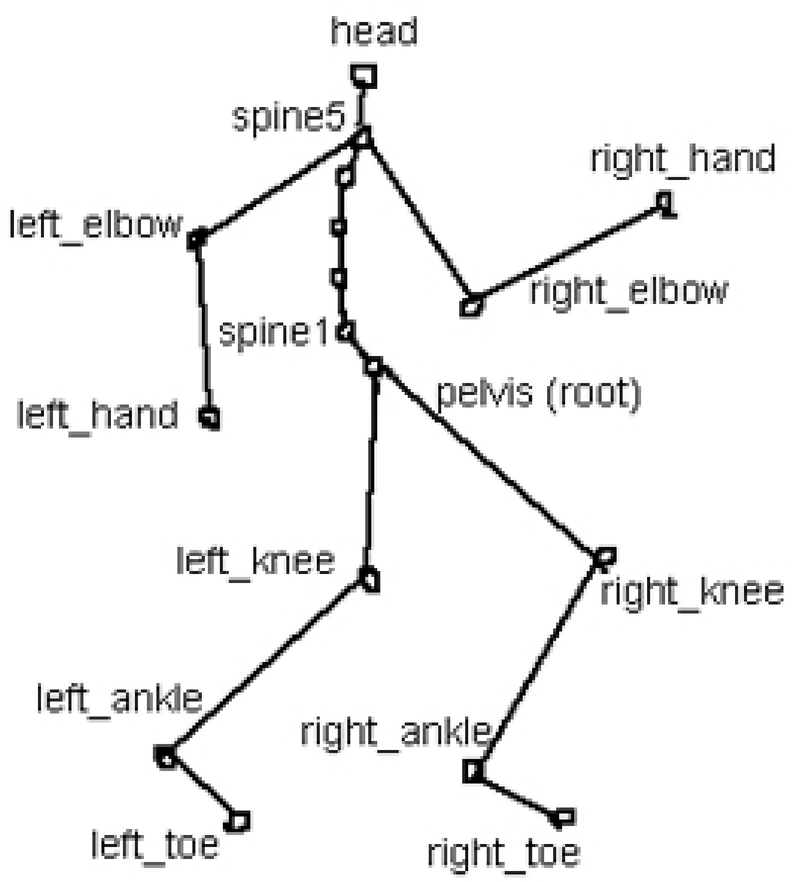
Animating Virtual Characters

Character Animation

Skeletal Animation

Skeleton structure



Characteristics

- Hierarchical representation

  All children follow the transformation of the parent

  Need to define a root: usually at the hips/pelvis

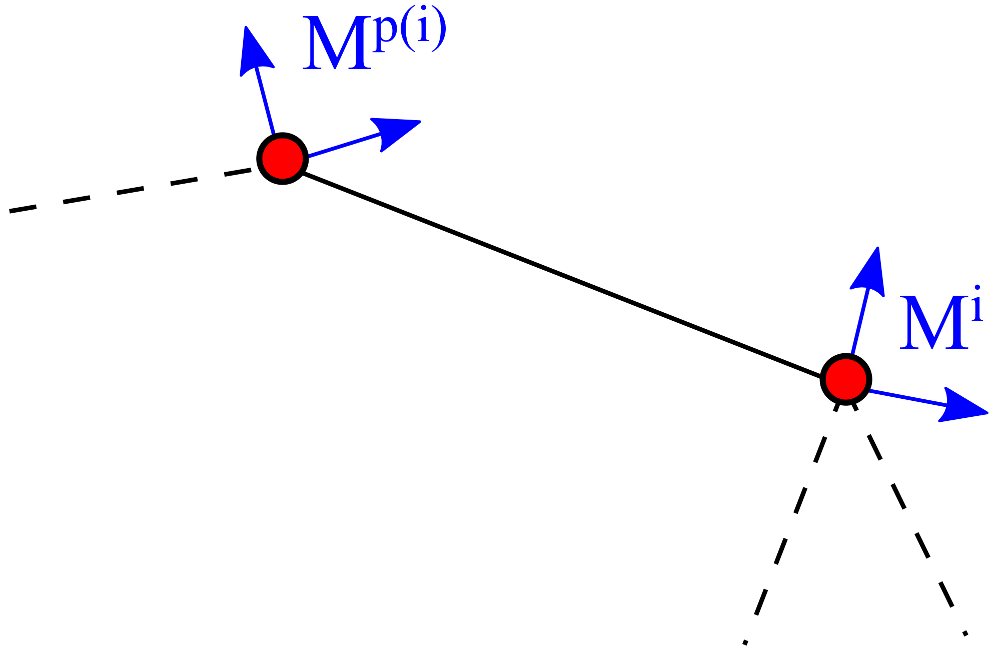
- Convenient to express relative transformation with respect to the parent

  ex. Ankle is at 20° *w/r knee*

Converting local to global frames/joint coordinates

- With 4x4 matrices M

$$M^i_{global} = M^{p(i)}_{global} \, M^i_{local}$$



- With translation t, rotation R

$$R^i_{global} = R^{p(i)}_{global} \, R^i_{local}$$

$$t^i_{global} = t^{p(i)}_{global} + R^{p(i)}_{global} \, t^i_{local}$$

Encoding hierarchical skeleton

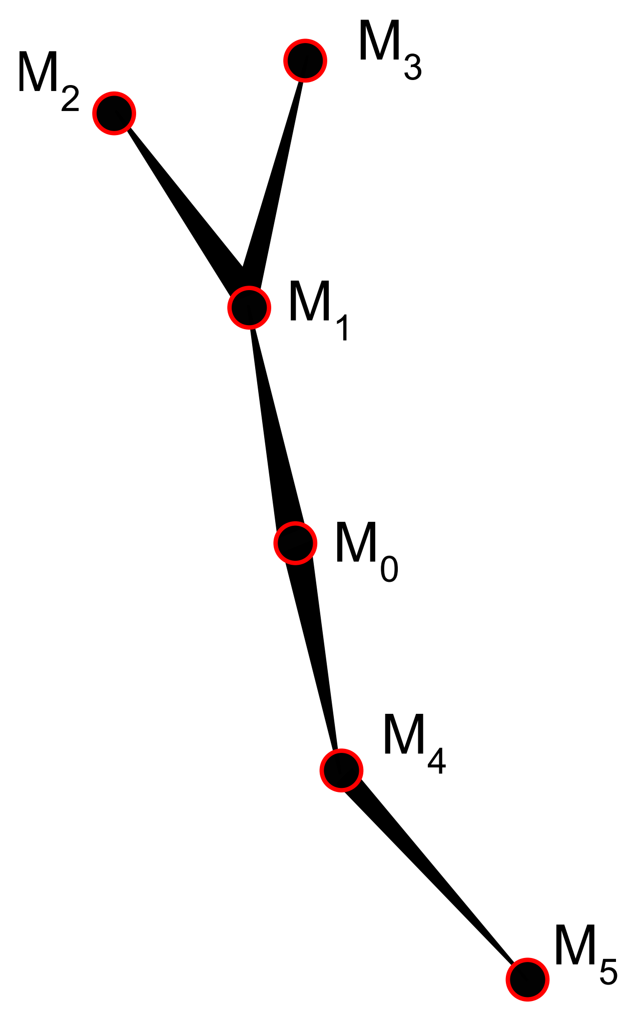
- Simplest encoding based on index within vector

```
Geometry=[M0, M1, M2, M3, M4, M5]
Parent = [-1,0,1,1,0,4]
```

- Convert local coordinates to global coordinates

```
local (Geometry)  <- std::vector of rotation (r), translation (p)
global (Geometry) <- std::vector of rotation (r), translation (p)

global[0] = local[0];
for(size_t k=1; k<N; ++k)
{
    int parent = Parent[k];
    global[k].r = global[parent].r * local[k].r;
    global[k].p = global[parent].r * local[k].p + global[parent].p;
}
```

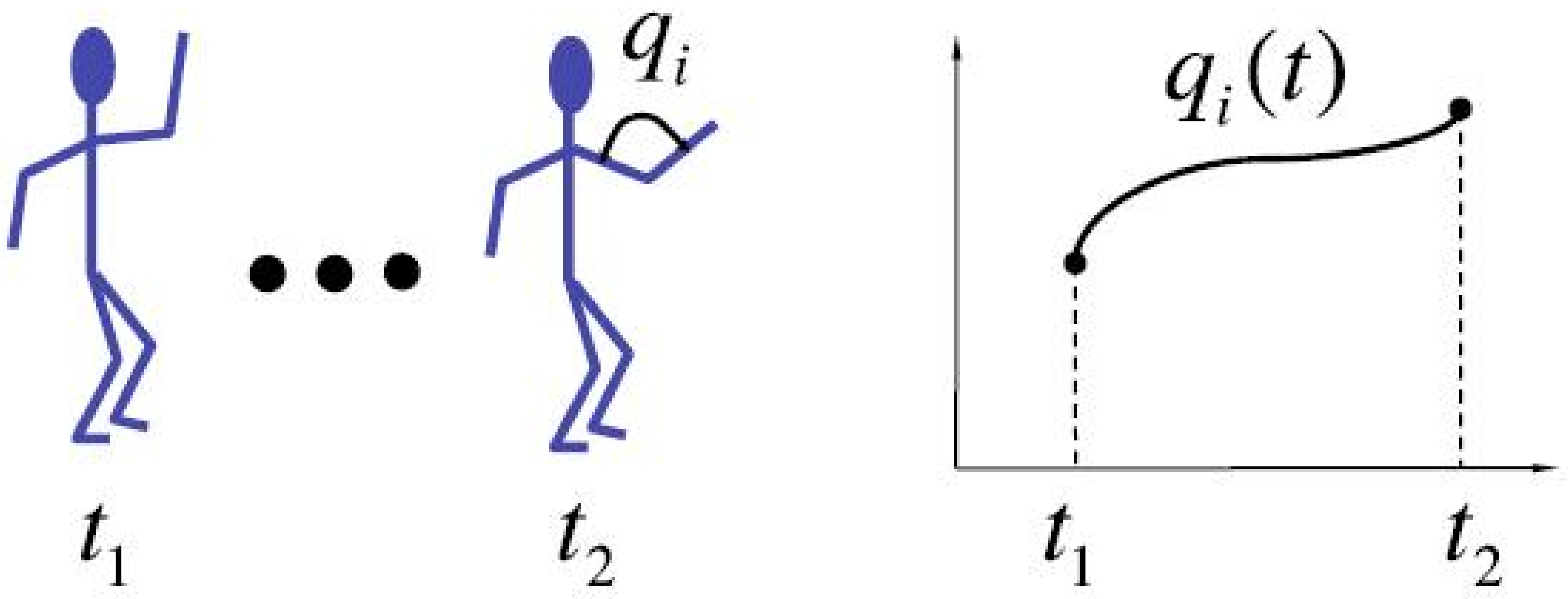


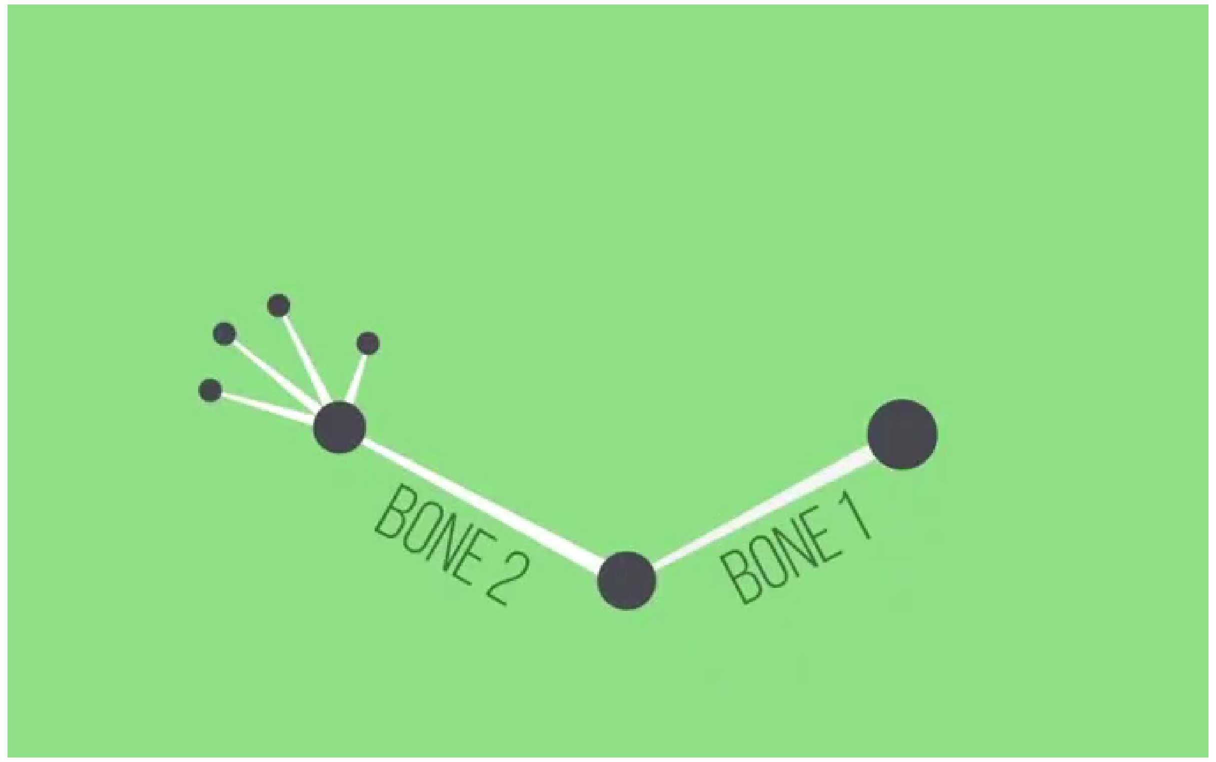
Forward kinematics

FK - **F**orward **K**inematics

- Each join angle is set manually
- Adapted to set orientation of specific parts
- Interpolate rotations during animation

(+) Generates curved trajectory naturally





MiloScerny Animation

Rotations

3D rotations have 3 dof, No unique representation

Matrix

$$R = \begin{pmatrix} R_{xx} & R_{xy} & R_{xz} \\ R_{yx} & R_{yy} & R_{yz} \\ R_{zx} & R_{zy} & R_{zz} \end{pmatrix}$$

$R^T R = \mathrm{I}$
$\det(R) = 1$

(+) Computationaly convenient
(-) Non-explicit dof, redundancies

Euler Angles

3 angles: (α, β, γ)

Composition of rotation around basic axes

Not unique (x-y-z, y-z-x, x-y-x', x-z-x', ...)

(+) Meaningfull parameters
(-) Gimbal-lock

Axis angle

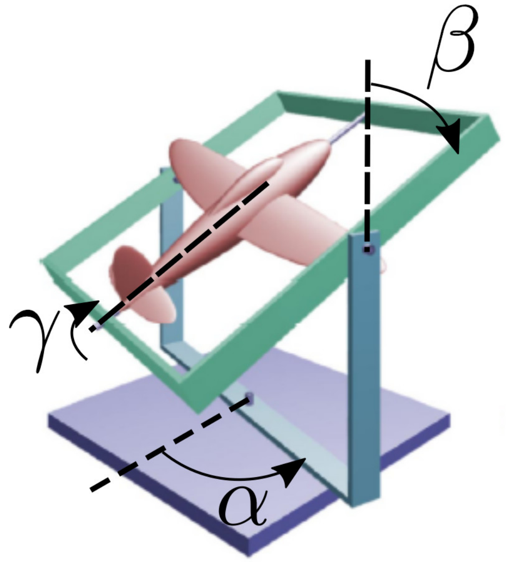
$(\mathbf{n}, \theta)$

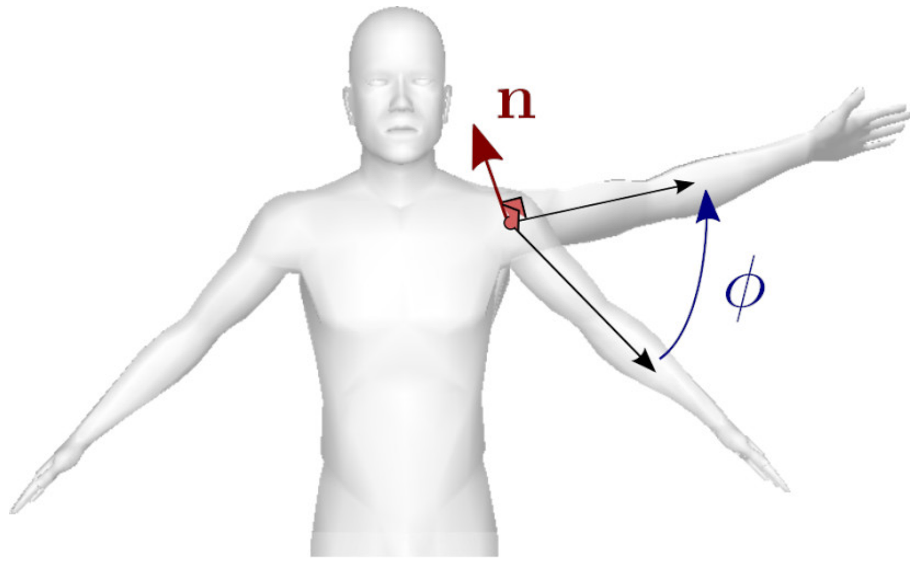
(+) Meaningfull parameters
(-) No direct composition

Quaternion

$$q = (x, y, z, w) = \left(\mathbf{n} \sin\left(\frac{\theta}{2}\right), \cos\left(\frac{\theta}{2}\right)\right)$$

(+) Composition and interpolation
(-) Less intuitive components





Interpolating rotation

Do not use componentwise-interpolation on rotation matrix

$\Rightarrow$ interpolate in **quaternion** space

Can use either:

- **SLERP** - Spherical Linear Interpolation

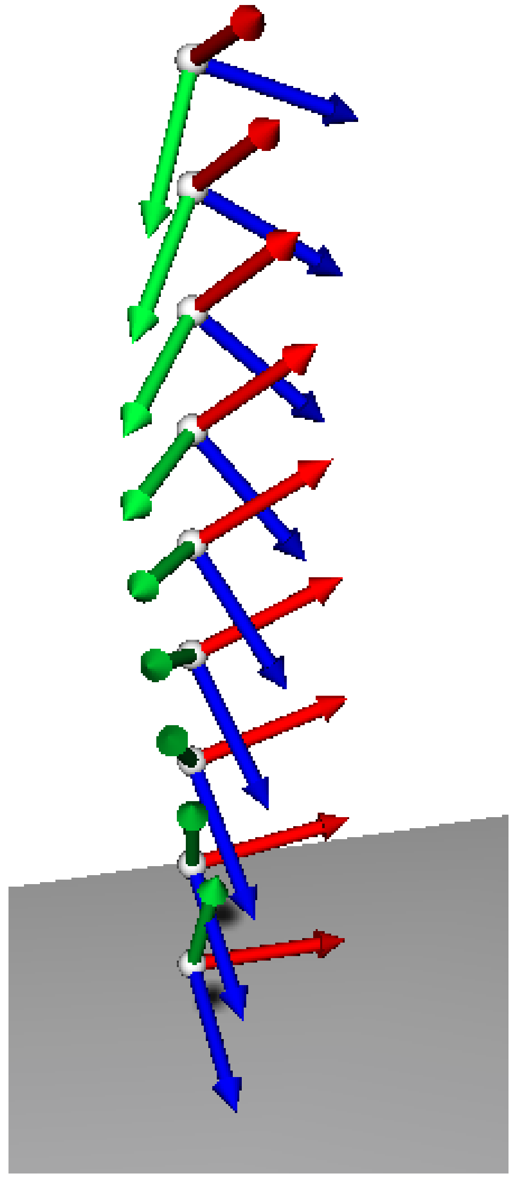
$$q(t) = \frac{\sin((1-t)\Omega)}{\sin(\Omega)} q_1 + \frac{\sin(t\Omega)}{\sin(\Omega)} q_2, \quad \text{with } \cos(\Omega) = q_1 \cdot q_2$$

Between two unit quaternions q_1, q_2

- **LERP** - Linear Interpolation

$$q(t) = \frac{\sum_j \alpha_j \, q_j}{\| \sum_j \; \alpha_j q_j \|}$$

When blending multiple quaternions q_j *with weights* α_j

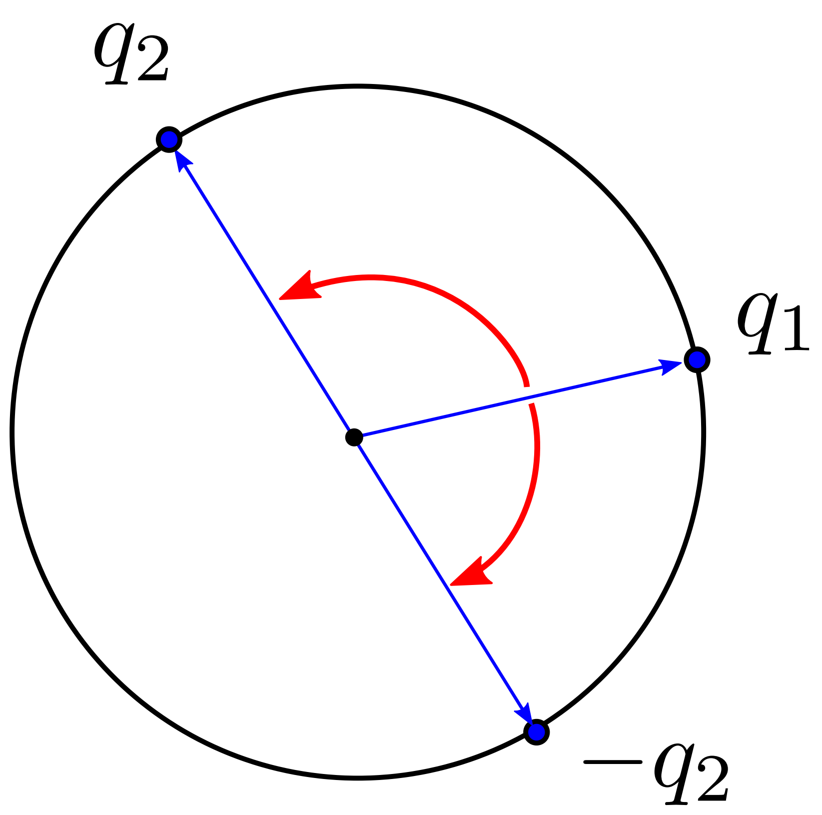


Rem.

