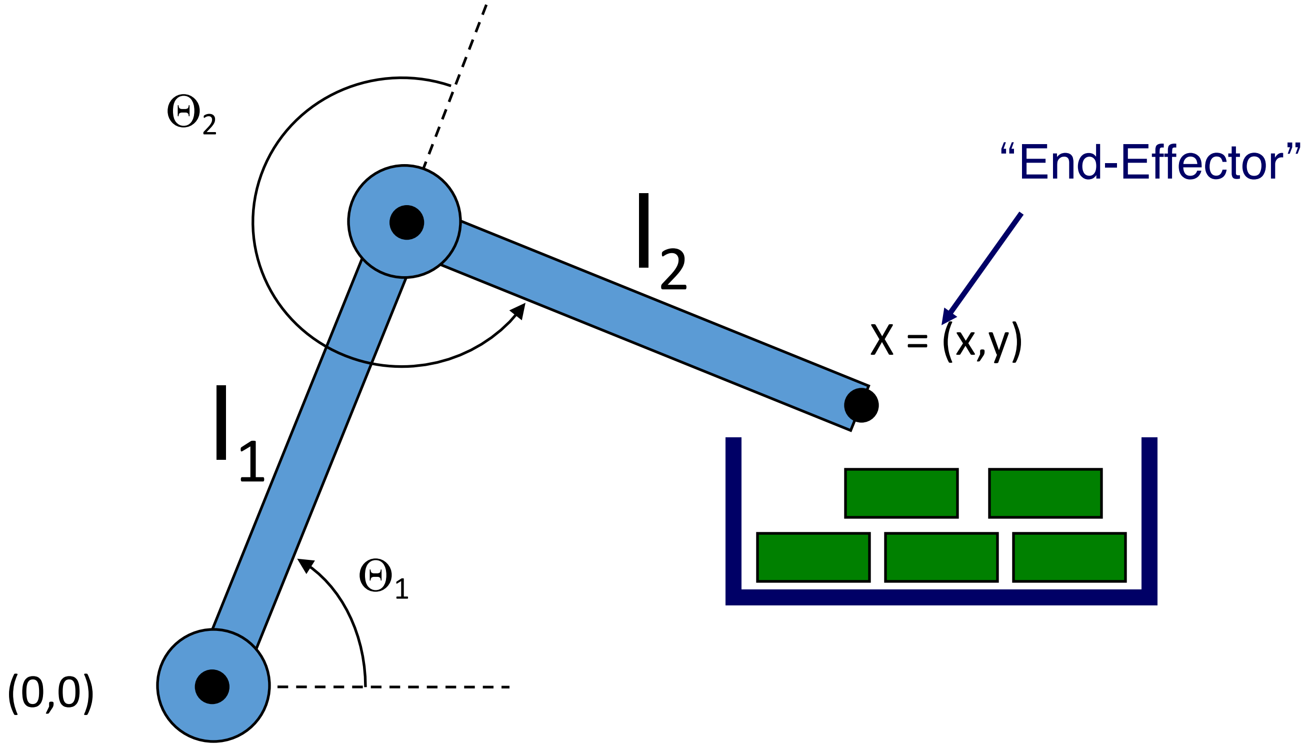
Watt & Watt

Example: walk cycle

https://www.youtube.com/watch?v=DuUWxUitJos

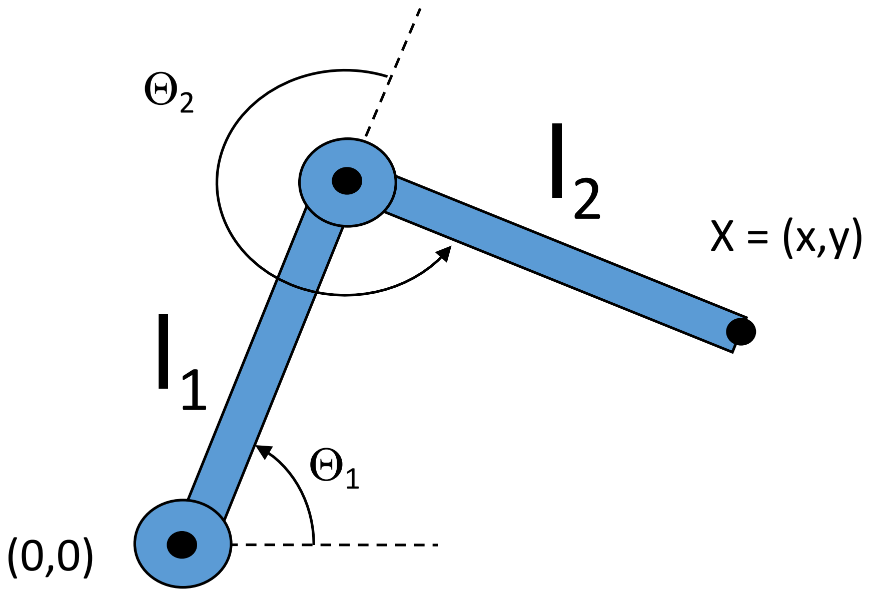
Inverse Kinematics

- What if animator knows position of "end-effector"?



Inverse Kinematics

- Animator specifies end-effector positions: X
- Computer finds joint angles: Θ_1 and Θ_2:



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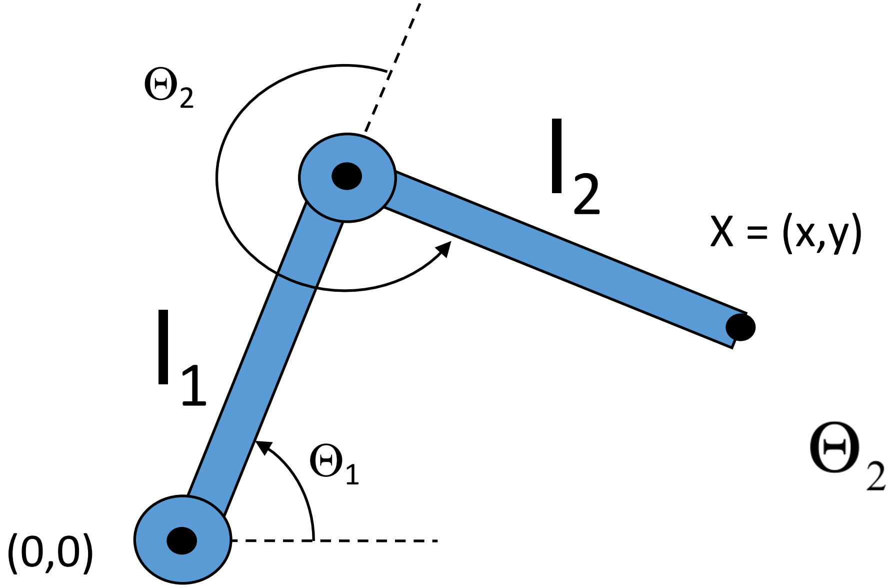
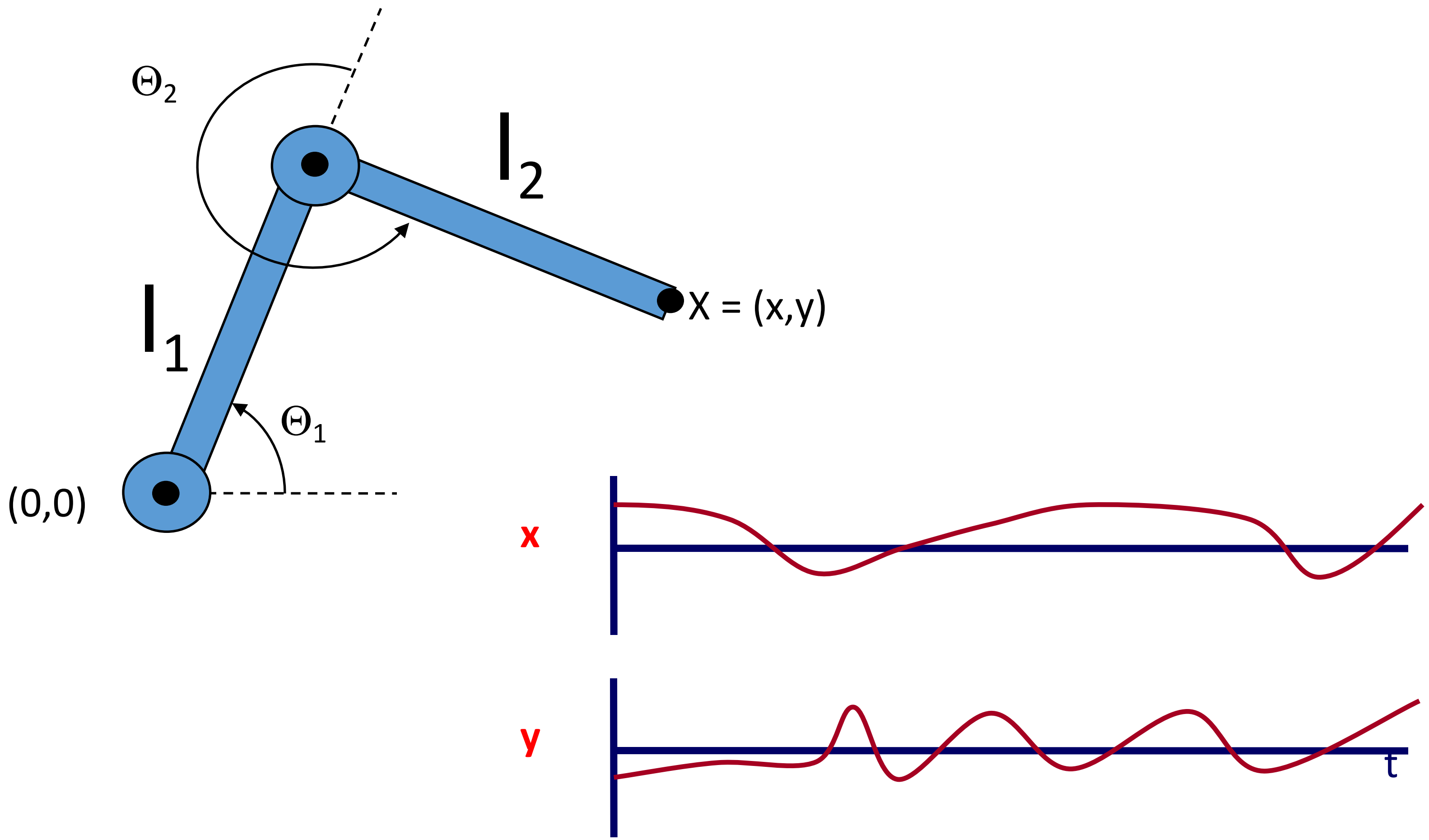


