Character Animation

Skeletal Animation

Skeleton structure

Characteristics

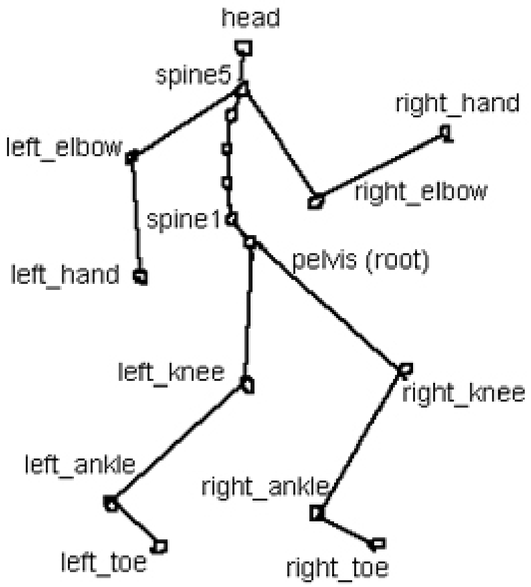
- Hierarchical representation

  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 parer

  ex. Ankle is at 20° w/r knee



Converting local to global frames/joint coordinates

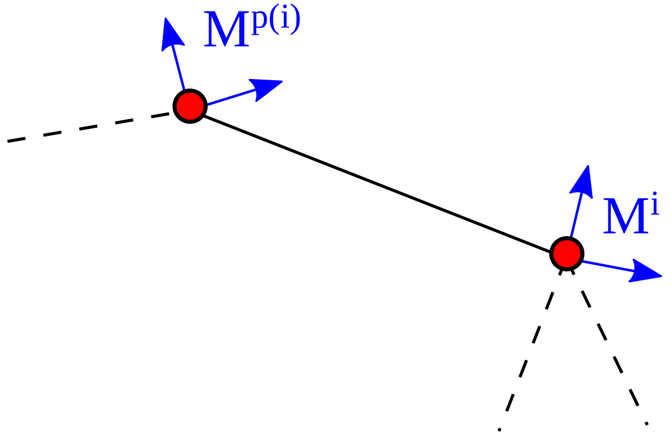
- With 4x4 matrices M

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

- 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

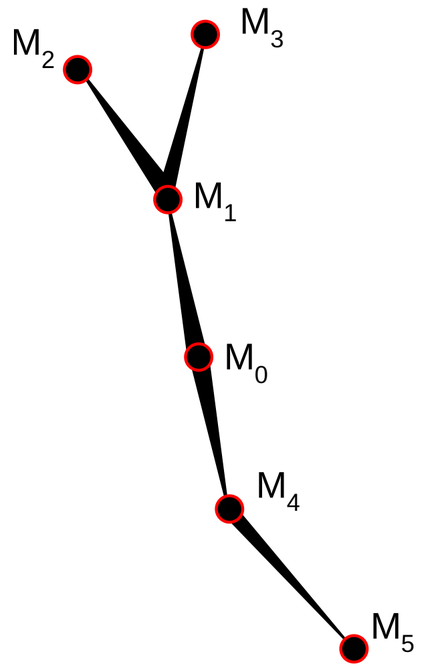
- Simplest encoding based on index within vector

```
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;
}
```