When interpolating b/w rotations and positions:

Use quaternion with rotation, componentwise-interpolation on position

Care with quaternion negation



$+q$ and $-q$ correspond to the same rotation ($n \to -n, \theta \to 2\pi - \theta$)

Warning $-q$ ***does not*** *corresponds to the rotation matrix* $-R$.

But to a **different path** when interpolated in the 4D quaternion space.

$\Rightarrow$ path $q_1 \to -q_2$ is shorter than $q_1 \to q_2$ when $q_1 \cdot q_2 < 0$.

In practice we check for the shorter path before applying SLERP.

Algorithm

```
if( dot(q1,q2)<0 )
    q2 = -q2

q(t) = SLERP(q1,q2,t)
```

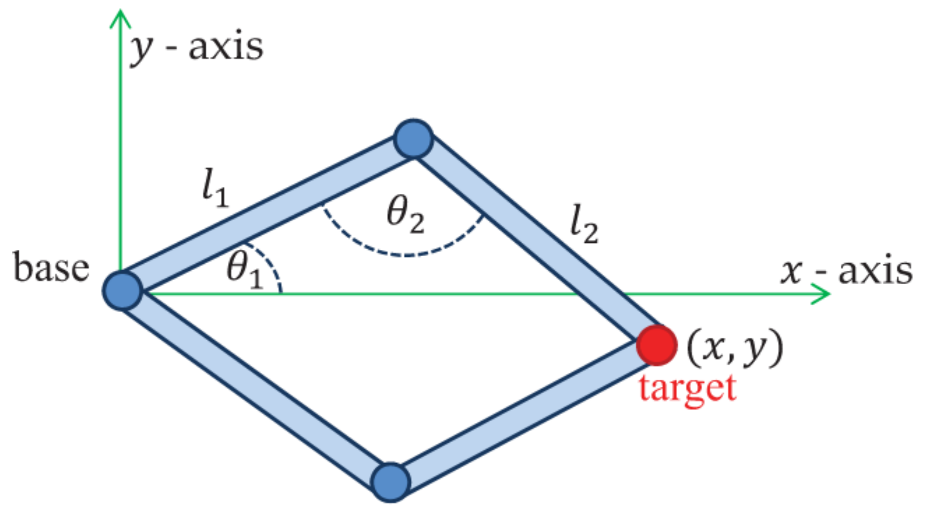
Inverse Kinematics

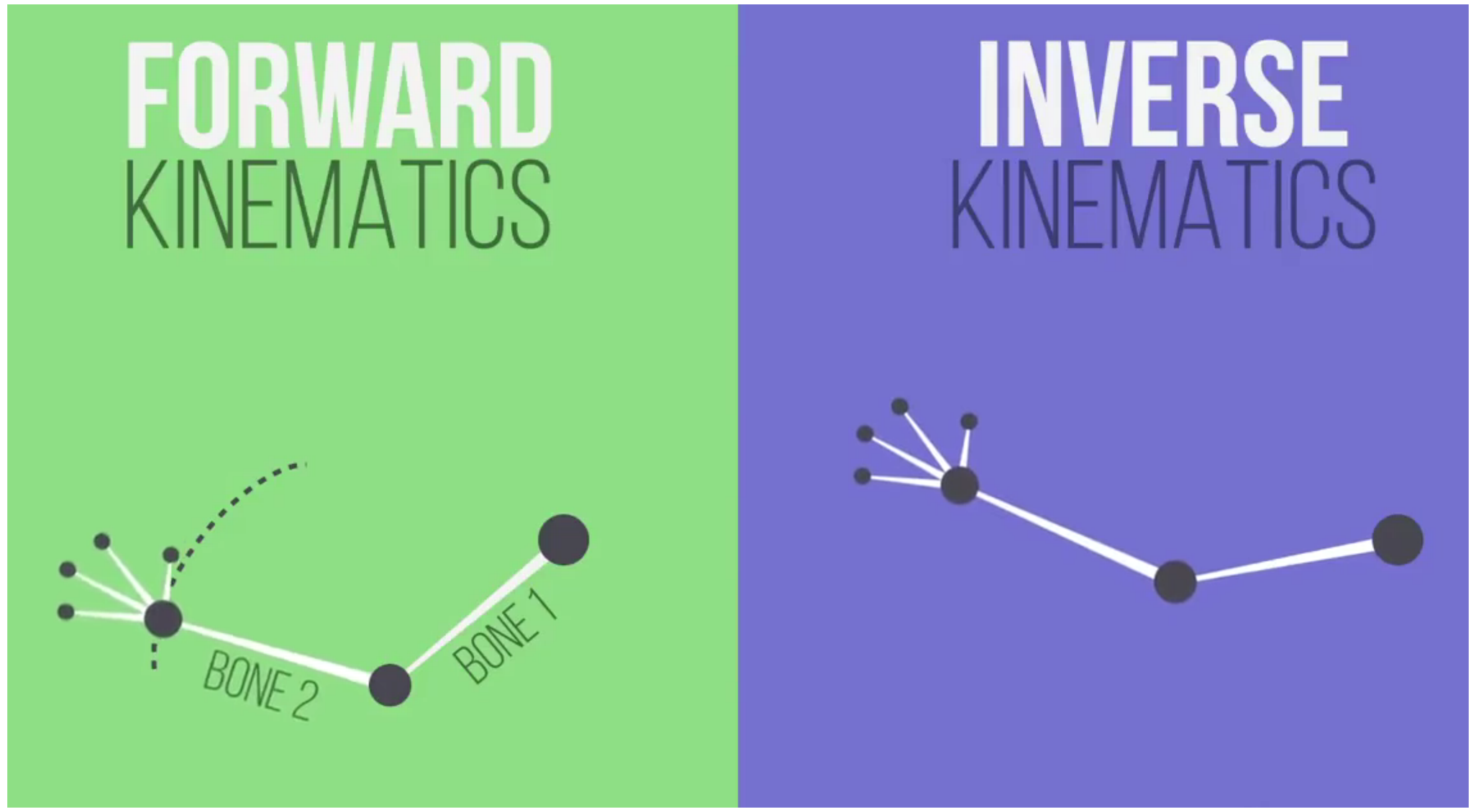
IK: **I**nverse **K**inematics

- Describe position (/and orientation) of *end-effectors* (contact, walking, etc)
- Compute joint angles reaching this position

$$p_k = p_0 + \sum_{i=0}^{k-1} l_i \; R_i \, u_i$$

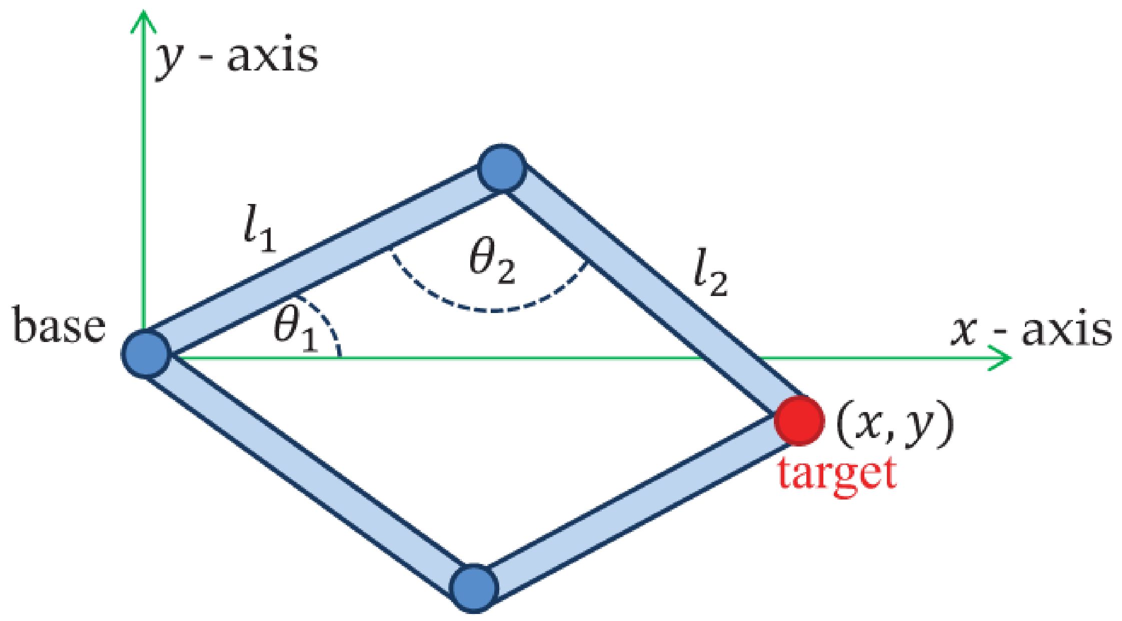
R_i can be expressed with various rotation parameters (Matrices, Euler angles, axis/angle, quaternions, etc)





MiloScerny Animation

IK Example with two bones



[Inverse Kinematics Techniques in Computer Graphics: A Survey. A. Aristidou et al. STAR EG. 2017.]

In general the general case $p_k = f(\theta_i)$

- Look for $\theta_i = f^{-1}(p_k)$
- f is a non linear function
- There may exists multiple solutions (or none)
- Solutions may exhibits discontinuities
- Closed form solution are not available

Two solutions defined by

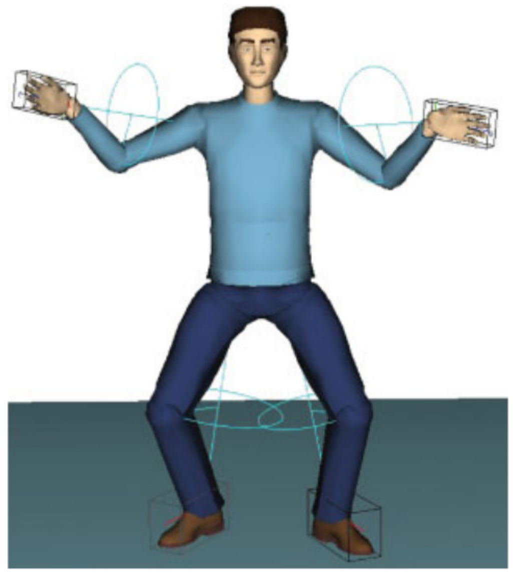
$$\cos(\theta_1) = \frac{l_1^2 + x^2 + y^2 - l_2^2}{2 l_1 \sqrt{x^2 + y^2}}$$

$$\cos(\theta_2) = \frac{l_1^2 + l_2^2 - (x^2 + y^2)}{2 l_1 l_2}$$

Some attempts for explicit solutions in specific cases

[Real-Time Inverse Kinematics Techniques for Anthropomorphic Limbs. D. Tolani et al. Graphical Models, 2000.]

[Analytical inverse kinematics with bodyposture control. M. Kallmann. Comp. Anim. & Virt. Worlds, 2008]



IK: Numerical methods

Numerical inversion of $p = f(\theta), \theta = (\theta_0, \cdots, \theta_{N-1})$.

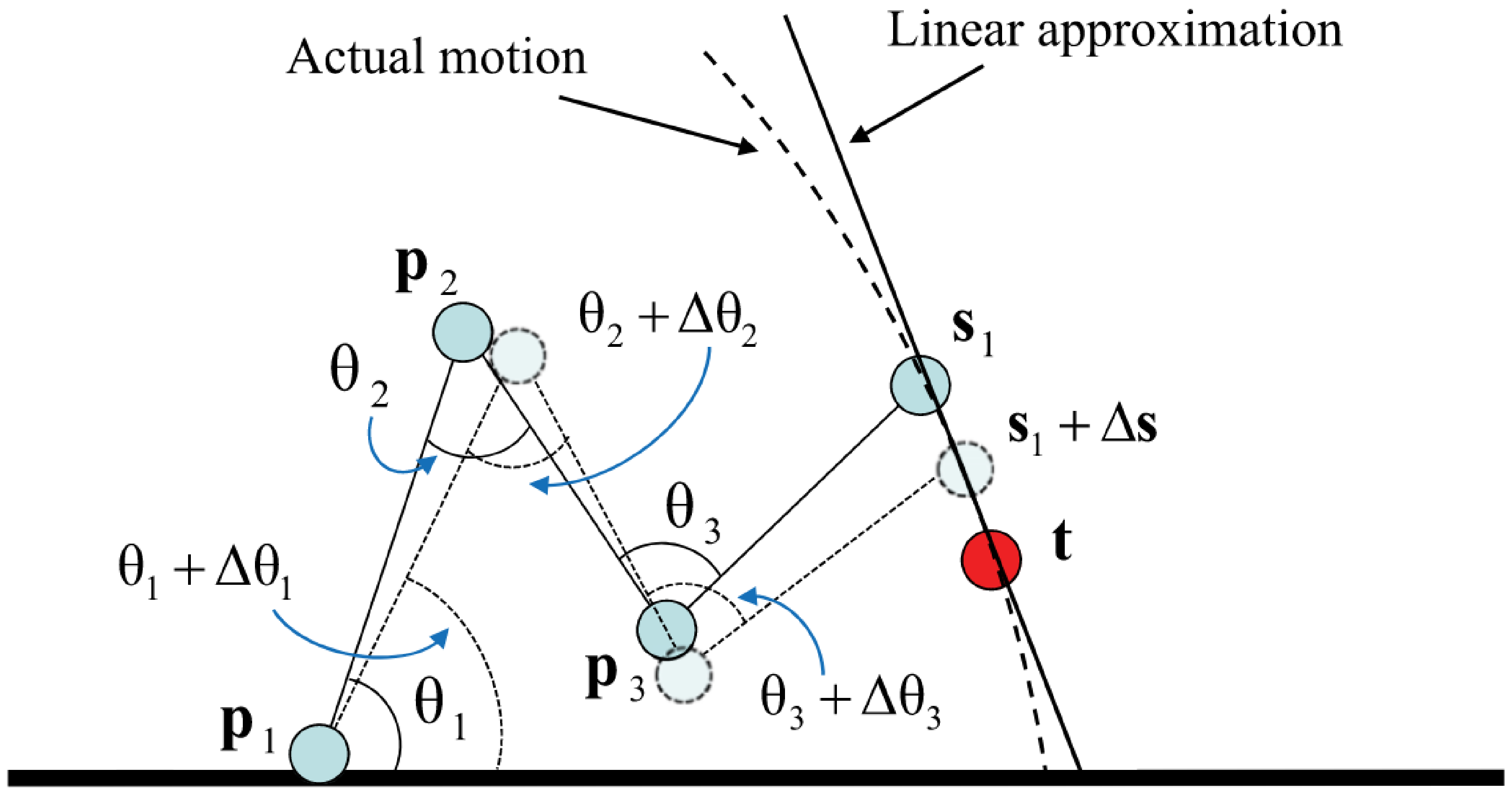
Consider small step size $p \to p + \Delta p$

$$\Delta p \simeq \underbrace{\left(\frac{\partial f}{\partial \theta}\right)}_{\text{J}} \Delta\theta$$

J - Jacobian matrix.

$\to$ Not square $(3 \times N)$, not invertible.

Unknown > # constraints



IK: Numerical methods

Several possible approaches to solve $\mathrm{J}\,\Delta\theta = \Delta p$

- Pseudo Inverse

$\Delta\theta = J^{+}\ \Delta p$, with $\mathrm{J}\mathrm{J}^{+} = \mathrm{I}$

$\mathrm{J}^{+} = \mathrm{J}^{T}\left(\mathrm{J}\,\mathrm{J}^{T}\right)^{-1}$

- Can also be computed using SVD: $\mathrm{J}^{+} = \mathrm{V}\Sigma^{+}\,\mathrm{U}^{T}$

$\Sigma_{ii} = \sigma_i, \Sigma^{+}_{ii} = 1/\sigma_i$ if $\sigma_i \neq 0, 0$ otherwise.

- Adding damping to compensate for singularities

$\Delta\theta = \mathrm{J}^{T}\left(\mathrm{J}\,\mathrm{J}^{T} + \lambda^{2}\,\mathrm{I}\right)^{-1}\ \Delta p$

- Using Newton's methods

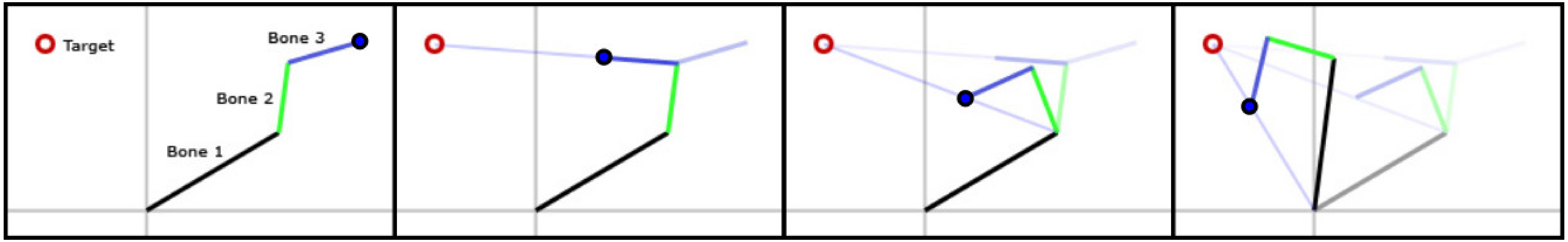
[Inverse Kinematics Techniques in Computer Graphics: A Survey. A. Aristidou. STAR EG 2017]

IK: Heuristic approach

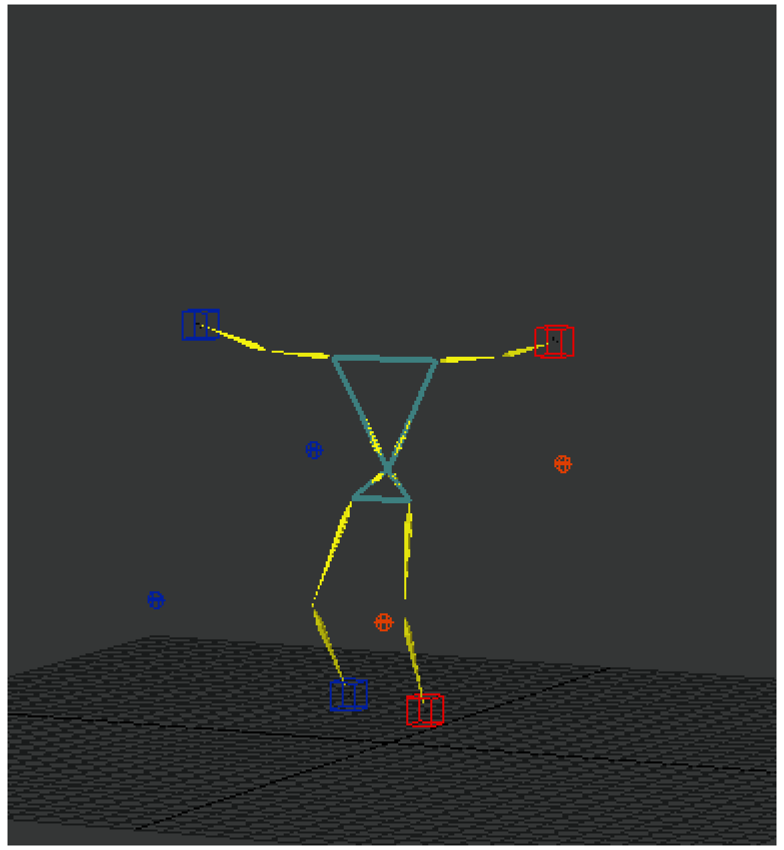
Cyclic Coordinates Descent (CCD)

- Iteratively rotates joint $j^N \rightarrow j^{i-1} \rightarrow \cdots \rightarrow j^1$ for the extremity (end effector) to be as close as possible from the target.
  = *End-effector aligned with the segment (joint,target)*
- Restart until convergence

[Making Kine More Flexible. Jeff Lander. Game Dev, 1998.]



IK: Heuristic approach



Fabrik

Iterate between

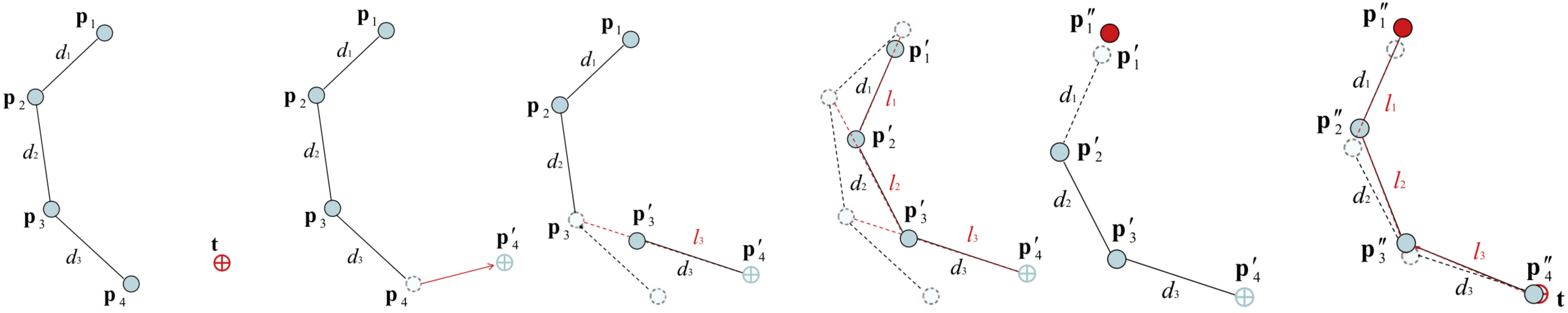
- Forward direction: Match the end-effector target

  propagate changes toward previous position to match bones' length.

- Backward direction: Match the starting position

  propagate changes toward following positions to match bones' length.