$$\Theta_2 = \cos^{-1}\left(\frac{x^2 + x^2 - l_1^{\,2} - l_2^{\,2}}{2 l_1 l_2}\right)$$

$$\Theta_1 = \frac{-(l_2 \sin(\Theta_2)x + (l_1 + l_2 \cos(\Theta_2))y}{(l_2 \sin(\Theta_2))y + (l_1 + l_2 \cos(\Theta_2))x}$$

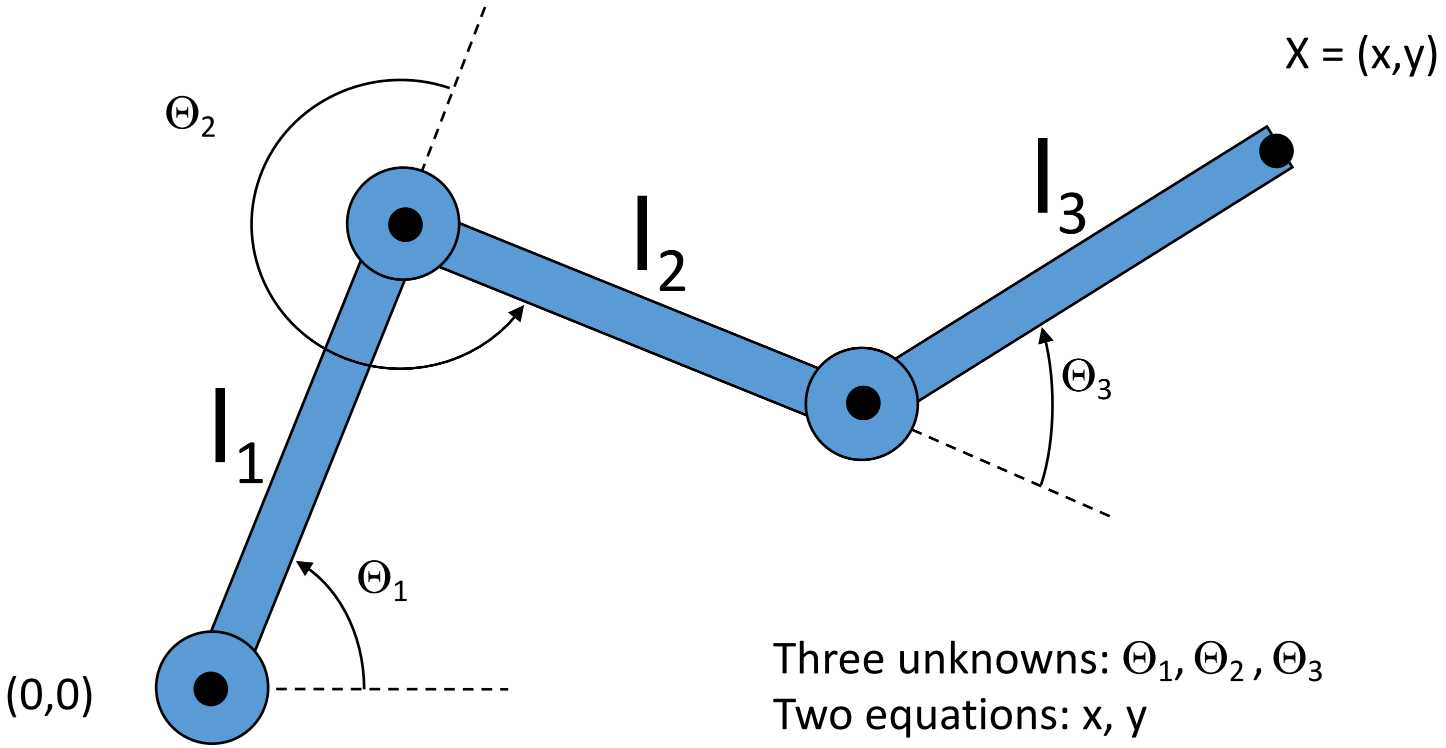
Inverse Kinematics

- End-effector postions can be specified by spline curves



Inverse Kinematics

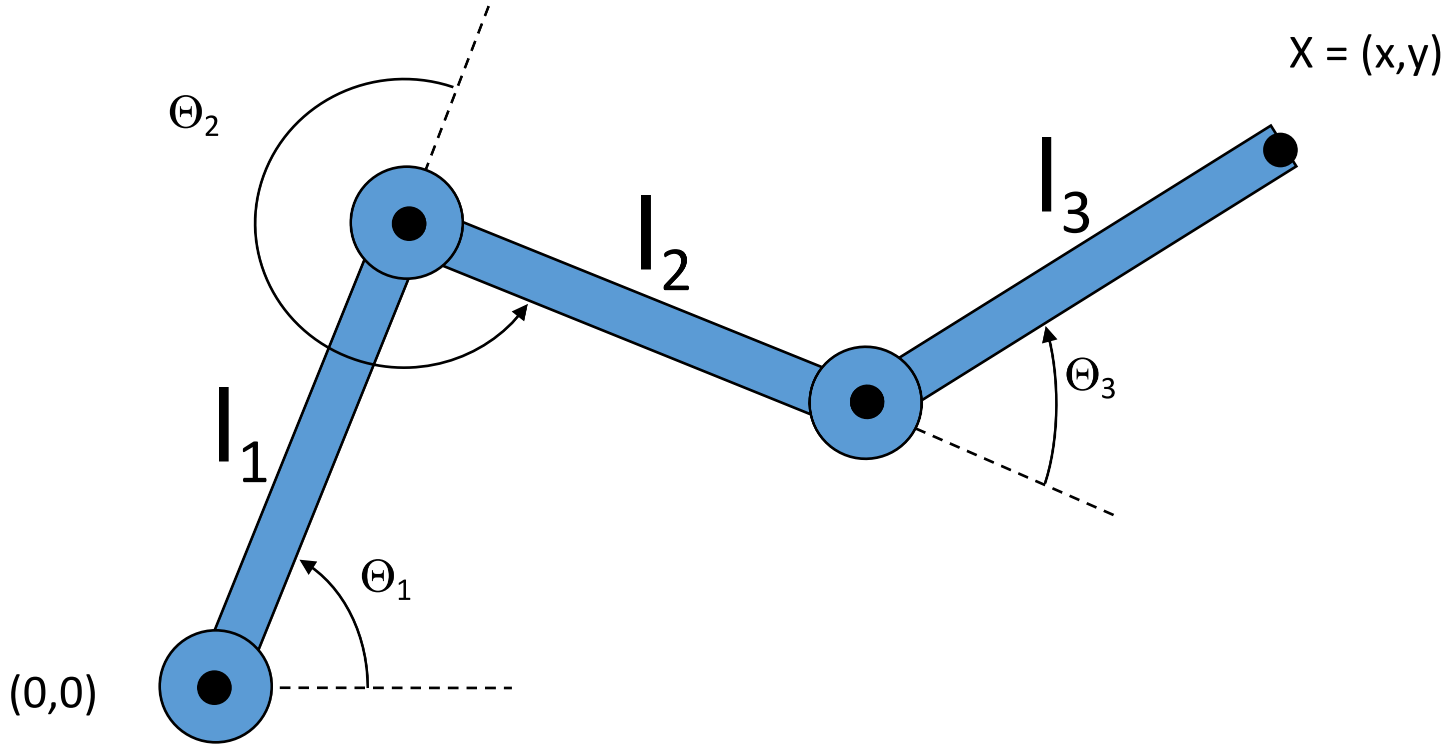
- Problem for more complex structures
  - System of equations is usually *under-constrained*