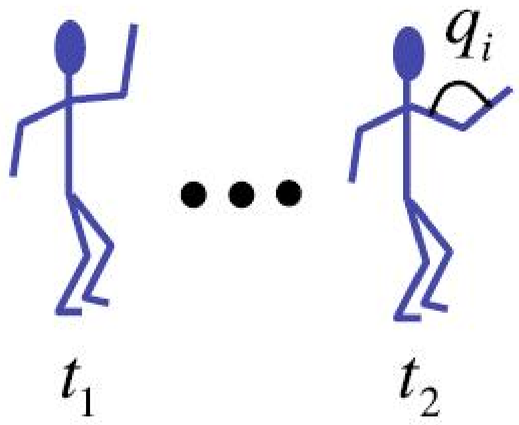


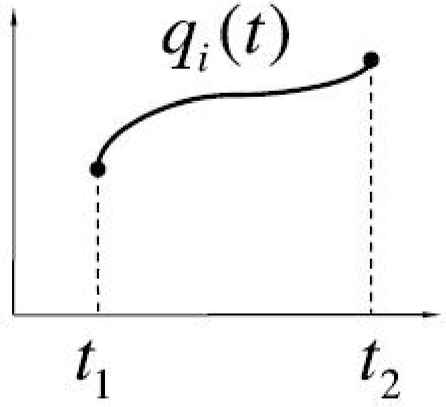
Forward kinematics

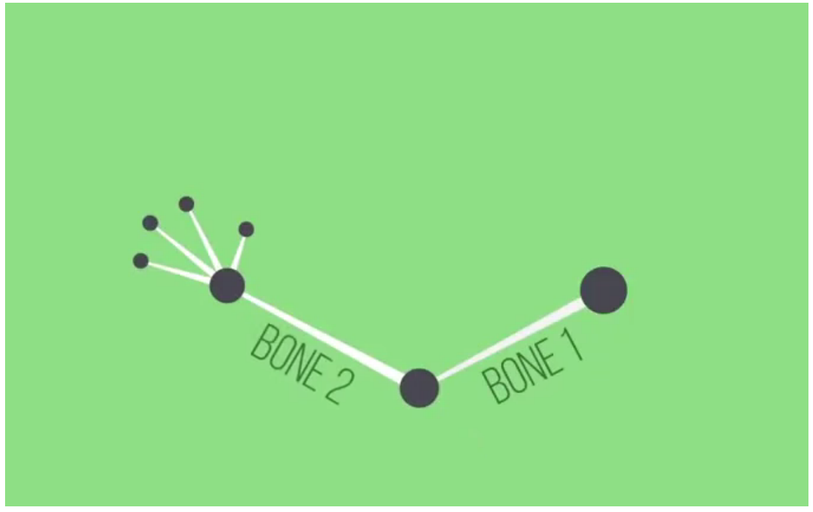
FK - **F**orward **K**inematics

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

(+) Generates curved trajectory naturally



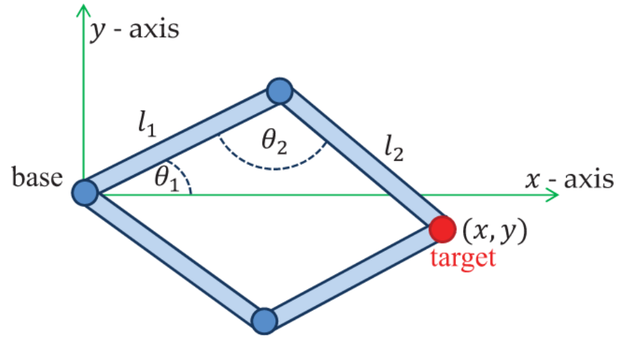




MiloScerny Animation

Inverse Kinematics

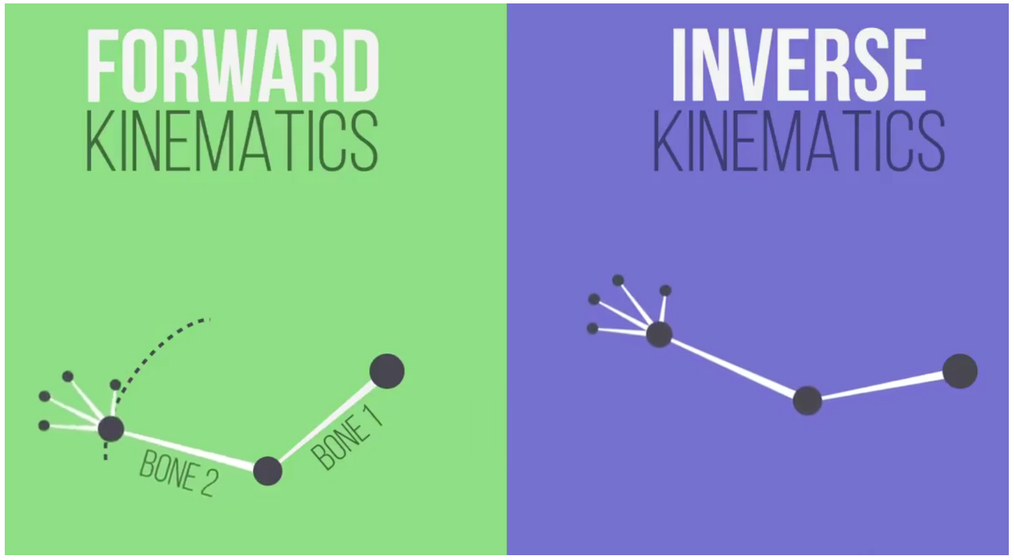
IK: Inverse **K**inematics



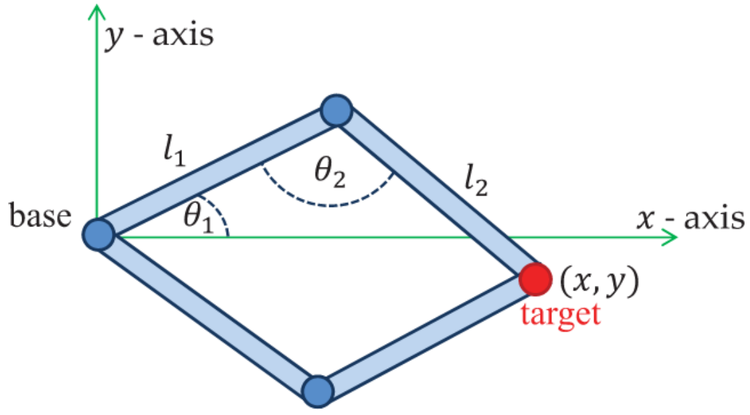
- Describe position (/and orientation) of *end-effectors* (contact, walking, etc)
- Compute joint angles reaching this position

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

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



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

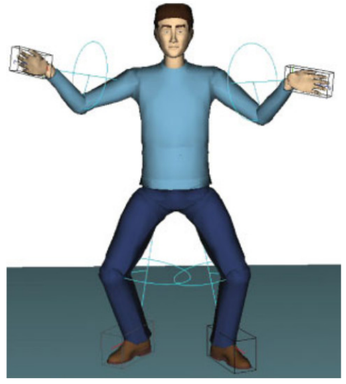
$$\cos(\theta_1) = \frac{l_1^2 + x^2 + y^2 - l_2^2}{2l_1\sqrt{x^2 + y^2}}$$

