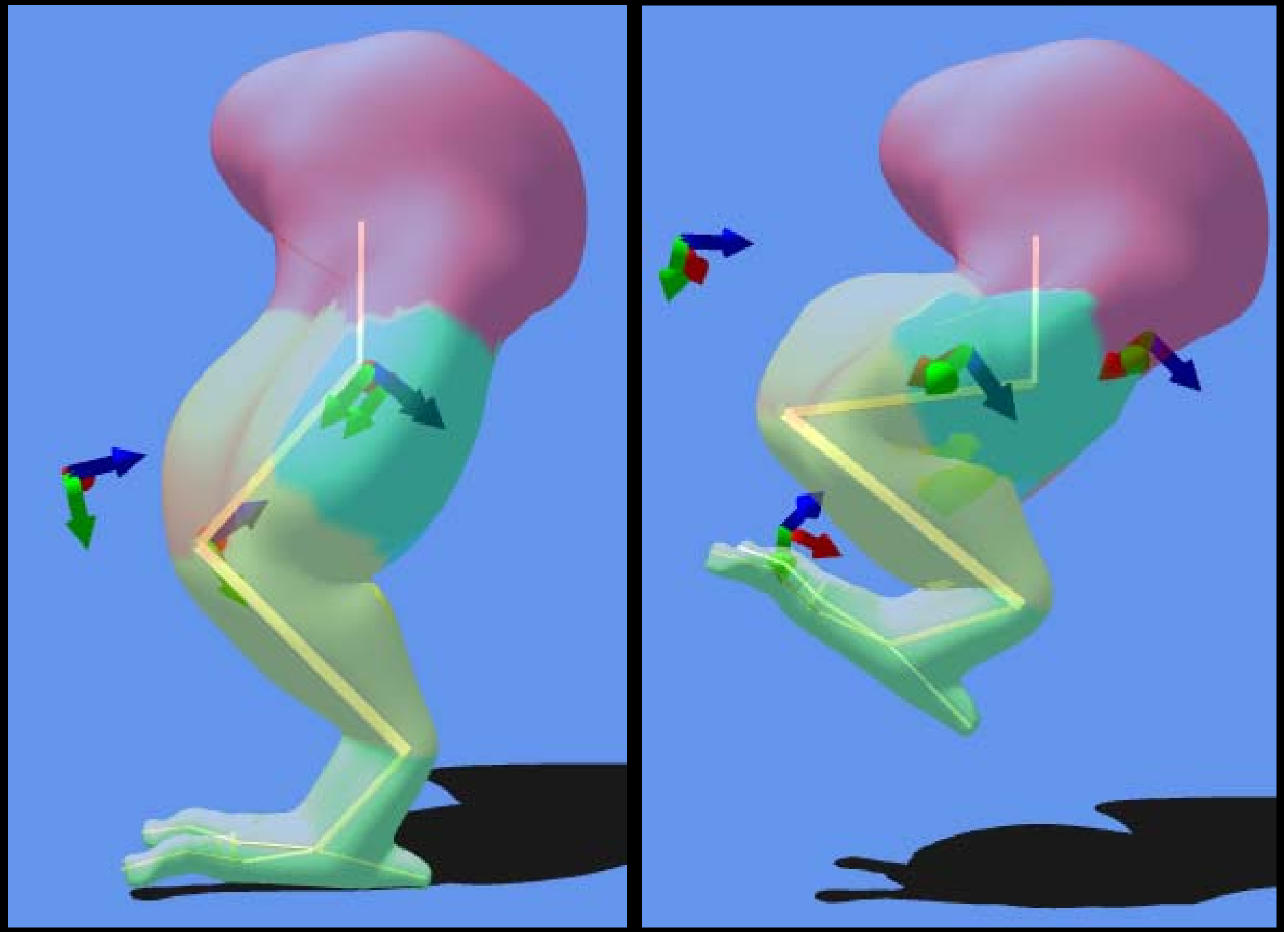
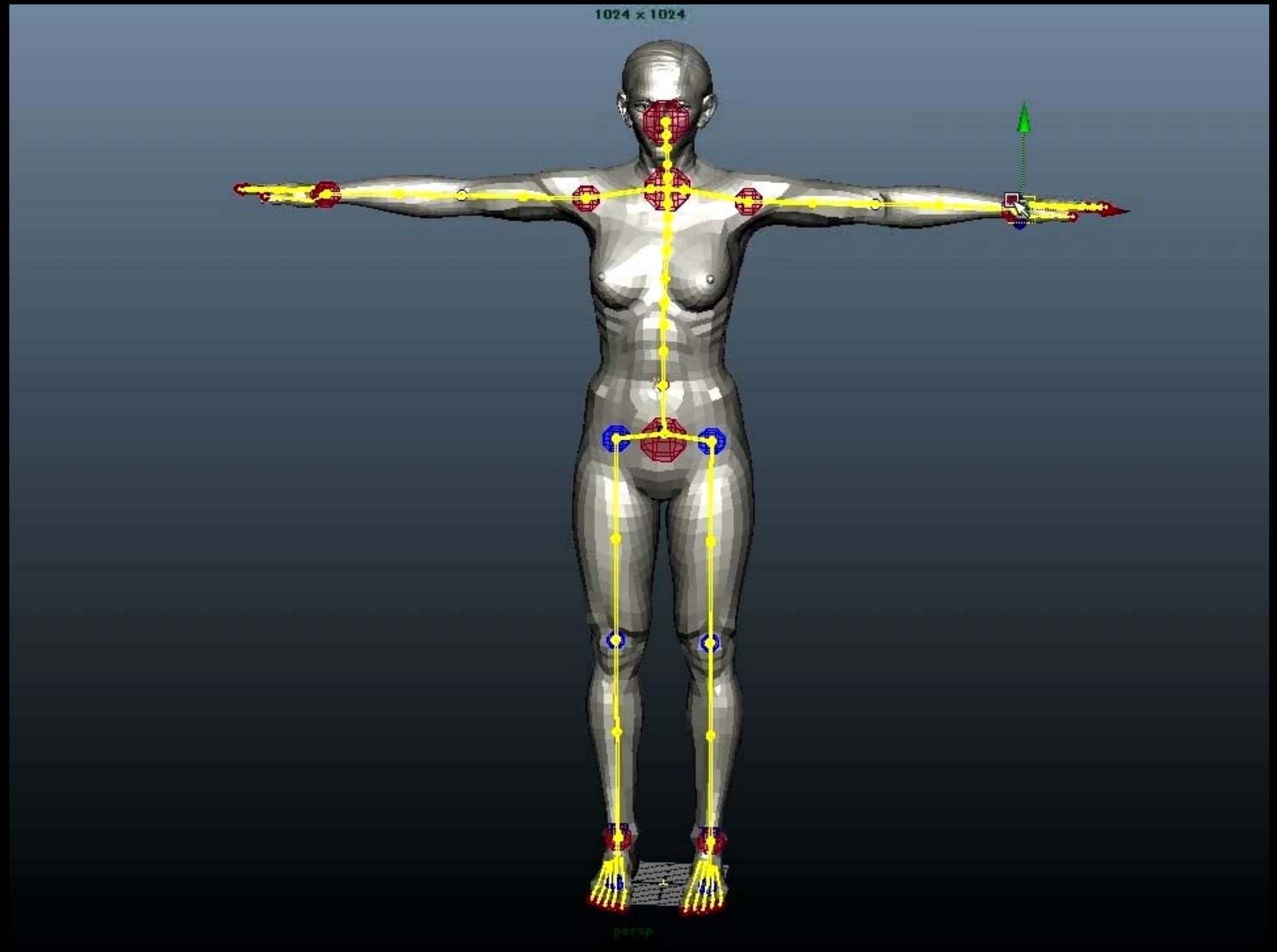
Building Helper Bone Rigs from Examples