[A fast iterative solver for the Inverse Kinematics problem. A. Aristidou. Graphical Models 2011.]



Inverse Kinematics

Example

Synthesizing and controling skeleton animation

Blending skeleton animation

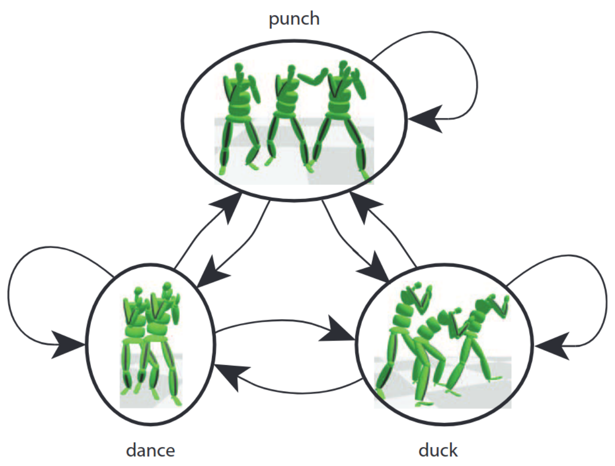
- Pre-store several looping animation
- Blend between animation for transition

three.js - Skeletal Animation Blending (model from realitymeltdown.com)

camera orbit/zoom/pan with left/middle/right mouse button
Note: crossfades are possible with blend weights being set to (1,0,0), (0,1,0) or (0,0,1)

Your graphics card does not seem to support WebGL.
Find out how to get it here.

Motion graphs



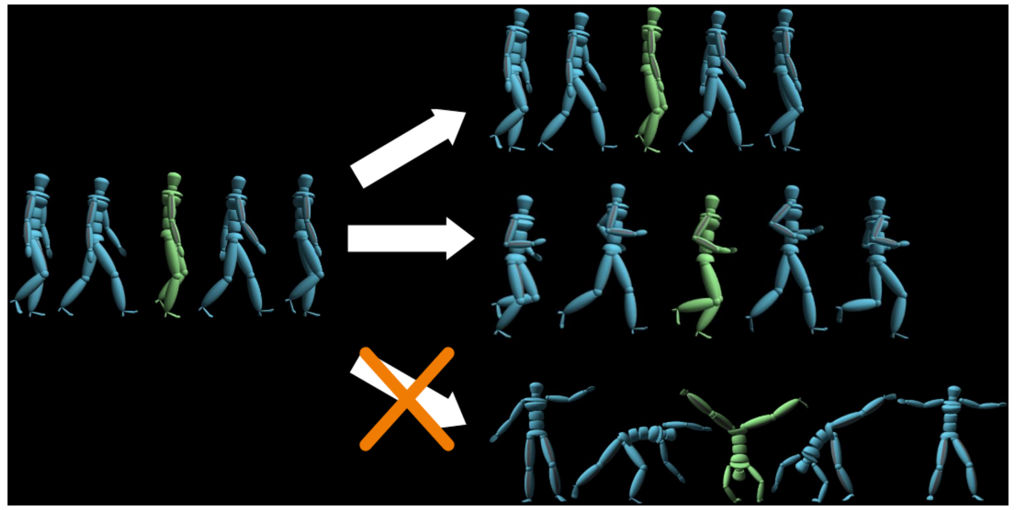
Also called Move Trees (highly used in video games)

- Pre-stores multiple precomputed animation

  Manually design, motion capture, etc

- Find optimal transitions between different motions

- *[Mizuguchi et al., Data driven motion transitions for interactive games, EG short paper, 2001]*
- *[Kovar et al., Motion Graphs, ACM SIGGRAPH 2002]*
- *[Heck and Gleicher, Parametric Motion Graphs, ACM SIGGRAPH 2007]*

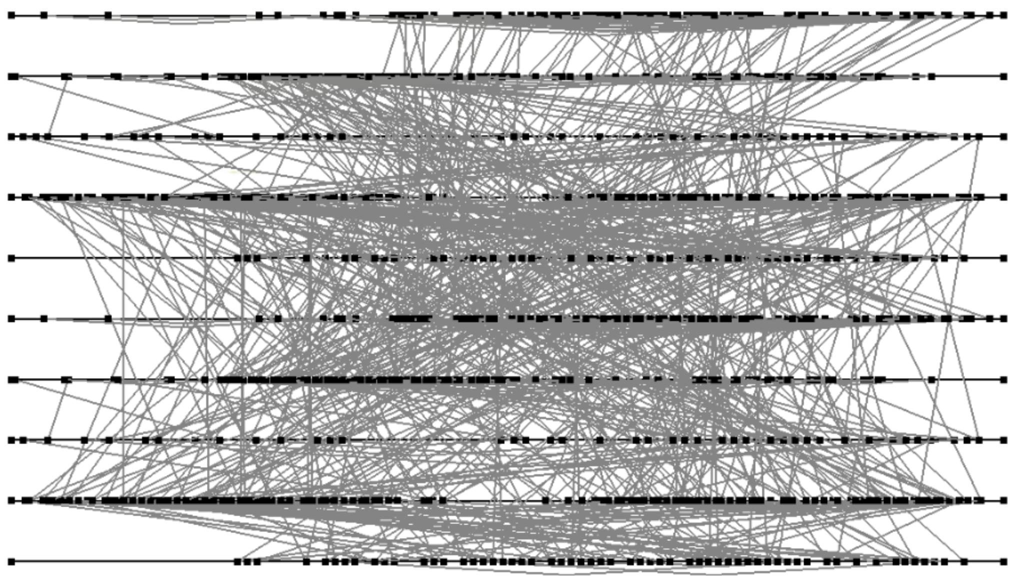


- More recent: Use of "Motion Matching"

  Predict dynamically best possible animation frame

  based on current and desired future state.

[Simon Clavet, Motion Matching and The Road to Next-Gen Animation, GDC 2016]



Controlers

Mix between predefined motions and physics $\rightarrow$ allow user perturbations

1 - Define target $(\theta_{target}(t), \theta'_{target}(t))$

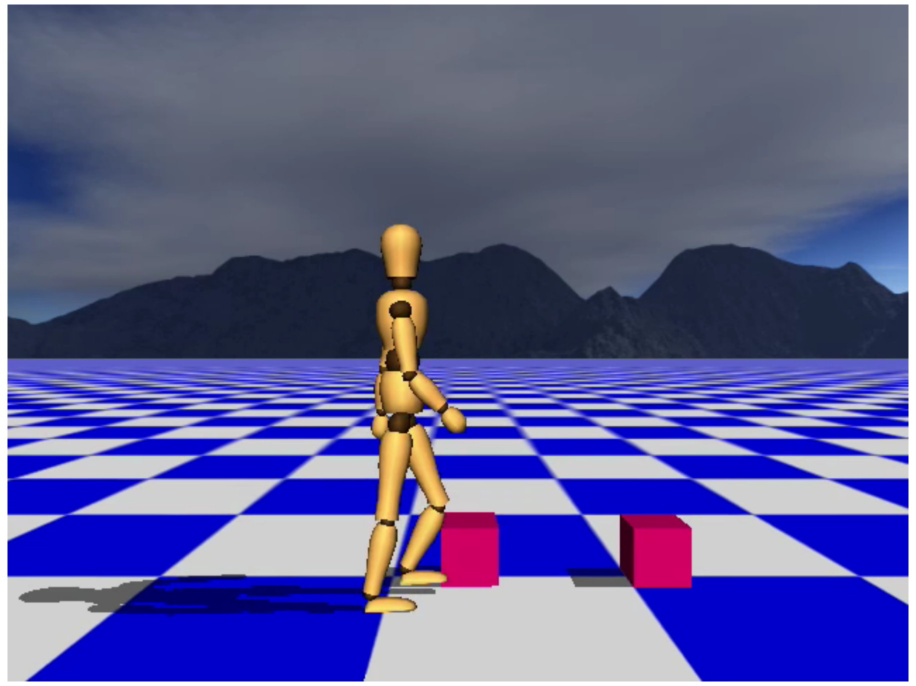
pre-defined finite state machine (Gait model)

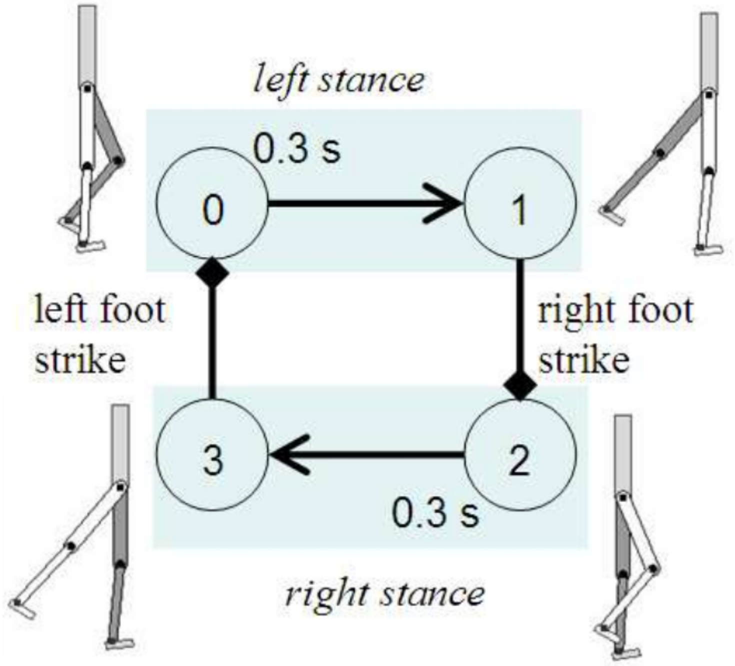
2 - Add user perturbation to the current state

3 - Use proportional derivative controlers to compute joint torque τ

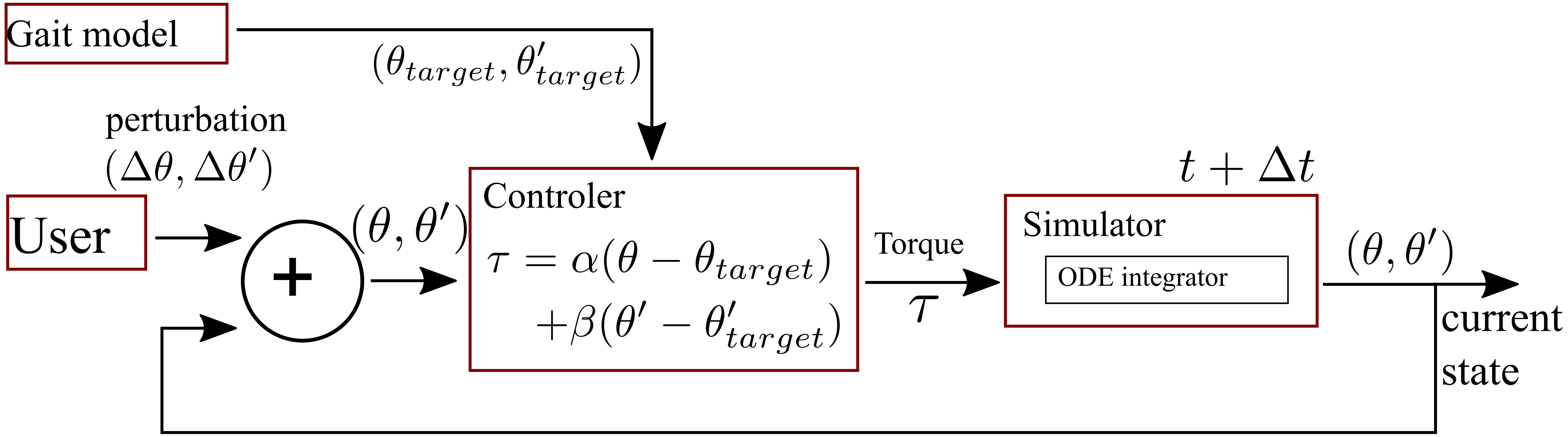
4 - Integrate torque using rigid body simulator

5 - Iterate





Gait model



[*M. Raibert and J. Hodgins. Animation of Dynamic Legged Locomotion, ACM SIGGRAPH 2001*]

[*K. Yin et al., SIMBICON: Simple Biped Locomotion Control, ACM SIGGRAPH 2007*]

Skin deformation

Skeleton based deformation - Skinning

Objective: Deform articulated character

Idea: Use skeleton to control limbs

- Articulations as rotations

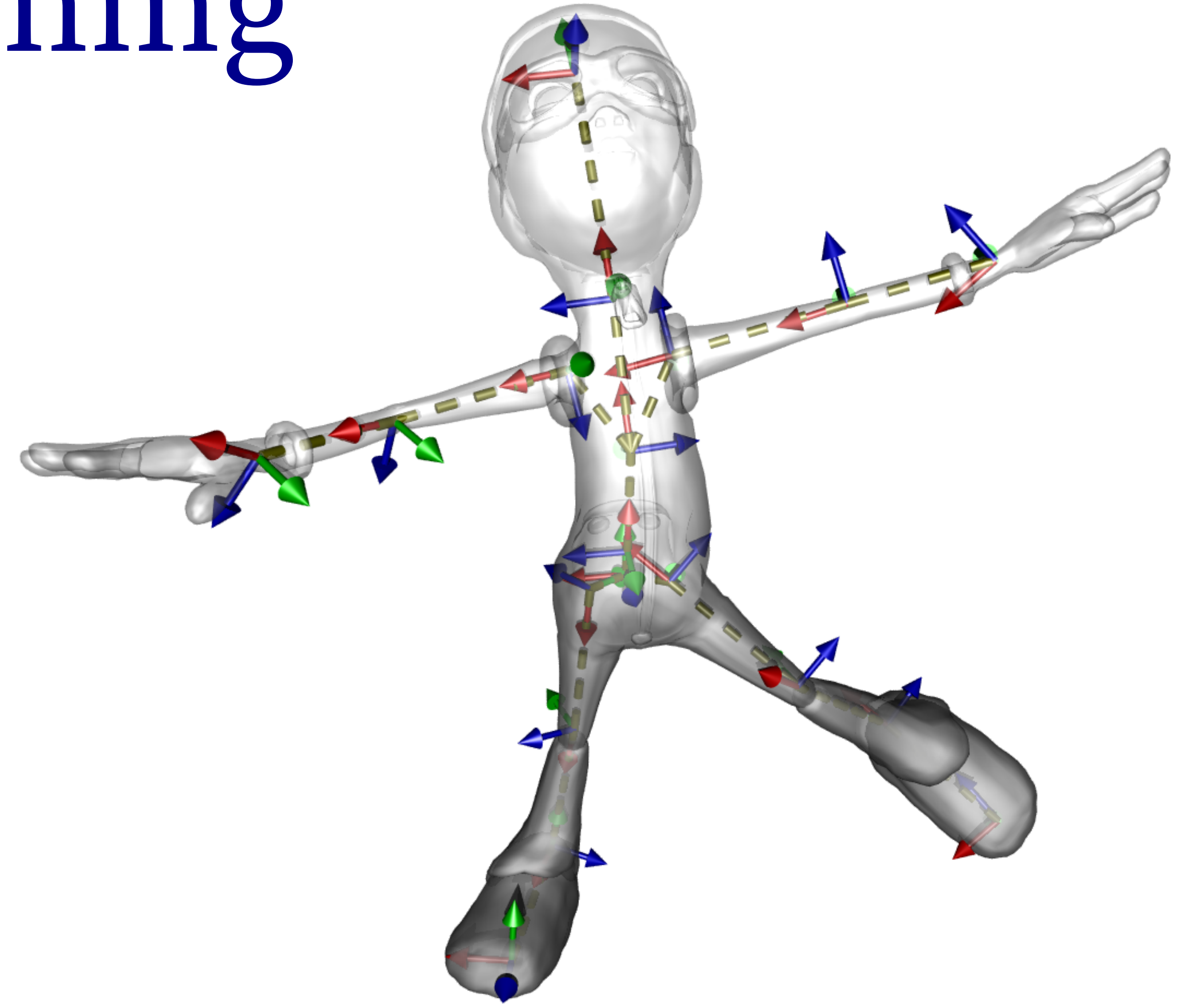
Animation Skeleton

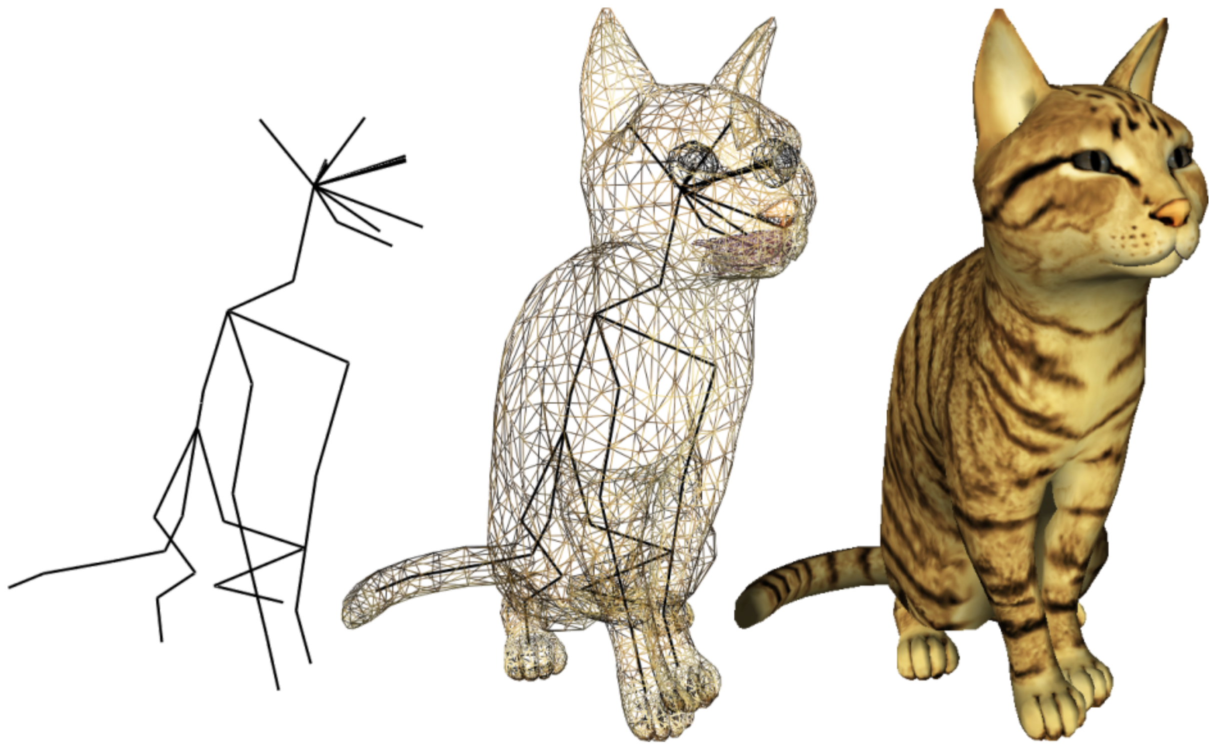
- Set of frames M_i: position, orientation
  - *Describe non-rigid parts of the character (dof)*

Terminology

- **Joint** = A frame M_i
- **Bone** = Segment between two joints

Note: Animation skeleton $\neq$ *Anatomical skeleton*

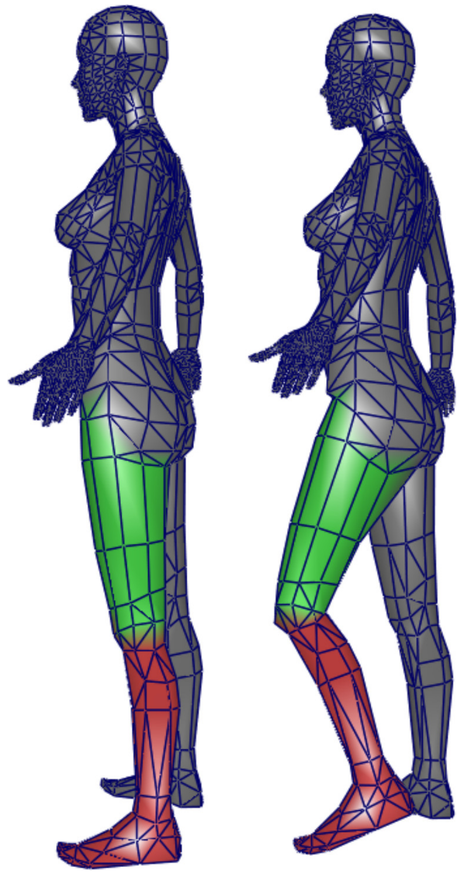


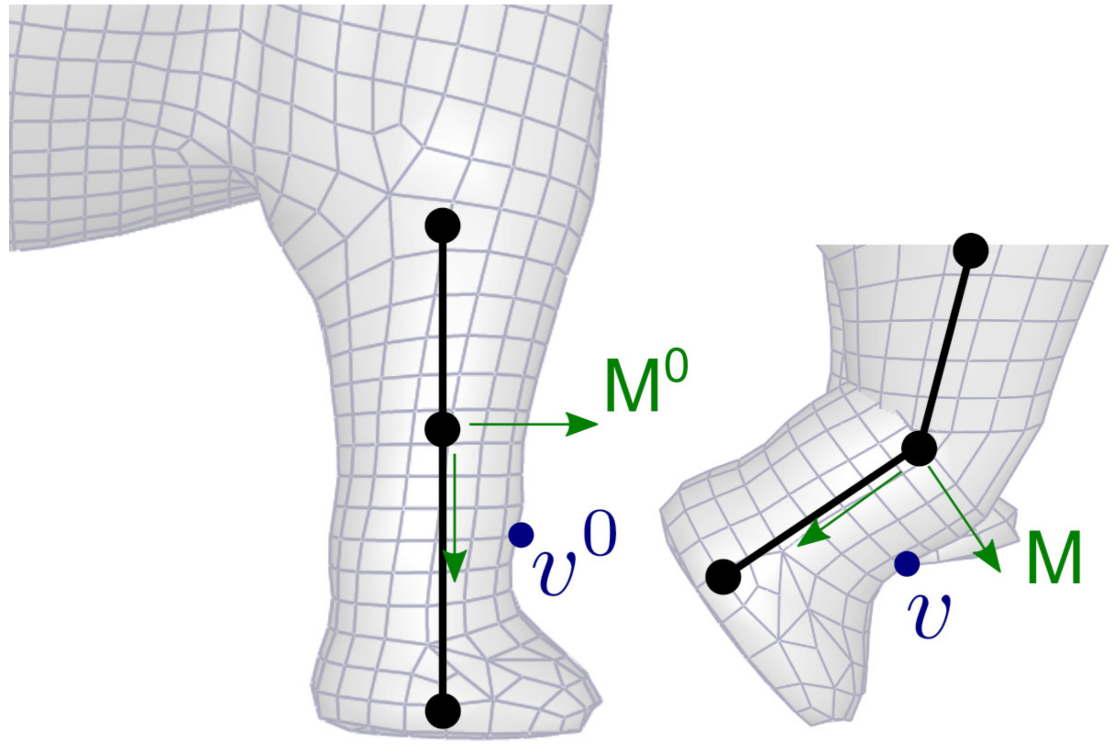


Rigid Skinning

Attach rigidly subset of vertices to specific bones, described by its root joint/frame.