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

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

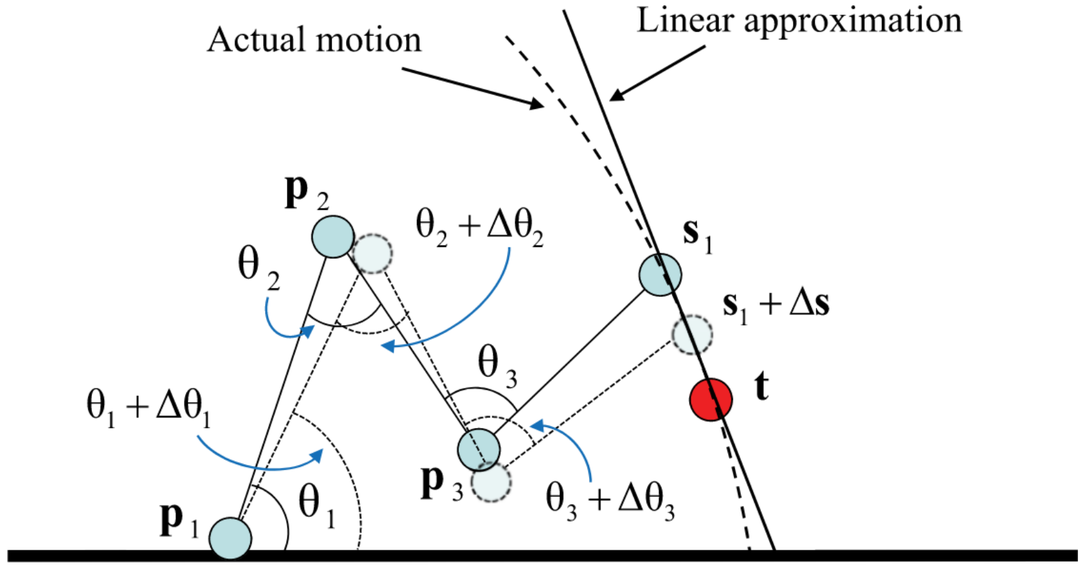
Consider small step size $p \to p + \Delta p$

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

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 $\quad \mathrm{J}\mathrm{J}^{+} = \mathrm{I}$

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

- 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

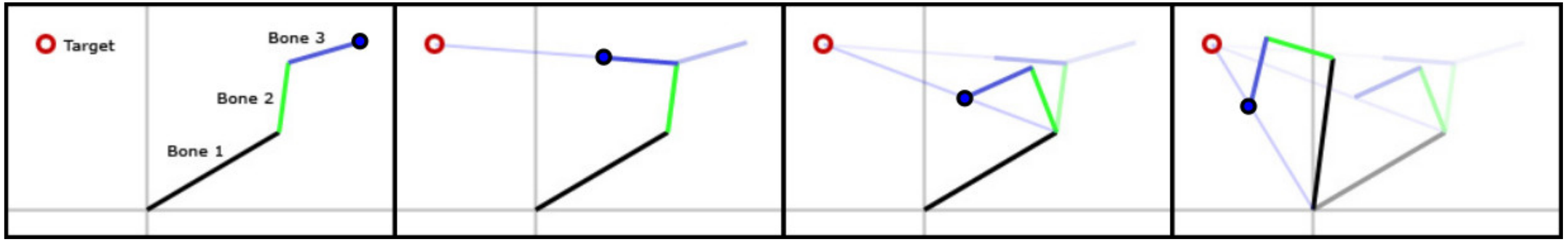
Cyclic Coordinates Descent (CCD)

- 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.

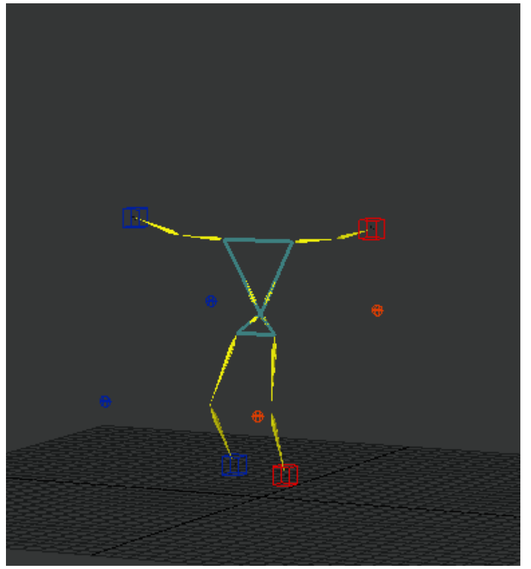
  = *End-effector aligned with the segment (joint,target)*

- Restart until convergence

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



IK: Heuristic approach

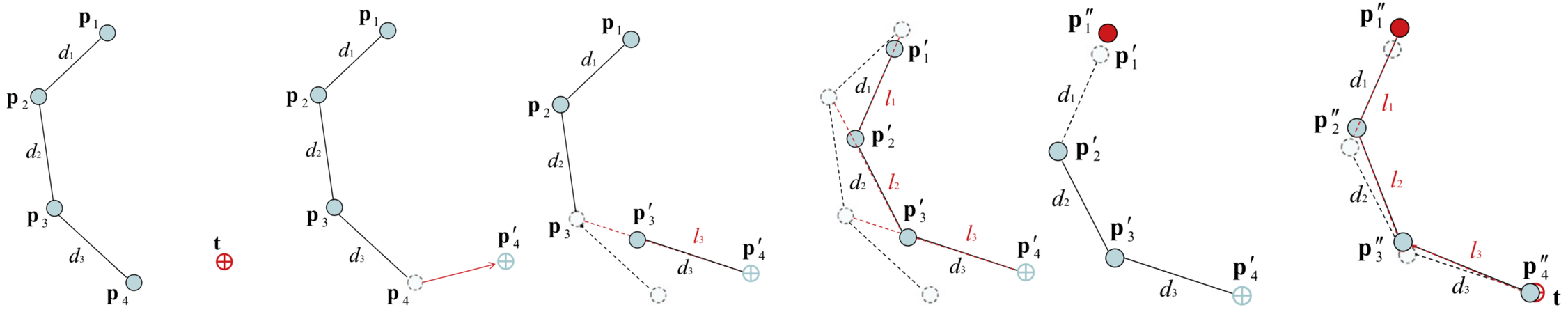


Fabrik

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.]



