Example-Based Skeleton Extraction

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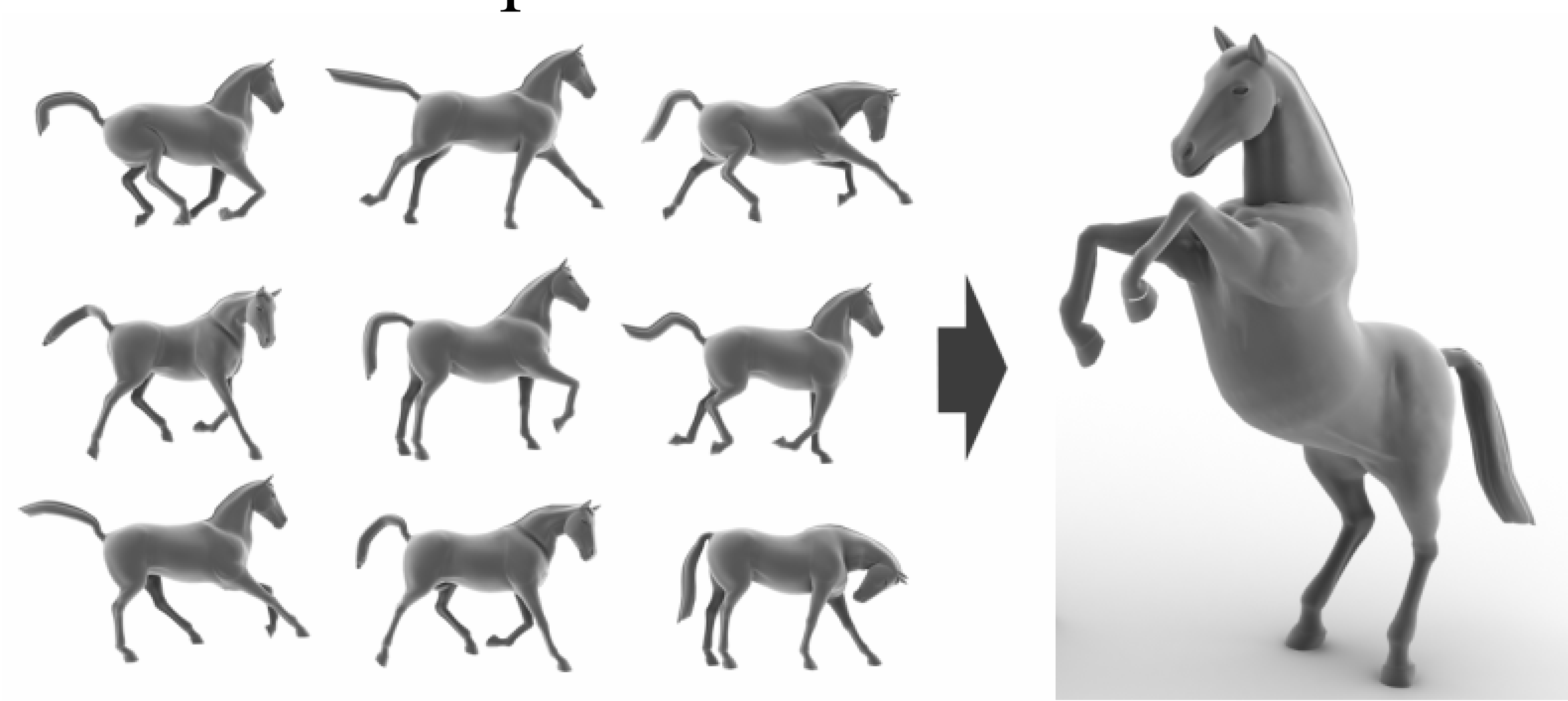
Example-Based Deformation

Examples



Previous Work

- Mesh-based Inverse Kinematics [Sumner et al. 2005], [Der et al. 2006]
  - Example-based deformation method
  - Non-linear minimization
  - Not real-time

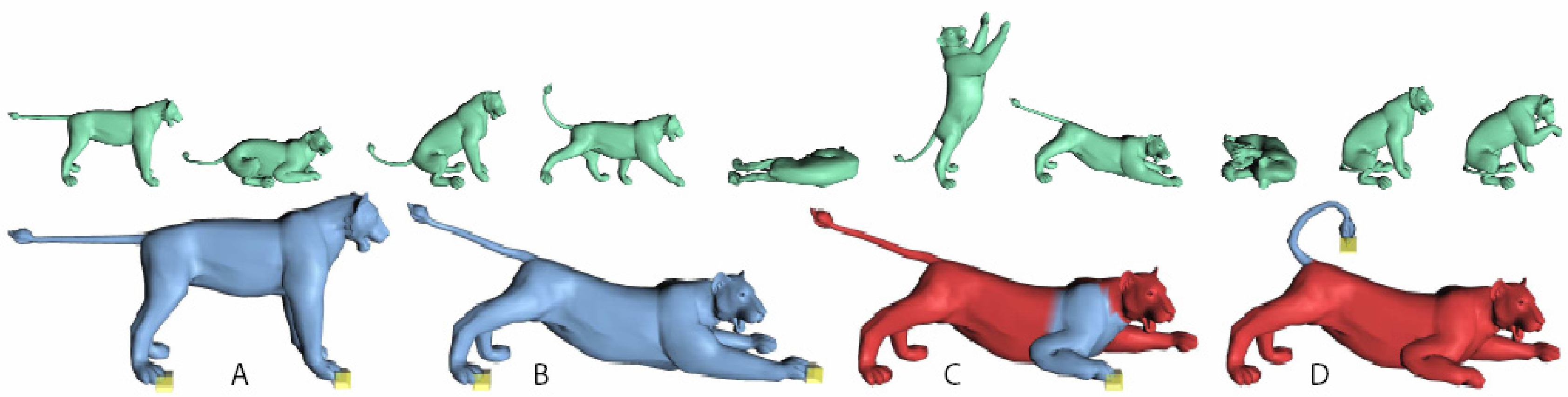
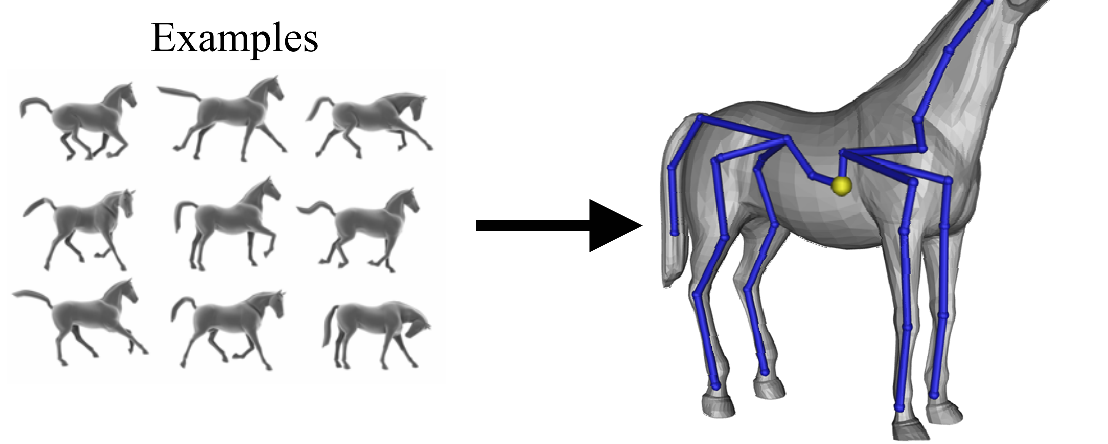


Image taken from [Sumner et al. 2005]