  - Multiple solutions



Three unknowns: $\Theta_1, \Theta_2, \Theta_3$
Two equations: x, y

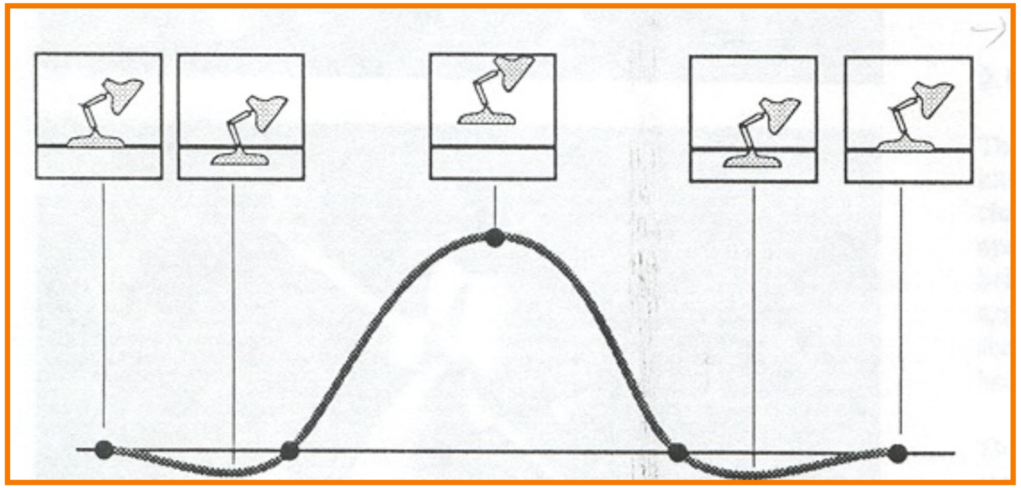
Inverse Kinematics

- Solution for more complex structures:
  - Find best solution (e.g., minimize energy in motion)
  - Non-linear optimization



Kinematics

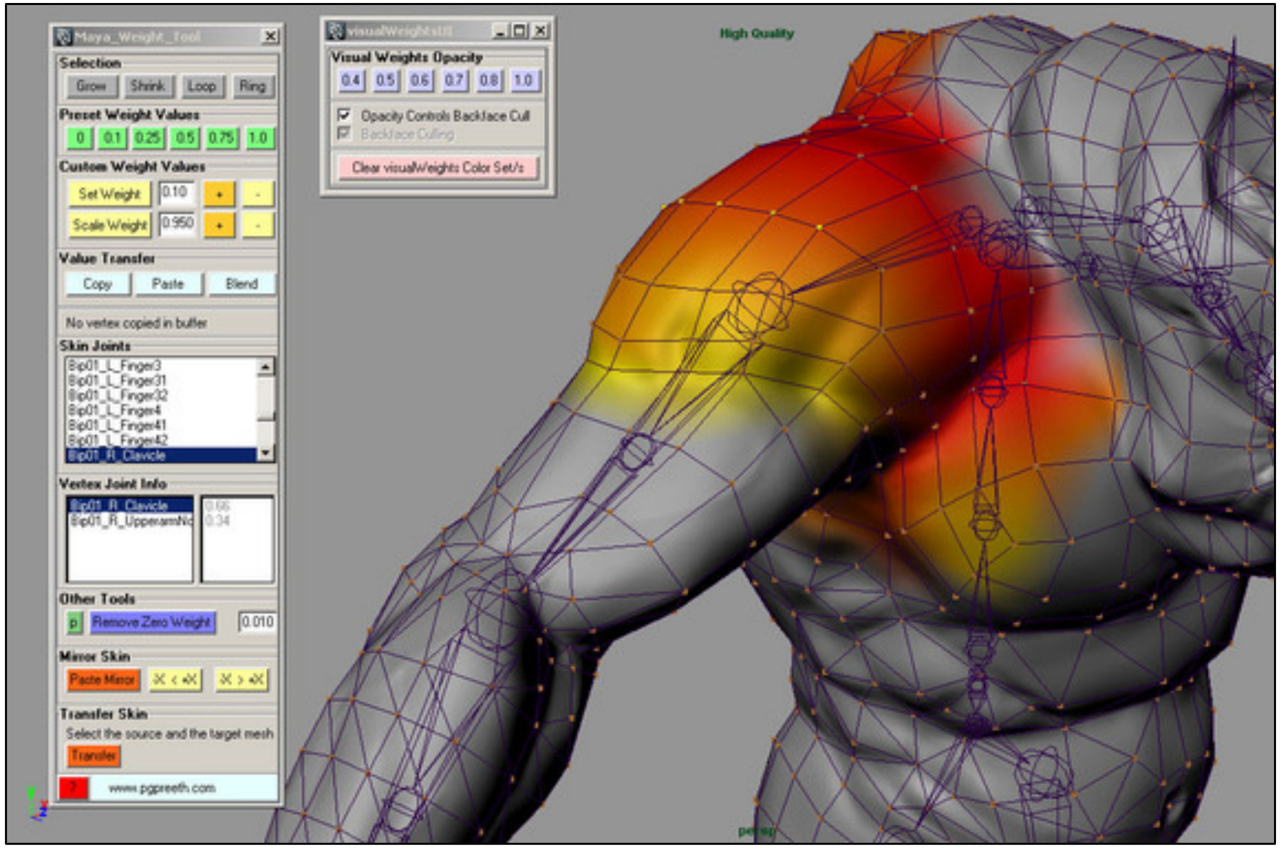
- Advantages
  - Simple to implement
  - Complete animator control
- Disadvantages
  - Motions *may not follow physical laws*
  - Tedious for animator