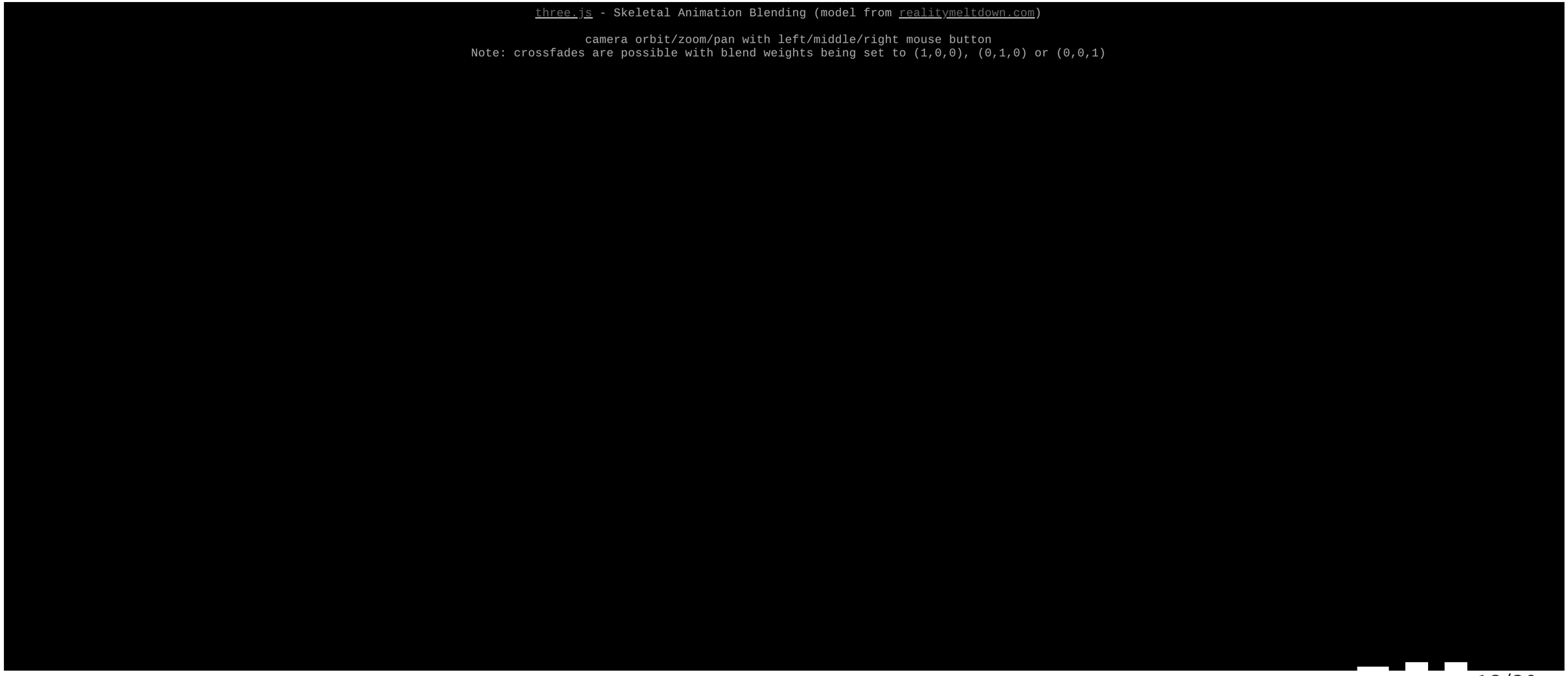
Inverse Kinematics

Example

Synthesizing and controling skeleton animation

Blending skeleton animation

Pre-store several looping animation
Blend between animation for transition



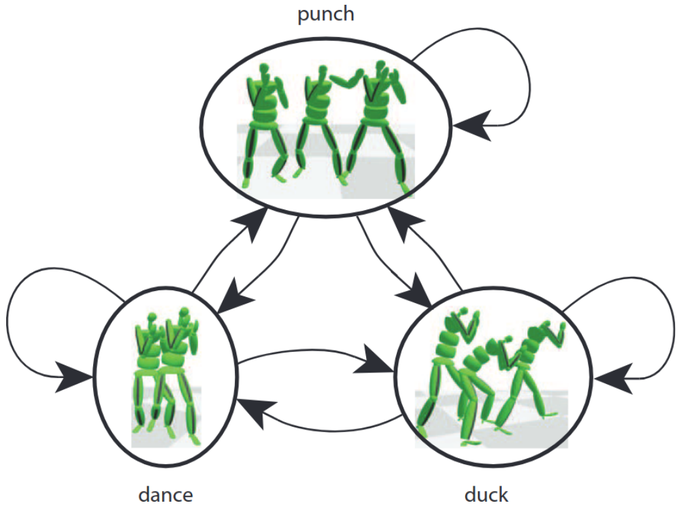
Motion graphs

Also called Move Trees (highly used in video games)