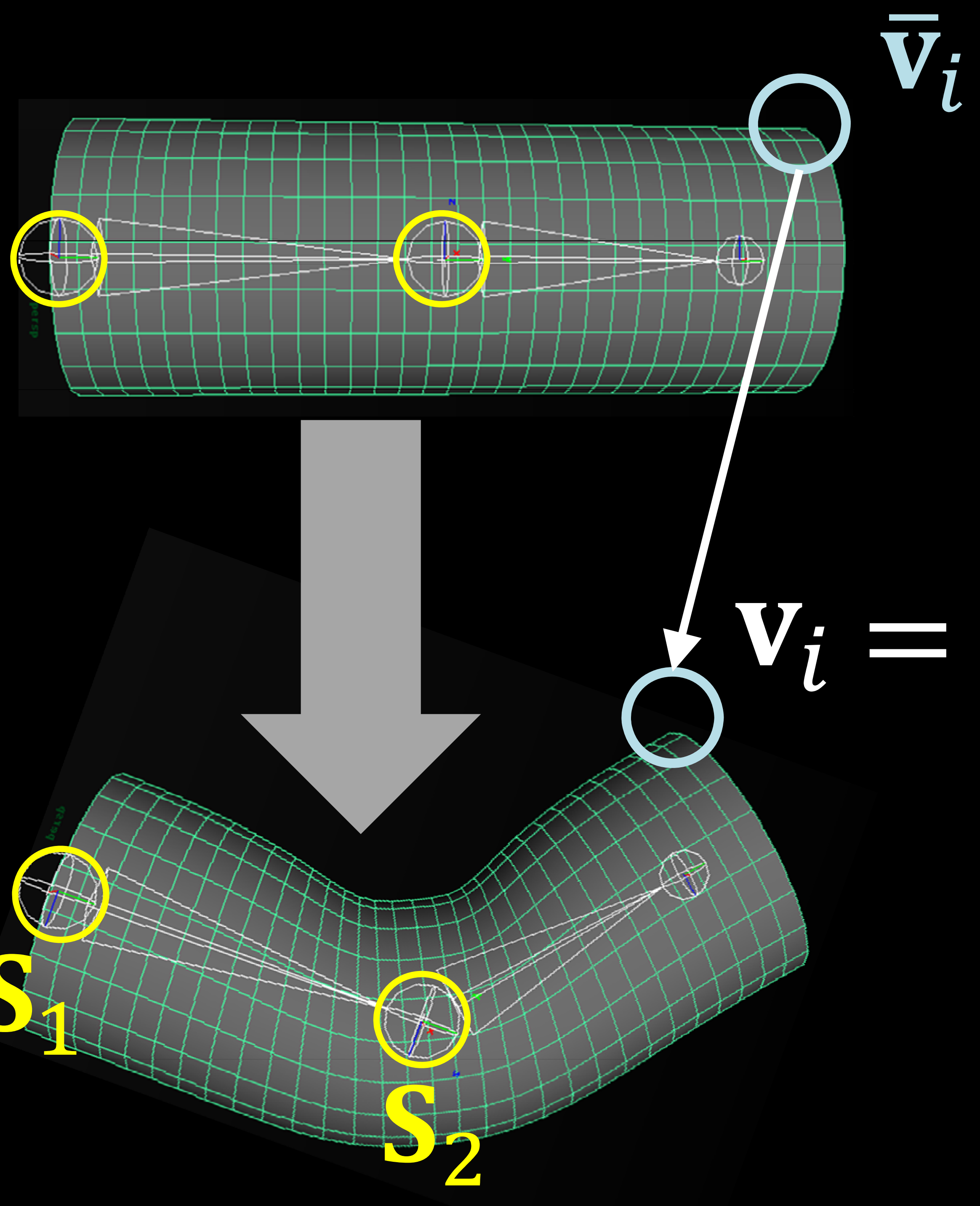


Tomohiko MUKAI

I3D 2015, Feb. 28

Linear Blend Skinning（LBS）



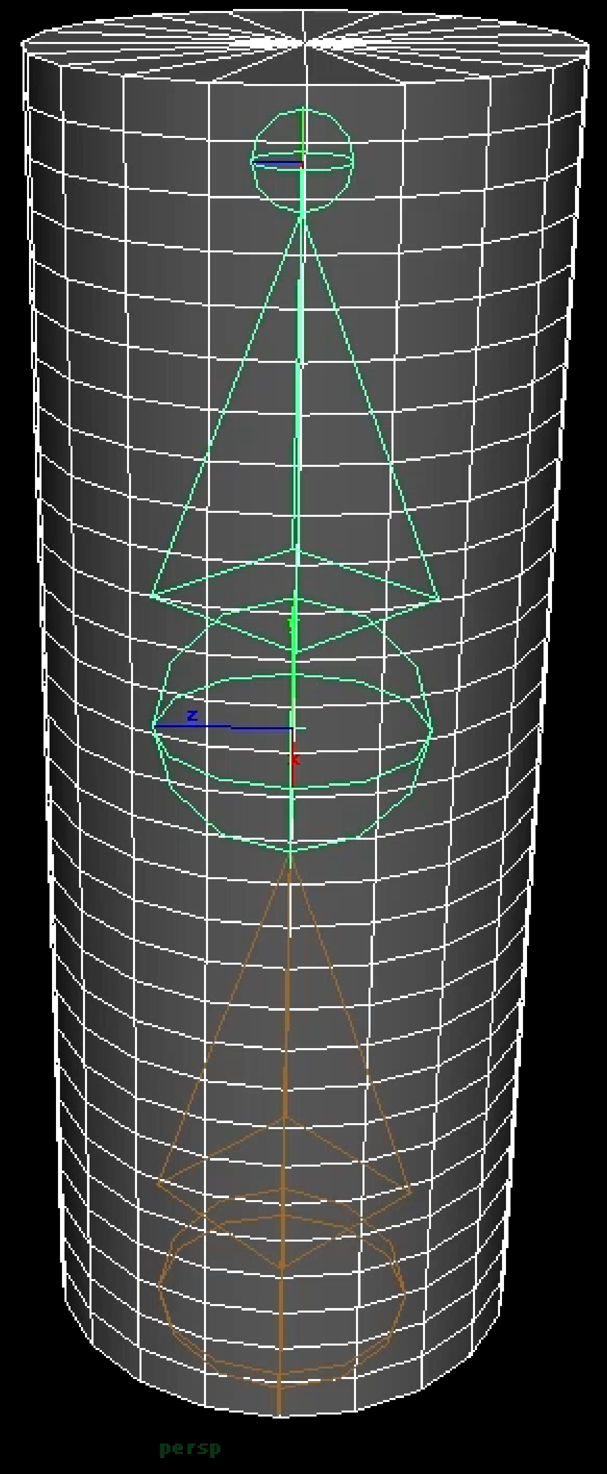


Rest position

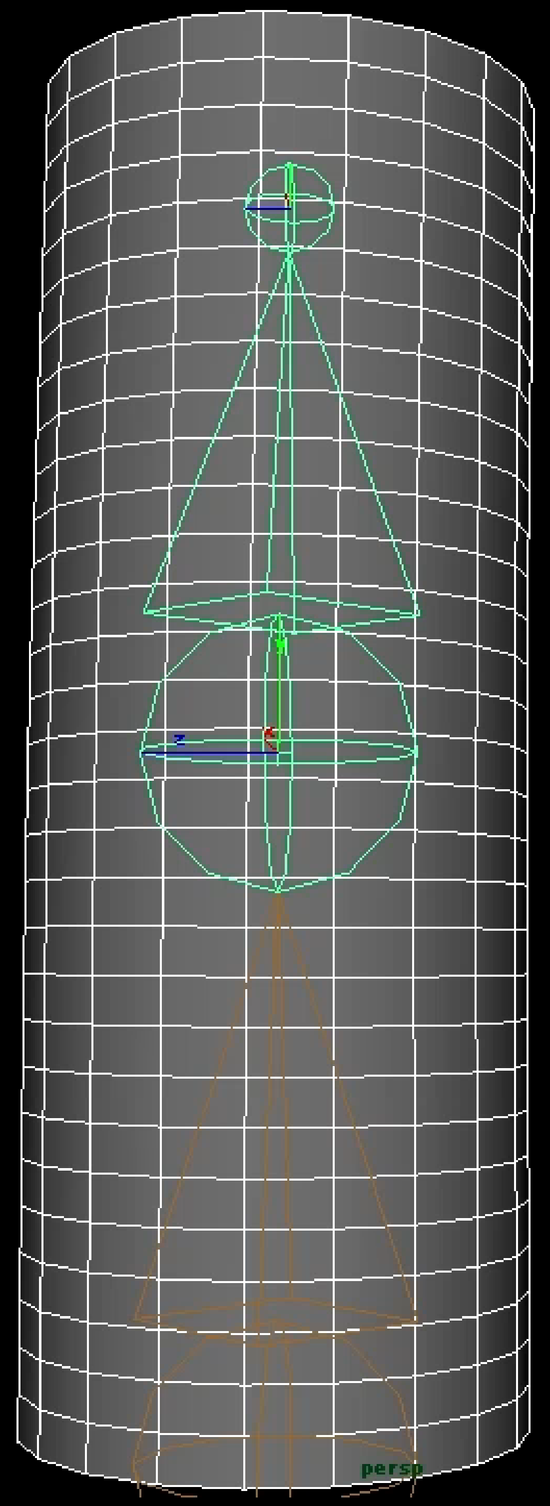
$$\mathbf{v}_i = \sum_{d=1}^{D} w_{i,d} \bar{\mathbf{v}}_i \mathbf{S}_d$$