Lasseter `87

Beyond Skeletons…

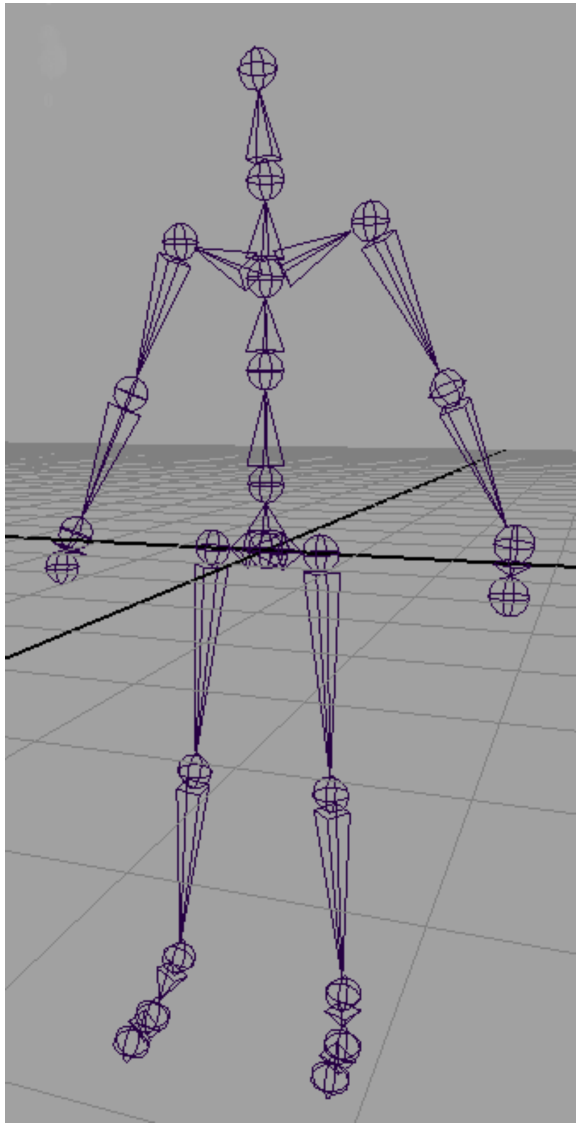
- Skinning



creativecrash.com

Kinematic Skeletons

- Hierarchy of transformations ("bones")
  - Changes to parent affect all descendent bones
- So far: bones affect objects in scene or parts of a mesh
  - Equivalently, each point on a mesh acted upon by one bone
  - Leads to discontinuities when parts of mesh animated



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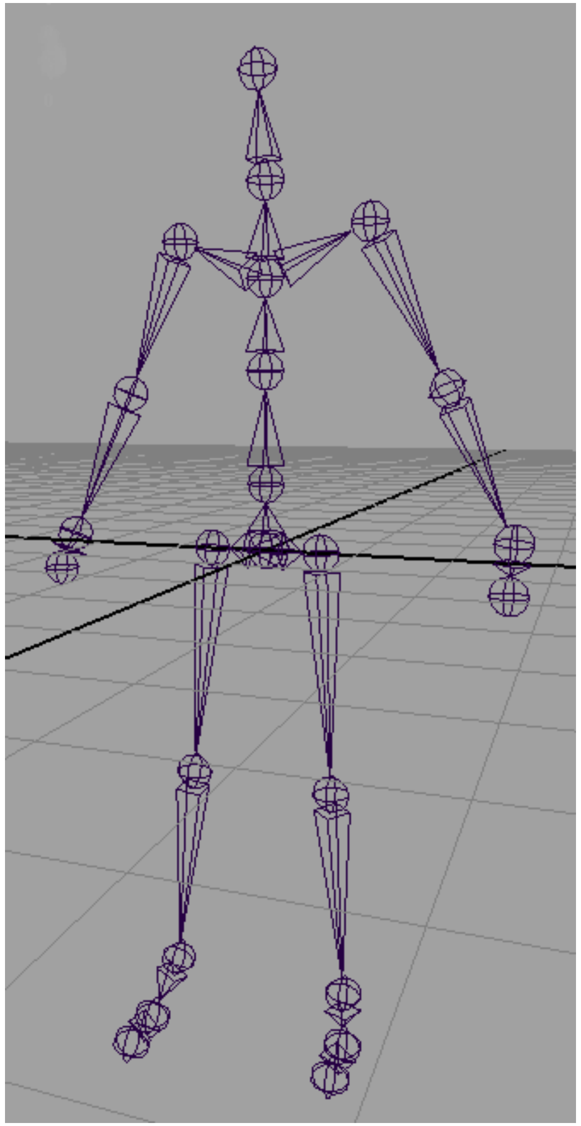
  - Leads to discontinuities when parts of mesh animated
- Extension: each point on a mesh acted upon by more than one bone



Linear Blend Skinning

- Each vertex of skin potentially influenced by all bones
  - Normalized weight vector $w^{(v)}$ gives influence of each bone transform
  - When bones move, influenced vertices also move

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- Computing a transformation T_v for a skinned vertex
  - For each bone
    - Compute global bone transformation T_b from transformation hierarchy
  - For each vertex
    - Take a linear combination of bone transforms T_v with
    - Apply transformation T_v to vertex in original pose

$$T_v = \sum_{b \in B} w_b^{(v)} T_b$$

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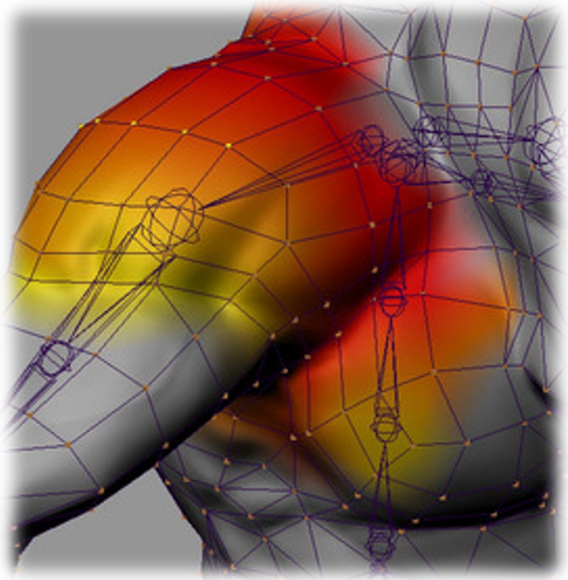
$$T_v = \sum_{b \in B} w_b^{(v)} T_b$$

- Equivalently, transformed vertex position is weighted combination of positions transformed by bones

$$v_{transformed} = \sum_{b \in B} w_b^{(v)} \left(T_b v \right)$$

Assigning *Weights*: “Rigging”

- Painted by hand
- Automatic: function of relative distances to nearest bones
  - Smoothness of skinned surface depends on smoothness of weights!



Assigning Weights: "Rigging"

- Painted by hand
- Automatic: function of relative distances to nearest bones
  - Smoothness of skinned surface depends on smoothness of weights!
  - Other problems with extreme deformations
    - Many solutions