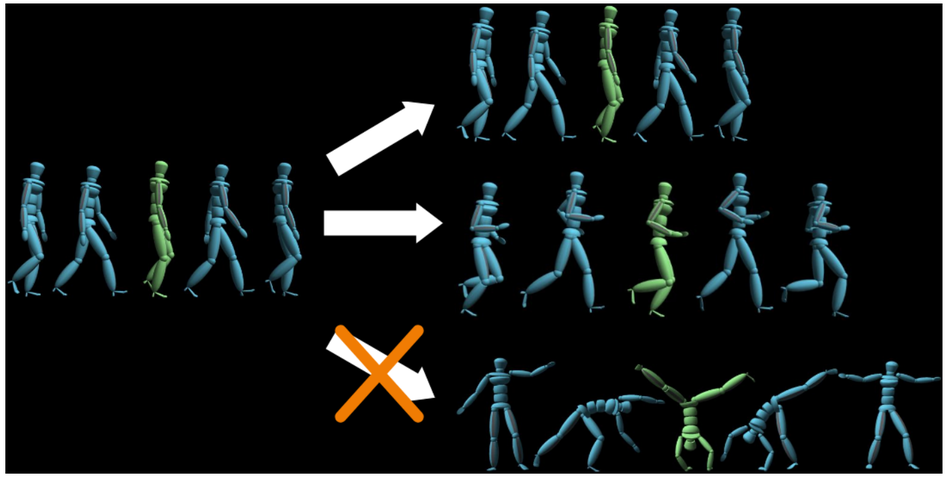
- Stores multiple precomputed animation

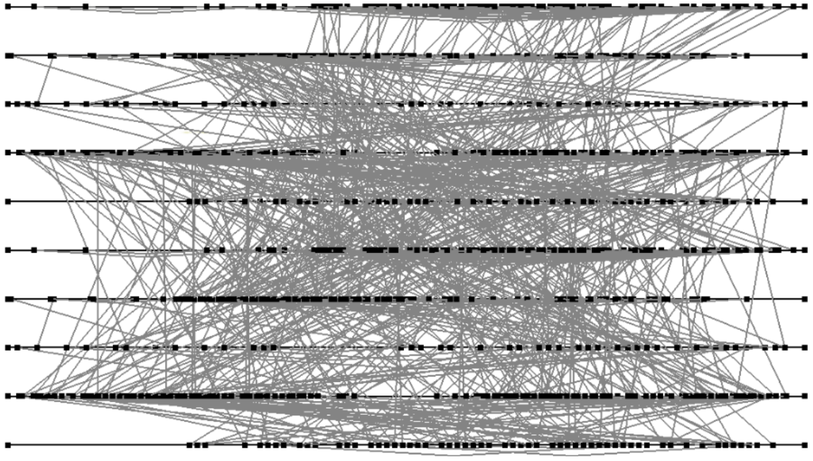
  Manually design, motion capture, etc

- 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]*





Controlers

Mix between predefined motions and physics → allow user perturbations

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

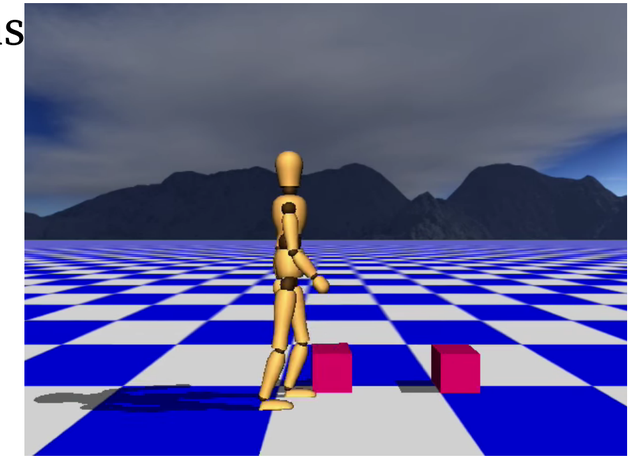
pre-defined finite state machine (Gait model)

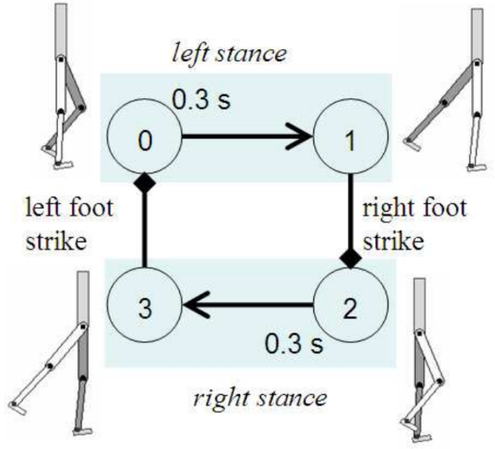
2 - Add user perturbation to the current state