Vertices are following rigid deformation of their associated frame.





Deformation formulation

Consider, at rest pose/initial state/Bind pose

- A frame M^0
- A vertex v^0 attached to this frame

After deformation

- New frame M
- New vertex position v

Question: What are the new coordinates v w/r M, M^0, v^0 ?

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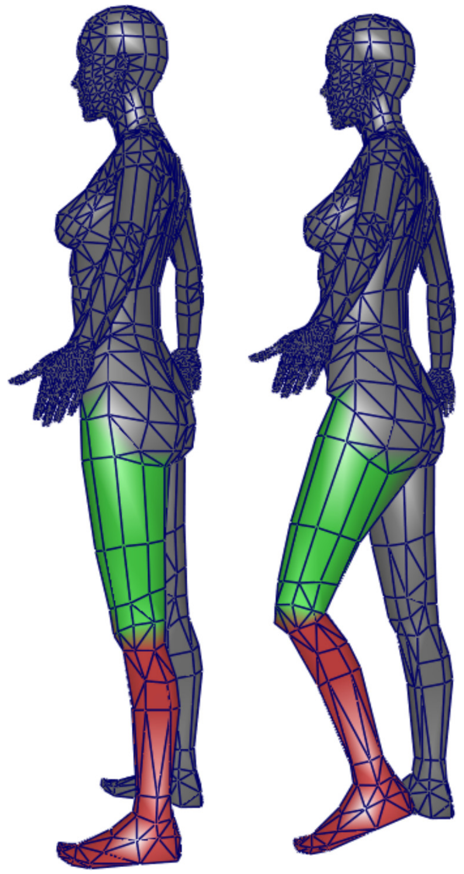

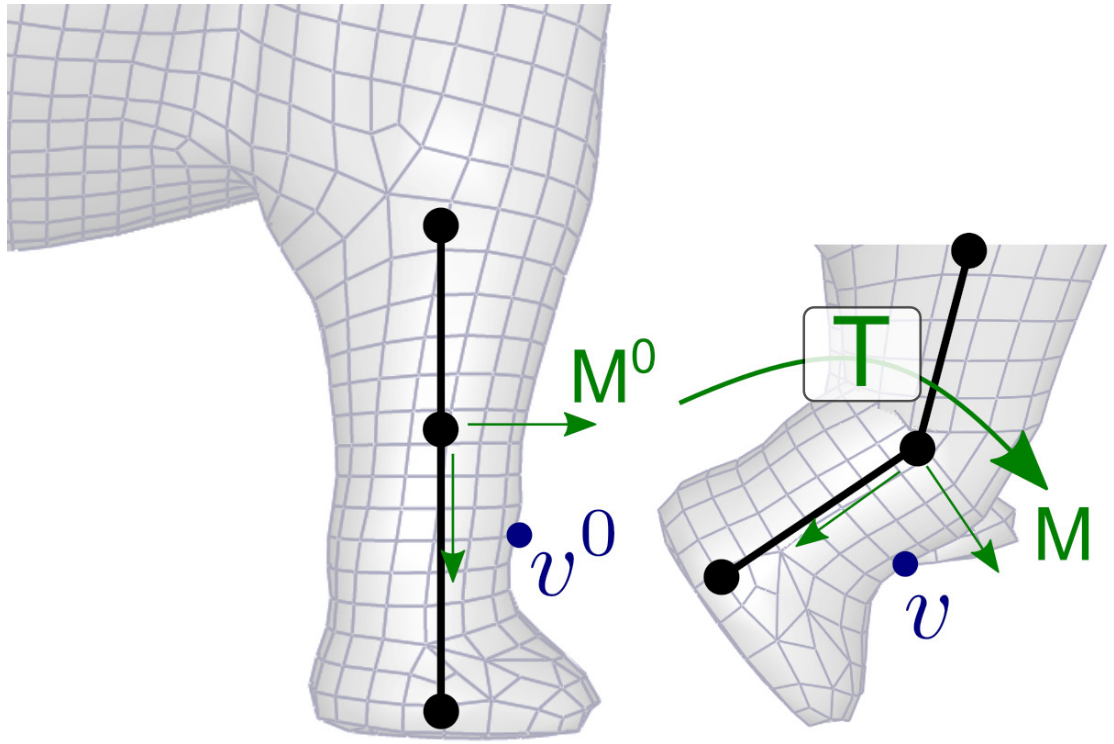

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- New vertex position v

Question: What are the new coordinates v w/r M, M^0, v^0 ?

v^0 and v have similar local coordinates w/r to M^0 and M

$\Rightarrow M^{-1} v = (M^0)^{-1} v_0$

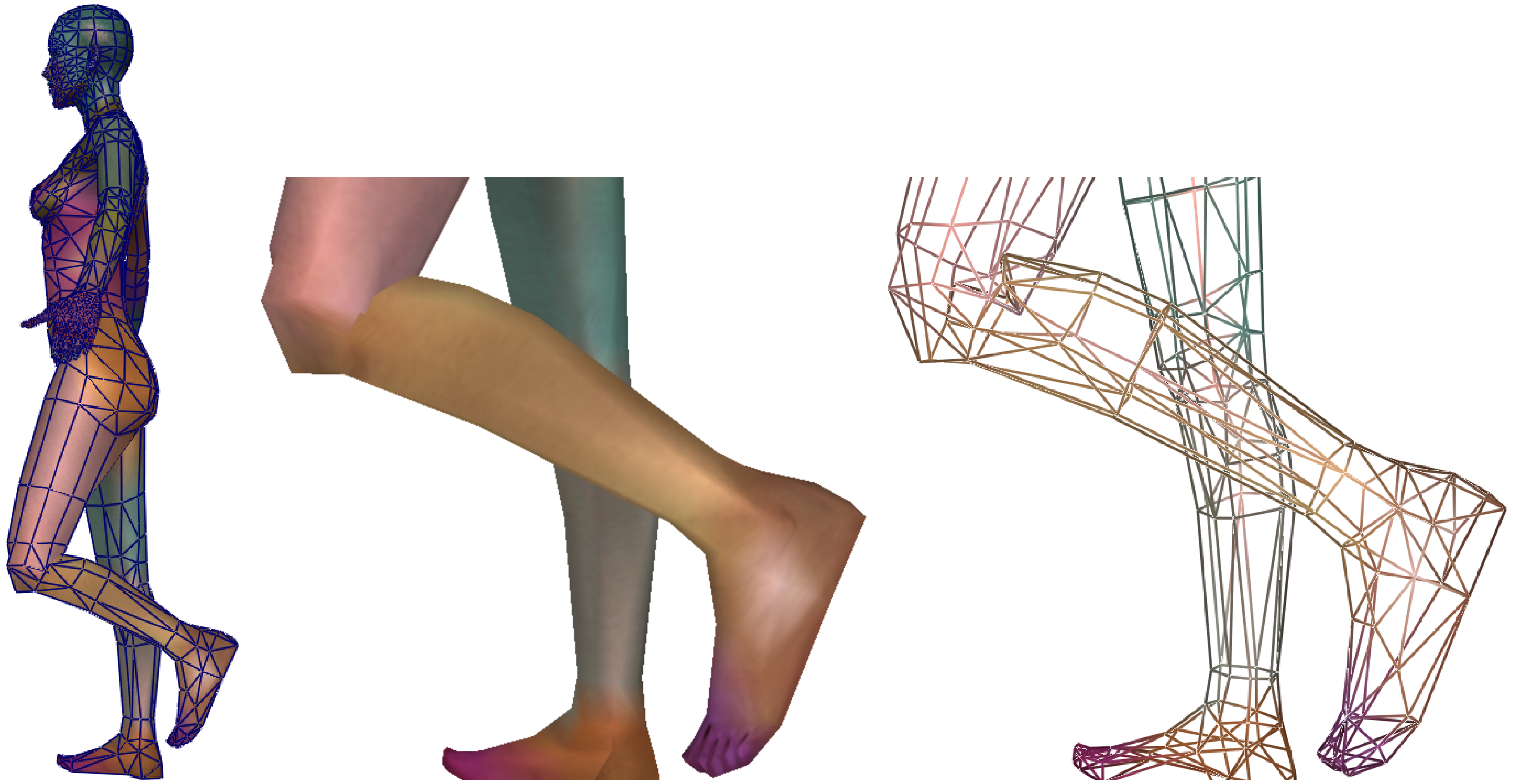
$$\Rightarrow v = M\,(M^0)^{-1} v_0 = T\,v_0$$

Rigid Skinning

(+) Skeleton is easy to build

(+) Skeleton interaction is intuitive to model rigid articulation

(-) Discontinuities/Inter-penetrations



Idea of smooth skinning: Blend discontinuous transformation around articulation

Smooth skinning

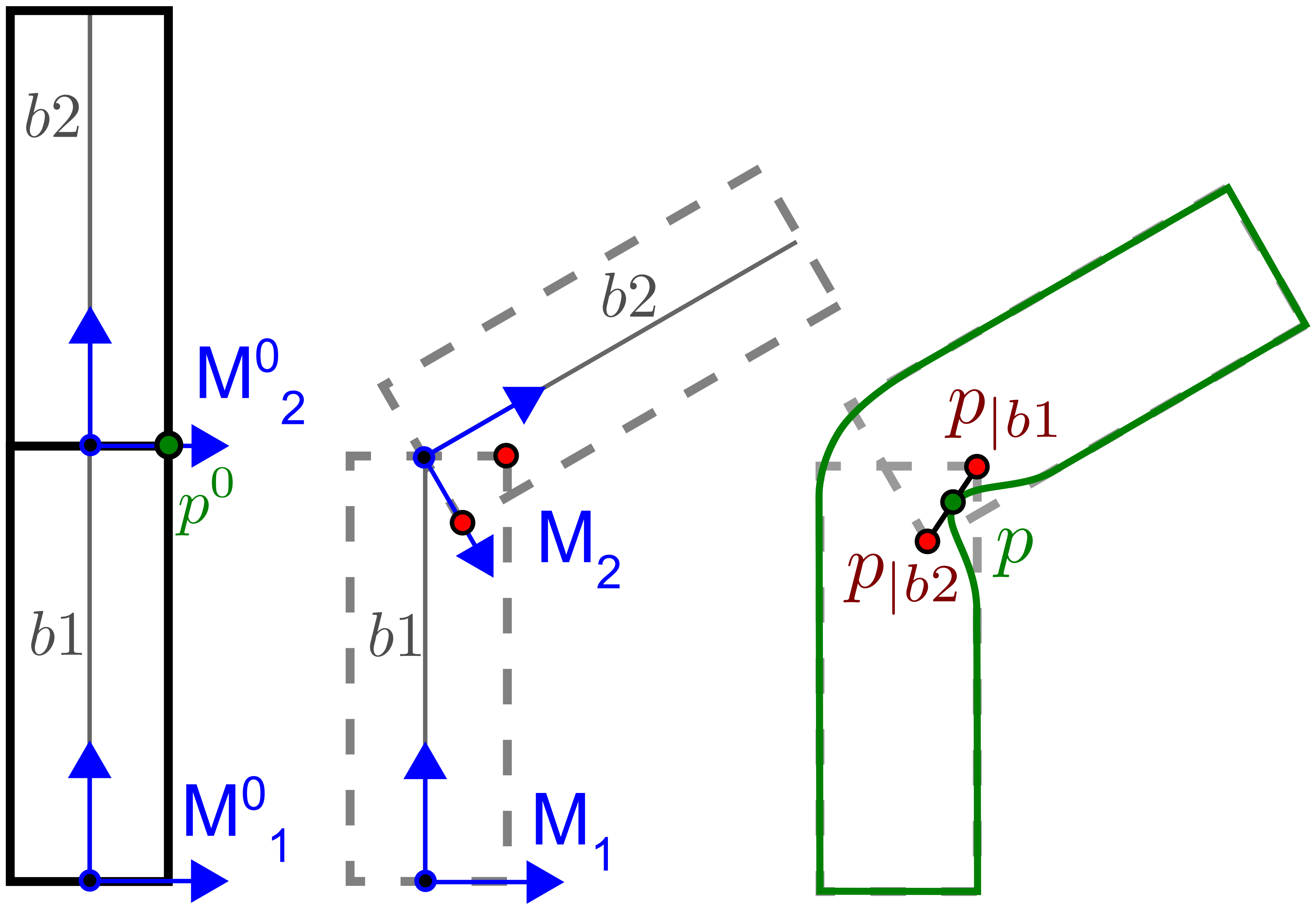
Linear Blend Skinning (LBS): Linear interpolation of positions between associated frames

Example at middle vertex position of a bending cylinder

$$p = 0.5\, p_{|b1} + 0.5\, p_{|b2}$$

$$p = 0.5\, \underbrace{\mathrm{M}_1\, (\mathrm{M}_1^0)^{-1}}_{\mathrm{T}_1}\, p^0 + 0.5\, \underbrace{\mathrm{M}_2\, (\mathrm{M}_2^0)^{-1}}_{\mathrm{T}_2}\, p^0$$

$$p = (0.5\, \mathrm{T}_1 + 0.5\, \mathrm{T}_2)\, p^0$$



Smooth skinning

Linear Blend Skinning (LBS): Linear interpolation of positions between associated frames

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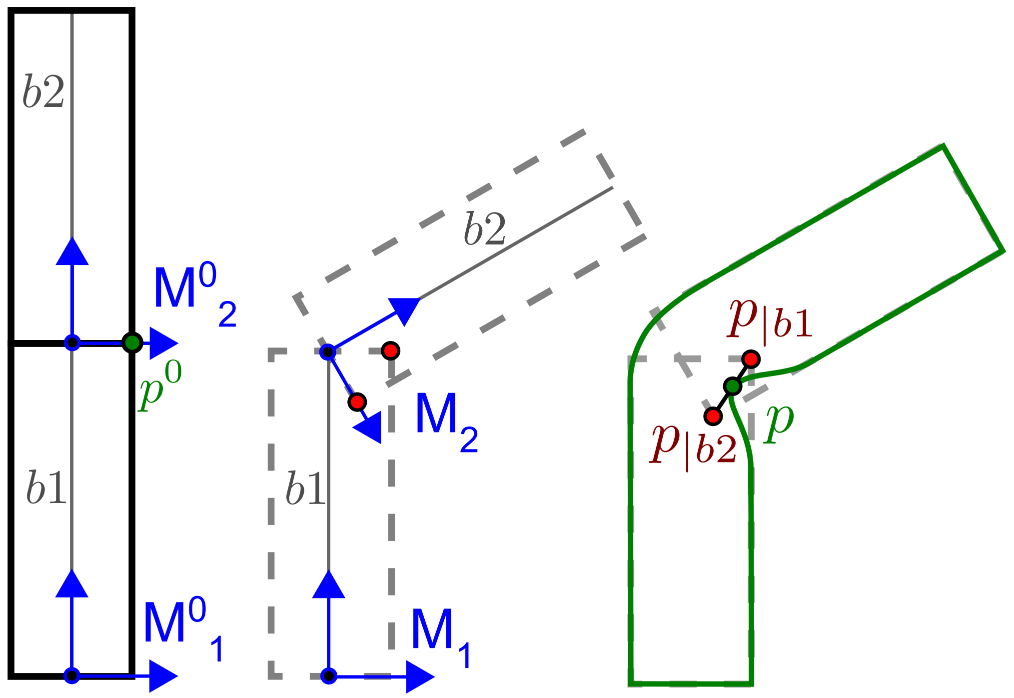
$$p = (0.5\, \mathrm{T}_1 + 0.5\, \mathrm{T}_2)\, p^0$$



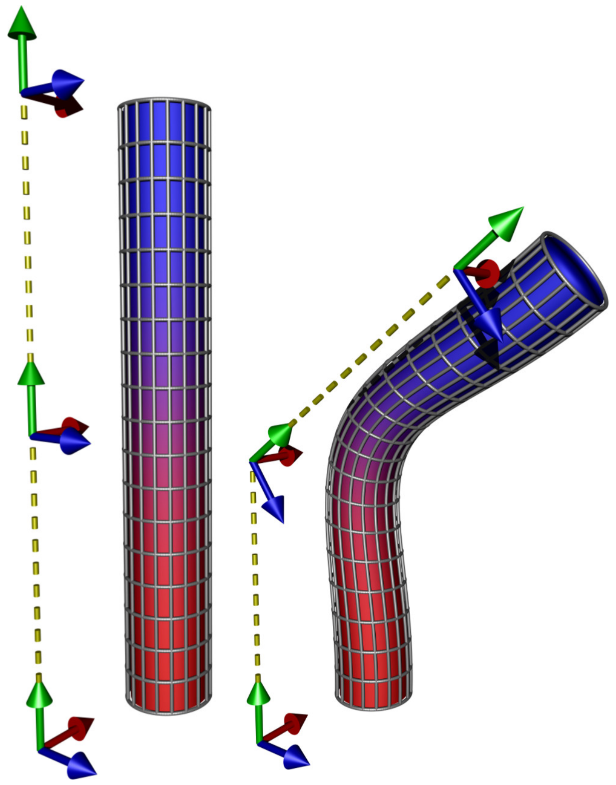
Can be generalized to arbitrary interpolation between two bones

$$p = \alpha\, p_{|b1} + (1-\alpha)\, p_{|b2} = (\alpha \mathrm{T}_1 + (1-\alpha)\, \mathrm{T}_2)\; p^0$$

α: skinning weights

Can be generalized to any number of bones

$$p = \sum_{j=0}^{N-1} \alpha_j\; p_{|bj} = \left(\sum_{j=0}^{N-1} \alpha_j\, \mathrm{T}_j \right)\; p^0 \;,\quad \sum_j \alpha_j = 1$$

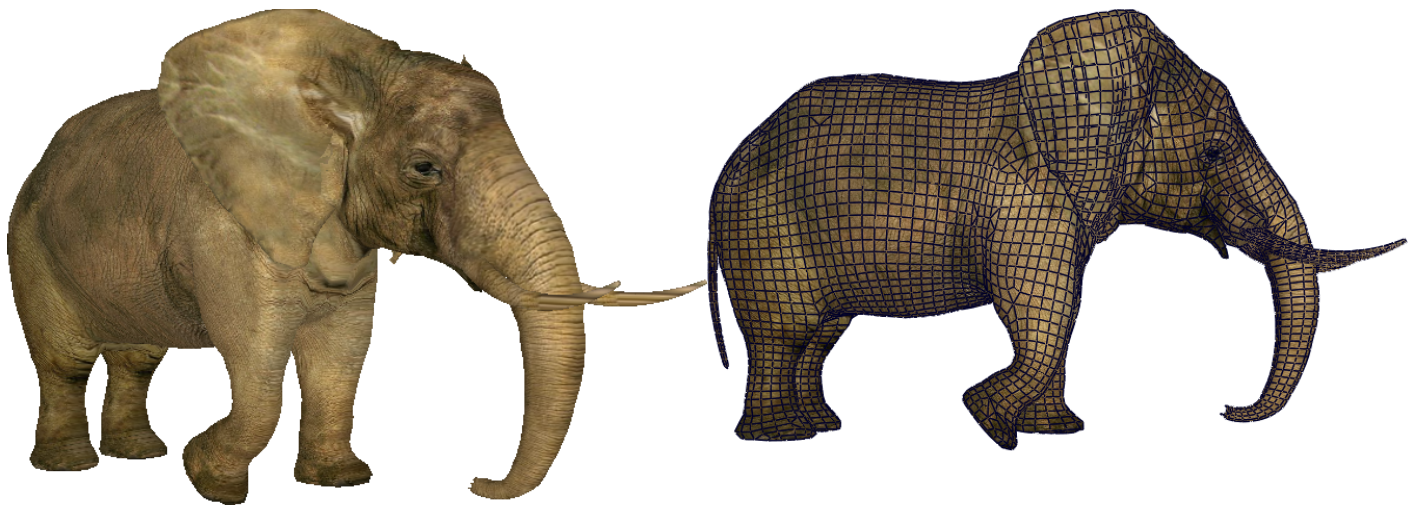


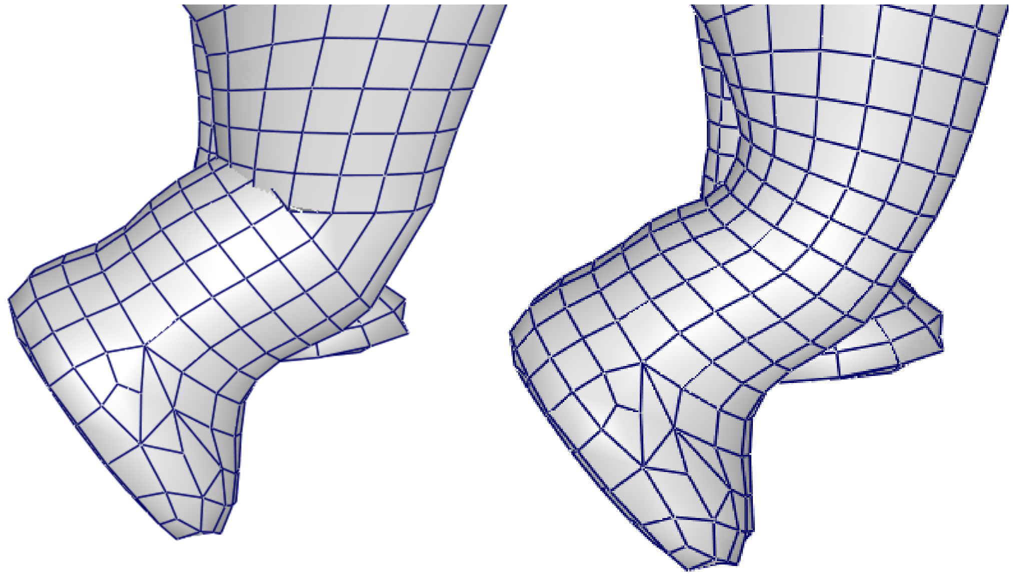
Smooth skinning - Summary

$$p_i = \left(\sum_{j=0}^{N-1} \alpha_{ij} \, \mathrm{T}_j \right) p_i^0 = \left(\sum_{j=0}^{N-1} \alpha_{ij} \, \mathrm{M}_j \, (\mathrm{M}_j^0)^{-1} \right) p_i^0$$