Objective

- Determine parameters for skeletal animation from set of examples
  - Bone transformations
  - Vertex weights
  - Bone connectivity
  - Joint locations
  - Root node



Previous Work

- Skeleton from shape decomposition
  - [Katz, Tal 2003]
  - [de Aguilar et al. 2004]
  - [Theobalt et al. 2004]
  - [Katz et al. 2005]
  - [Lien et al. 2006]

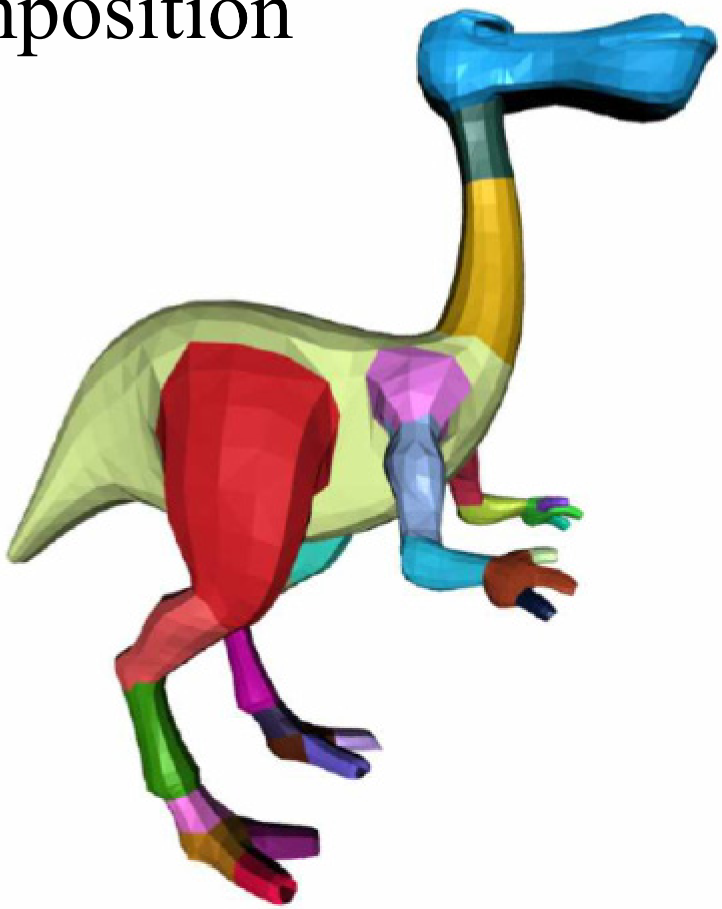


Image taken from [Lien et al. 2006]

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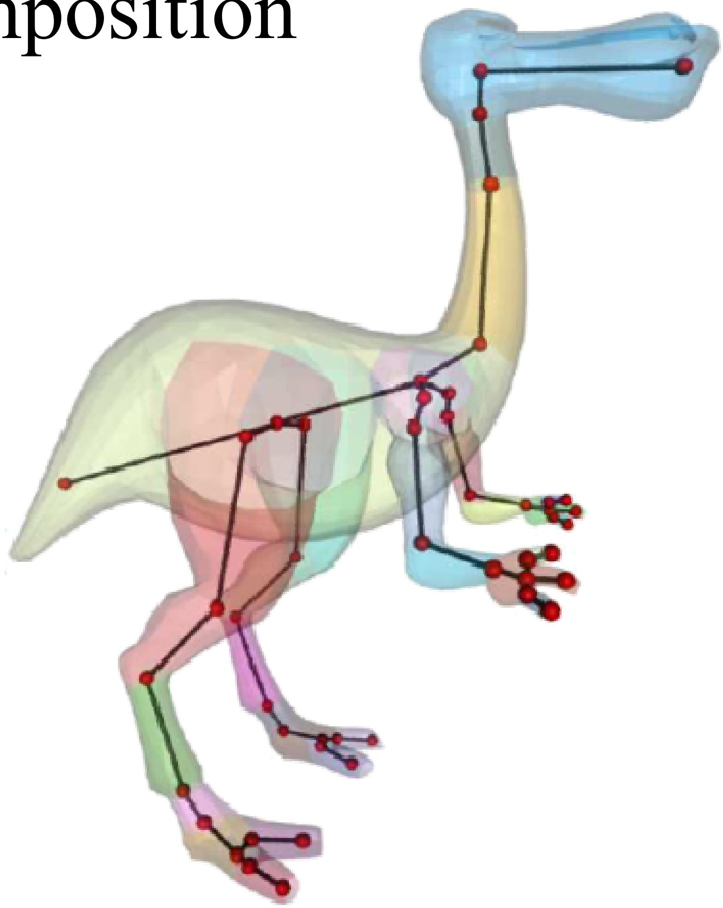

Image taken from [Lien et al. 2006]

Previous Work

- Example-based skinning
  - [Wang et al. 2002]
  - [Mohr, Gleicher 2003]

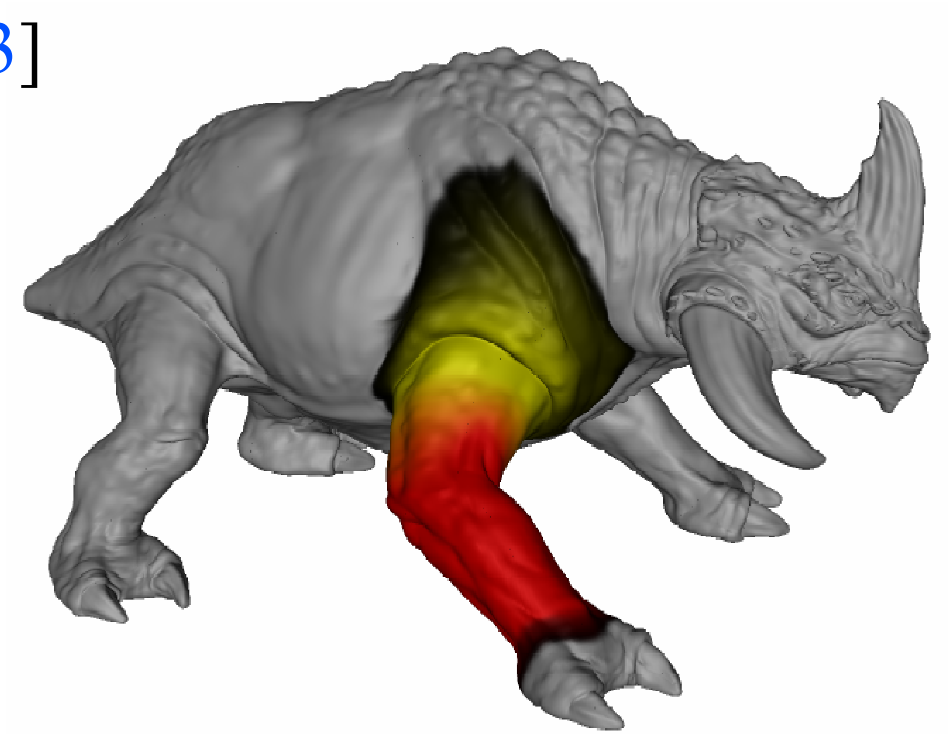

Image taken from [Wang et al. 2002]

Previous Work

- Skinning Mesh Animations [James, Twigg 2005]
  - Robust face clustering for bone estimation
  - Non-negative least squares for weights
  - Compresses animations for display on GPU
  - No connectivity/hierarchy/joint positions

Image taken from [James, Twigg 2005]

Previous Work

- Skeletons from real world data
  - [Kurihara, Miyata 2004]
  - [Anguelov et al. 2004]
  - [Kirk et al. 2005]