3 - Use proportional derivative controlers to compute joint torque τ

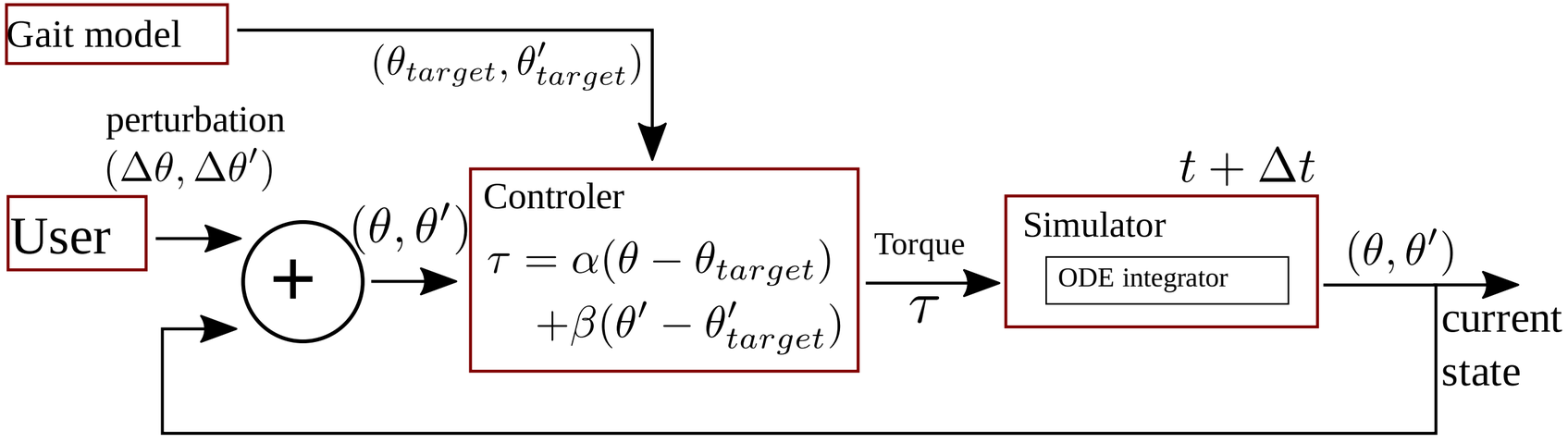
4 - Integrate torque using rigid body simulator

5 - Iterate





Gait model

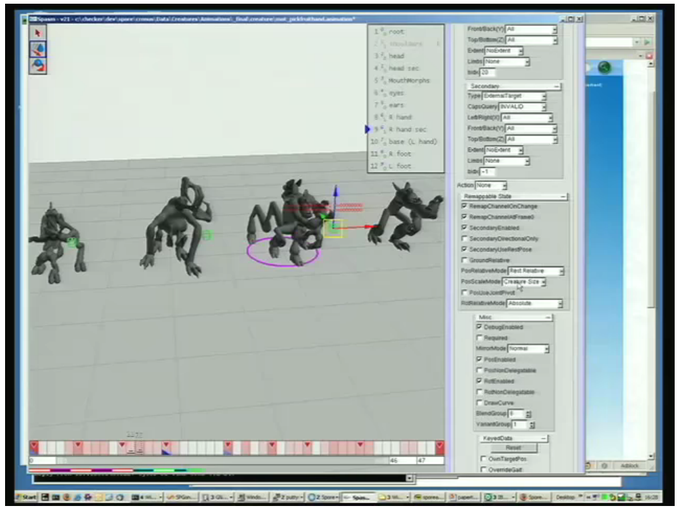


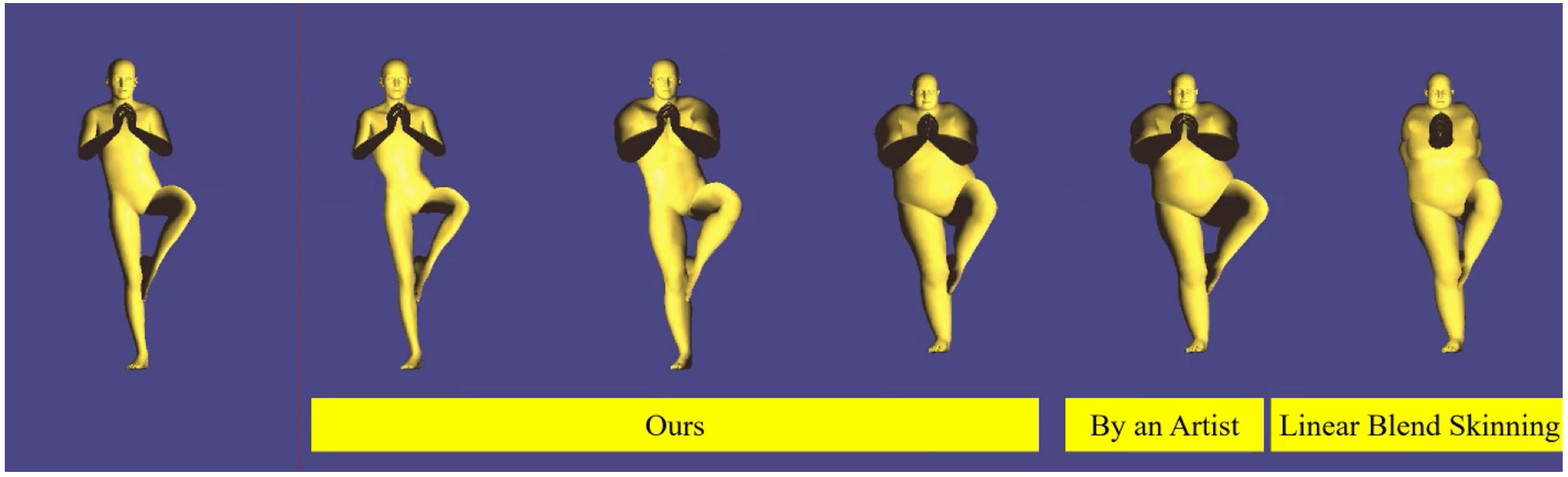
[M. Raibert and J. Hodgins. Animation of Dynamic Legged Locomotion, ACM SIGGRAPH 2001]