$\forall j \,,\ \alpha_{ij} \in [0, 1]$, and $\sum_{j=0}^{N-1} \alpha_{ij} = 1$

M_j^0: Bind Pose





The current **standard** for almost all articulated character deformations

- Intuitive deformation
- Controlable shape (*through weights*)
- Fast to compute (GPU compatible)
  matrix average, multiplication matrix-vector

$\Rightarrow$ Heavily used in Animation cinema & Video Game

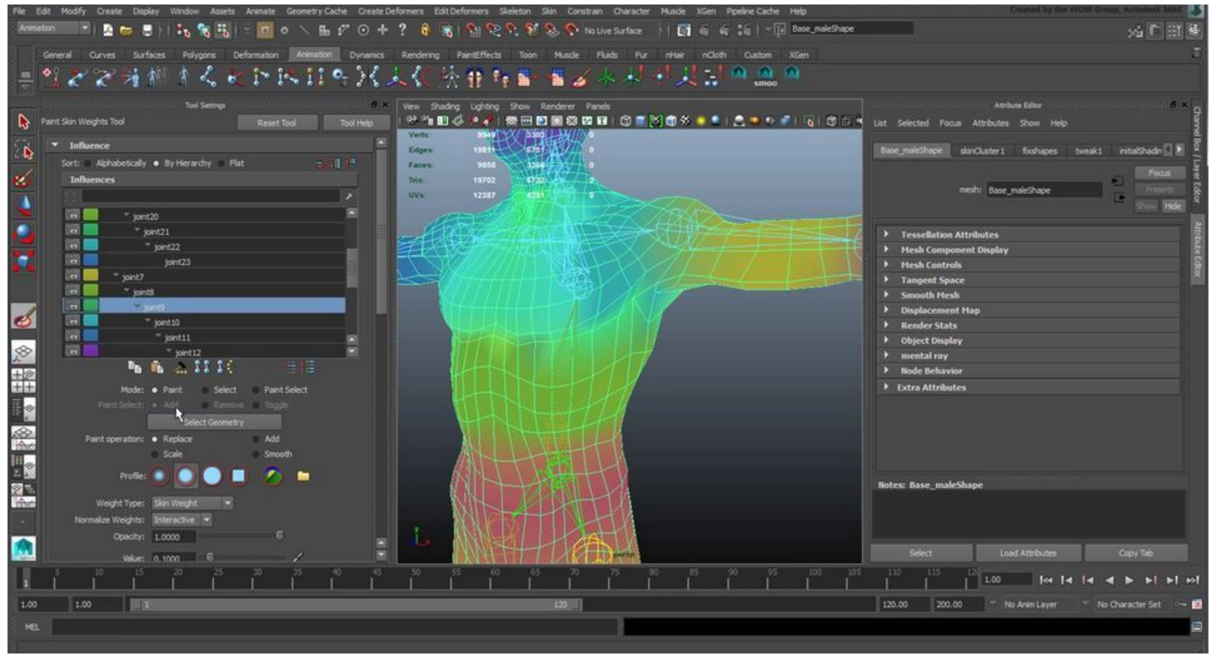
[Joint-Dependent Local Deformations for Hand Animation and Object Grasping. Nadia Magnenat-Thalmann, Rochard Laperière, Daniel Thalmann. Graphics Interface, 1988]

[Over My Dead, Polygonal Body. Jeff Lander. Game Developer Magazine, 1998]

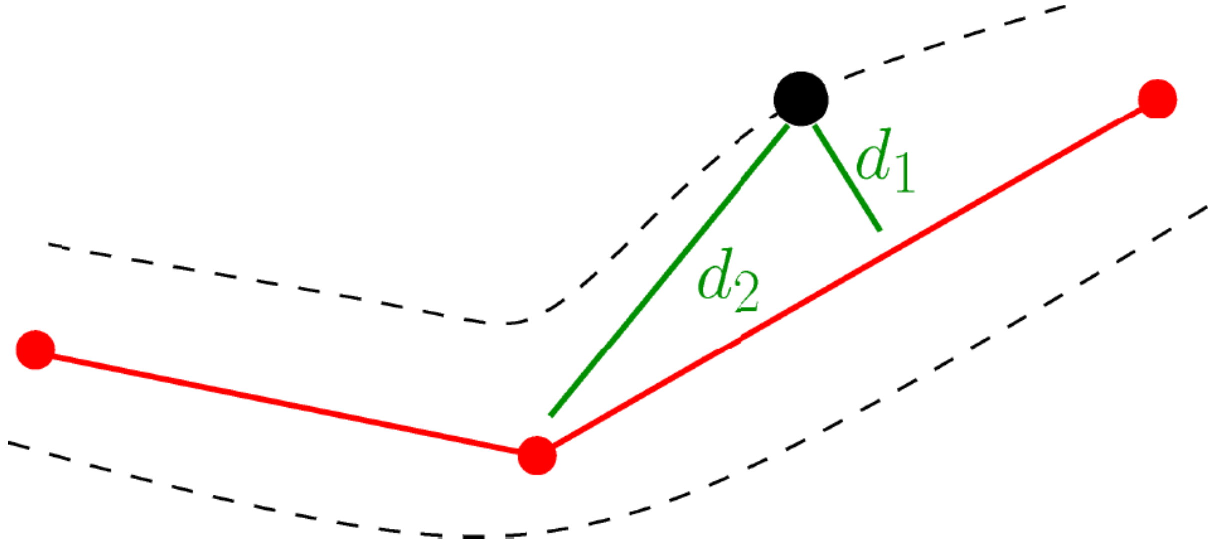
Skinning weights

How to generate skinning weights ?

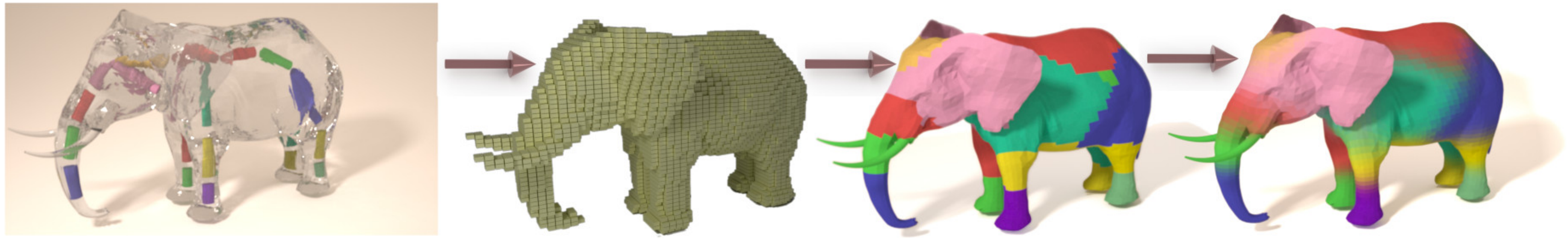
- Paint them manually
- Automatic computation



ex. Using cartesian distances: $\alpha_1 = d_1^{-1}/(d_1^{-1} + d_2^{-1})$



Or using diffusion on the volume/surface



Rigging: Associating bones and skinning weights (or any animation handle) to mesh parts

Skinning: File Format

Unfortunately few standard open format to store skinning animation data

- Main open format: Collada (XML), glTF (JSON)
- Common software related formats: FBX, Blend, 3DS, ...

krissie Maya 7.0 | ColladaMaya v2.04 | FCollada v1.14 Collada Maya Export Options:
bakeTransforms=0;exportPolygonMeshes=1;bakeLighting=0;isSampling=0;
curveConstrainSampling=0;exportCameraAsLookat=0; exportLights=0;exportCameras=1;exportJointsAndSkin=1;
exportAnimations=1;exportTriangles=0;exportInvisibleNodes=0;
exportNormals=1;exportTexCoords=1;exportVertexColors=0;exportTangents=0;
exportTexTangents=0;exportConstraints=0;exportPhysics=0;exportXRefs=0;
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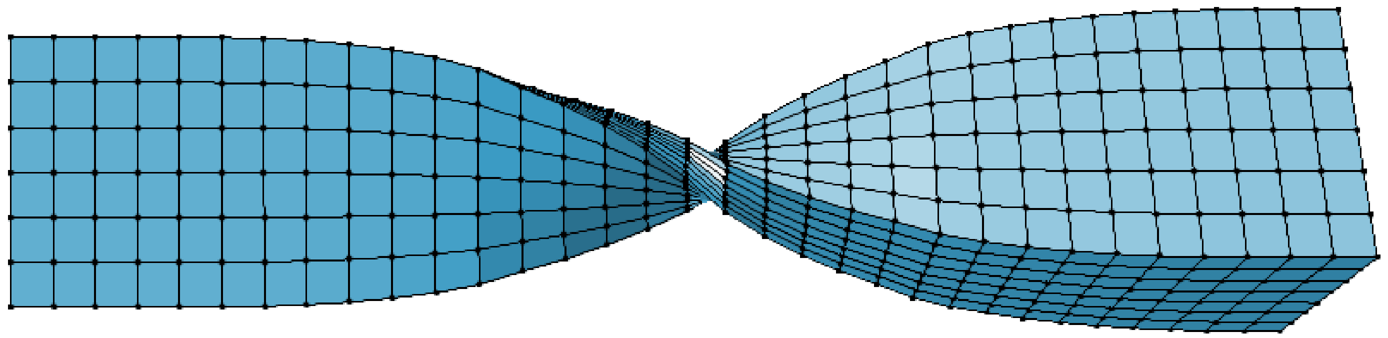
Linear Blend Skinning - Limitations

- Non-trivial rigging settings
- Artifacts for large rotations: Candy wrapper, Collapsing ellbow

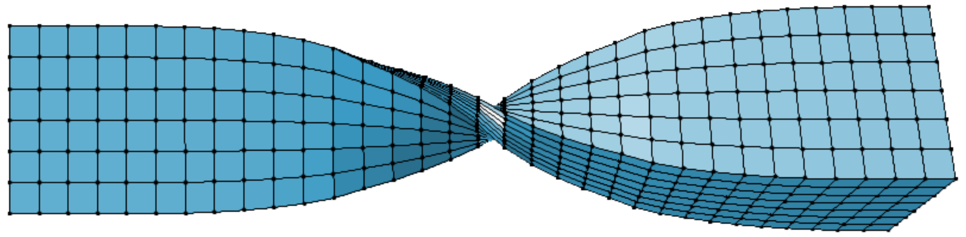
Candy wrapper

Collapsing elbow

Linear blending between rigid transformation matrices



Skinning improvement



Avoid linear blending b/w affine transform matrices

First idea: Split rigid transformation matrices in
- rotation part: blend using quaternions (solve candy wrapper)
- translation part: blend linearily

But doesn't work for general deformation: Arbitrary center of rotation
Rotation and translations are treated sepa[redacted]

Possibility to compute an optimal center of rotation at each frame
[Spherical Blend Skinning: A Real-time Deformation of Articulated Models. L. Kavan, J. Zara. I3D 2005.]

Skinning improvement: Dual Quaternion

Second idea: Use of **dual quaternion**

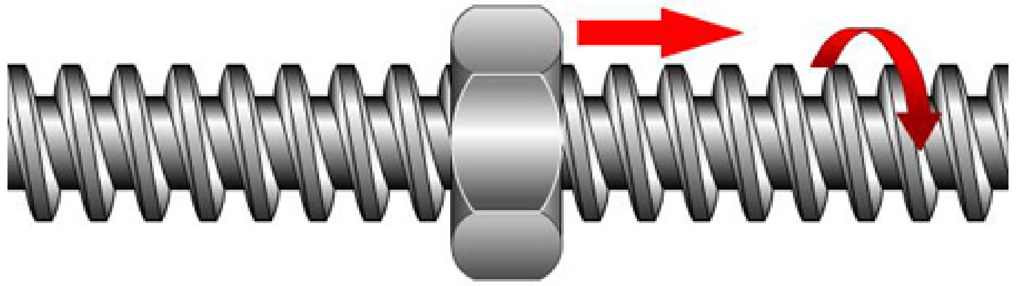
$\hat{q} = q_0 + \epsilon\, q_\epsilon \;, \quad \epsilon$ dual element.

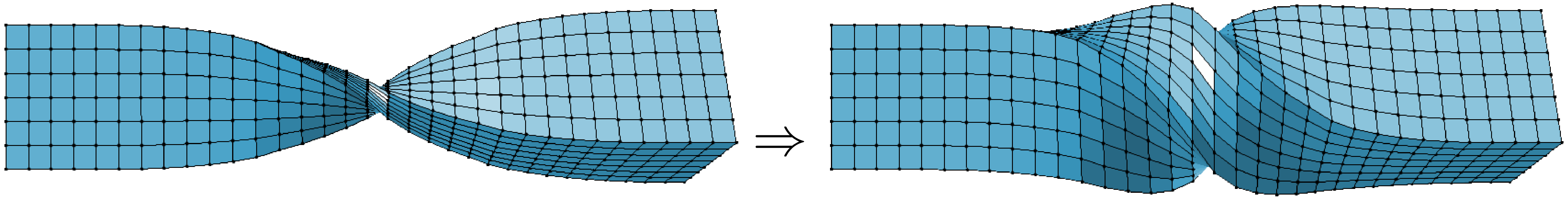
Dual quaternion = generalization of quaternion to handle *rigid transformation*

Rotation + translation

Unit dual quaternion models rigid transformation as **screw motions**

= *rotation about an axis followed by a translation in the direction of this axis*





LBS $\Rightarrow$ *DQS*

Dual number and dual quaternion

Dual number $a = a_0 + \epsilon a_\epsilon$

Dual element ϵ is nilpotent : $\epsilon \neq 0, \epsilon^2 = 0$

ϵ commonly used to model infinitesimal quantity (ex. automatic differentiation)

Dual quaternion $\hat{q}$ = Generalization of quaternion to dual numbers

$\hat{q} = q_0 + \epsilon\, q_\epsilon$

- q_0: pure rotation component
- q_ϵ: encodes translation component (dual part)

Given a unit quaternion q_0, and a translation $t = (t_x, t_y, t_z)$, the associated unit dual quaternion is

$$\boxed{\hat{q} = q_0 + \frac{\epsilon}{2}\, q_t\, q_0} \qquad q_t = (t_x, t_y, t_z, 0)$$

Unit dual quaternion ($||\hat{q}|| = 1$) describe the set of rigid transformation as screw motion.

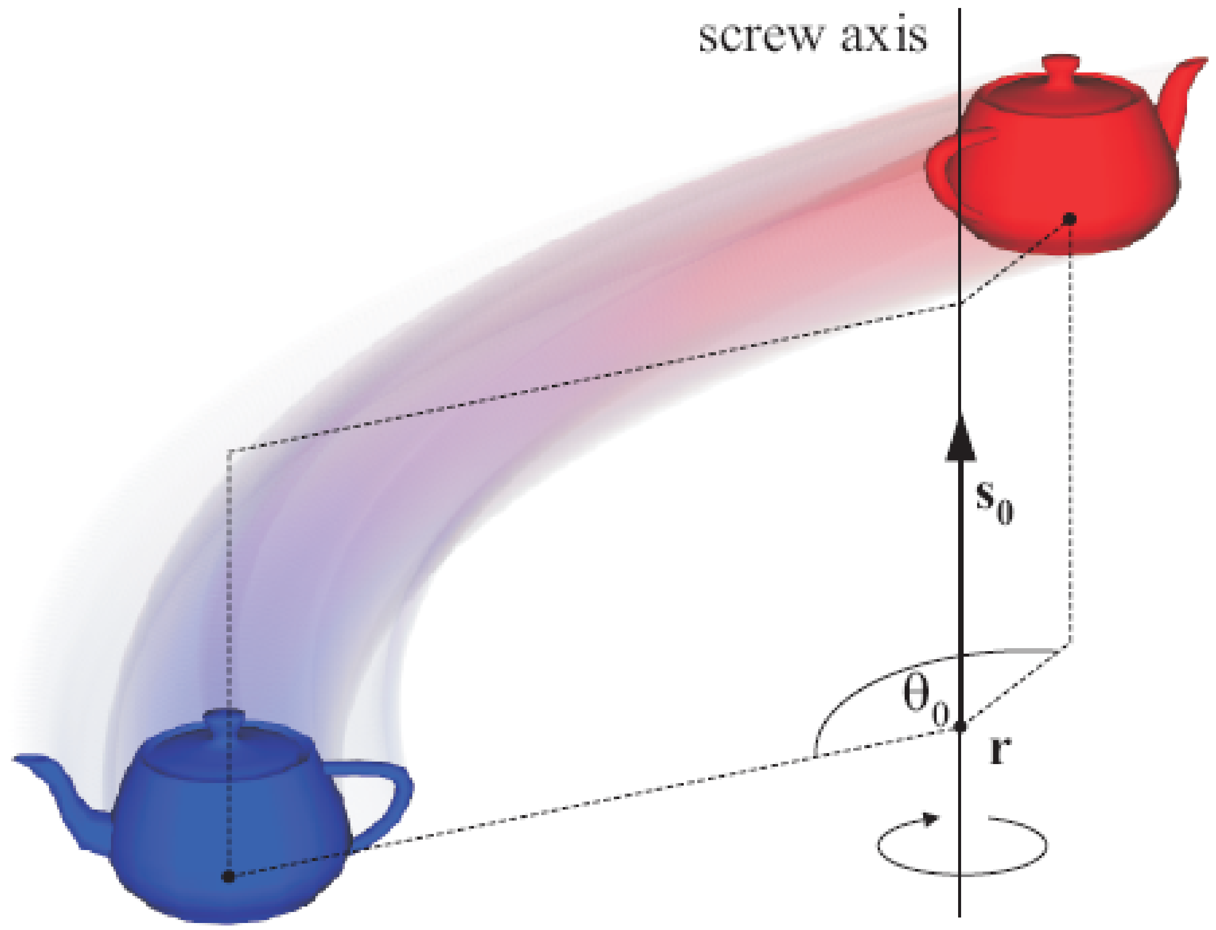
Axis-angle representation with dual quaternion

Similarly to quaternion: "angle/axis" correspondance

- $\hat{q} = \cos(\hat{\theta}/2) + \hat{n}\,\sin(\hat{\theta}/2)$

- $\hat{\theta} = \theta_0 + \epsilon\theta_\epsilon$
  - θ_0: angle of rotation
  - $\theta_\epsilon = t \cdot n_0$: quantity of translation along n_0

- $\hat{n} = n_0 + \epsilon\, n_\epsilon$
  - n_0: axis of rotation
  - $n_\epsilon = \frac{1}{2}\left((n_0 \times t)\, cotan(\theta_0/2) + t\right) \times n_0$: called the moment of the rotation axis.



Convert dual quaterion to rotation/translation

Given a non-unit dual quaternion as input $\hat{q}' = q'_0 + \epsilon q'_\epsilon$

How to compute the components of $\hat{q}'/\|\hat{q}'\| = \hat{q} = q_0 + \epsilon q_\epsilon$?

$\Rightarrow$ Force the parameterization in rotation-translation:

$$\hat{q} = q_0 + \frac{\epsilon}{2} q_t\, q_0 \;, \quad q_t = (t_x, t_y, t_z, 0)$$

First, normalize with the non dual component: $\hat{q}'/\|q'_0\|$

$$\Rightarrow \boxed{q_0 = q'_0/\|q'_0\|} \;, \boxed{q_\epsilon = q'_\epsilon/\|q'_0\|}$$

Second, enforce the parameterization of the dual component: $\frac{1}{2} q_t\, q_0 = q_\epsilon$

$\Rightarrow \boxed{q_t = 2\, q_\epsilon\, q_0^\star}$, $q_0^\star$ conjugate of q_0

Dual Quaternion Skinning (DQS)

1- Encode rigid transformation (q^i, t^i) into dual quaternion

$$\hat{q}^i = q_0^i + \frac{\epsilon}{2} q_t^i \, q_0^i \,, \quad q_t^i = (t_x^i, t_y^i, t_z^i, 0)$$

2- Compute blending in the dual quaternion space (ScLERP)

$$\hat{q}' = \sum_i \omega_i \, \hat{q}^i = q_0' + \epsilon \, q_\epsilon'$$

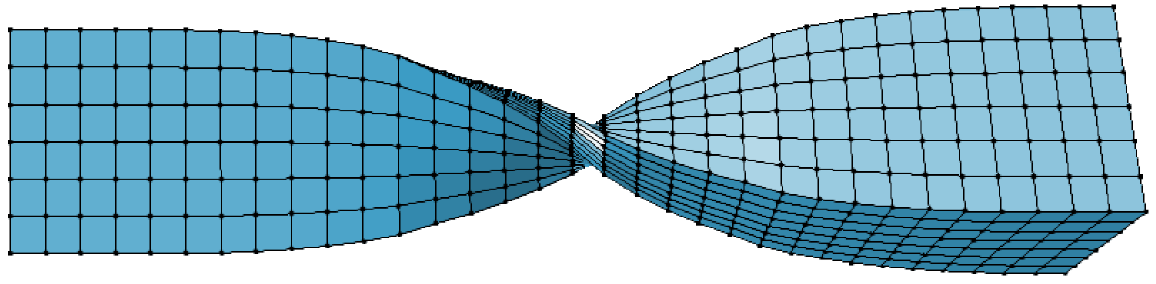
3- Extract components (q, t) from $\hat{q}'$

- $q_0 = q_0' / \|q_0'\|, \; q_\epsilon = q_\epsilon' / \|q_0'\|$
- $(t_x, t_y, t_z, 0) = 2 \, q_\epsilon \, q_0^\star$

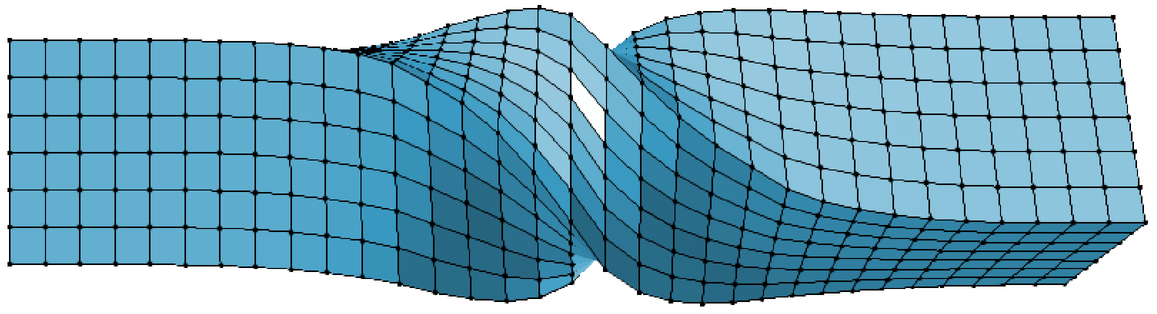
$q_0^\star$: conjugate of q_0.