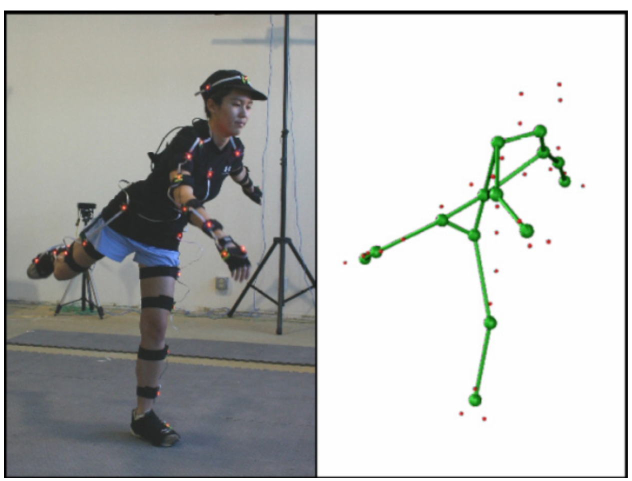

Image taken from [Kirk et al. 2005]

Image taken from [Kurihara, Miyata 2004]

Outline

- Bone estimation
- Skinning
- Finding bone connectivity
- Estimating joint locations

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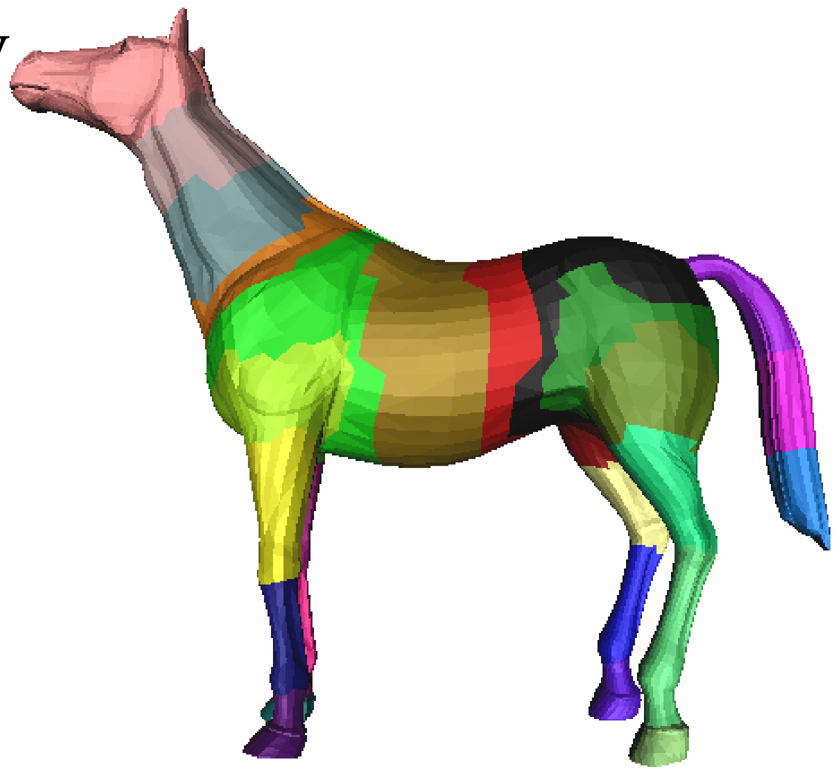

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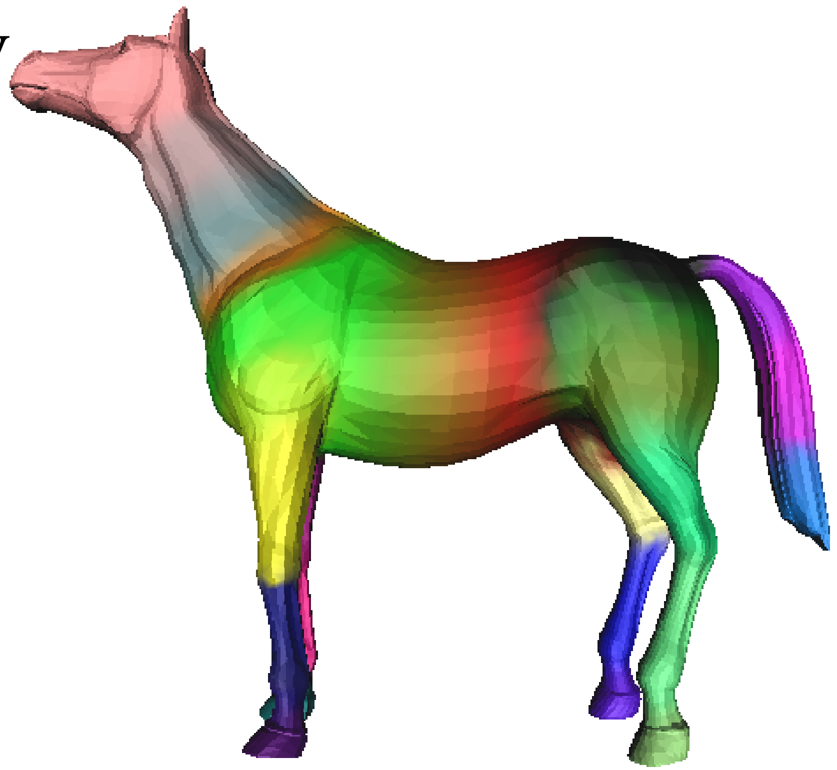

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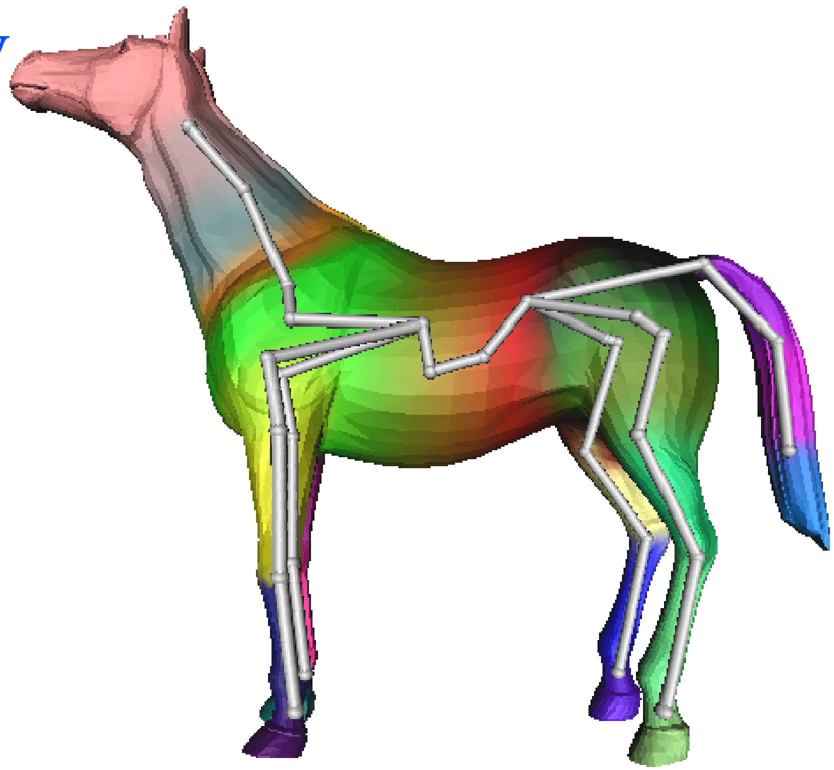