Skinning weight

Bone trans-formation



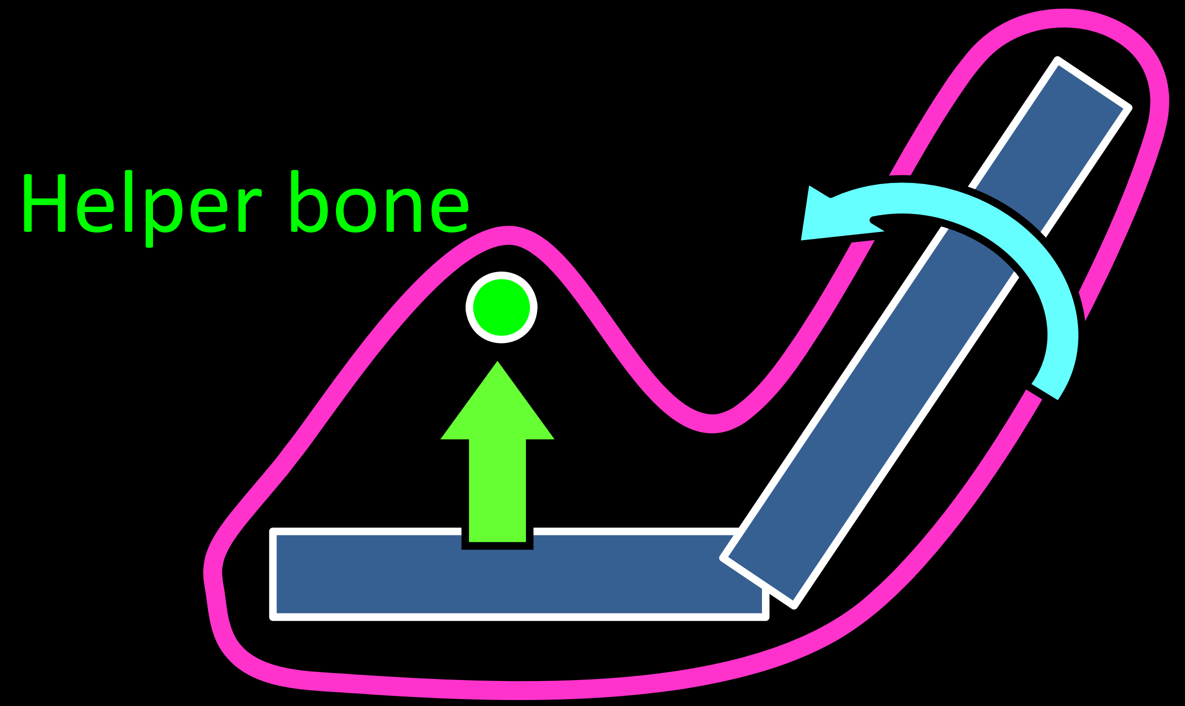
Candy-wrapper



Elbow-collapse

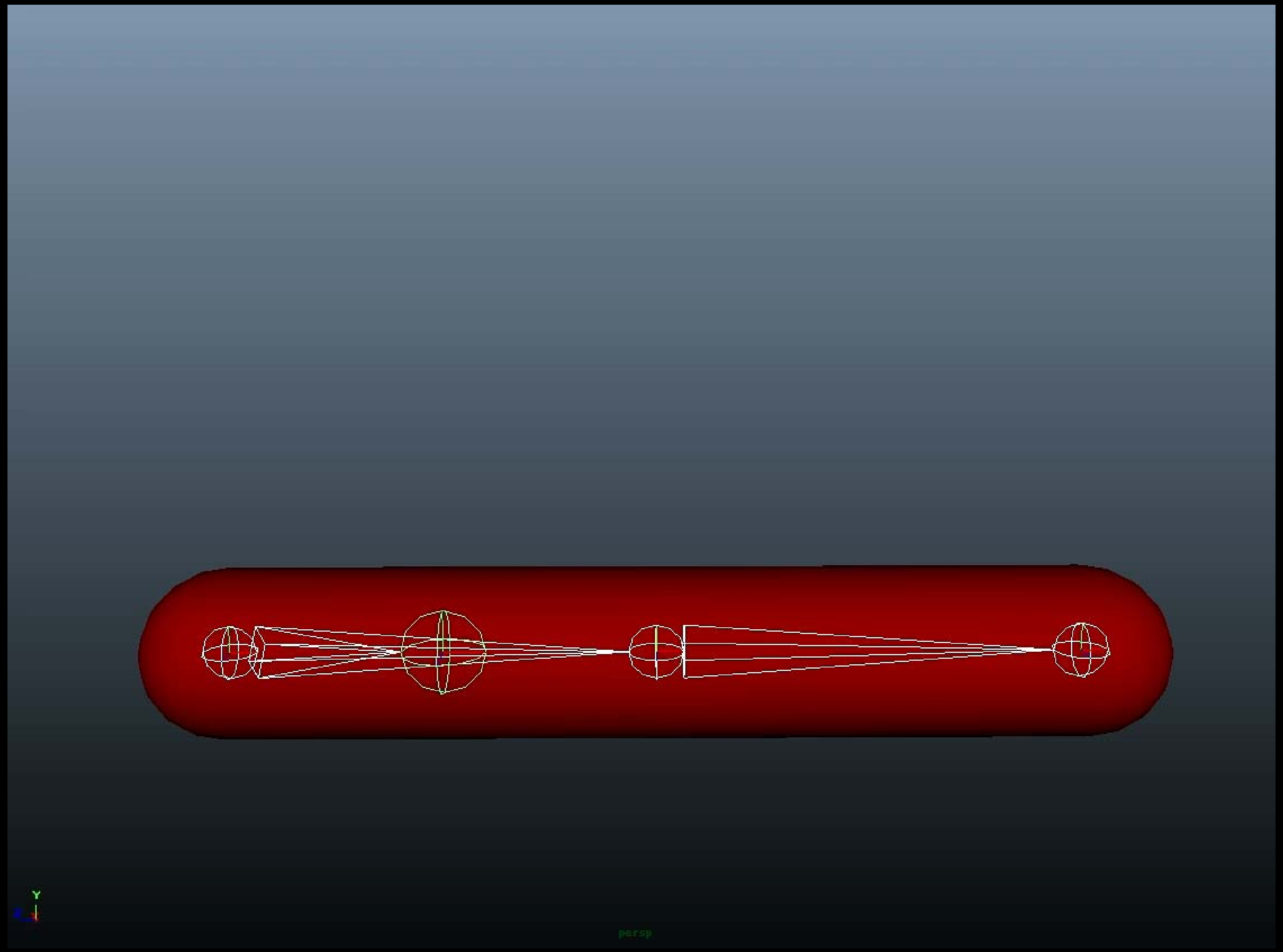
Helper Bone System

[Mohr et al., 2003, Parks 2005@GDC]



Maya expression

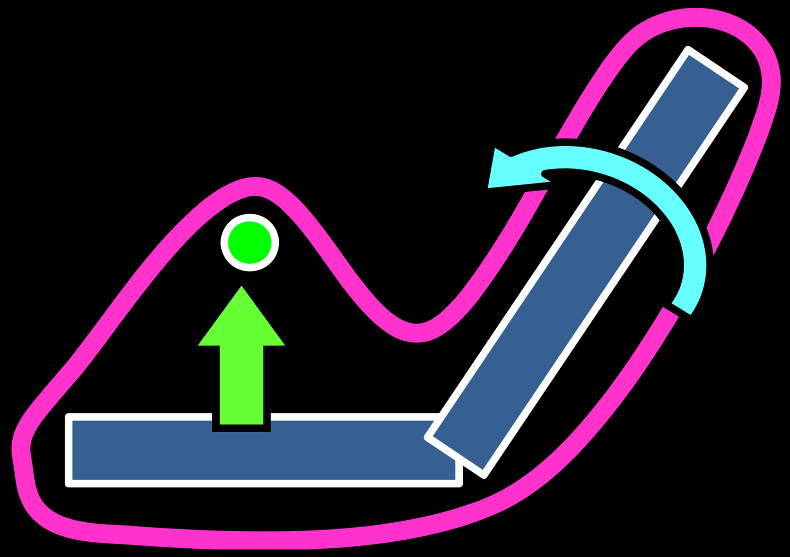
HelperBone.translateY
= 0.02 * joint.rotateZ



Helper Bone Rigging

[Mohr et al., 2003, Parks 2005@GDC]

- No physical / anatomical meaning
  - How many?
  - Where to add?
  - Which primary bone does drive?

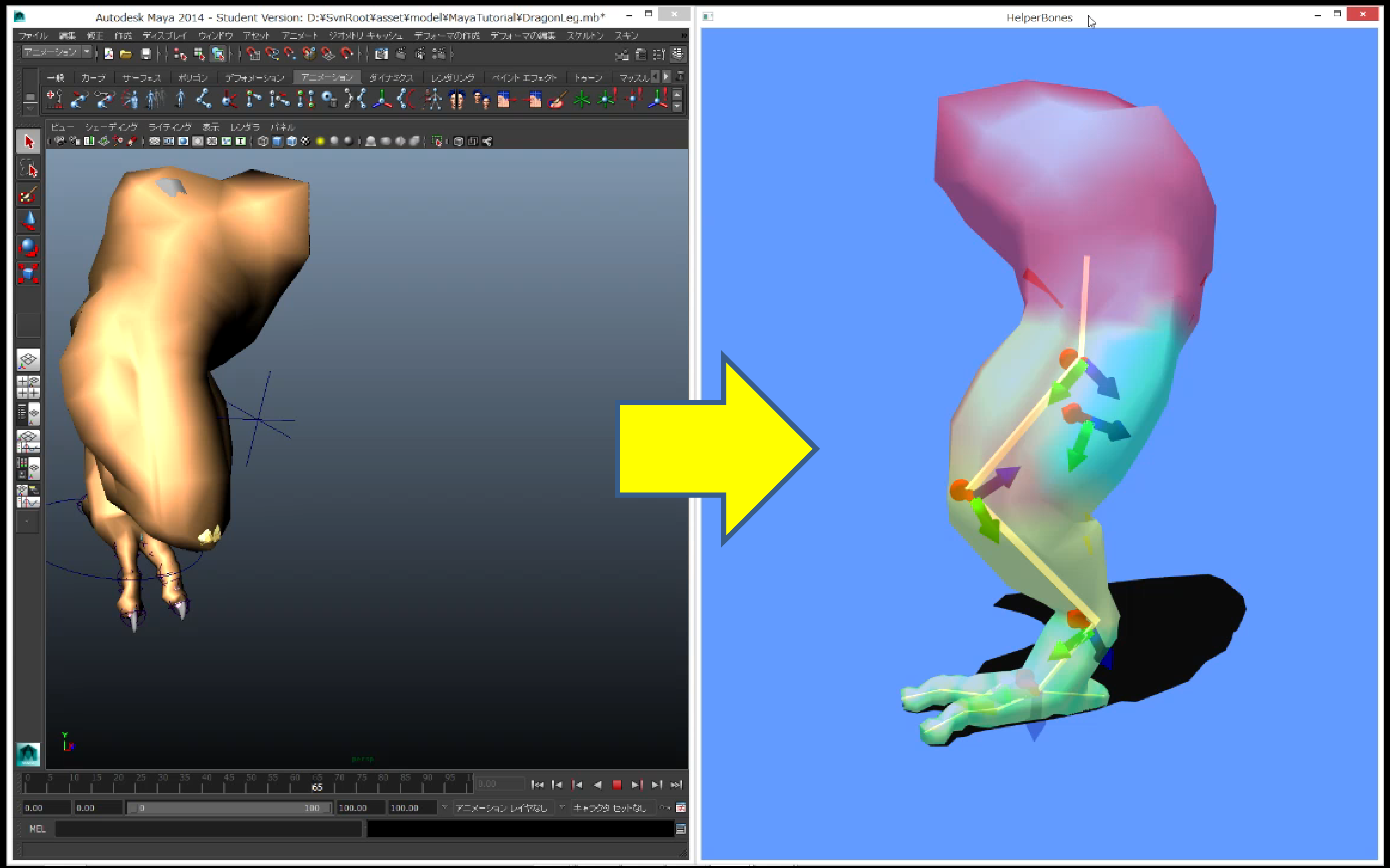


Expression

HelperBone.transform
= ???