4- Apply finaly the transformation (q, t) to position p_0

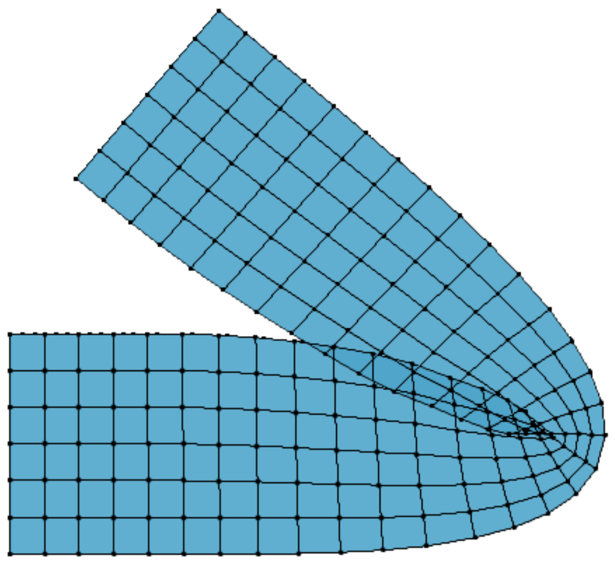
[Skinning with Dual Quaternions. Kavan et al. I3D, 2007]



LBS



DQS



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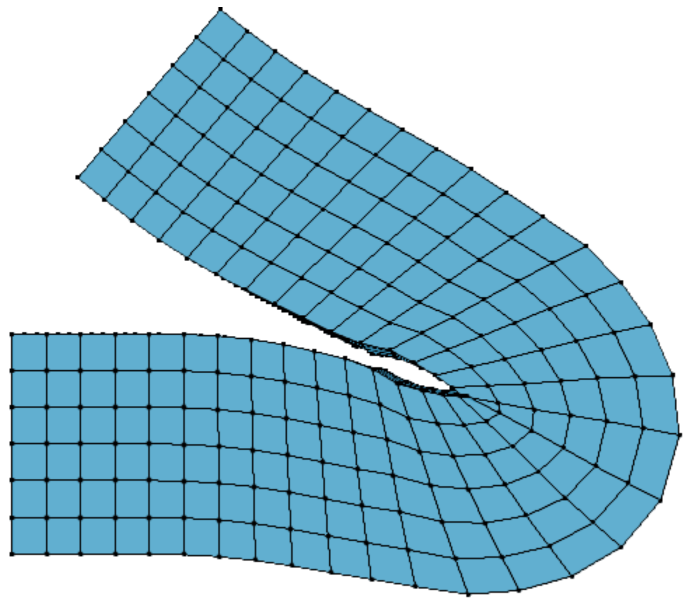
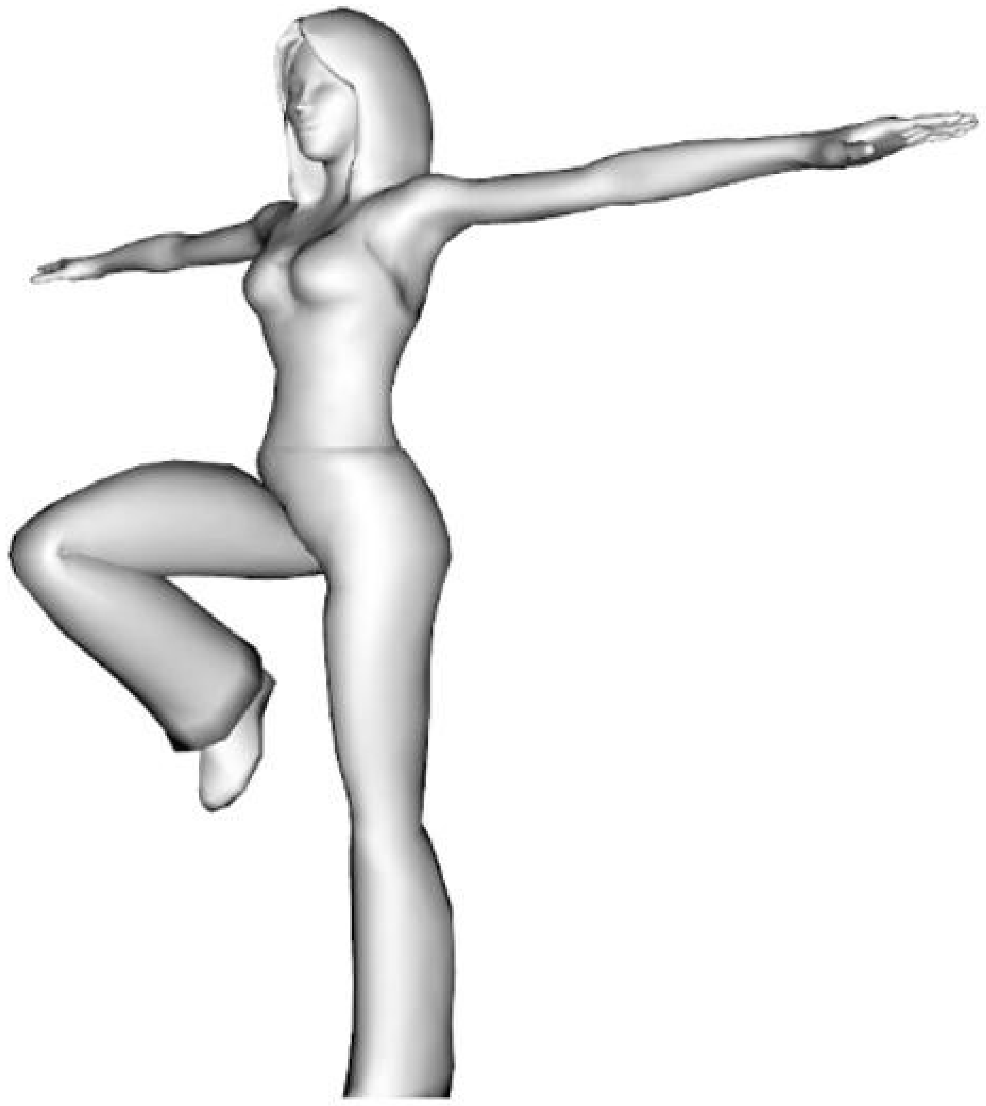


DQS

Dual Quaternion VS LBS

- Dual quaternion
  - (+) Fully solves *candy wrapper* artifact
  - (+) Almost as efficient as LBS
  - (-) May create artificial/unwanted bulge
    - *Not always prefered to LBS*
    - *Both solutions (LBS, DQS) are proposed in standard tools*



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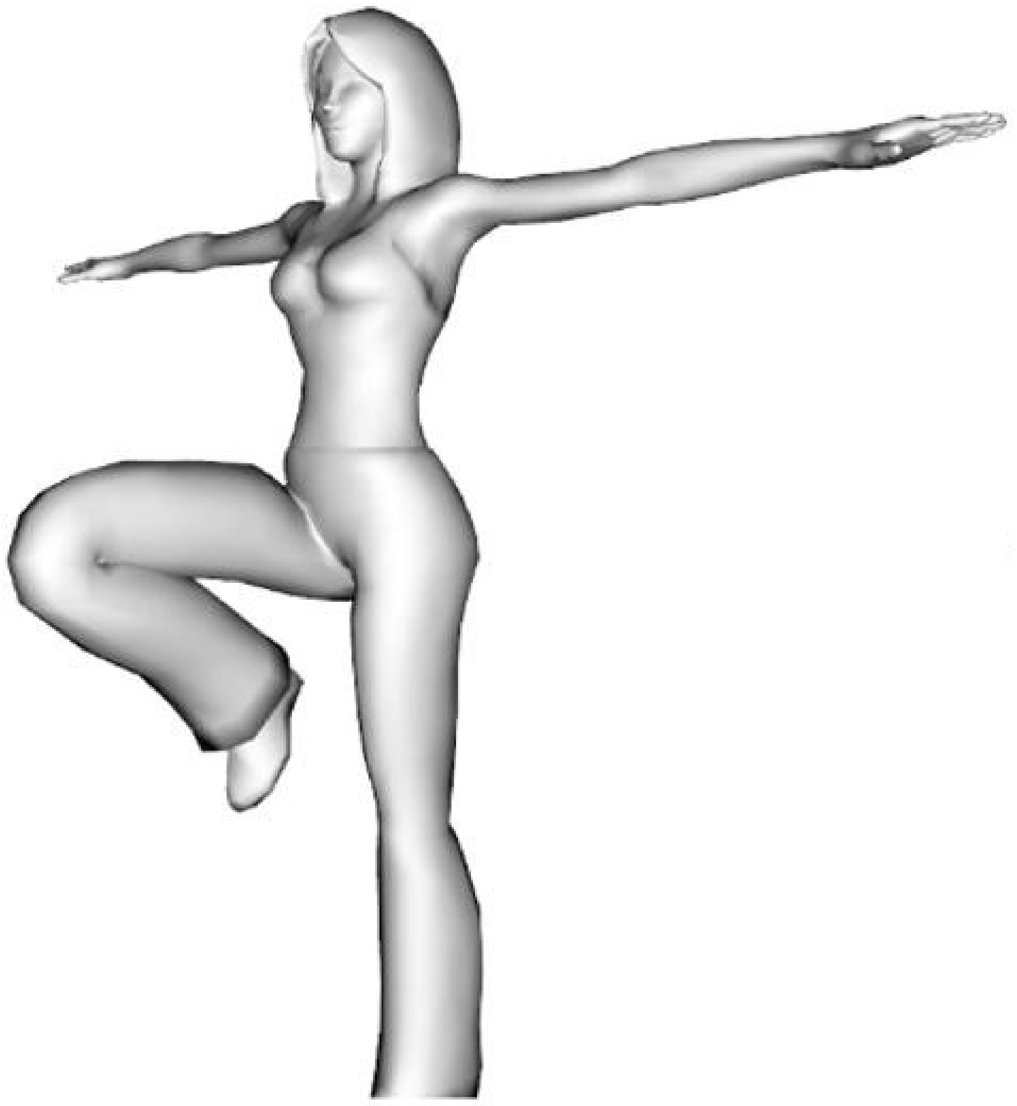


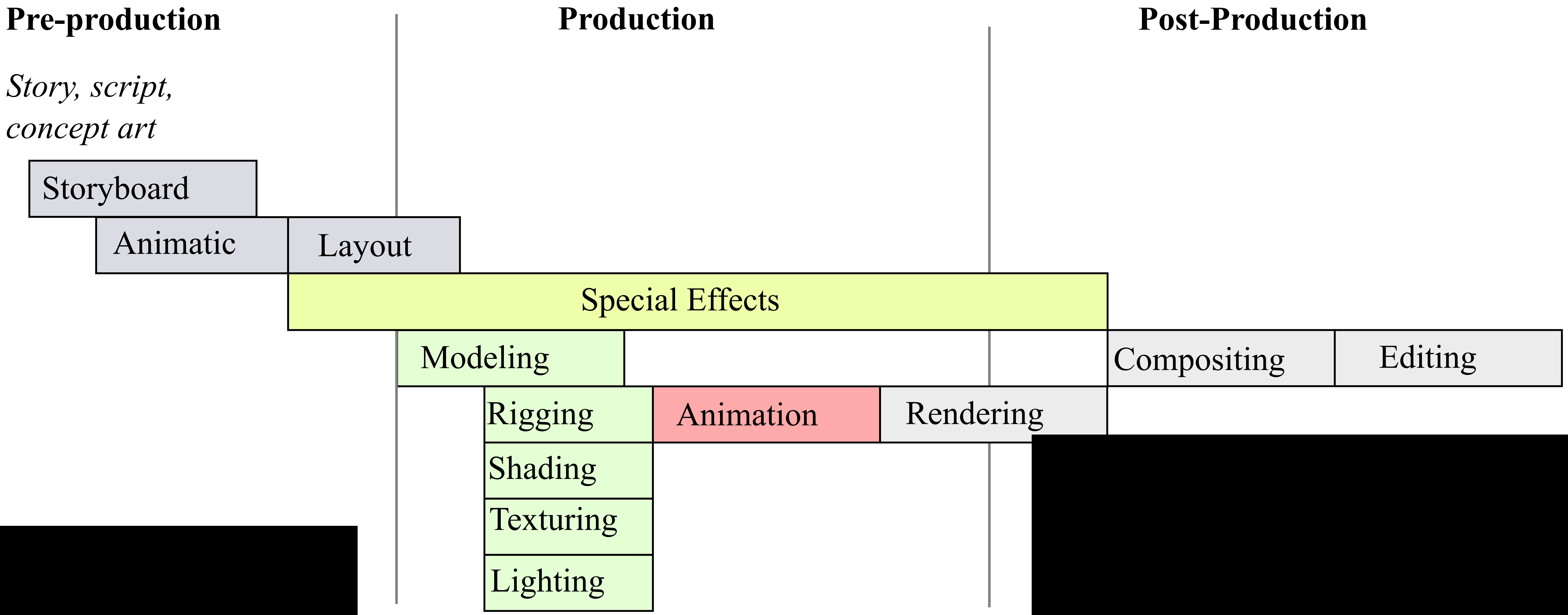
DQS

Production Pipeline

Case of Animation Cinema production

Production Pipeline

Fundamental structure for VFX/animation movie production.



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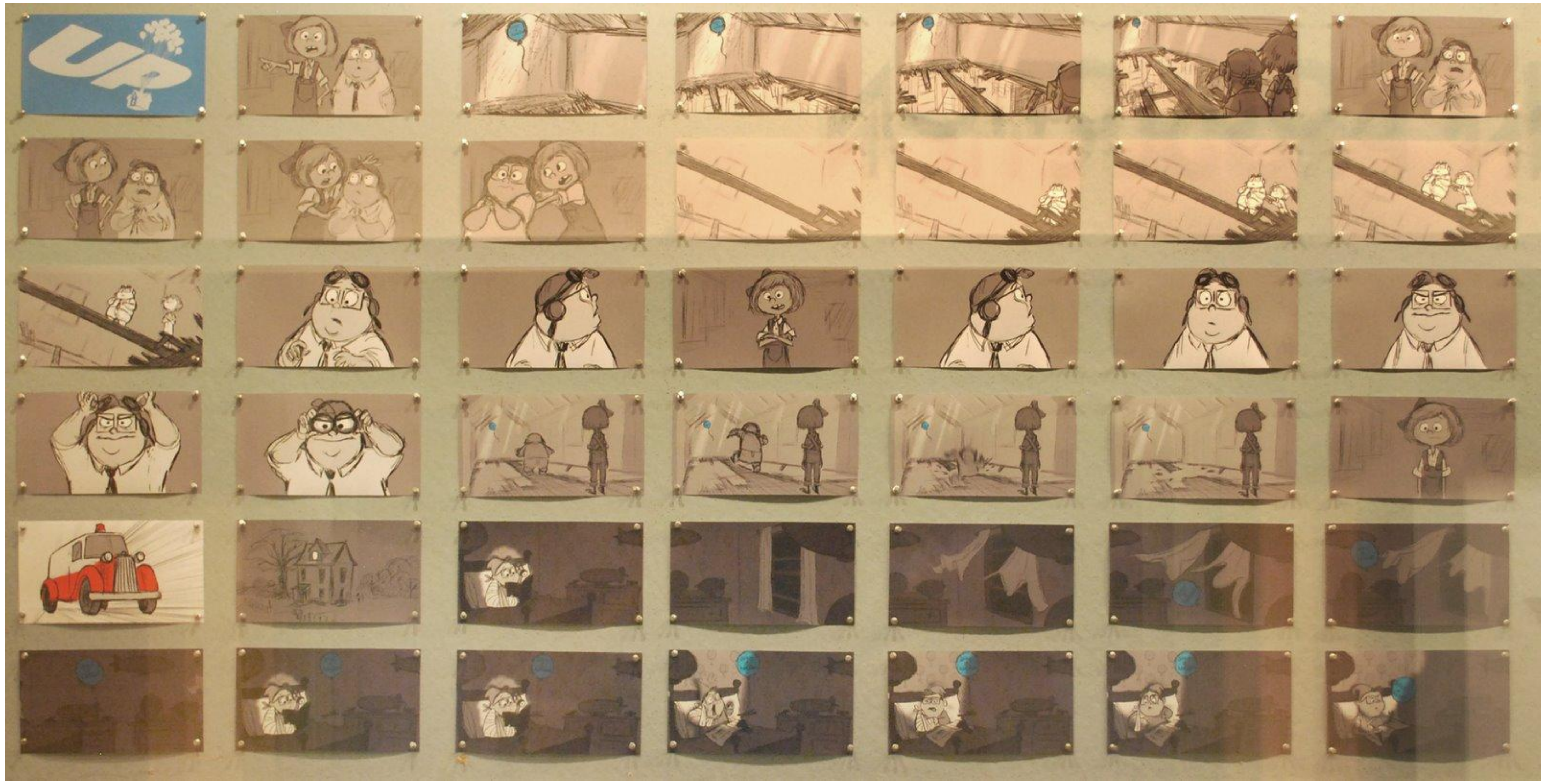
[redacted]

Story-board



Few 2D drawings: express the story

Before mostly non-technical - artistic/creative based
Curently increase of Storytelling-related researches in CG
ex. Disney Research Studios

Animatic

≃ Animated story-board, Various format

Rough sense of timing, visual, action: details not necessarily followed precisely in the final version.