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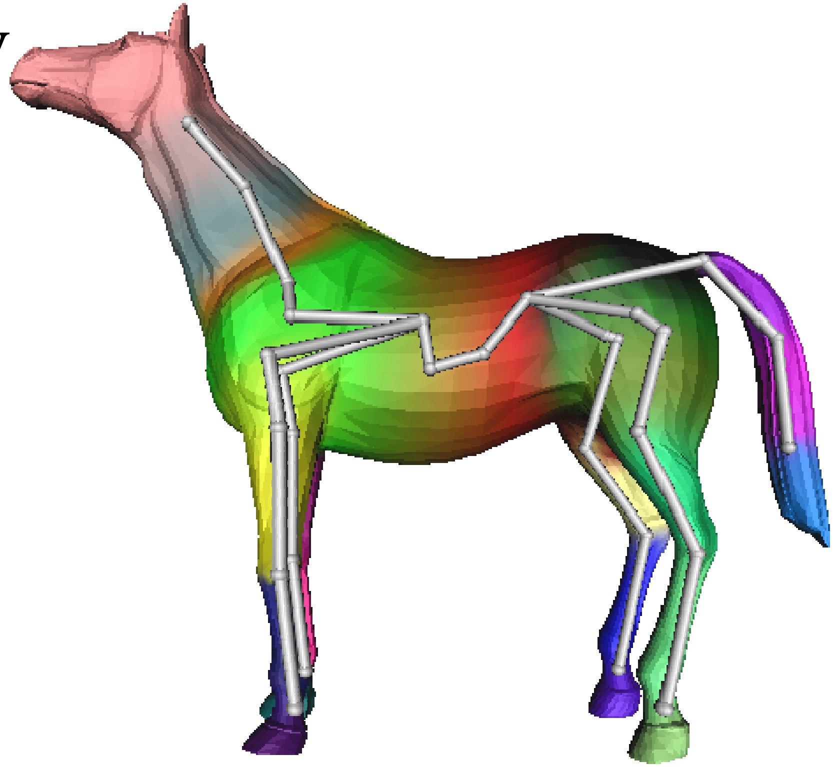
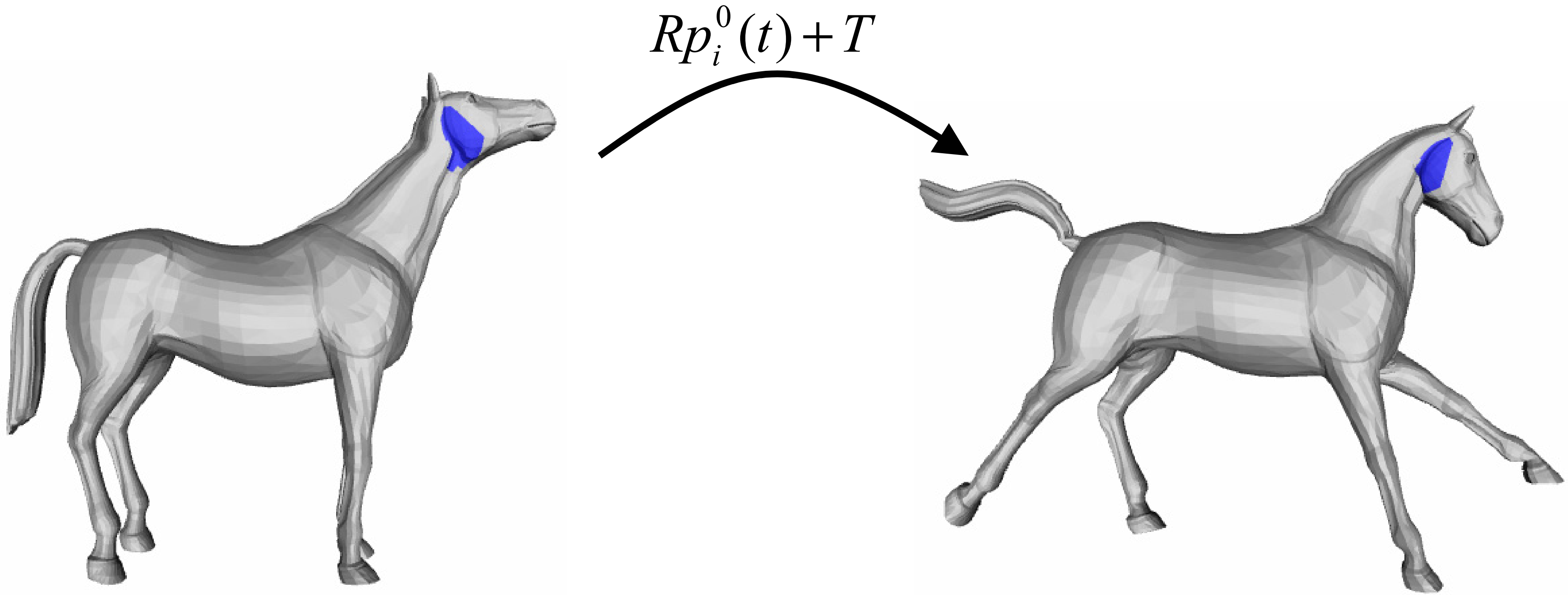


Bone Estimation

- Cluster faces that transform in the same rigid manner

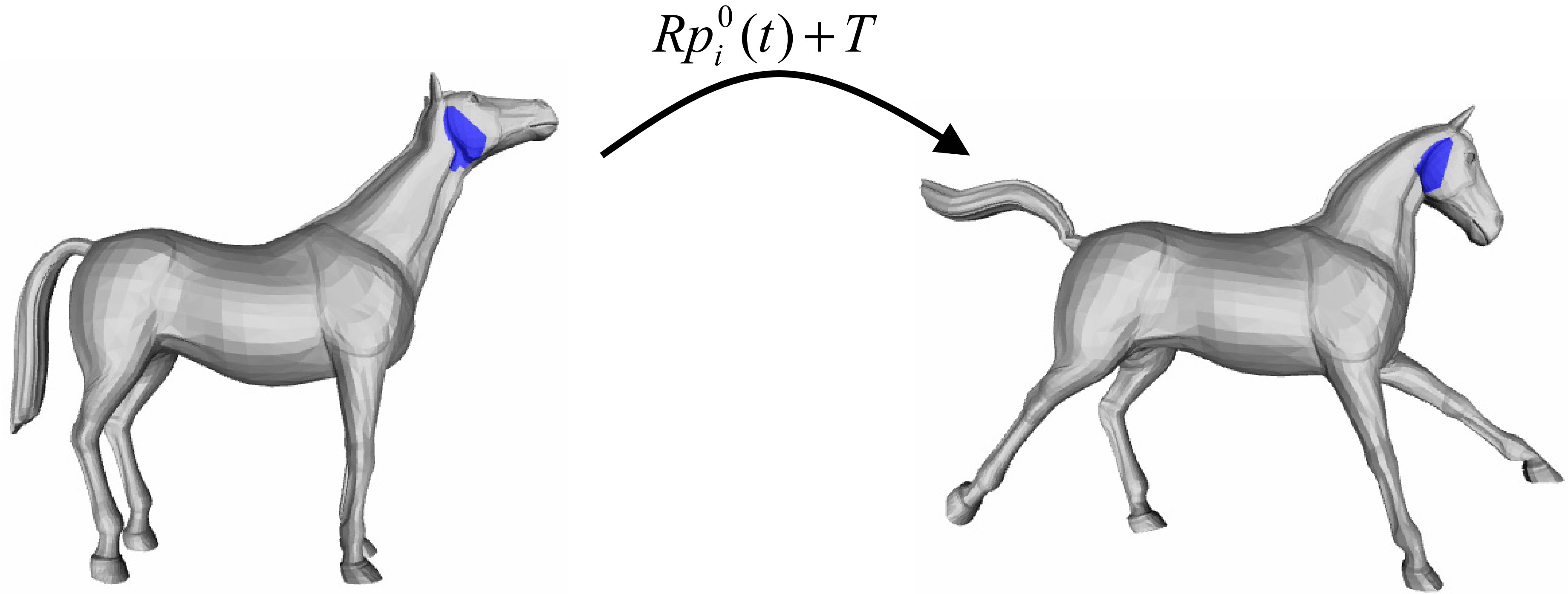
Rigid Error Functions

$$\min_{R^T R = I, T} \sum_i \int_t \left| R p_i^0(t) + T - p_i^k(t) \right|^2 dt$$