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

Motion transfert

- Local coordinates mapping from skeletal motions
  - [C. Hecker et al., Real-time Motion Retargeting to Highly Varied User-Created Morphologies, SIGGRAPH 2008] (Spore)
- Including shape morphology
  - [Z. Liu et al., Surface based Motion Retargeting by Preserving Spatial Relationship, MIG 2018]





Animation design

Based on the *Line of Action*

- [Guay et al., The Line of Action: an Intuitive Interface for Expressive Character Posing, ACM SIGGRAPH Asia 2013]
- [Guay et al., Space-time sketching of character animation, ACM SIGGRAPH 2015]
- [Choi et al., SketchiMo: Sketch-Based Motion Editing for Articulated Characters, ACM SIGGRAPH 2016]

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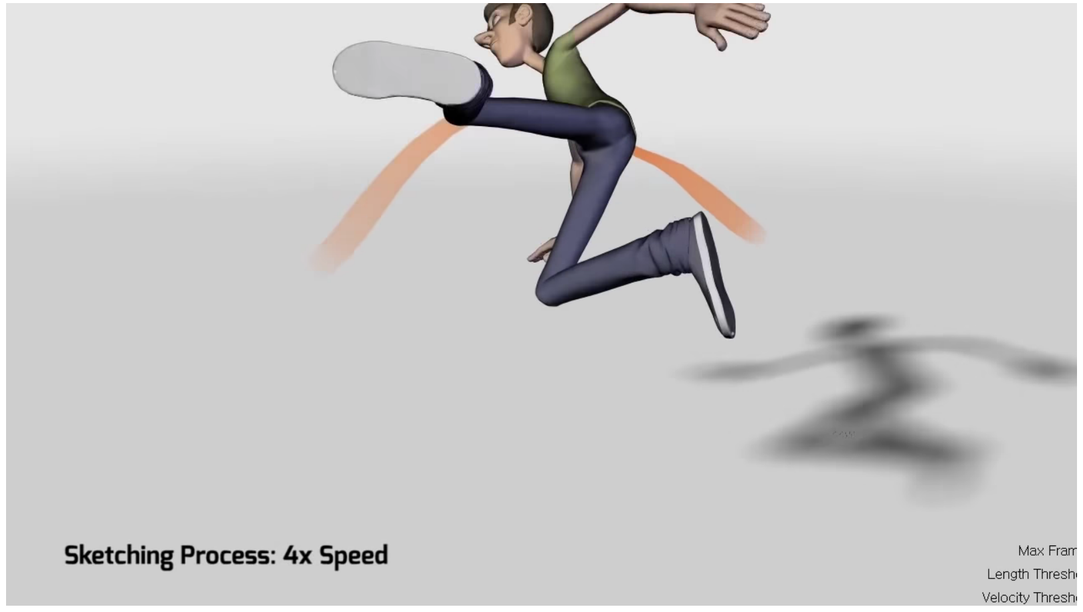

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Automatic synthesis of skeletal animation

Seminal works

- [Evolving Virtual Creatures. Karl Sims. SIGGRAPH 1994]

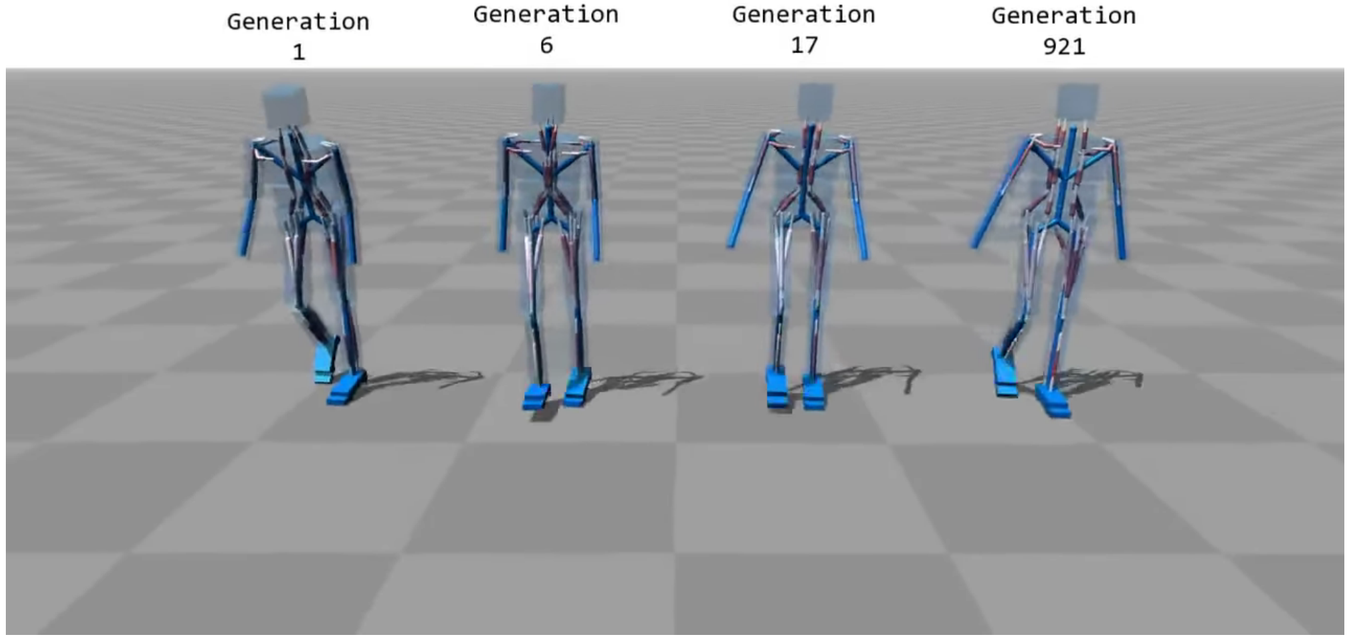
- [Automated Learning of Muscle-Actuated Locomotion Through Control Abstraction. Radek Grzeszczuk and Demetri Terzopoulos. SIGGRAPH 1995]