- Heuristic scripting
  - Polynomial?
  - IF-THEN rule?

Goal



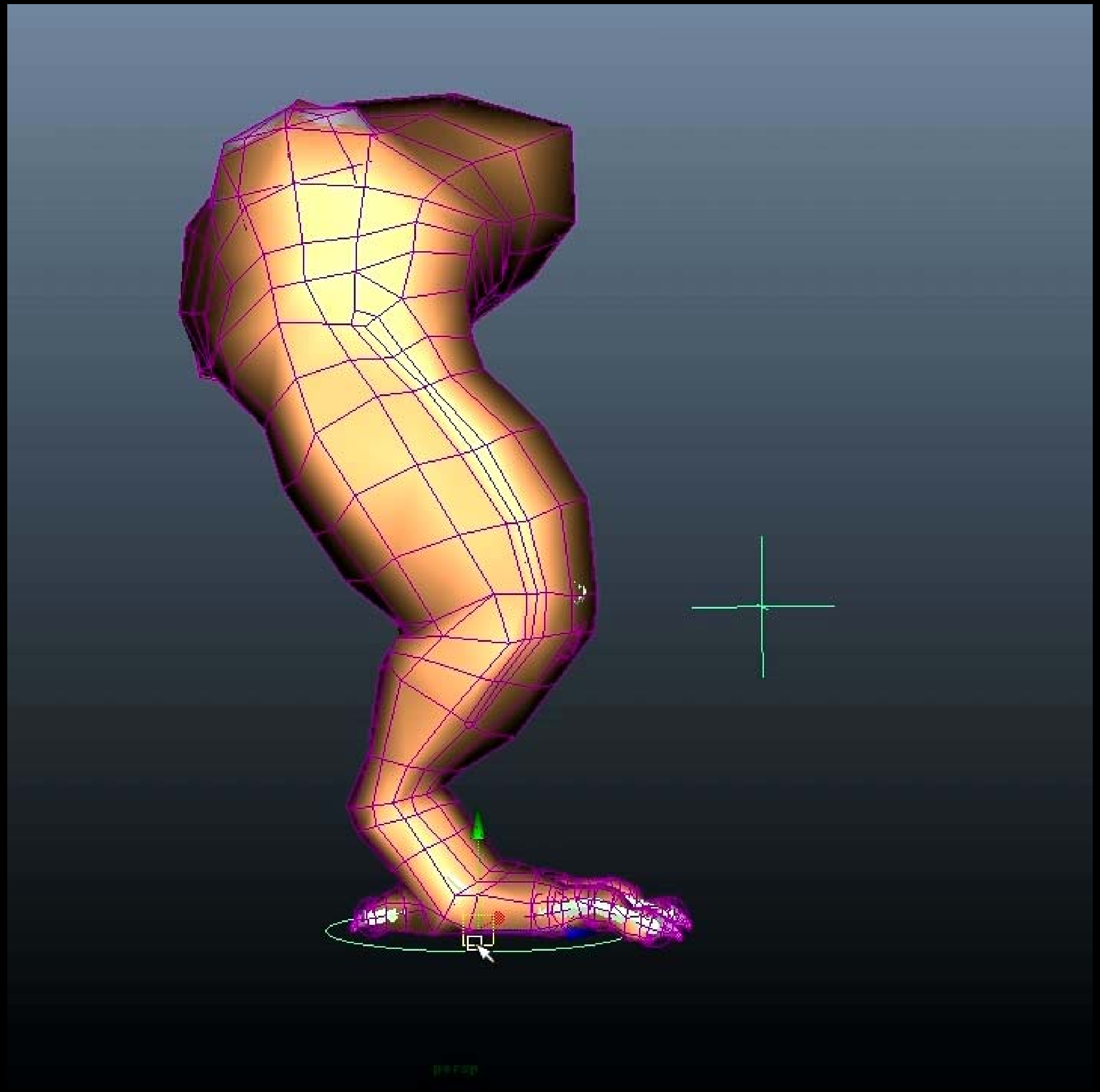
Skin shape + skeleton pose
(crafted asset, physics simulation)

Real-time helper bone rig

Experiment - *DragonLeg*

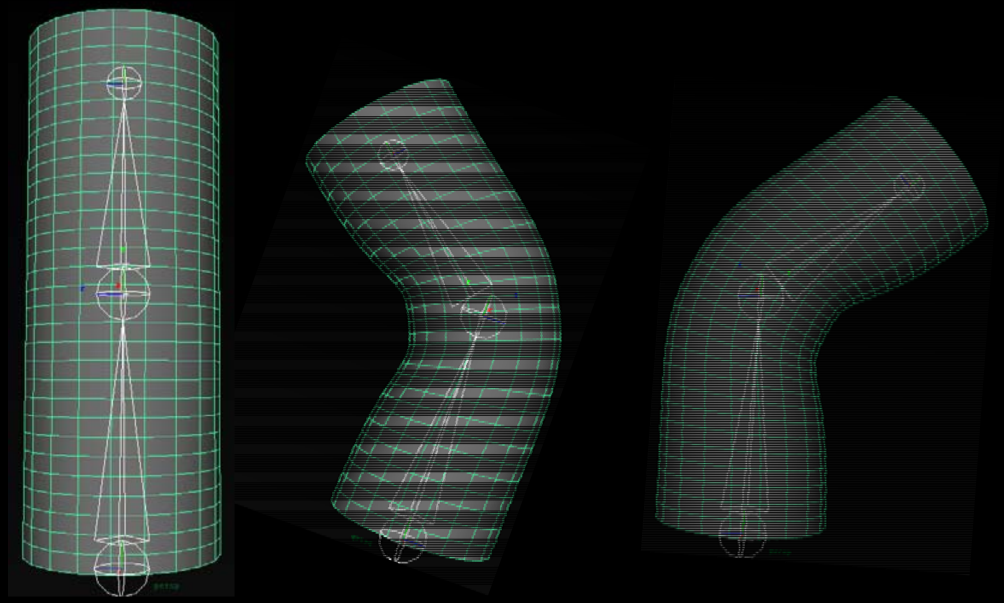
- 663 vertices
- 5 DOFs of primary skeleton
- 11 virtual muscles

- 6,750 pairs of examples
  - Uniform sampling of joint DOFs



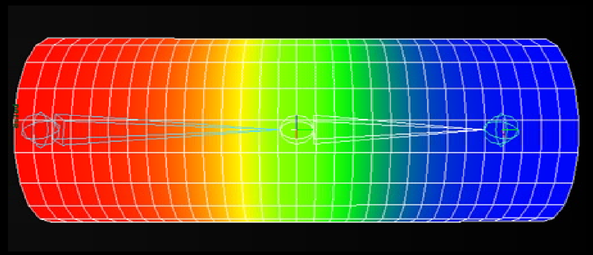
Input & Output

- Input
  - Bind mesh ＋ primary skeleton
  - Example shape ＋ skeleton pose
  - Number of helper bones