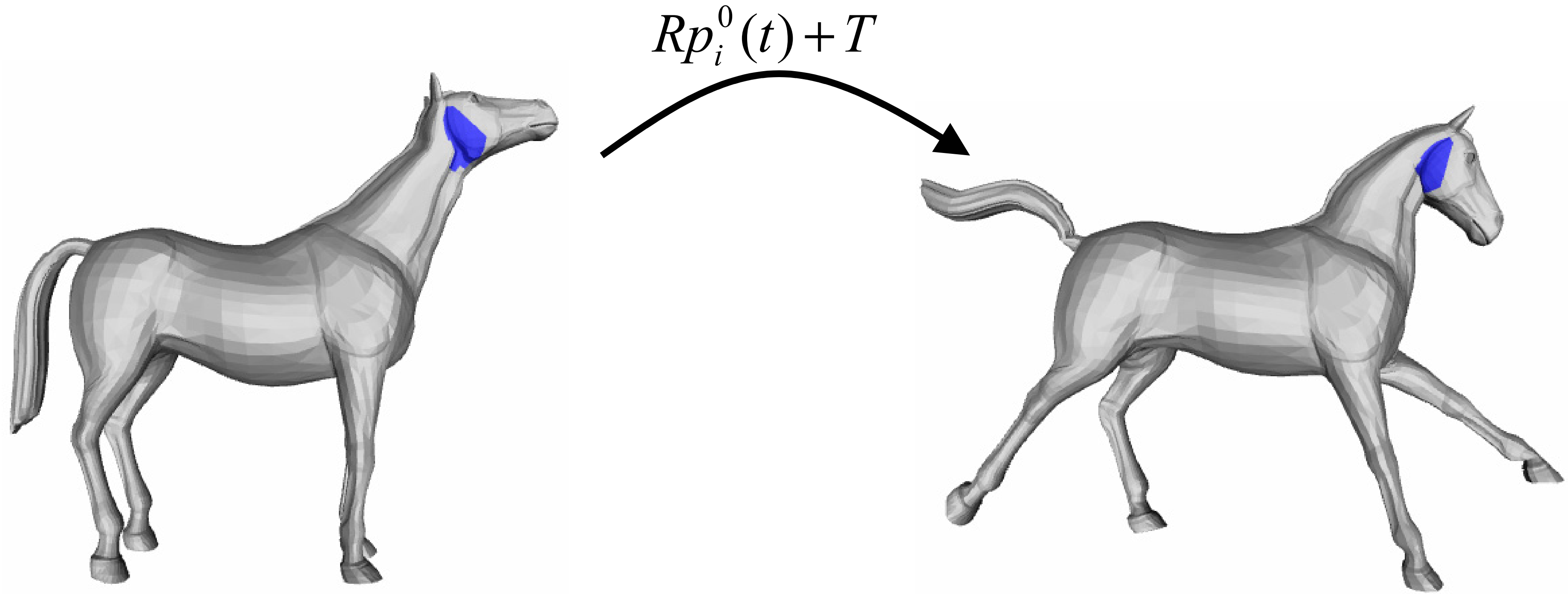
Rigid Error Functions

$$T = \bar{p}^k - R\bar{p}^0 \qquad \text{where} \qquad \bar{p}^k = \frac{\sum_i \int_t p_i^k(t)\,dt}{\sum_i \int_t dt}$$



Rigid Error Functions

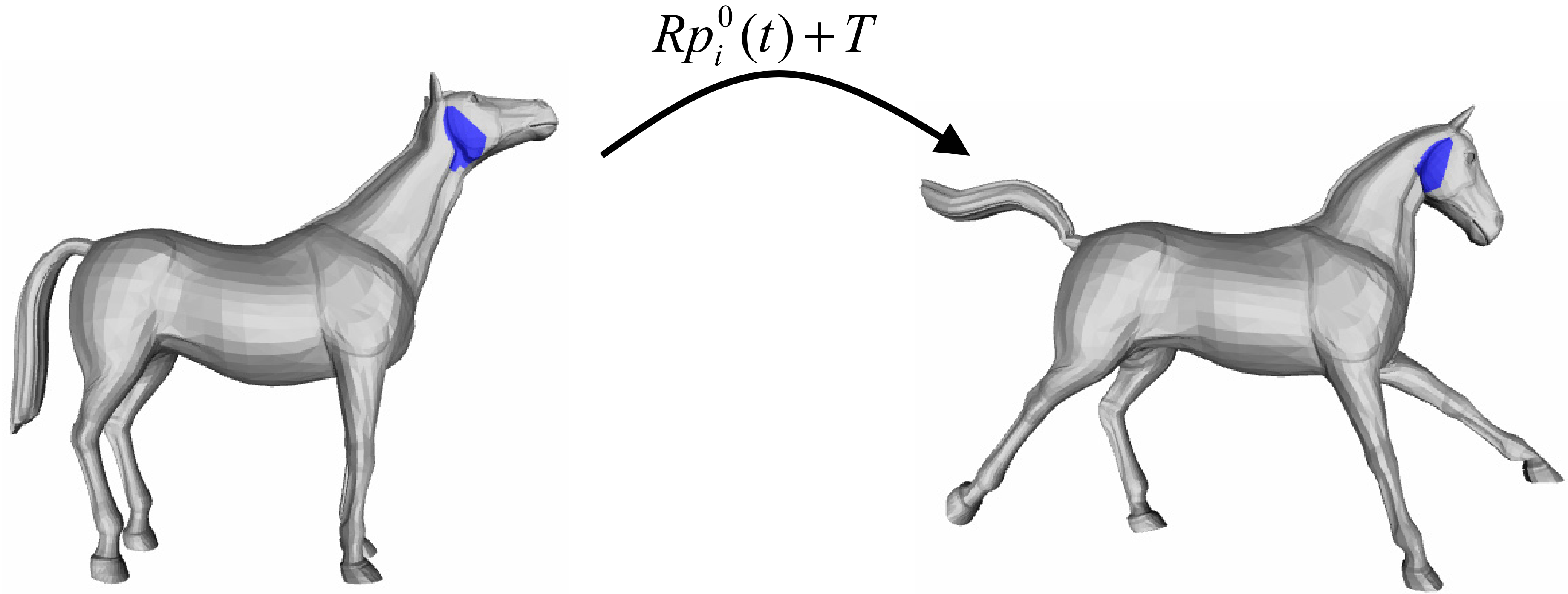
$$M = \int_t \hat{p}_i^0(t)\,\hat{p}_i^k(t)^T\,dt \quad \text{where} \quad \hat{p}_i^k(t) = p_i^k(t) - \overline{p}_i^k$$