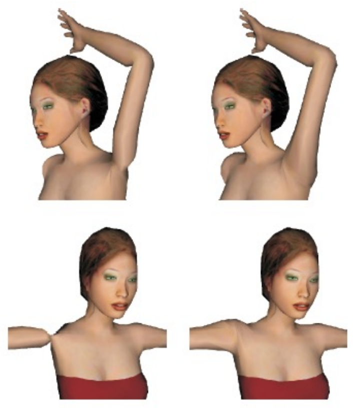
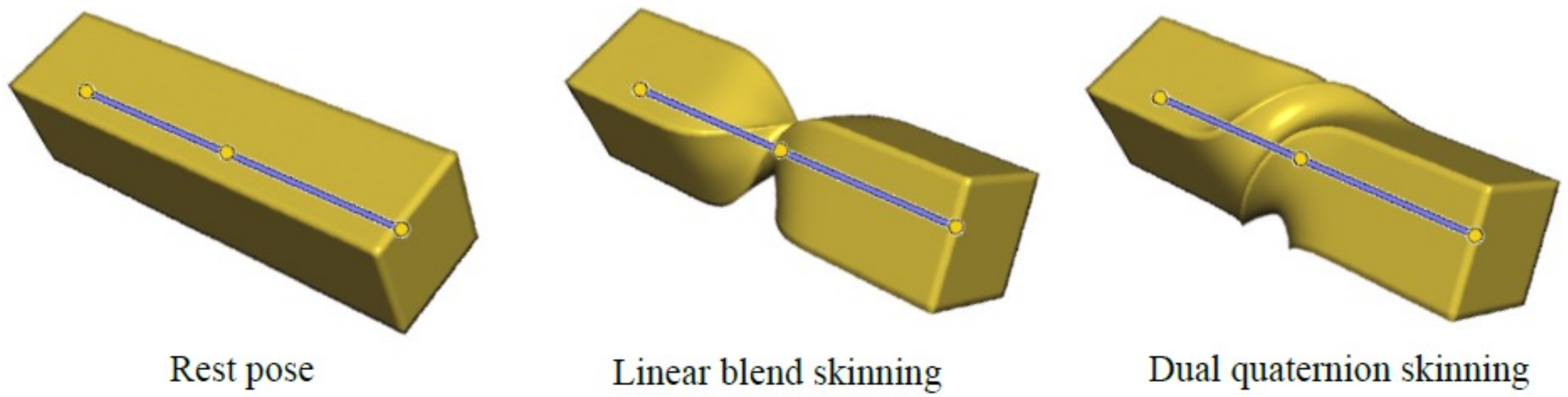


Figure 14: Comparison of linear (left) and dual quaternion (right) blending. Dual quaternions preserve rigidity of input transformations and therefore avoid skin collapsing artifacts.

[Kavan et al. SG '08]



[Kavan, SG'14 course]

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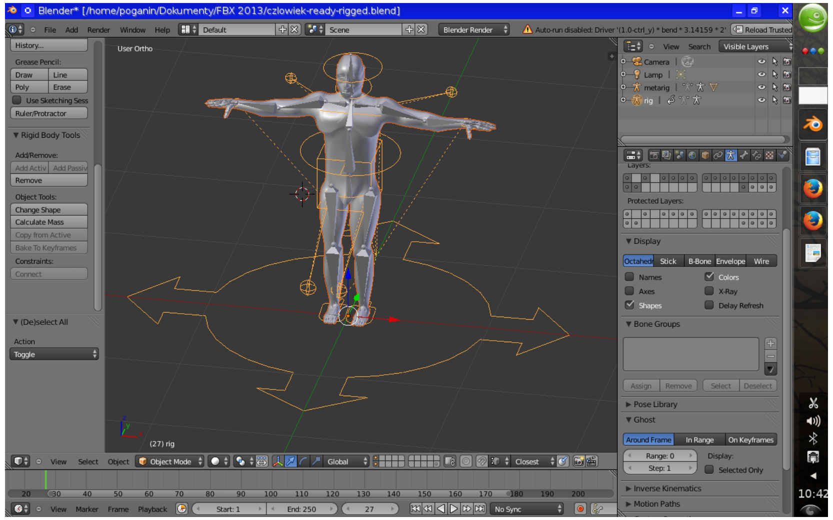

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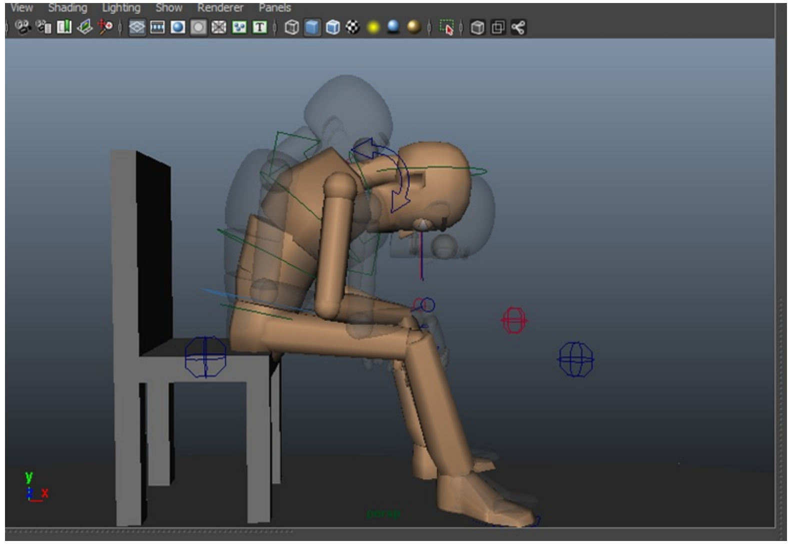

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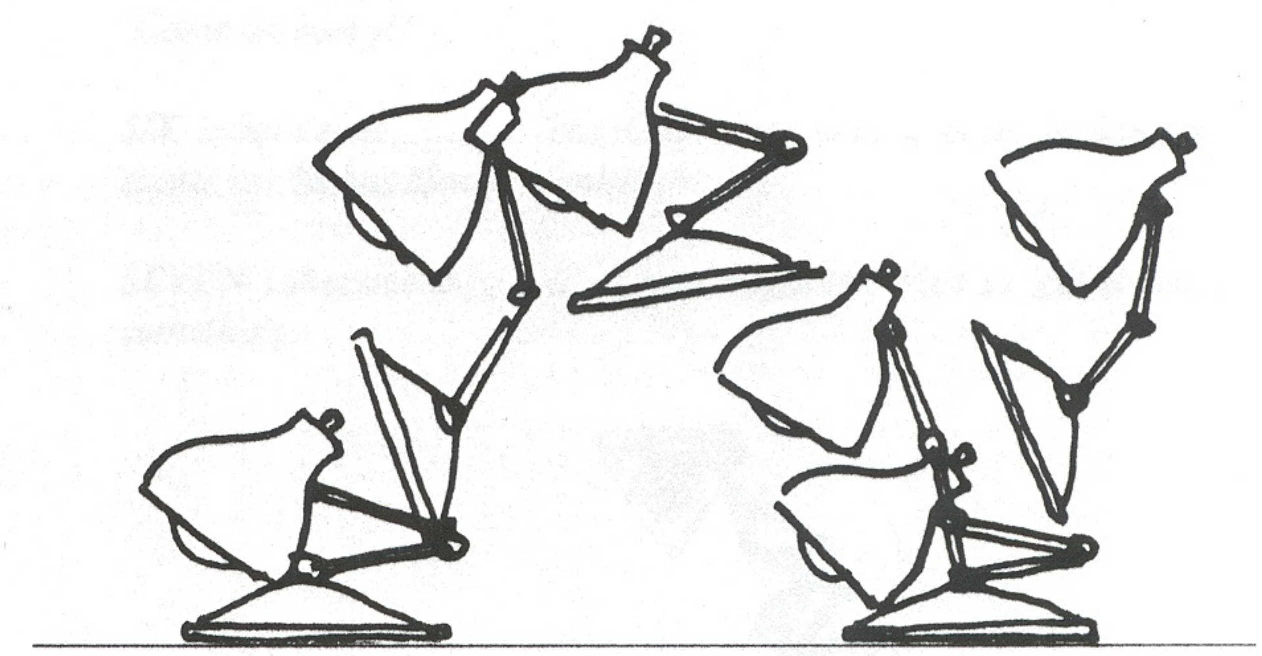
Keyframe Animation