…

- Output
  - Skinning weight
  - Helper bone controller

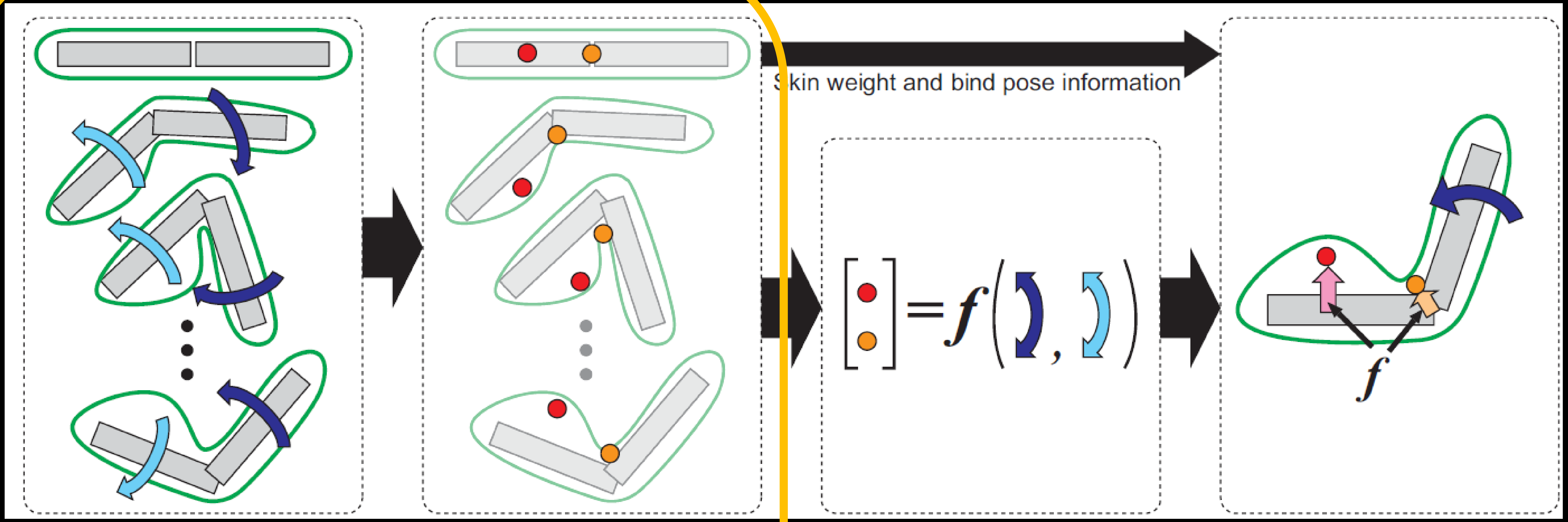


Expression

HelperBone.transform
= *???*

- Least-square approximation
  - Reconstruction error of vertex position

Approach



Examples Bone trans-formation Bone controller Procedural control

Optimal Skinning Weights and Helper Bone Transformation

\# of examples

\# of vertices

Skinning weight

Helper bone transformation

$$\min \sum_{n=1}^{N} \sum_{j=1}^{J} \left| \tilde{\mathbf{v}}_{j,n} - \boxed{\sum_{d=1}^{D} w_{j,d} \bar{\mathbf{v}}_j \tilde{\mathbf{S}}_{d,n}} - \boxed{\sum_{h=1}^{H} \hat{w}_{j,h} \bar{\mathbf{v}}_j \hat{\mathbf{S}}_{h,n}} \right|_2^2$$

Example shape and skeleton pose

Constrained Least Square Problem

$$\min \sum_{n=1}^{N}\sum_{j=1}^{J}\left\|\tilde{\mathbf{v}}_{j,n} - \sum_{d=1}^{D} w_{j,d}\bar{\mathbf{v}}_j\tilde{\mathbf{S}}_{d,n} - \sum_{h=1}^{H}\hat{w}_{j,h}\bar{\mathbf{v}}_j\hat{\mathbf{S}}_{h,n}\right\|_2^2$$

Subject to $\hat{\mathbf{S}}_{h,n}$: Rigid transformation（rotation & translation）

$w_{j,d}, \hat{w}_{j,h}$: Non-negative

$w_{j,d}, \hat{w}_{j,h}$: Partition of unity for each vertex

$w_{j,d}, \hat{w}_{j,h}$: Maximum count of non-zeros for each vertex

Previous Work

- **S**mooth **S**kinning **D**ecomposition with **R**igid bones : **SSDR** model [Le and Deng 2012, 2014]

Extension of SSDR Model

- SSDR model

$$\min \sum_{n=1}^{N} \sum_{j=1}^{J} \left\| \tilde{\mathbf{v}}_{j,n} - \sum_{d=1}^{D} w_{j,d} \bar{\mathbf{v}}_j \mathbf{S}_{d,n} \right\|_2^2$$

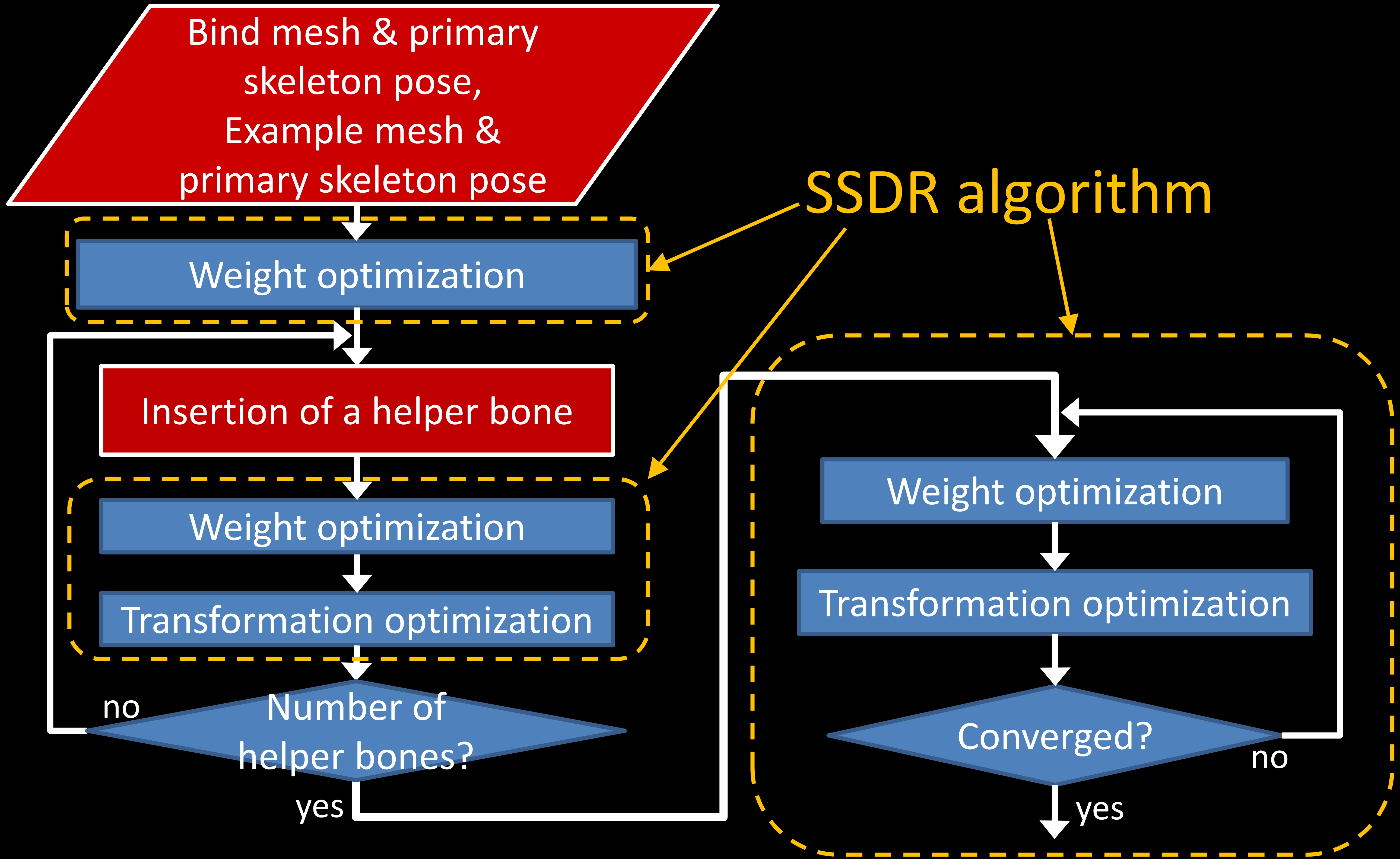
- Helper bone rigging

Example

$$\min \sum_{n=1}^{N} \sum_{j=1}^{J} \left\| \tilde{\mathbf{v}}_{j,n} - \sum_{d=1}^{D} w_{j,d} \bar{\mathbf{v}}_j \tilde{\mathbf{S}}_{d,n} - \sum_{h=1}^{H} \hat{w}_{j,h} \bar{\mathbf{v}}_j \hat{\mathbf{S}}_{h,n} \right\|_2^2$$

(Under same constraints)