Rigid Error Functions

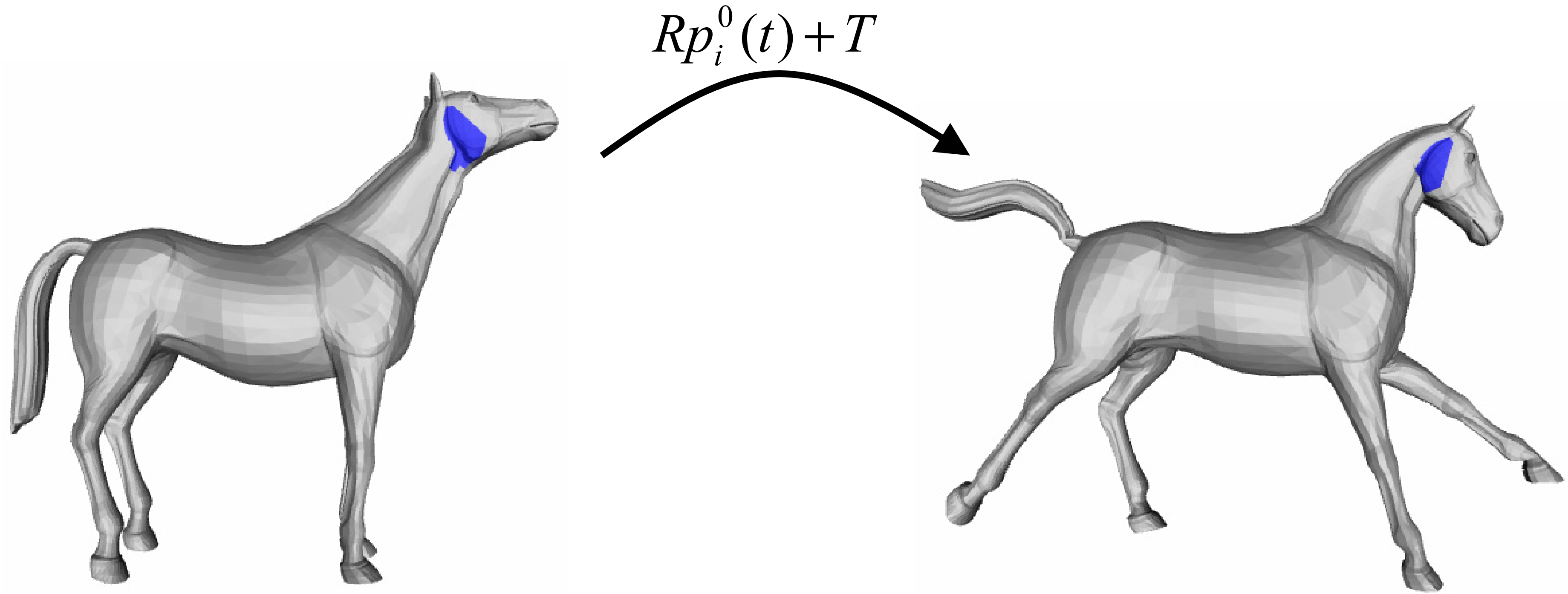
$$M = RS \quad \text{where} \quad S = S^T \quad \text{and} \quad R^T R = I$$

[Shoemake et al. 1992], [Alexa et al. 2000], [Müller et al. 2005]



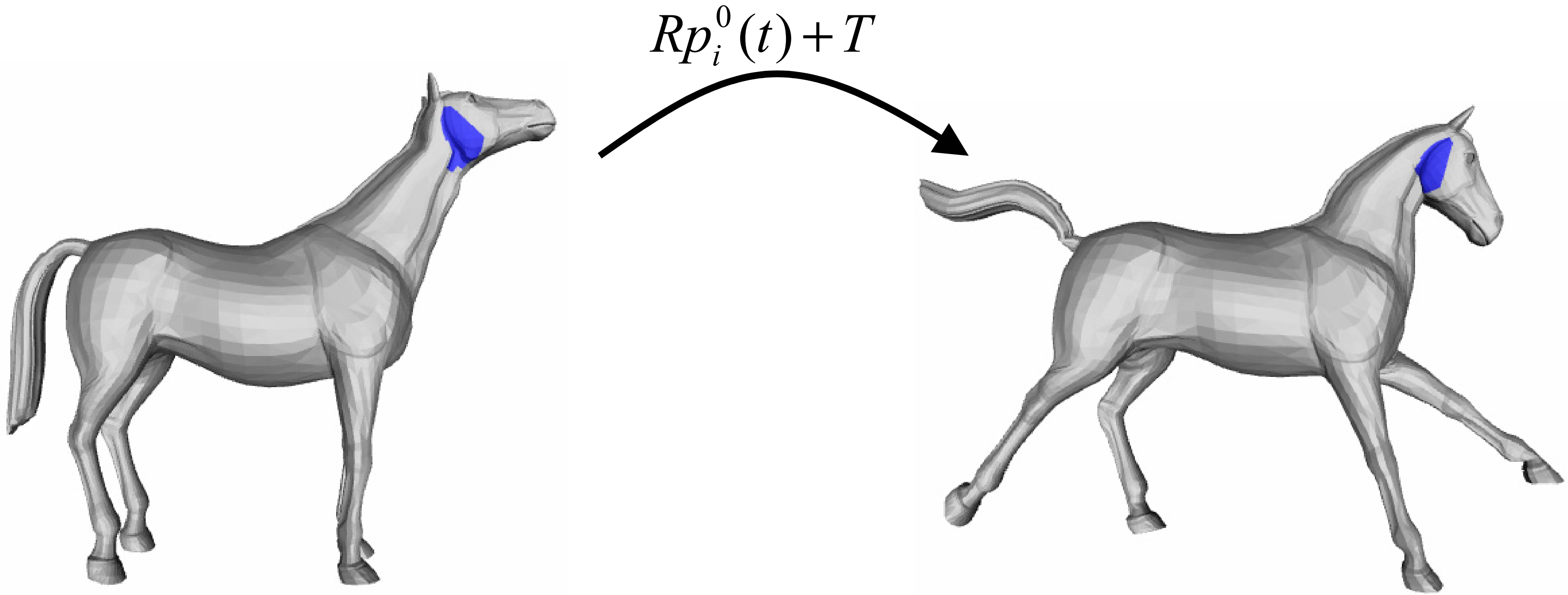
Rigid Error Functions

- Eigen decomposition of 4x4 matrix [Horn 1987]



Rigid Error Functions

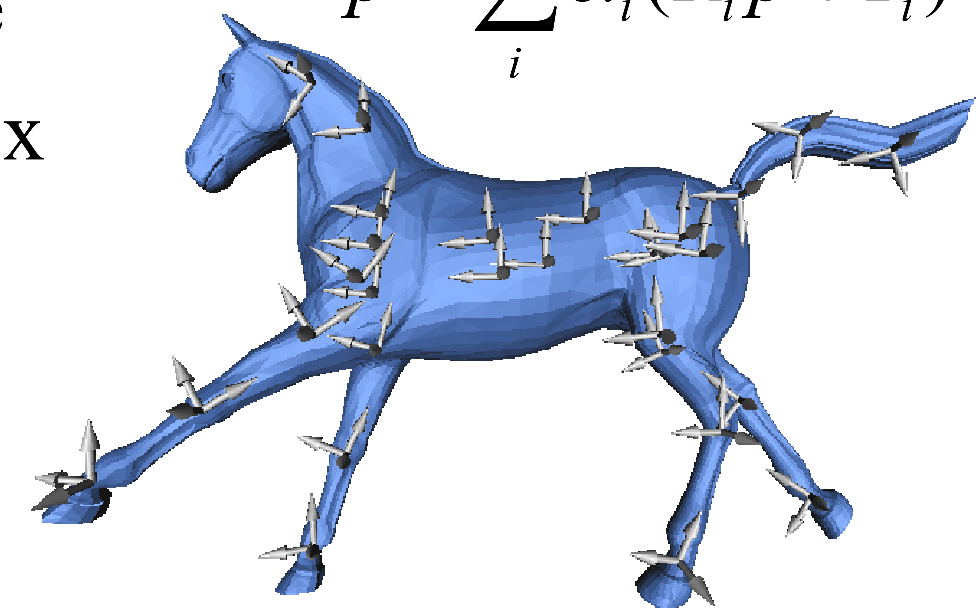
- Compact representation (17 floats)