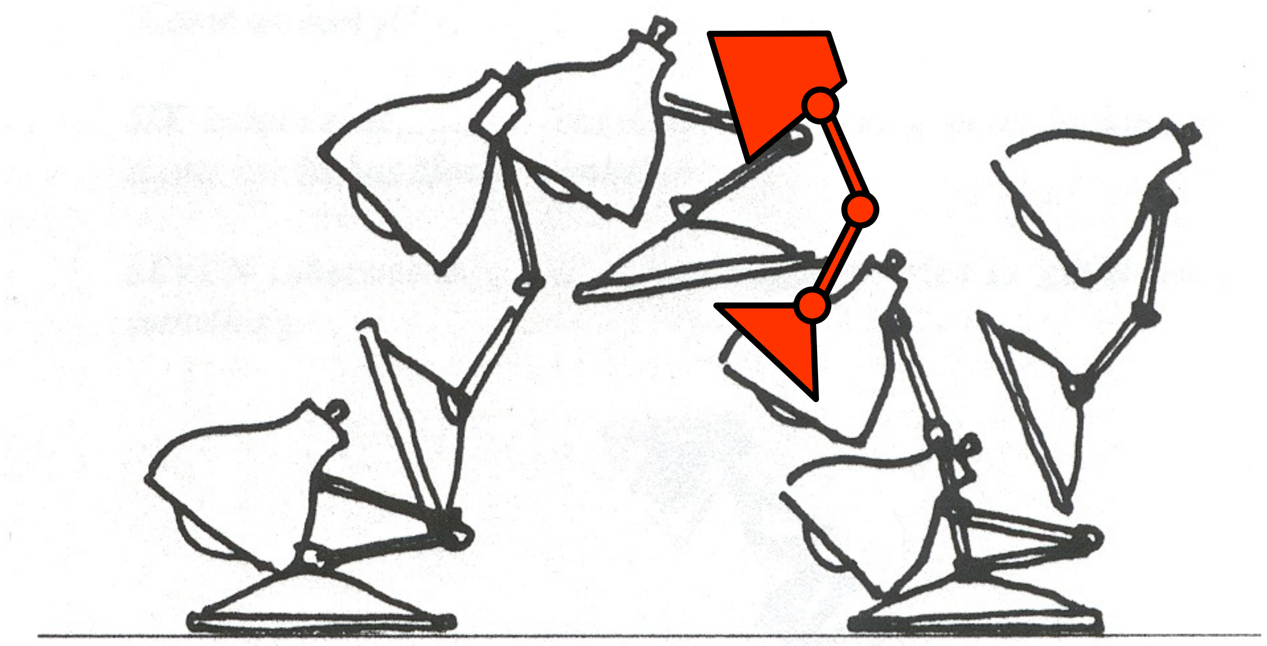
- Define character poses at specific time steps called “keyframes”



Lasseter `87

Keyframe Animation

- Interpolate variables describing keyframes to determine poses for character in between



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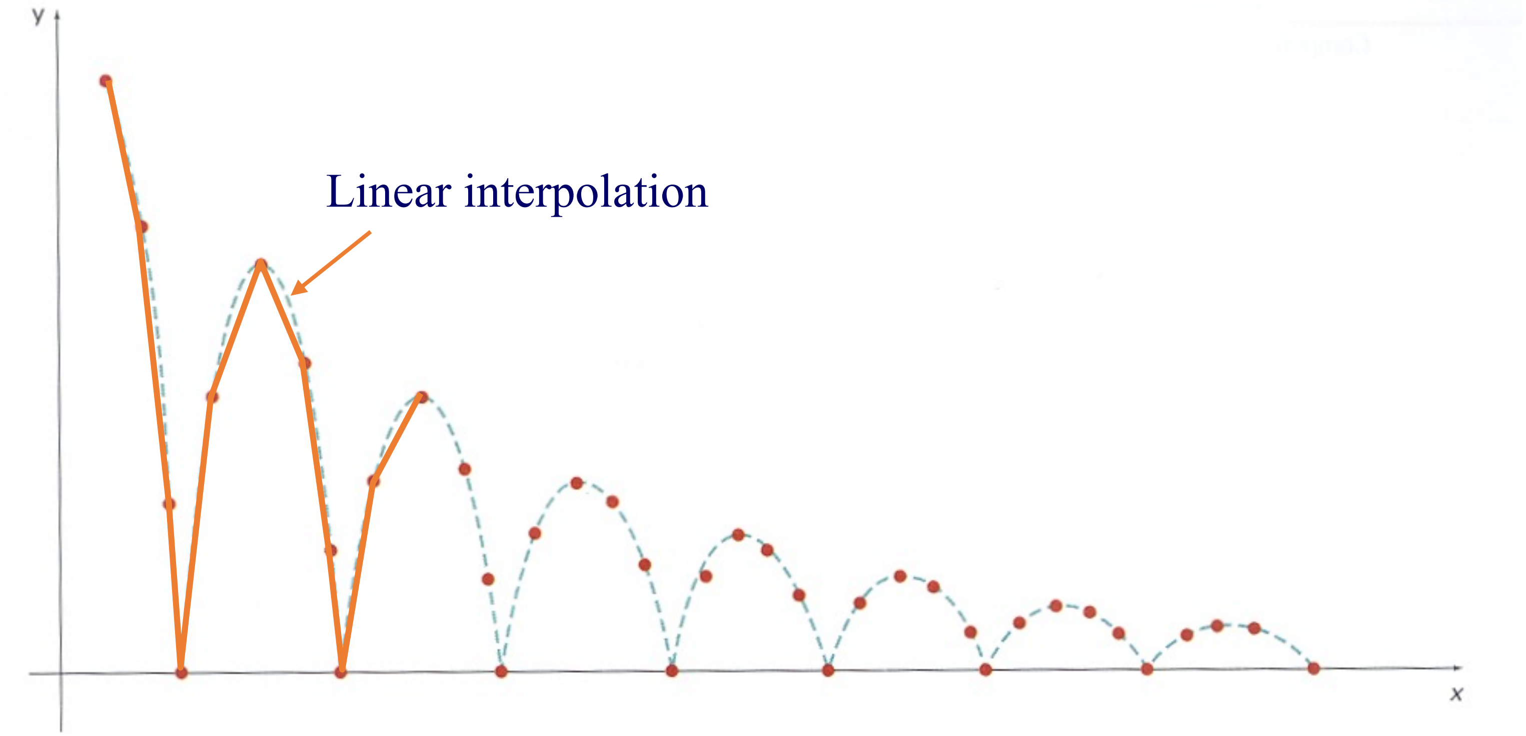
Keyframe Animation

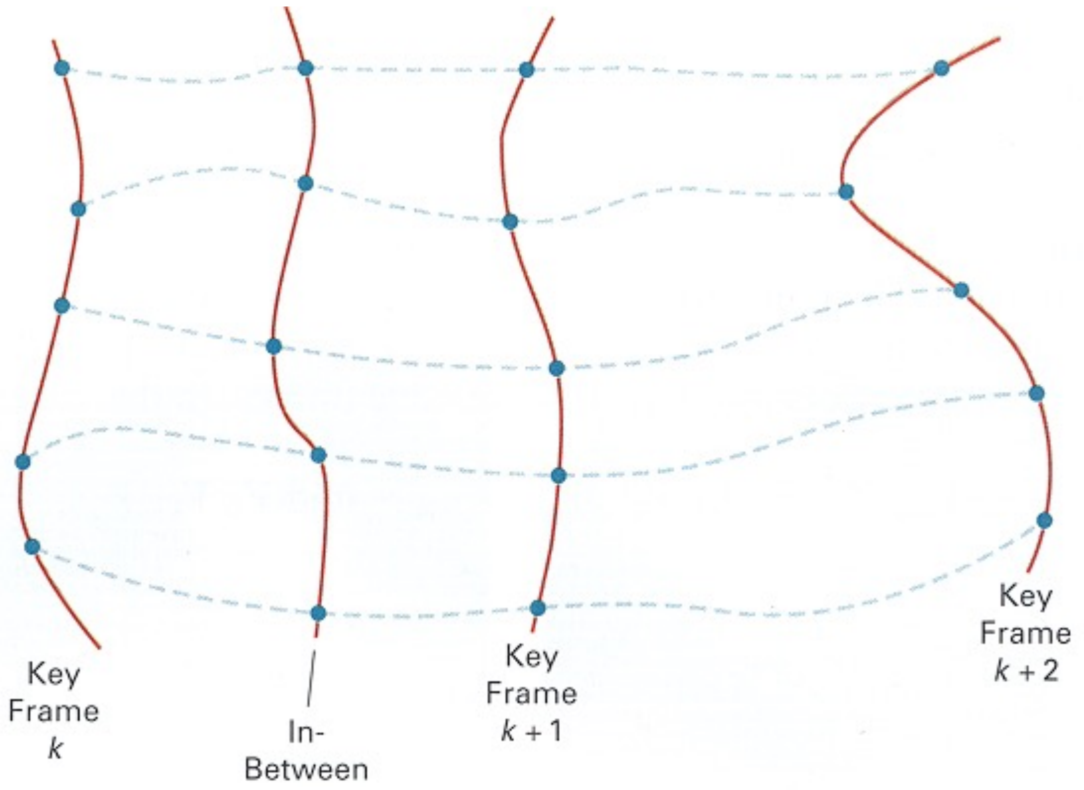
- Inbetweening:
  - Linear interpolation - usually not enough continuity