Optimization Procedure

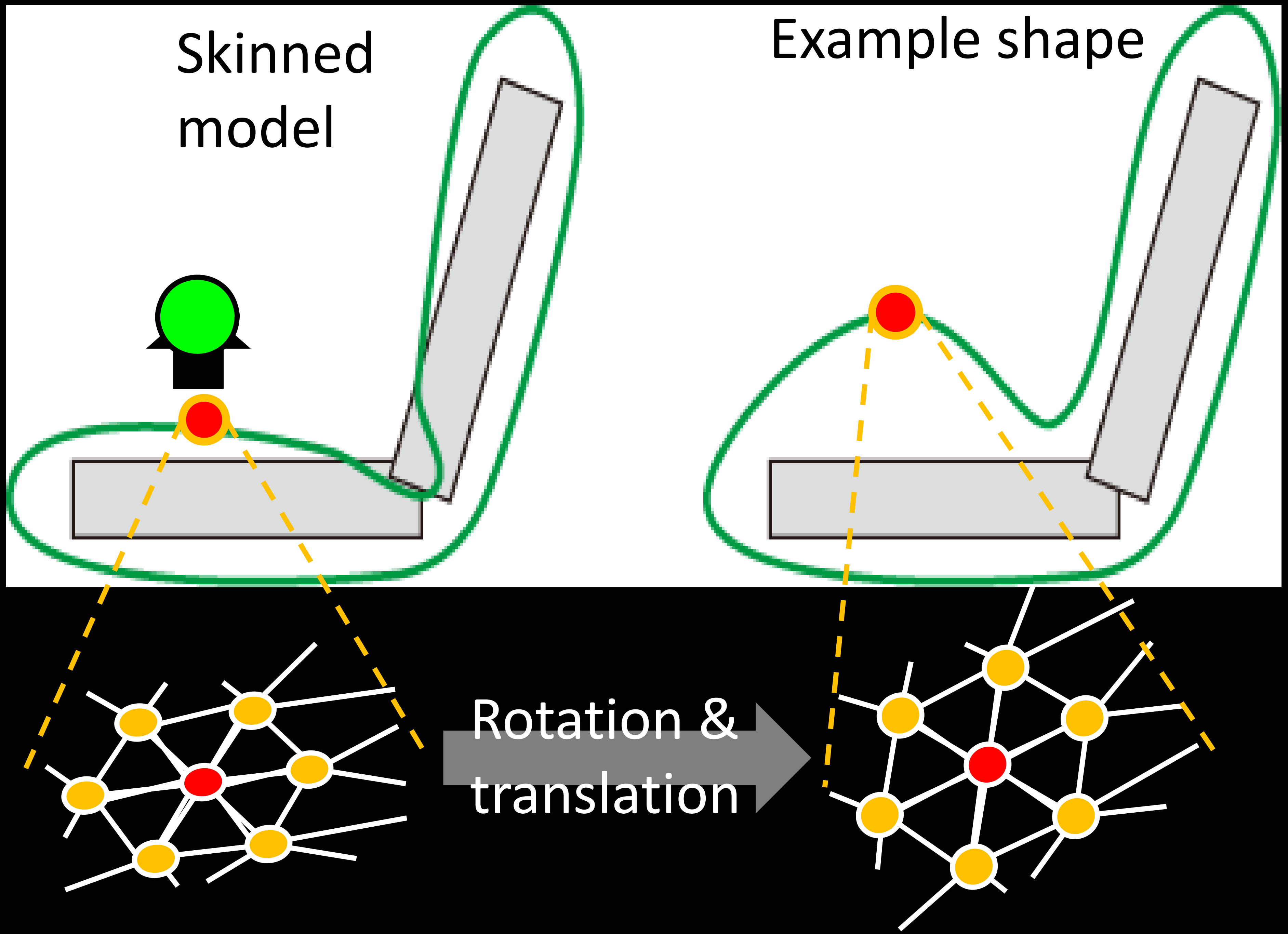


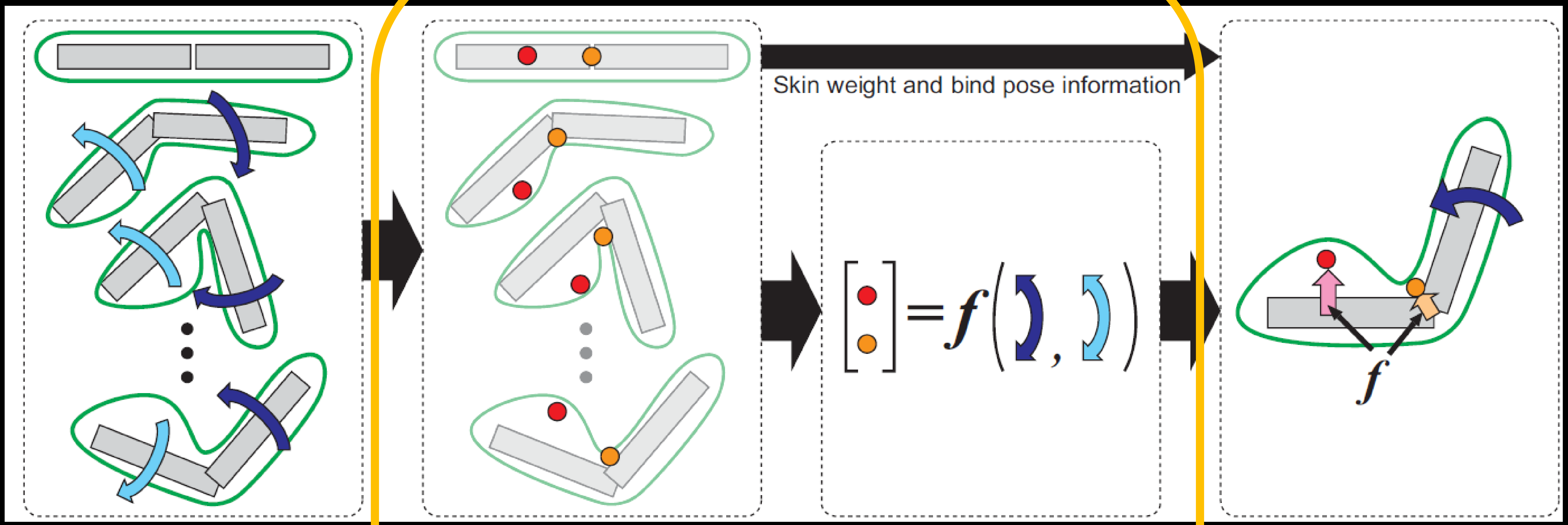
Insertion of Helper Bone

1. Find a vertex showing the largest error
   and its 1-ring neighbors

2. Estimate rigid transformation ⇧

3. Inserting a new helper bone using the rigid transformation





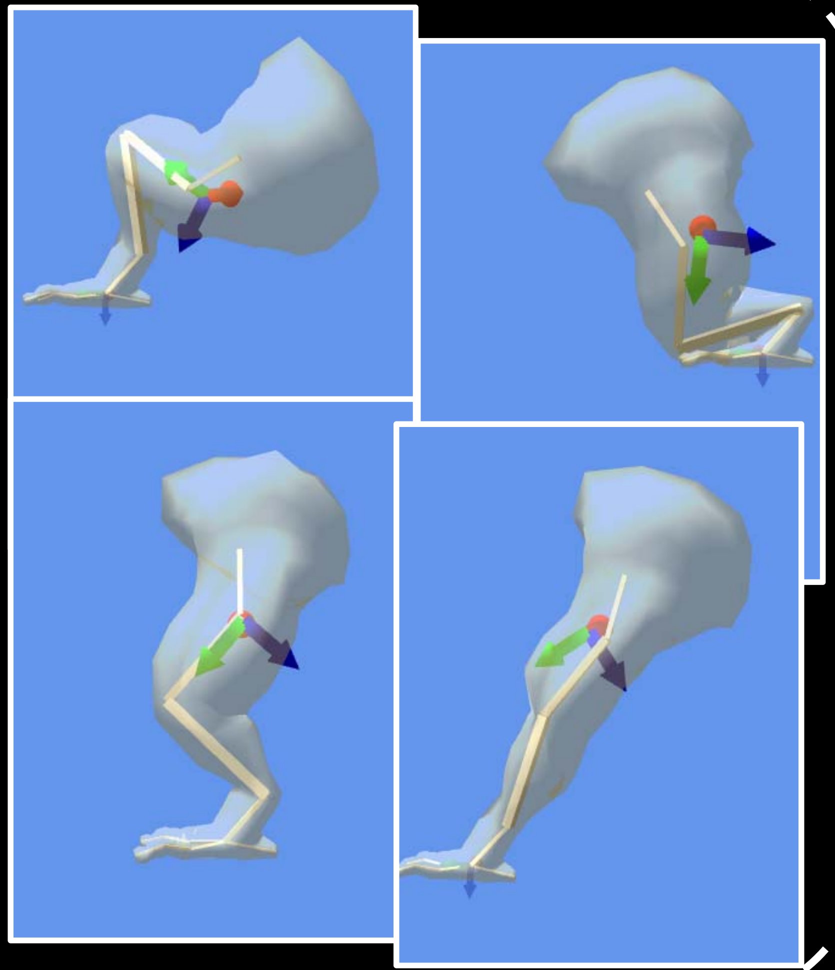
Examples

Bone trans-
formation

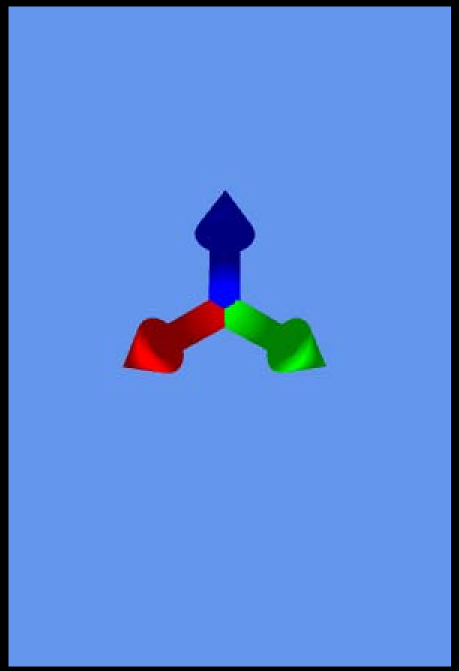
Bone
controller

Procedural
control

Bone Controller Construction



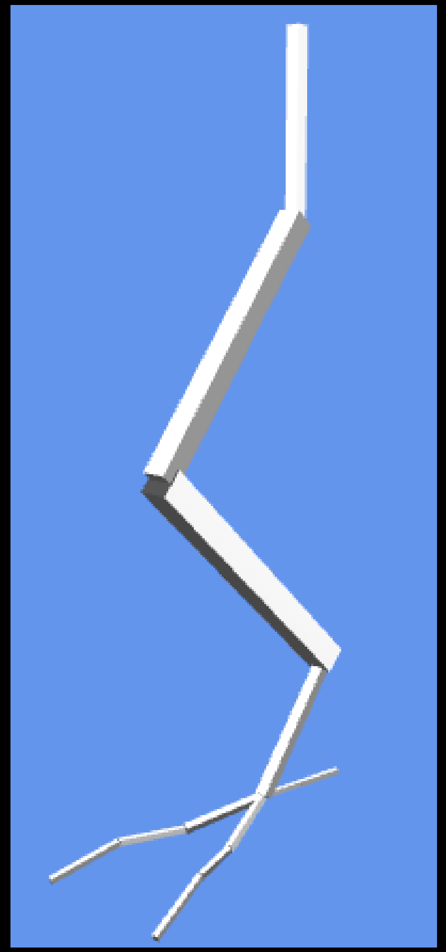
Primary skeleton pose
Skin shape
Estimated helper bone