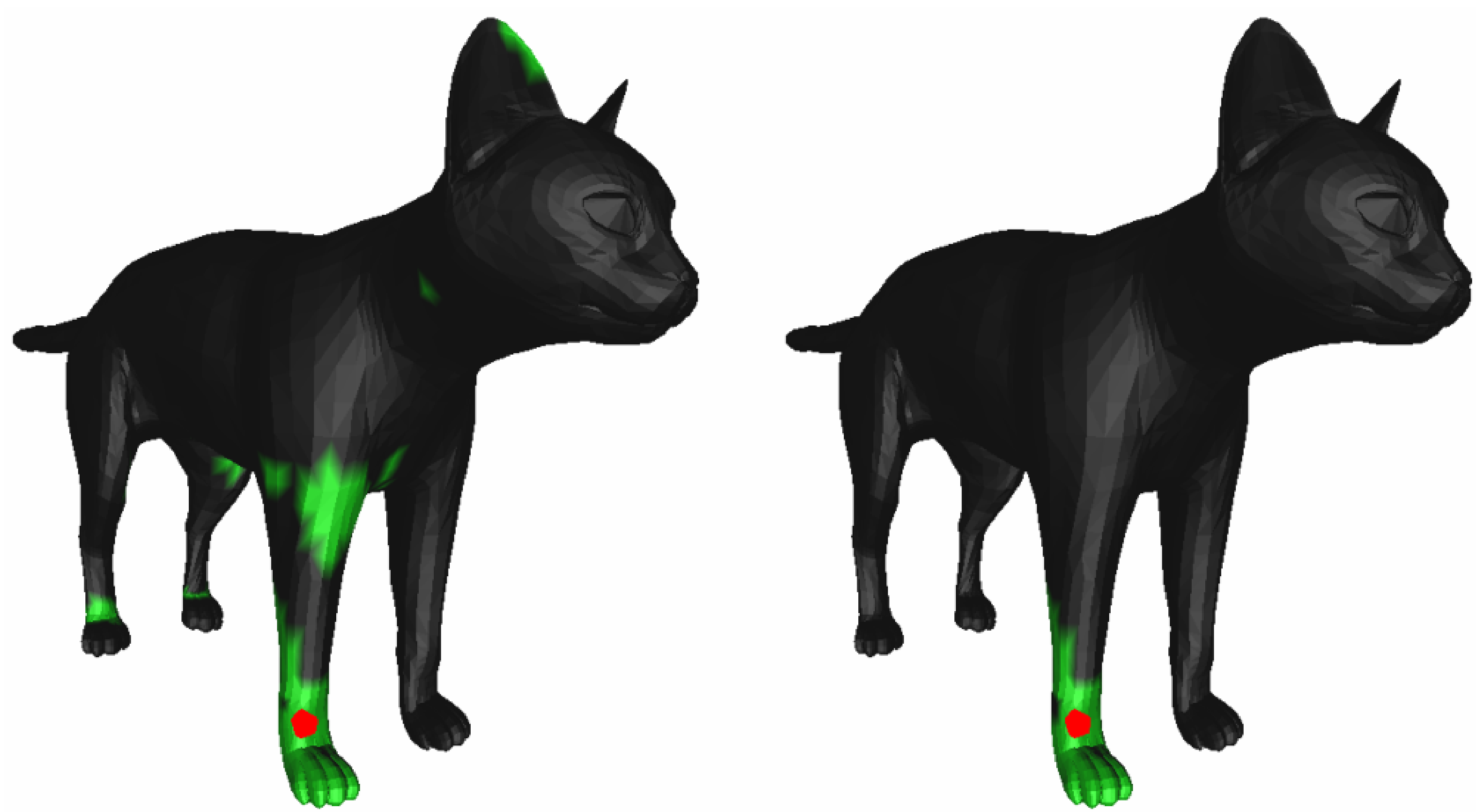
Skin Weights

- Weight properties:
  - Match the motion of the example poses
  - Translation invariant
  - Four or less bone weights per vertex
  - Positive weights

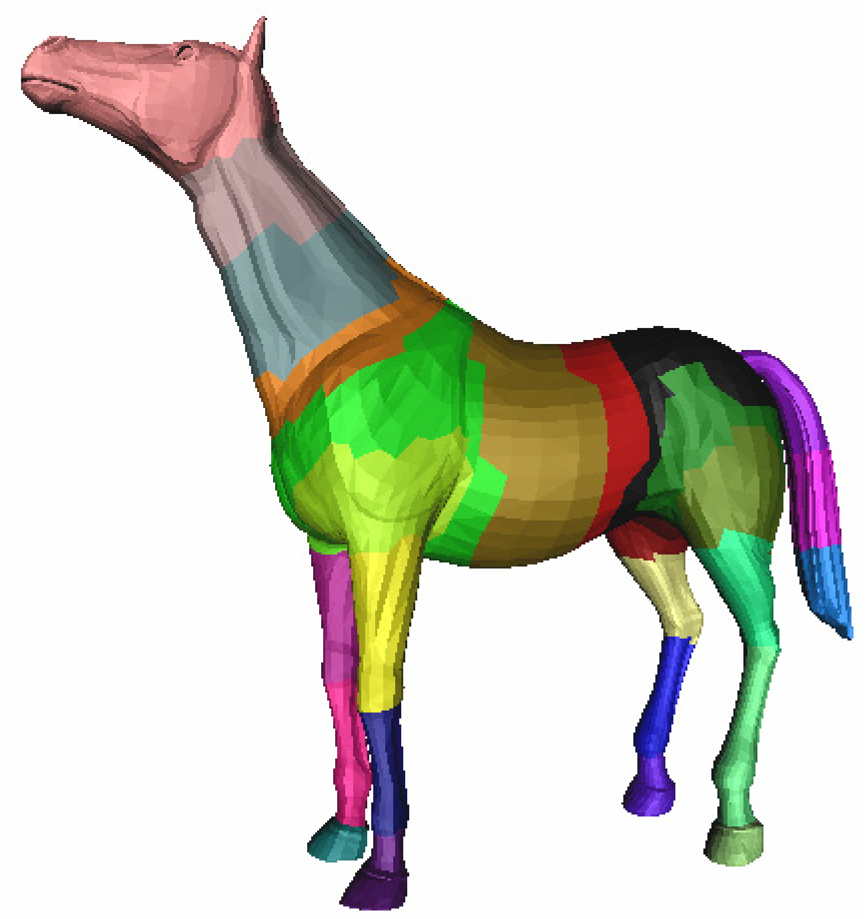
$$\hat{p} = \sum_i \alpha_i (R_i p + T_i)$$