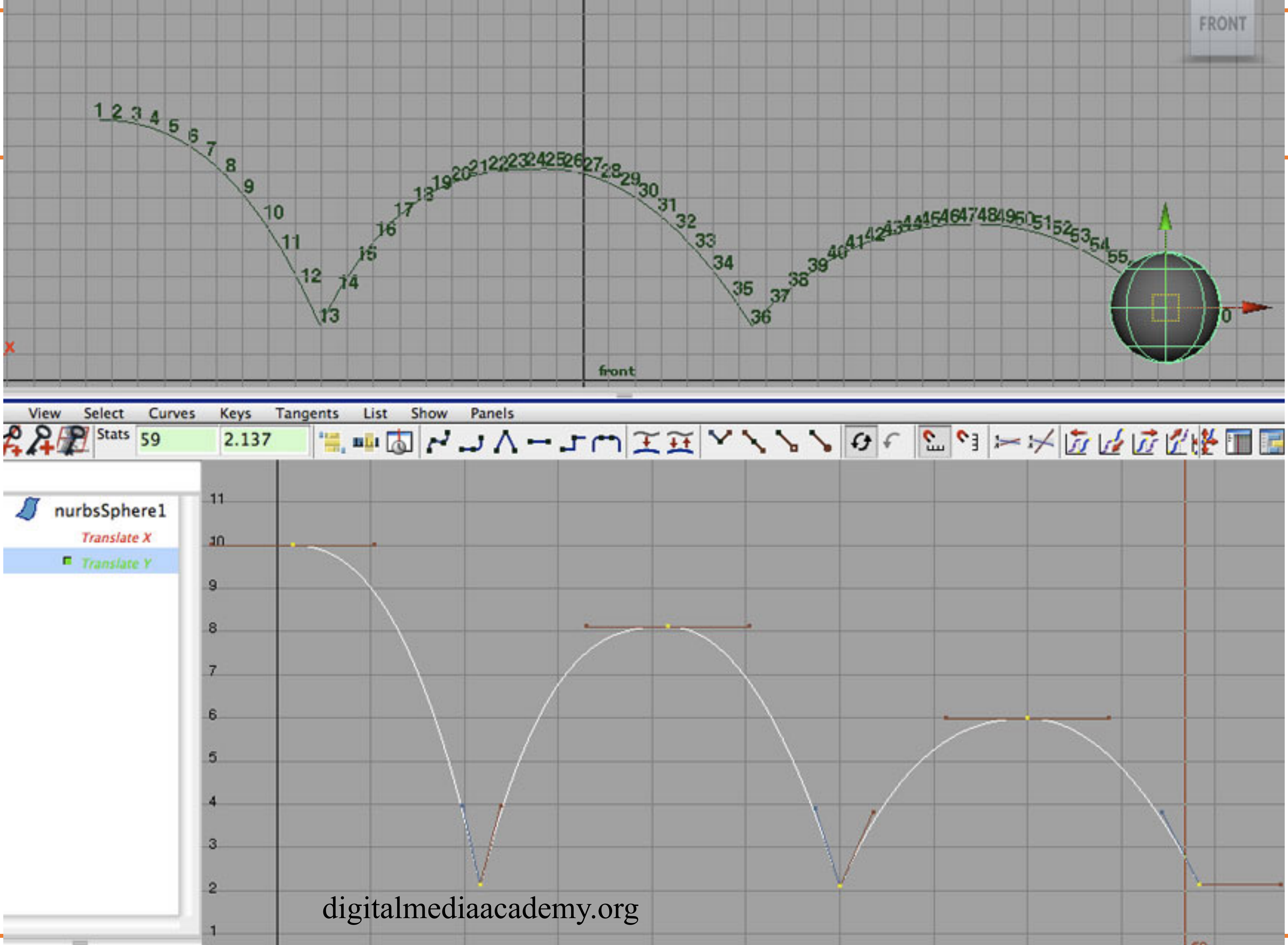
H&B Figure 16.16

Keyframe Animation

- Inbetweening:
  - Spline interpolation - maybe good enough



H&B Figure 16.11



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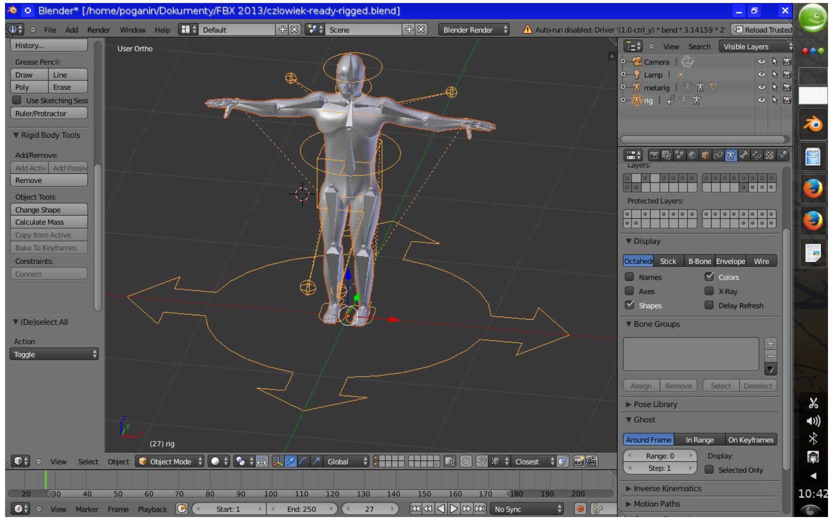
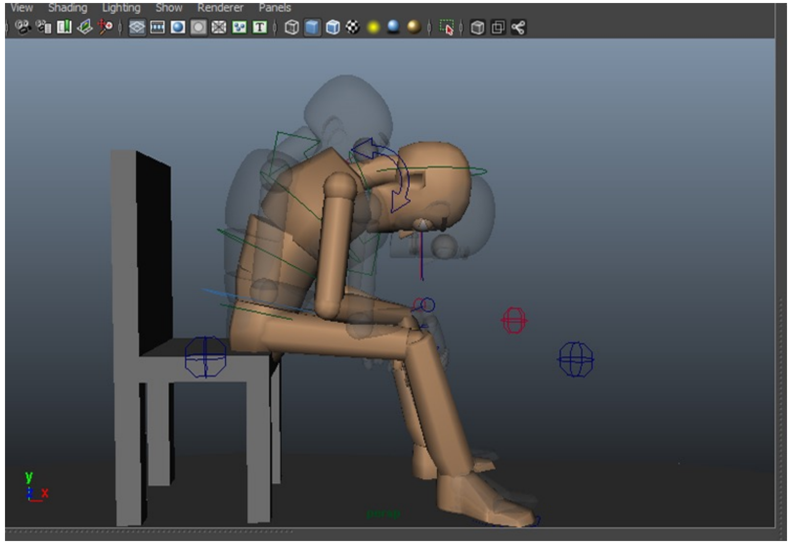
Character Animation Methods

- Modeling (manipulation)
  - Deformation
  - Blendshapes
  - Skeletons
- Interpolation
  - Key-framing
  - Kinematics
  - Motion Capture