Helper bone transformation

$= f($

Bone controller



$)$

Primary skeleton pose

Second Degree Polynomial as Controller

HelperBone.translateX

f1 * joint1.rotateX + ***f2*** * joint1.rotateY + ***f3*** * joint1.rotateY
+ ***f4*** * joint1.rotateX^2 + ***f5*** * joint1.rotateY^2 +
… + ***f53*** * joint9.rotate^2 + ***f54*** * joint9.rotateZ^2 + ***f55***

HelperBone.translateY

⋮

HelperBone.rotateZ

Second Degree Polynomial as Controller

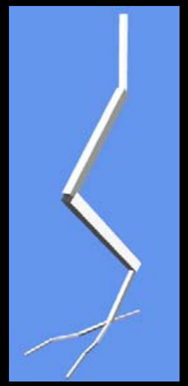
HelperBone.translateX

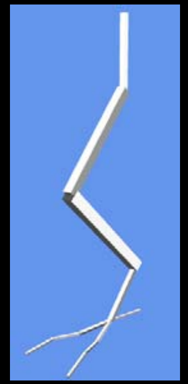
f1 * joint1.rotateX + ***f2*** * joint1.rotateY + ***f3*** * joint1.rotateY
+ ***f4*** * joint1.rotateX^2 + ***f5*** * joint1.rotateY^2 +
… + ***f53*** * joint9.rotate^2 + ***f54*** * joint9.rotateZ^2 + ***f55***

HelperBone.translateX =

$$\begin{pmatrix} f1 \\ f2 \\ f3 \\ \vdots \\ f54 \\ f55 \end{pmatrix}^T$$

^2





1 ← constant term

Regression with Sparsity Constraint

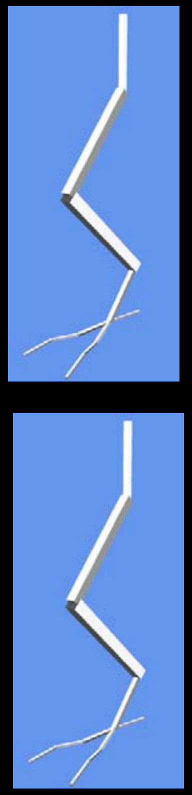
HelperBone.translateX

f1 * joint1.rotateX + *0* * joint1.rotateY + *f3* * joint1.rotateY
+ *0* * joint1.rotateX^2 + *f5* * joint1.rotateY^2 +
… + *0* * joint9.rotate^2 + *0* * joint9.rotateZ^2 + *f55*

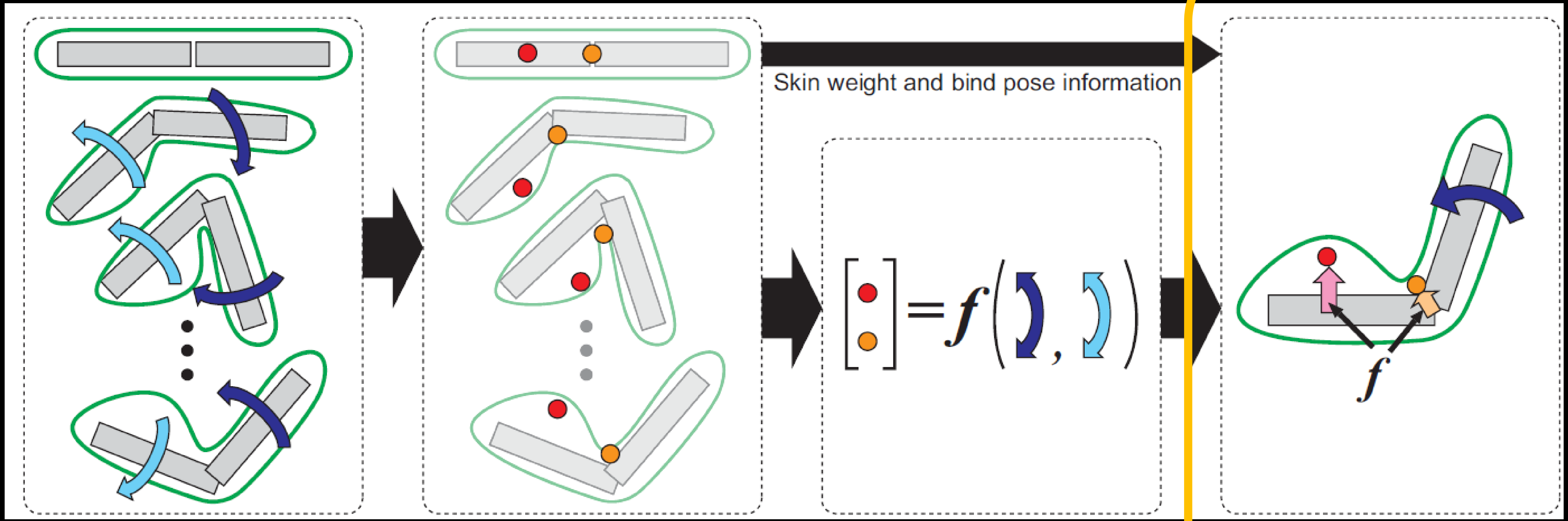
HelperBone.translateX ÷

LASSO
solver

$$\begin{pmatrix} f1 \\ 0 \\ f3 \\ \vdots \\ 0 \\ f55 \end{pmatrix}^T$$

( ^2 … 1)