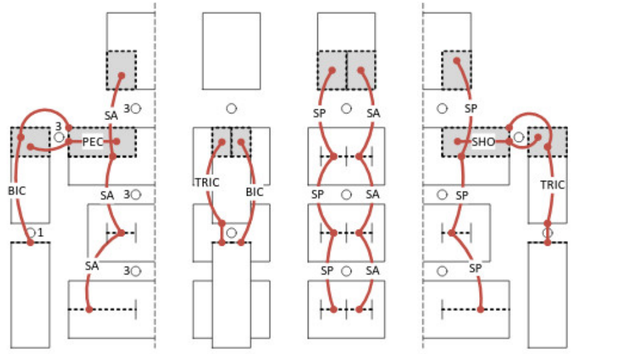
- *Optimization toward objective function coupled with rigid bodies simulations*
- *Morphological variation from genetic algorithm*

Optimizing muscle activation

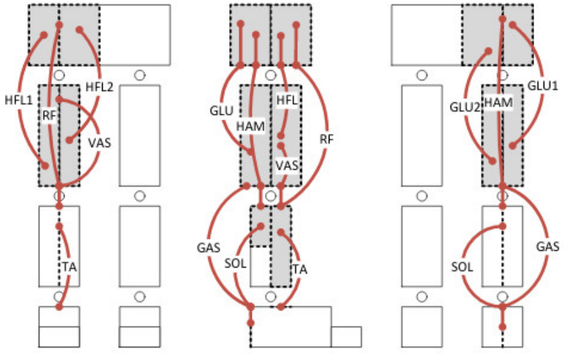
- Take into account simple biomechanical model
- Optimize sequence of activation via reinforcement learning

[Flexible Muscle-Based Locomotion for Bipedal Creatures, T. Geijtenbeek et al. SIGGRAPH Asia 2013.]

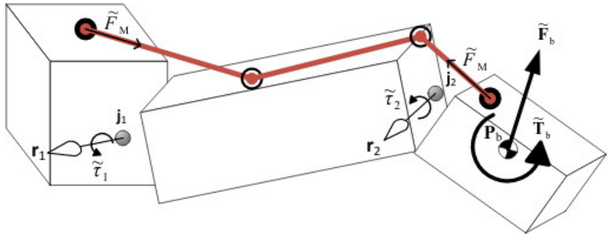




(a) Humanoid upper-body model: front, side arm, side body, and back.



(c) Humanoid lower-body model: front, side and back.

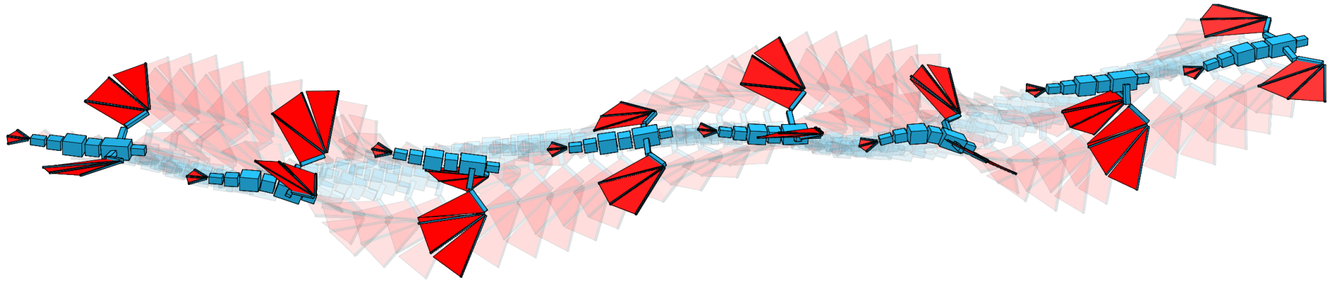


Use of deep learning

Deep reinforcement learning for complex optimization

Learn muscle activation

[Won et al. How to Train Your Dragon: Example-Guided Control of Flapping Flight, ACM SIGGRAPH Asia 2017]



Deep learning for real-time motion control

Learn phase of the motion cycle.

Use large data base of motion capture data

[Holden et al., Phase-Functioned Neural Networks for Character Control, ACM TOG 2017]