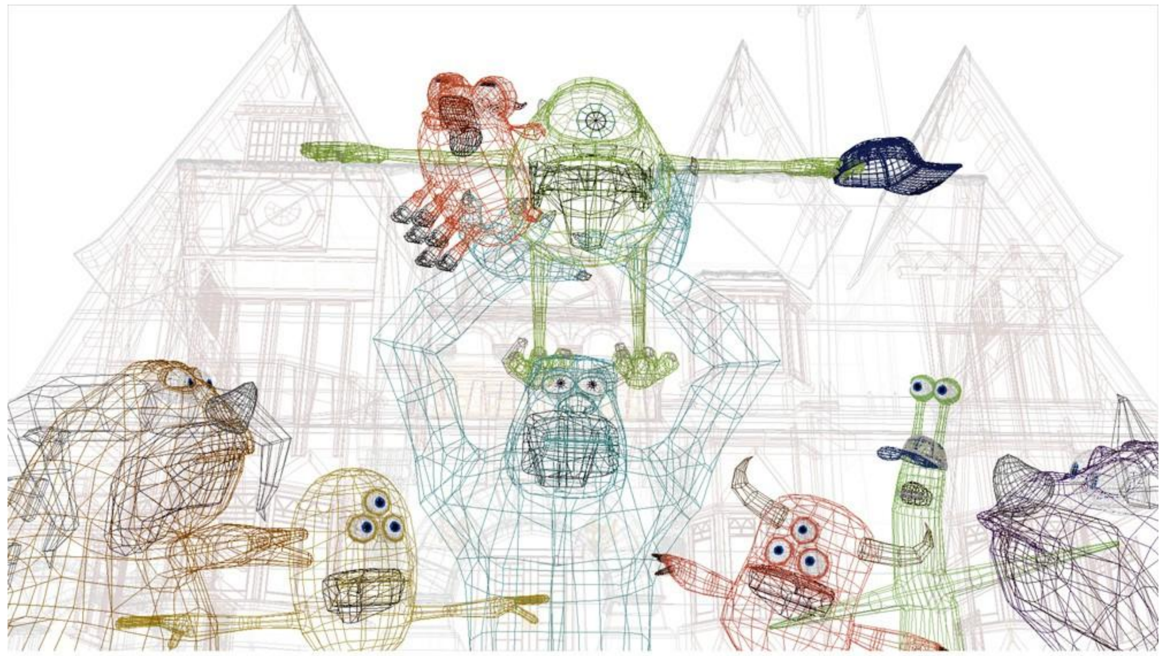


Layout: Moving into 3D

1st step: Rough 3D modeling and placement of

- Camera: visual field, perspective
  3D much more constrained than 2D drawings
- Shape volumes, continuity
  No details: face, etc.
  Choice between 3D/2D elements

"MONSTERS UNIVERSITY" Progression Image 1 of 6: STORY



"MONSTERS UNIVERSITY" Progression Image 3 of 6: MODELING

"MONSTERS UNIVERSITY" Progression Image 4 of 6: LAYOUT

3D Modeling

In production

- Polygonal mesh modeling

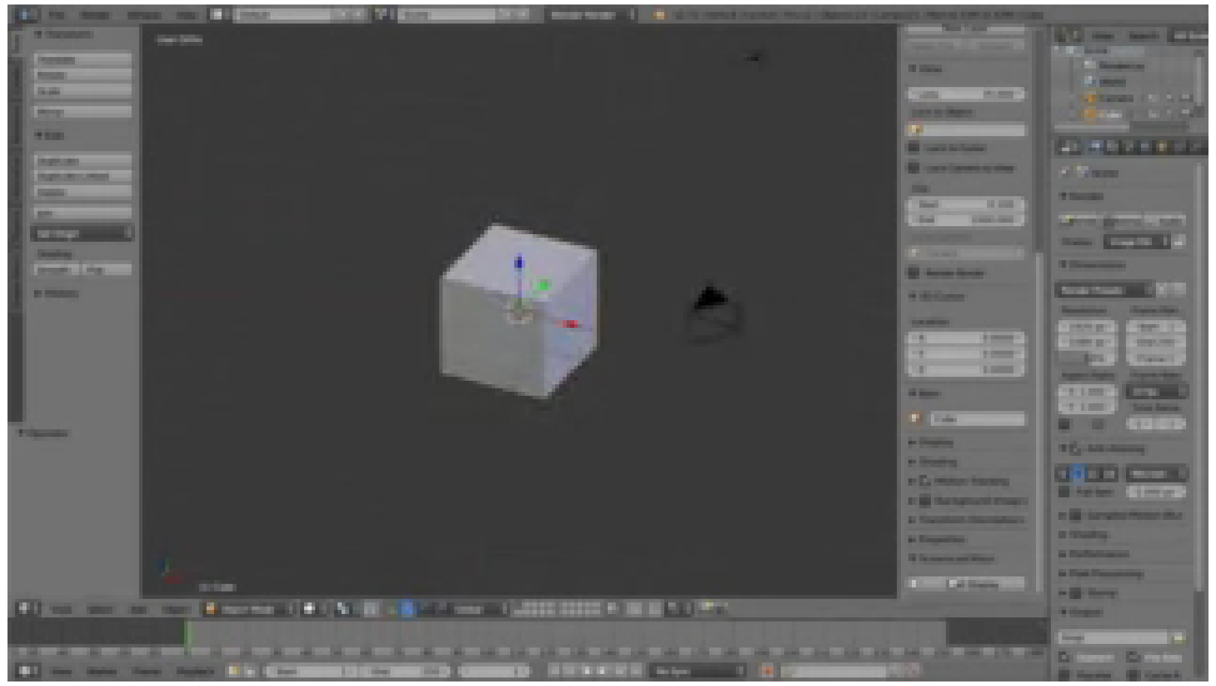
  Coarse to fine approach

  1. Low res modeling (extrusion)

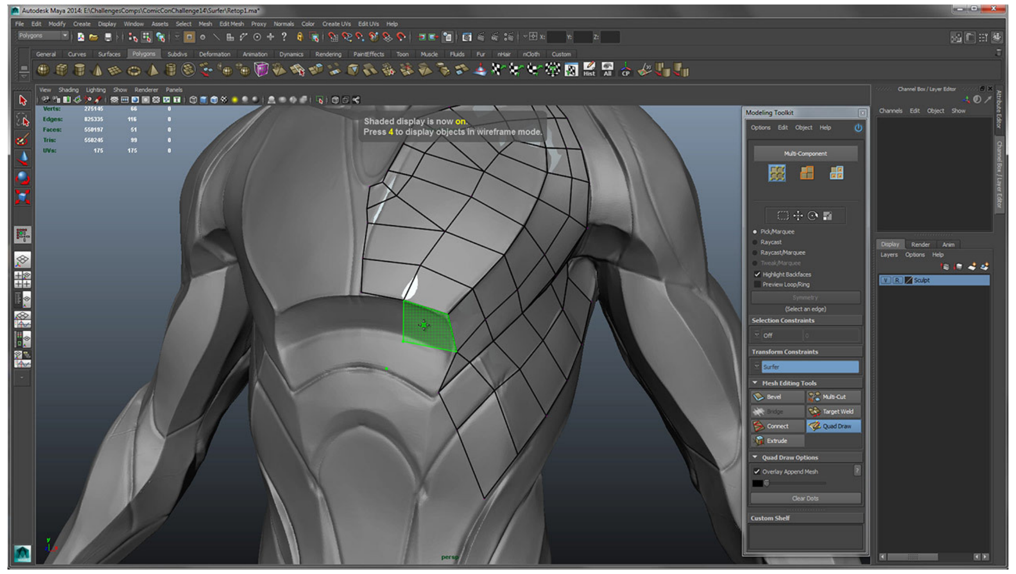
  2. Subdivide, Refine

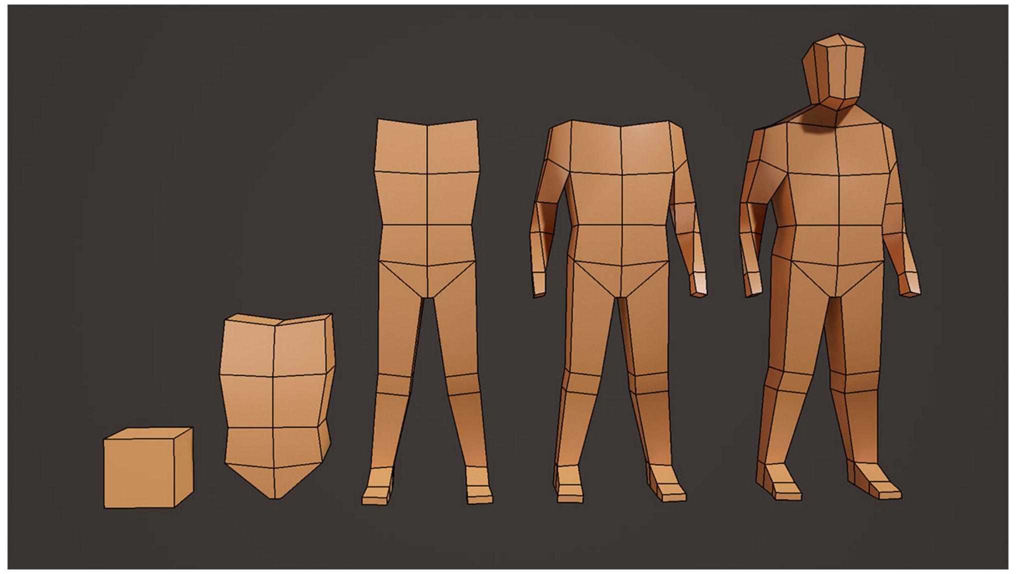
- Parametric (NURBS) modeling

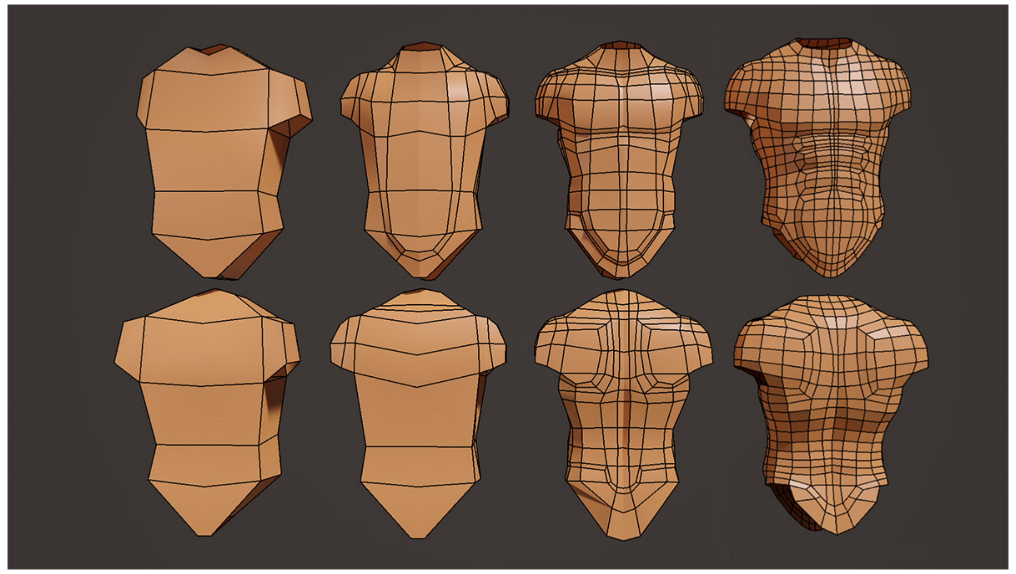
Everything else is "VFX"



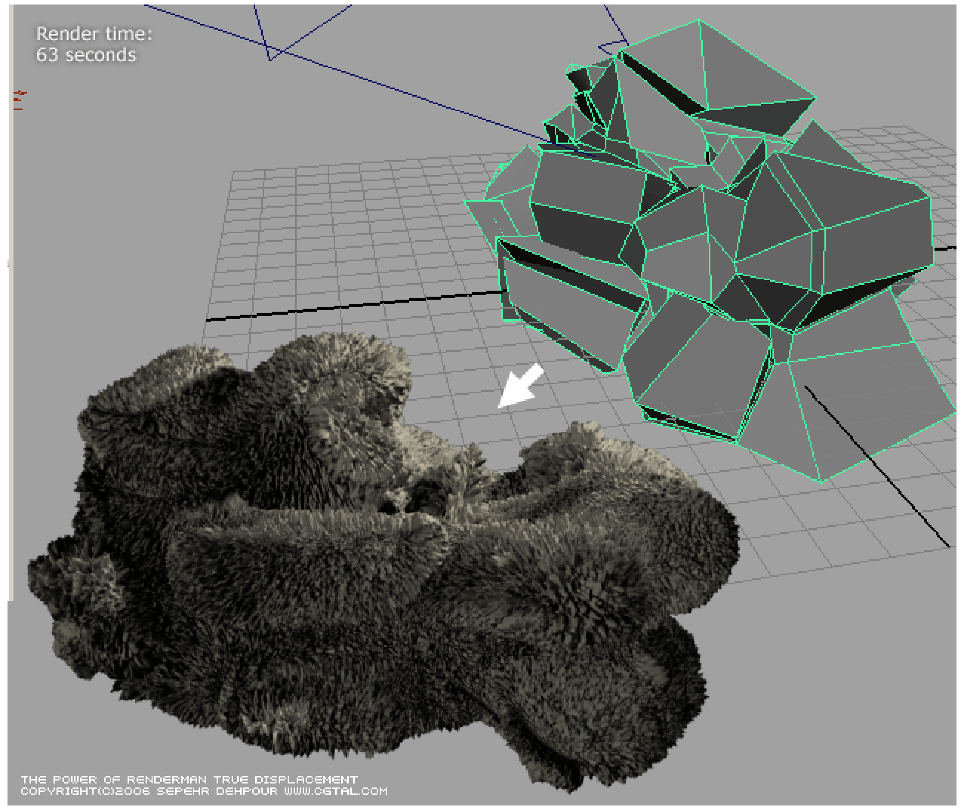
Common tools: Maya, 3DSMax, Cinema4D, Blender, etc.



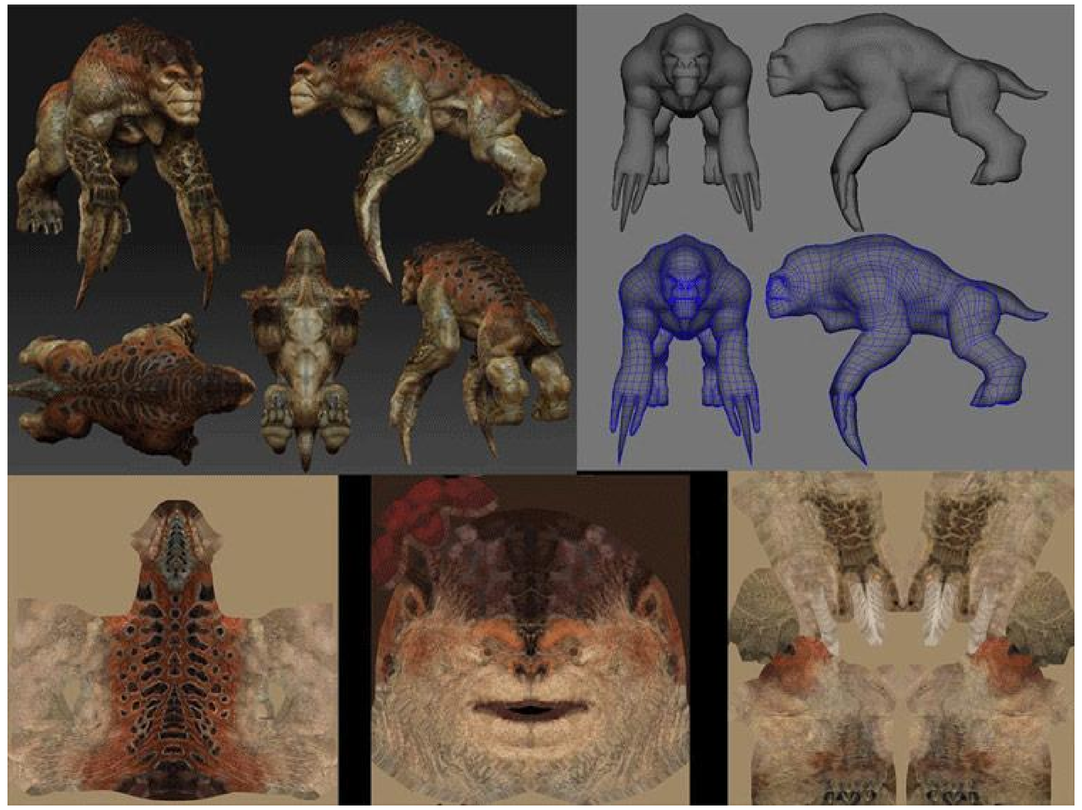




Modeling appearance - Rendering purpose

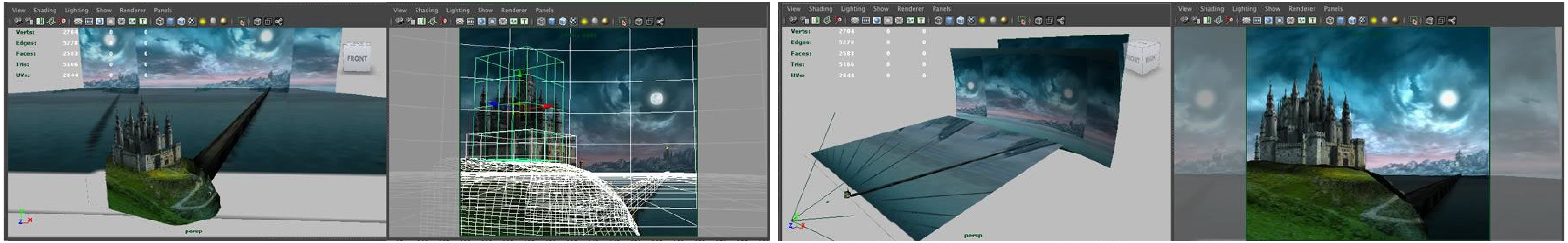


Shading



Texturing

Lighting

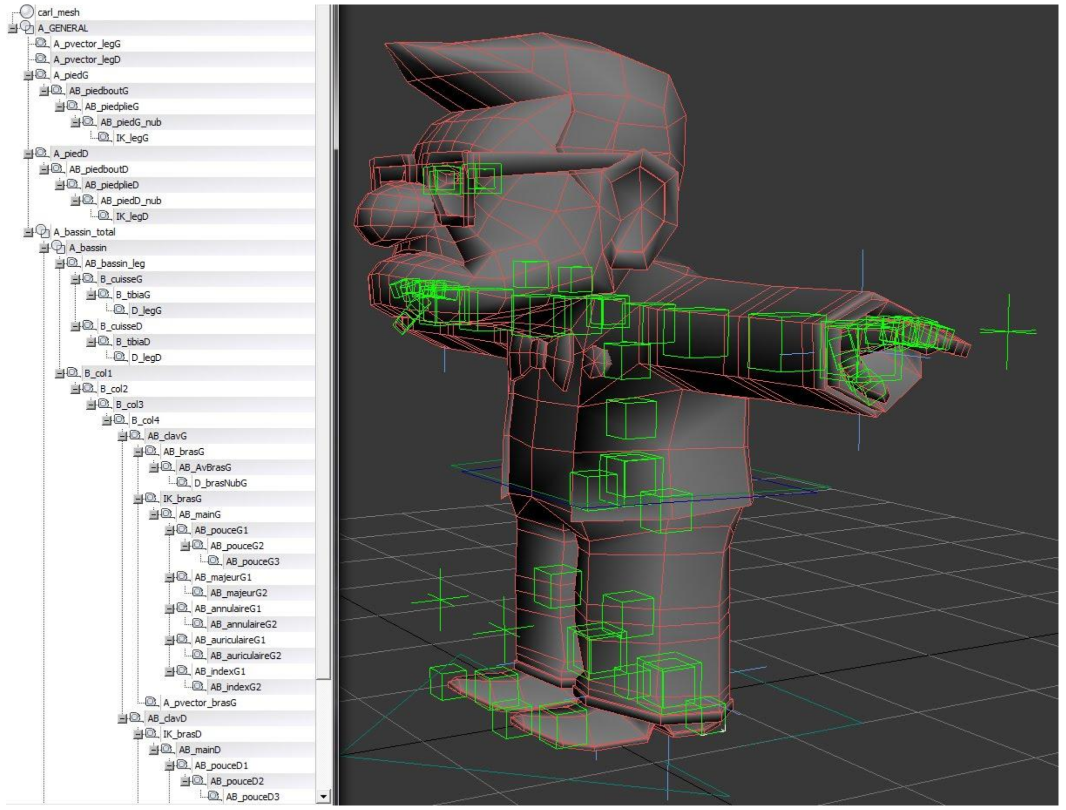


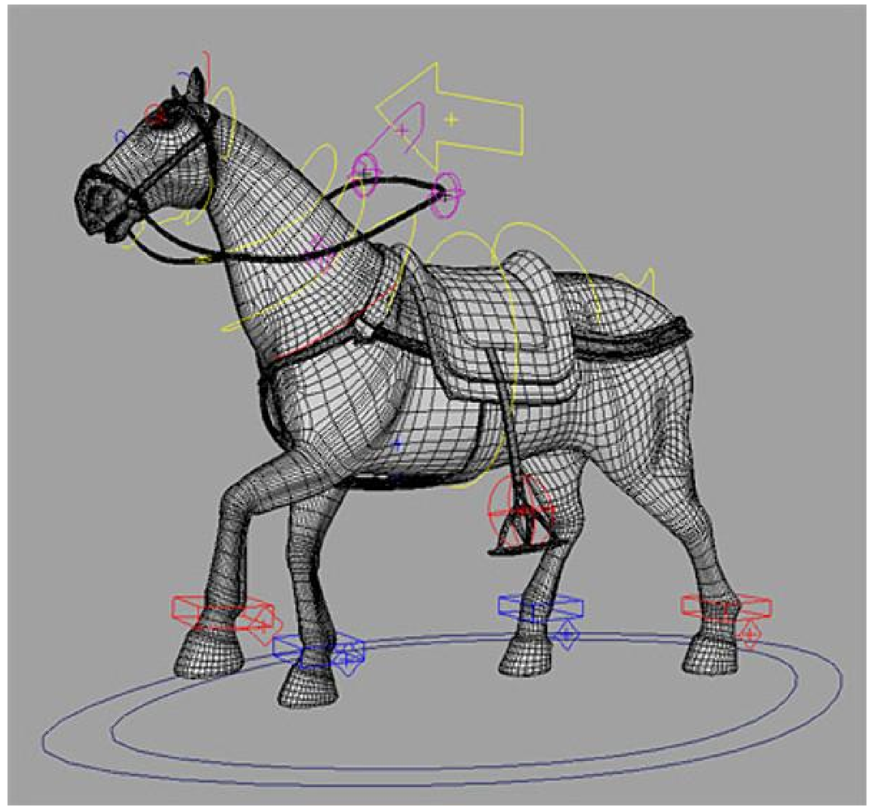
Mate painting

Rigging

Attach deformation handles to the mesh
Each handle (controler) is associated to a deformation - degrees of freedom

Rigging is a technical part
- Python script, Mel (Maya), Lua, etc.