Experimental Results

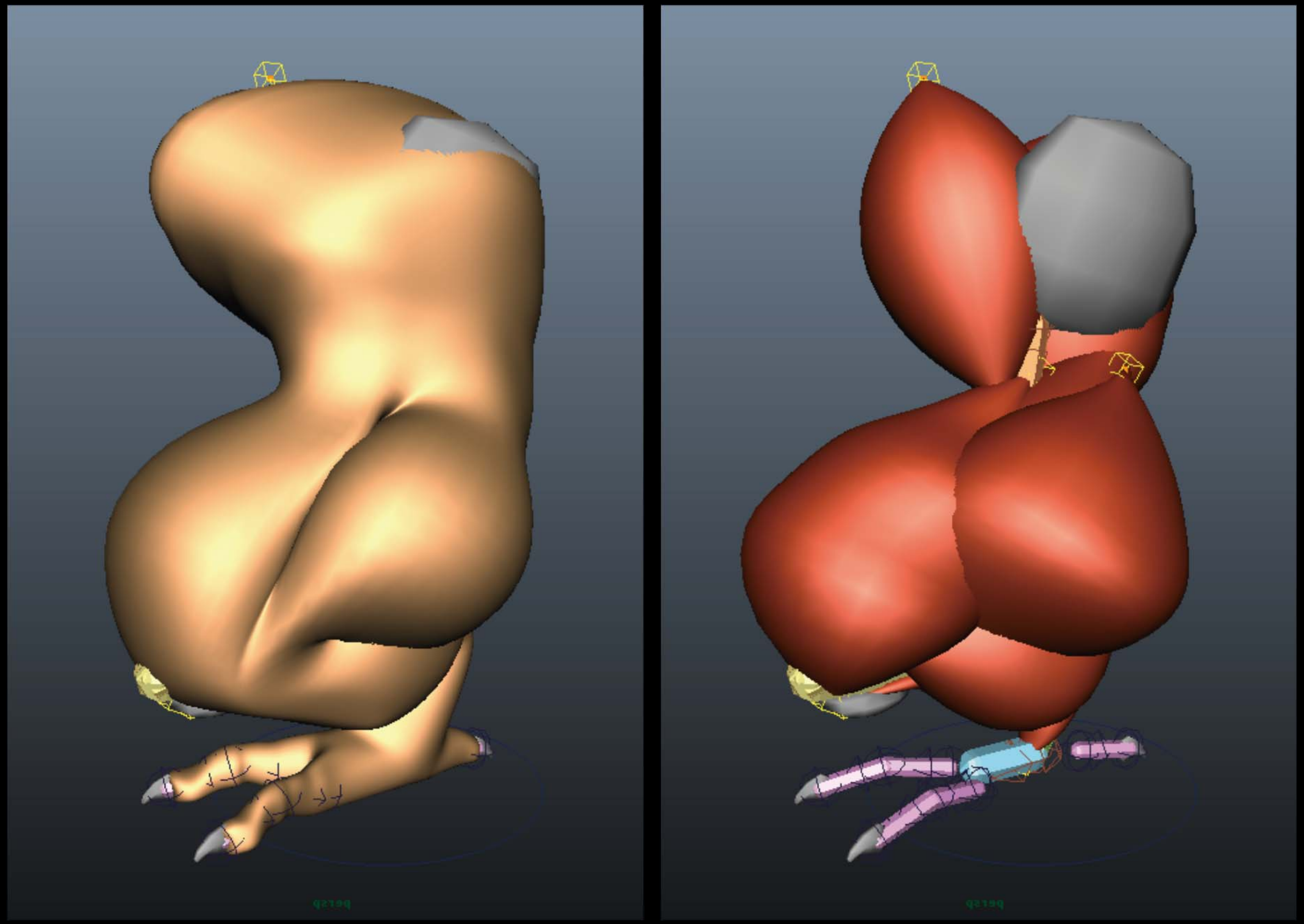


Examples | Bone trans–formation | Bone controller | Procedural control

Experiment - *Stylized DragonLeg*

- 8322 vertices
- 5 DoF of primary skeleton
- 11 exaggerated muscles

- Uniform sampling of joint DOF
- 6,750 pairs of examples

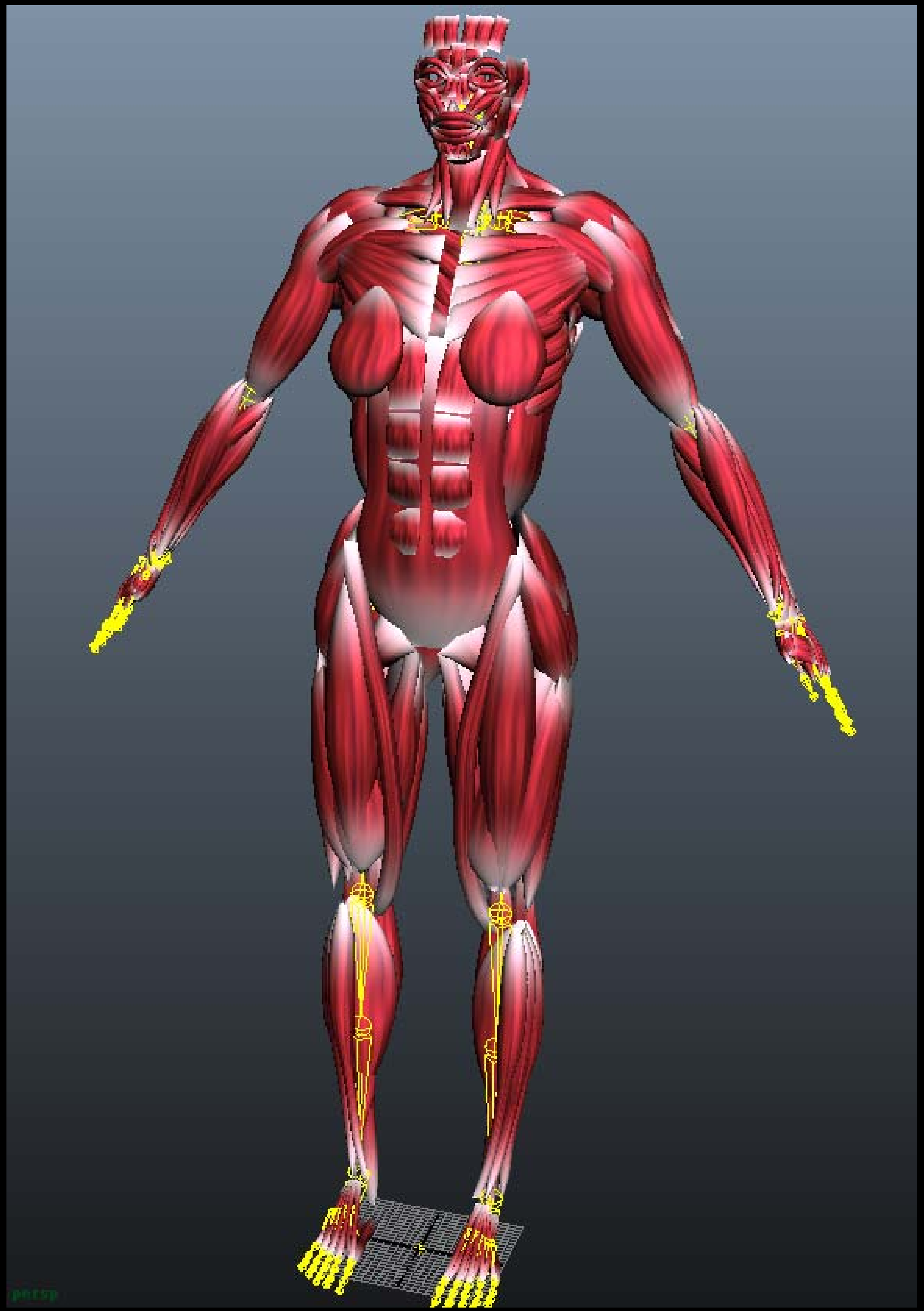


Experiment - *Miranda*

- 14,470 vertices
- Whole body skeleton
- A lot of muscles

- Rigging of only arm
  - Shoulder : 3 DOFs
  - Elbow : 1 DOF
  - Wrist : 1 DOF

- About 20,000 examples



Quantitative Evaluation

- DragonLeg (4 bones)
  - 32 sec for build (7k examples)
  - ~ 5 usec/bone for control
  - RMSE = 2.1 cm (height = 2 m)
- Miranda (4 bones)
  - 17 min for build (20k examples)
  - ~ 5 usec/bone for control
  - RMSE = 2.7 cm (height = 1.7m)
- Stylized DragonLeg (4 bones)
  - 420 sec for build (7k examples)
  - ~ 5 usec/bone for control
  - RMSE = 2.9 cm (height = 2m)

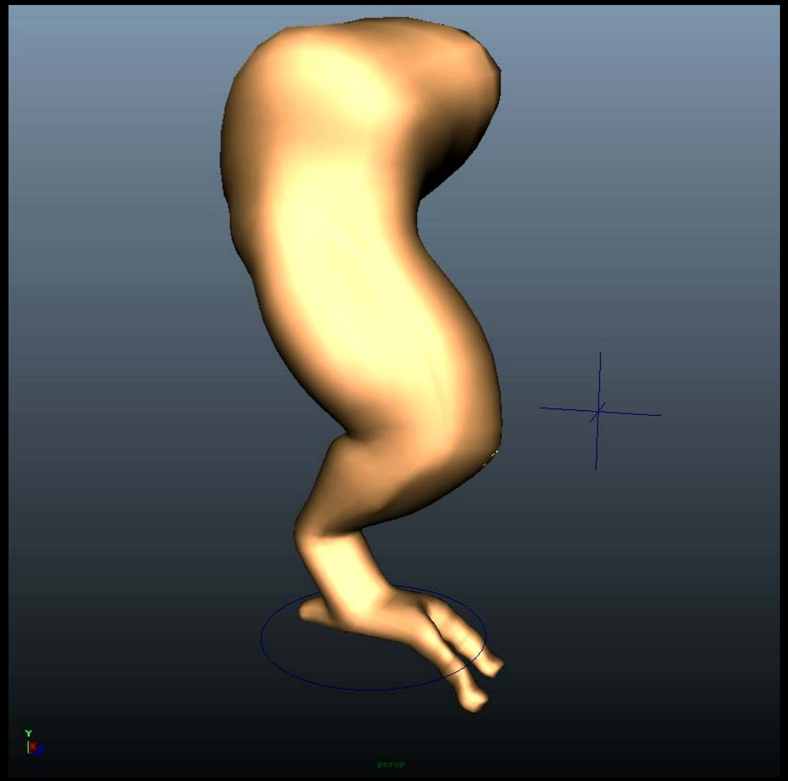
Dual Xeon E5-2687W 3.1GHz
(40 logical cores)
64 GB RAM
VC++2013, Intel TBB, MKL

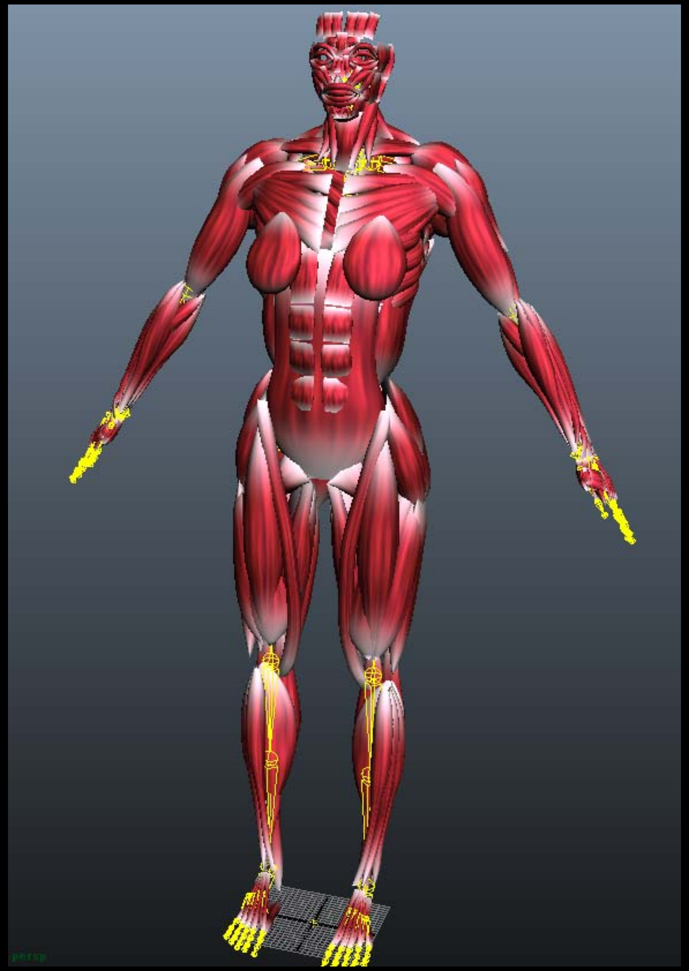
Discussion

- Creating sufficient number of examples
  - Physically-based deformation [Li et al. 2010, Fang et al. 2014]
  - Shape capture [Neumann et al, 2013]
- Helper bone system
  - vs Scattered-data interpolation (PSD)
    - ○ Faster, more memory efficient
    - ✕ Less accurate

Future Work

- Dynamic skin deformation
  - Velocity and acceleration
- High-res mesh, many joint DOFs
  - Minimal number of example data
  - Level-of-detail control





Building Helper Bone Rigs from Examples

Acknowledgement

- Reviewers
- Tokai University Educational System Research Organization
- TAISO, Renpoo (BEHIND-UNIVERSE)
- Advanced Technology Division, SQUARE ENIX

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