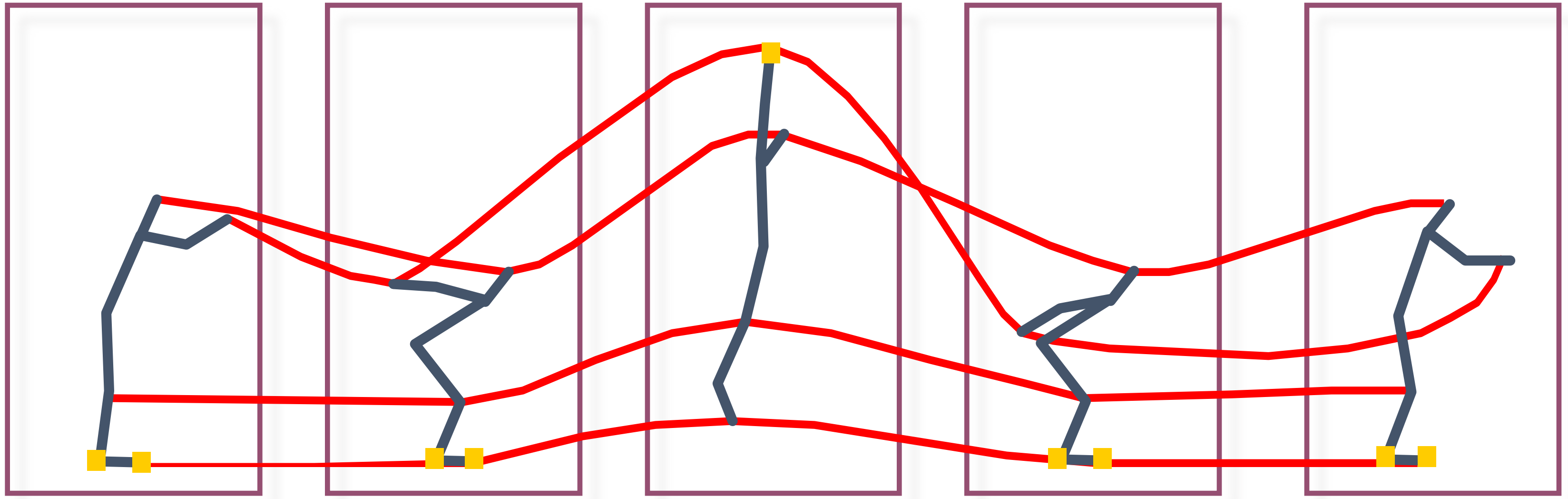
https://blenderartists.org/



focus.gscept.com

Motion Capture

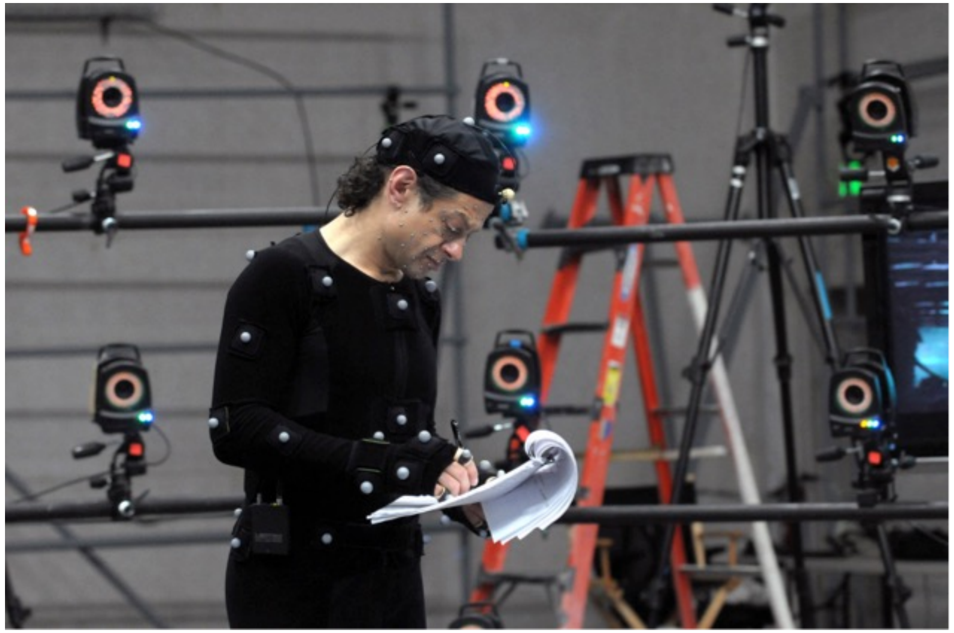
- Measure motion of real characters and then simply "play it back" with kinematics



Captured Motion

Motion Capture

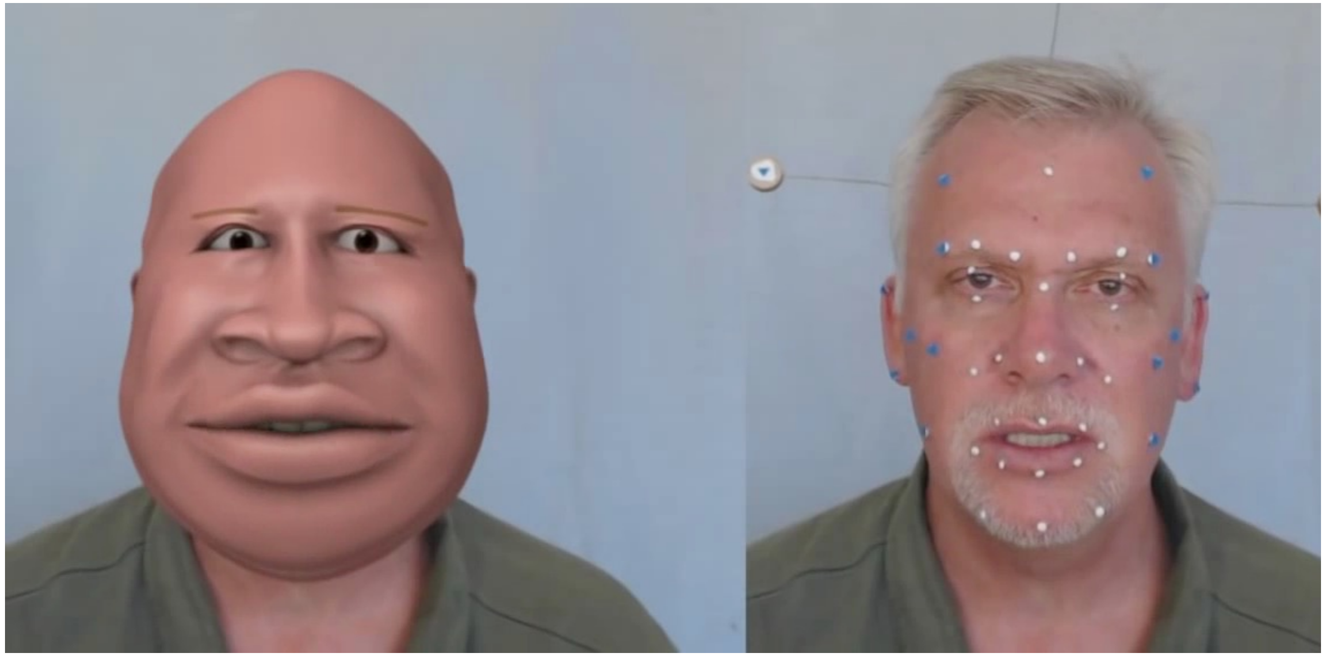
- Measure human motion
- Play back with kinematics



https://www.youtube.com/watch?v=MVvDw15-3e8

Motion Capture for Faces

- Could be applied on different parameters
  - Skeleton Transformations
  - Direct mesh deformation
- Advantage:
  - Physical realism
- Challenge:
  - Animator control



Summary

- Kinematics
  - **Animator specifies poses (joint angles or positions) at keyframes** and computer determines motion by kinematics and **interpolation**
- Dynamics
  - Animator specifies **physical attributes**, constraints, and starting conditions and computer determines motion by **physical simulation**
- Motion Capture
  - Compute **captures motion of real character** and provides tools for animator to edit it