Animation

In production terminology: Animation = Key-frame animation of the rigged character

- Set animation curves on rig controlers

Everything else is VFX

Animating the walk cycle (×40)

Result

Up to 75% of artists production studios are animators

- Animation = The key element - higher cost - for production studios

One animator → 1-10 s of animation per day

Animation sub-parts

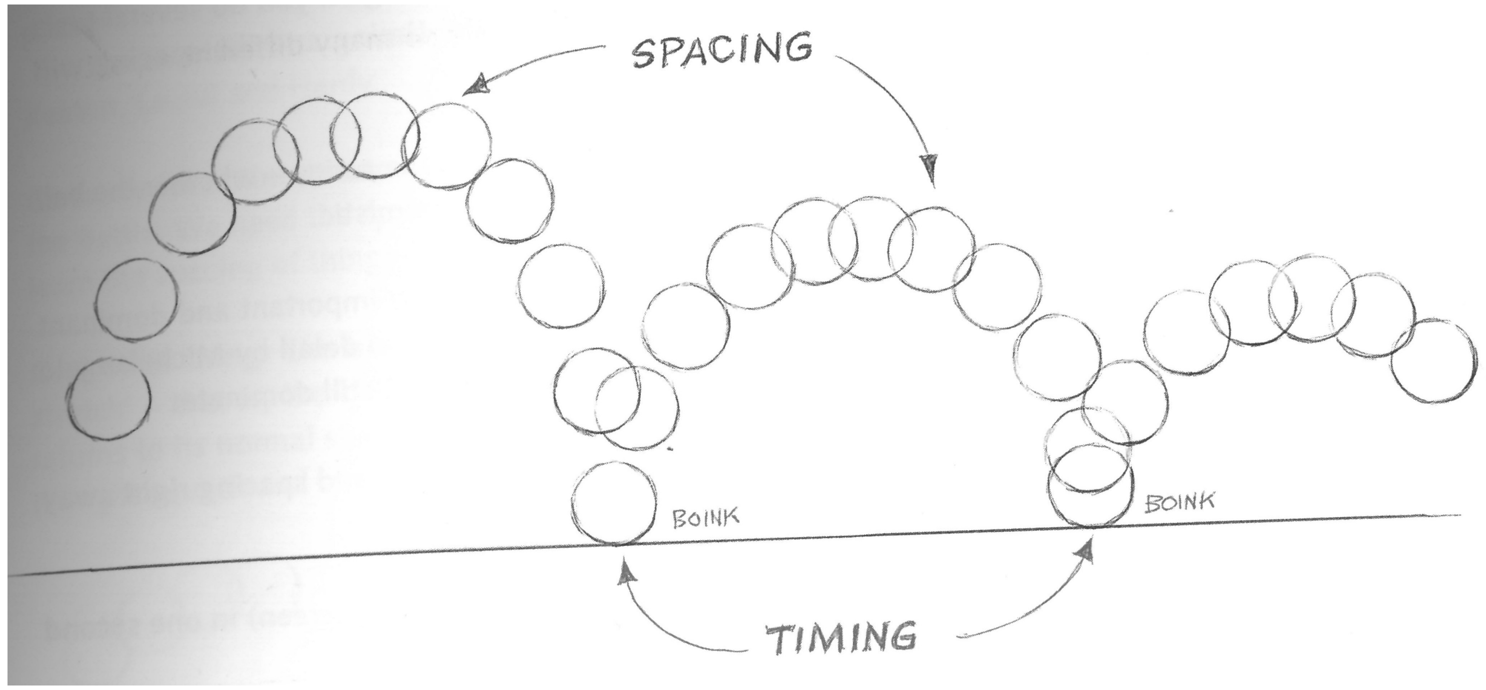
1- **Posing** the *key frames*

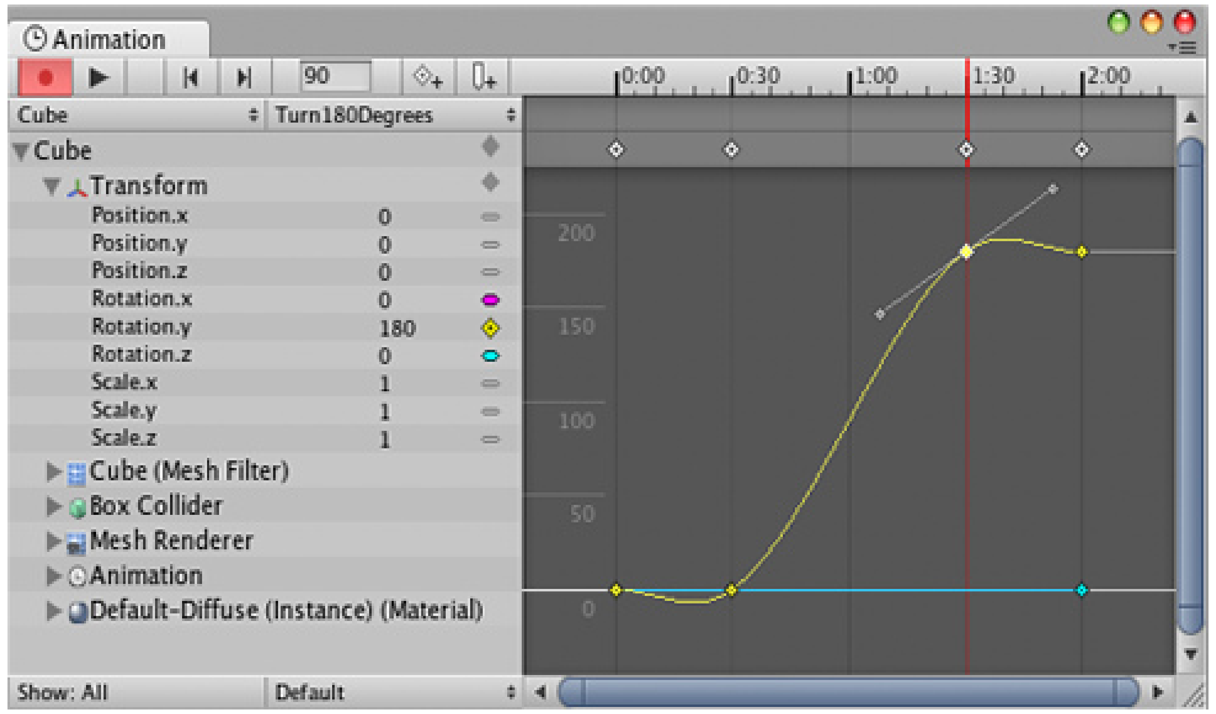
Set the main general posture of the character

*Linked to geometric **character deformation**, time is not involved*

2- **Animating** the in-betweens

- **Timing** : Place key frames at specific times (global length of an action)
- **Spacing** : Speed of the interpolation (dynamic of the action)





Special Effects (VFX)

- Everything which is not handled by traditionnal modeling/rigging/animation
  - *Physics (explosion, fluids, dynamic hairs, cloth, ...), particles systems, complex shape, crowd, etc.*
- Technical R&D part: One element can lead to the development of a dedicated system.
- Main software: Houdini (SideFX)

Post Production

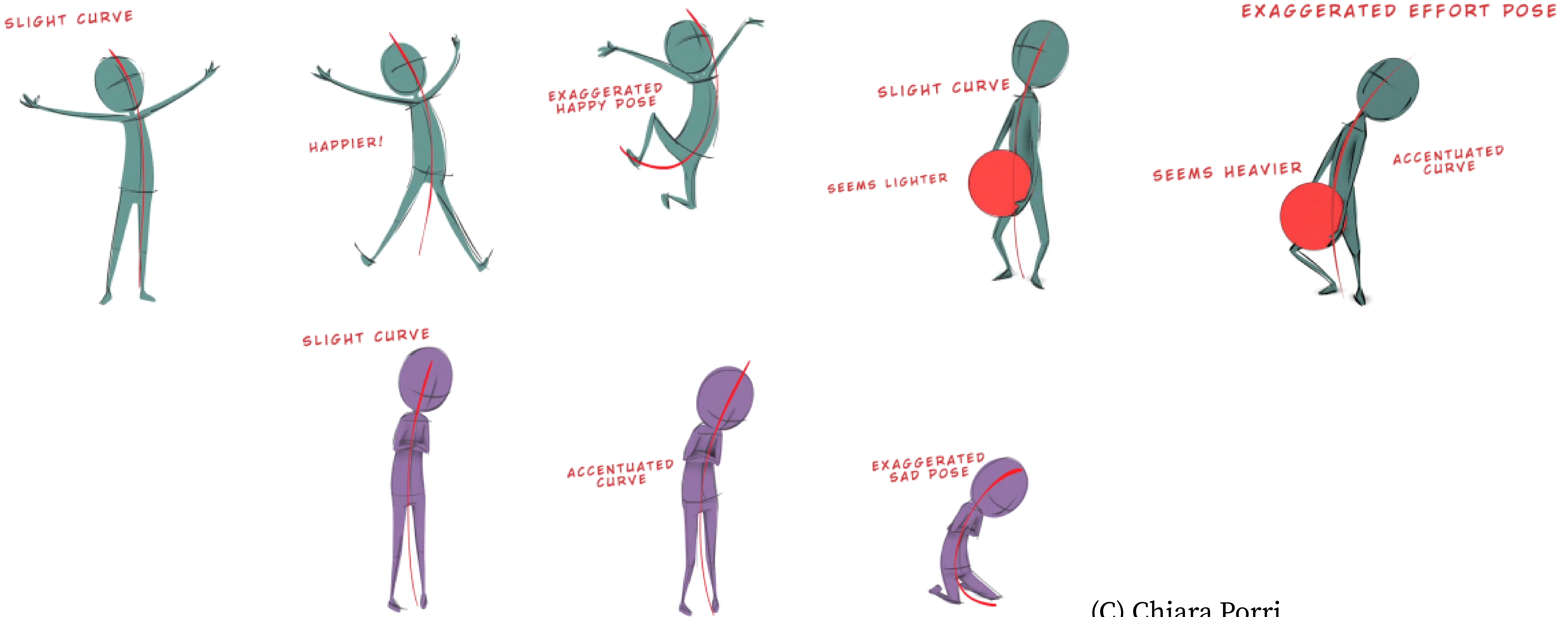
Compositing

- Blend all layers: Rendered and real ones
  - Note: Rendering of color layers but also depth and normals.
- Main software: Nuke (Foundry)

Expressive Animation

Character Animation Posing - Line of Action

- Line of action: *Medial axis* expressing the character pose
- Express *statically* the dynamic of the action
  - Unstable pose ⇒ Dynamic action/motion



(C) Chiara Porri

Principles of animation

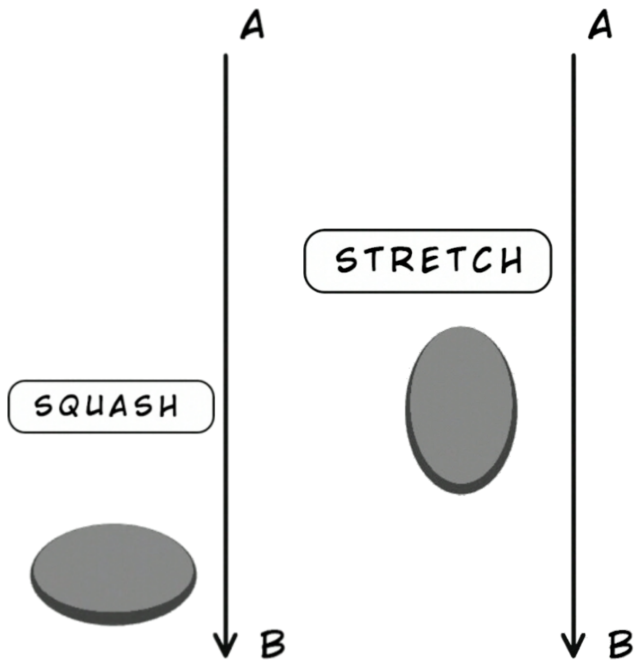
- Interpolation between realistic poses isn't enough for expressive animation
- *12 principles of animation* by Disney *Illusion of Life, 1981*

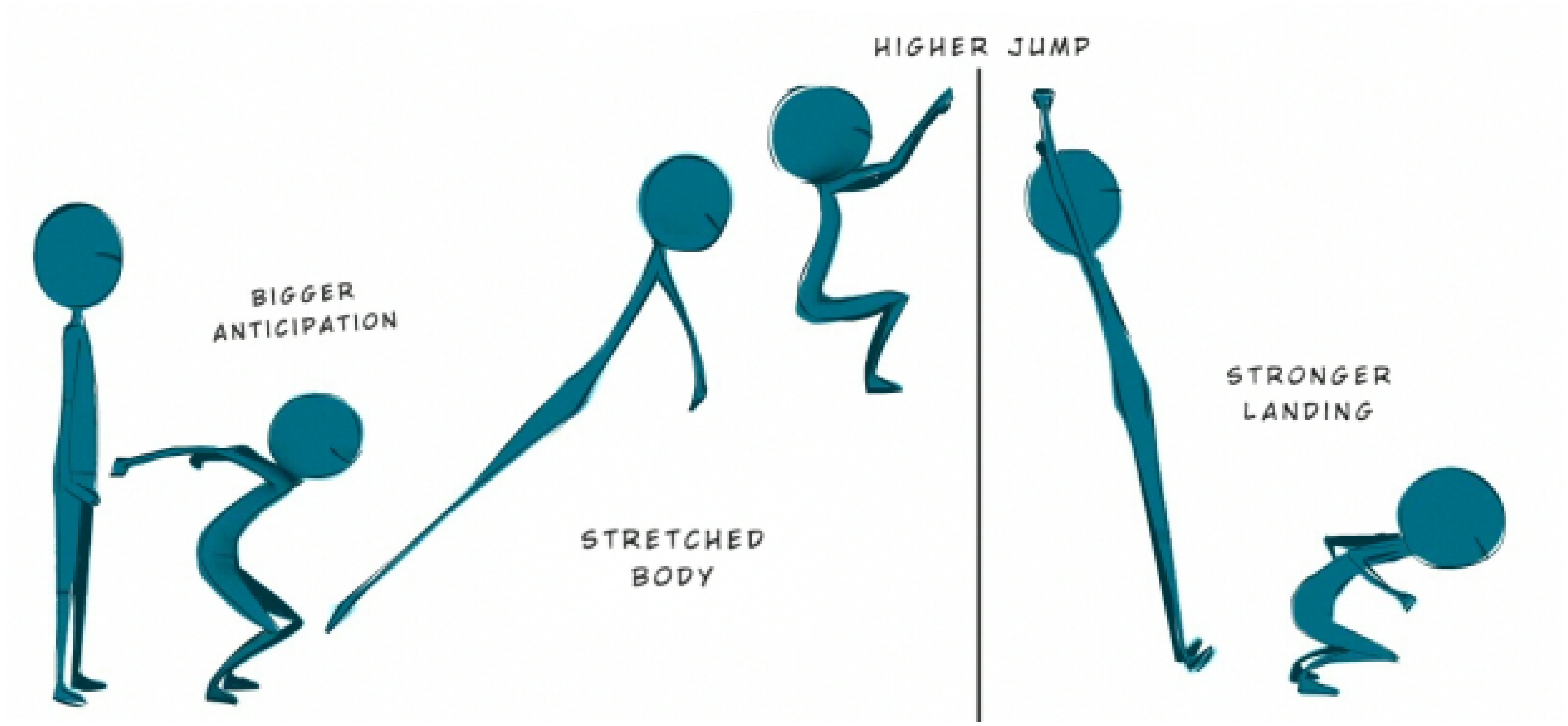
1. Timing
2. Spacing
3. Slow-in, Slow-out
4. Squash & Stretch
5. Anticipation
6. Follow Through
7. Secondary Action
8. Exaggeration
9. Appeal
10. Arcs
11. Staging
12. Straight Ahead/Pose to Pose

Expressive animation

Squash & Stretch

- Very common in cartoon
- Unrealistic, but surprizingly *plausible*

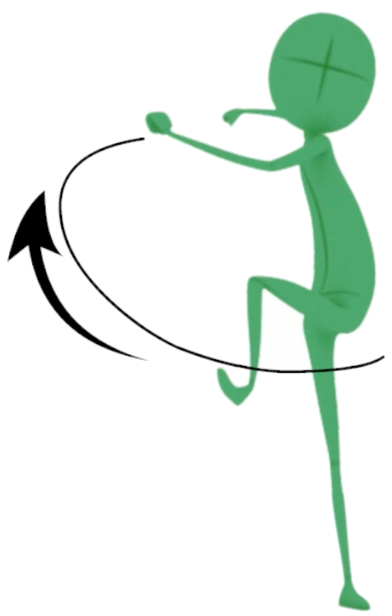


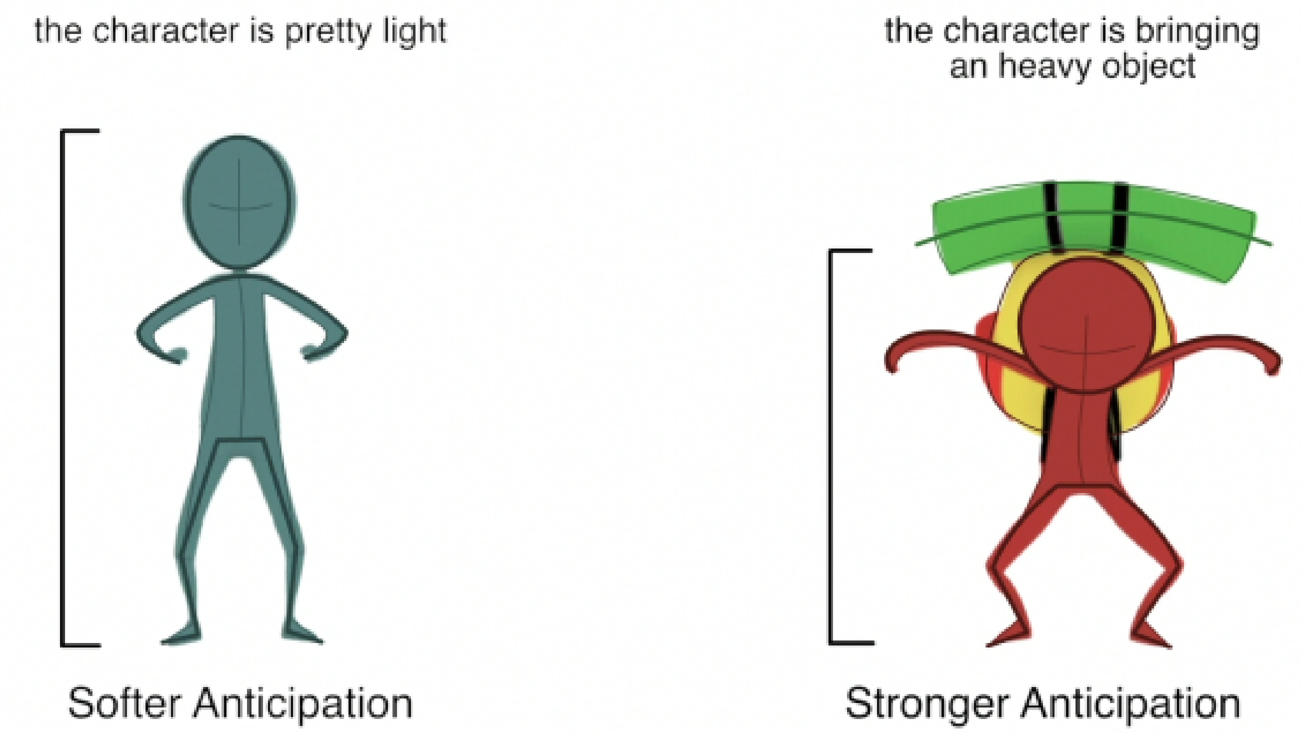


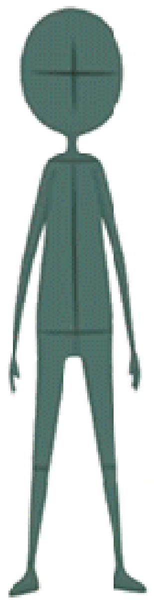
(C) Chiara Porri

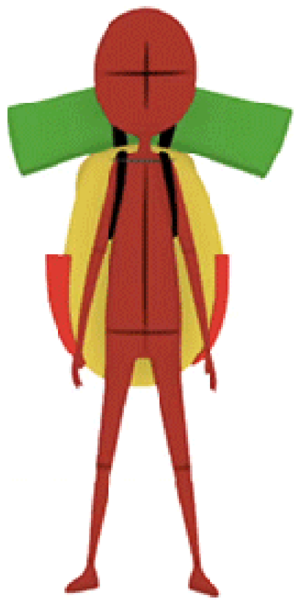
Expressive animation

Anticipation



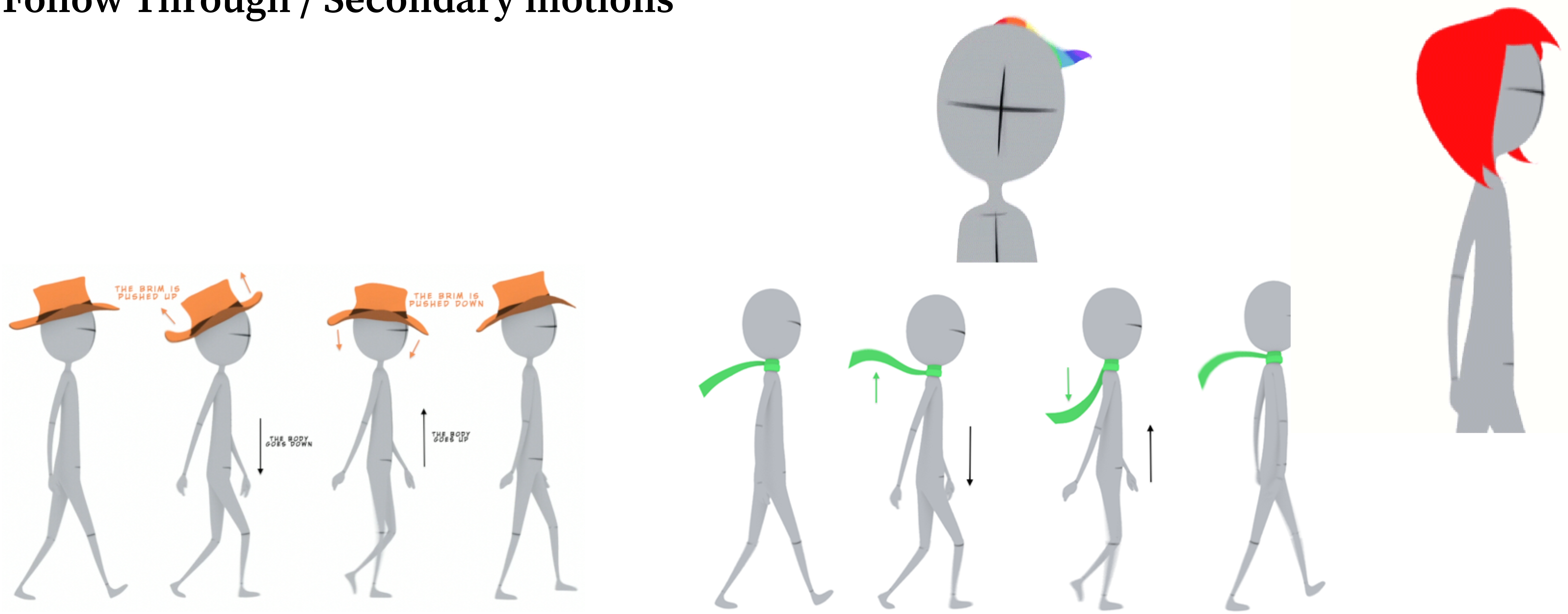






Expressive animation

Follow Through / Secondary motions



(C) Chiara Porri