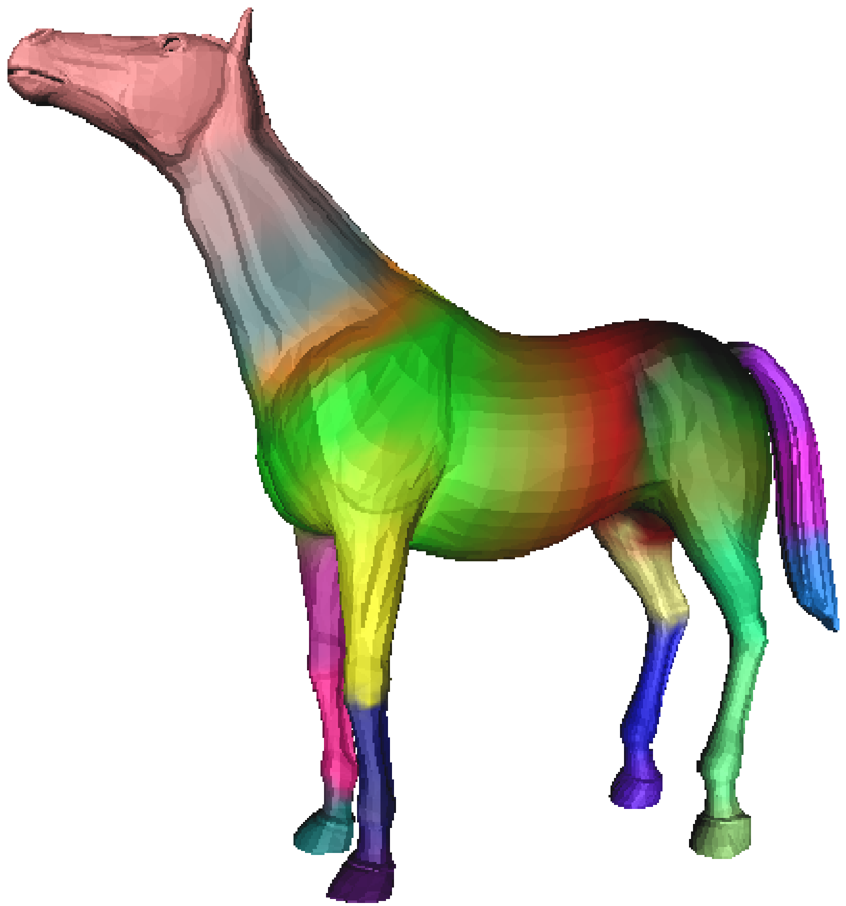
Skin Weights



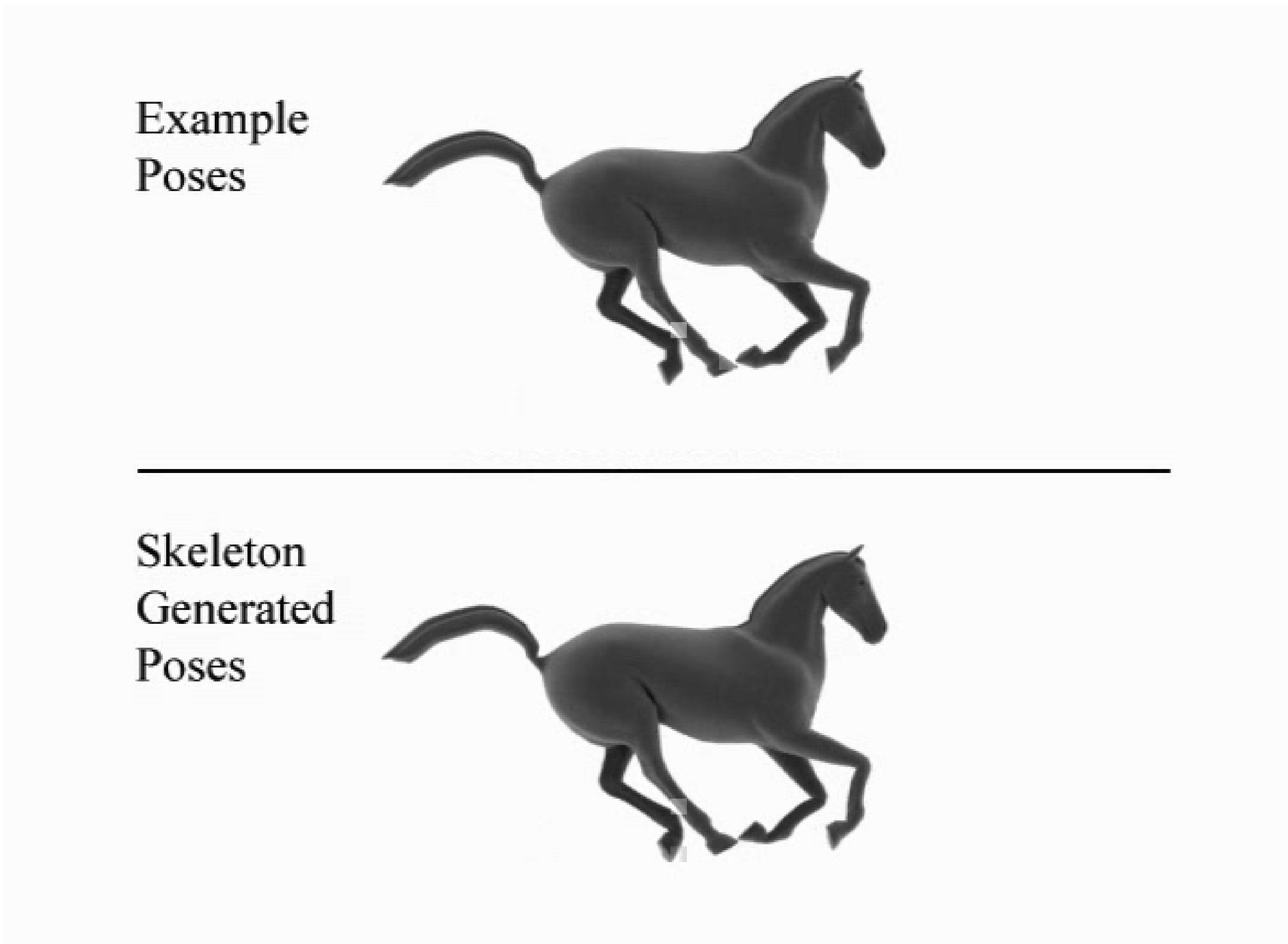
Skin Weights



Skin Weights

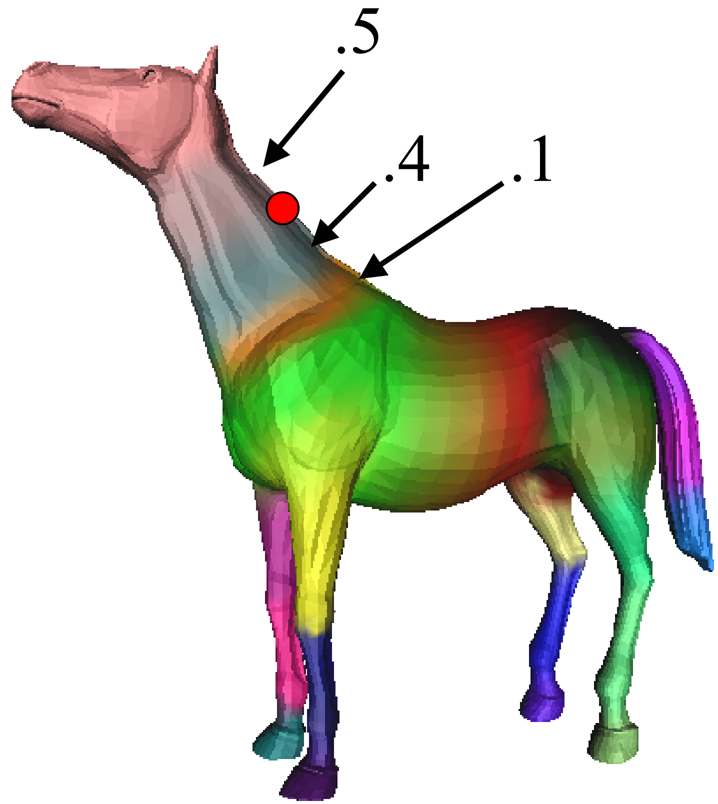


Skin Weight Validation



Bone Connectivity

- Vertex weights indicate information about bone connectivity!!!



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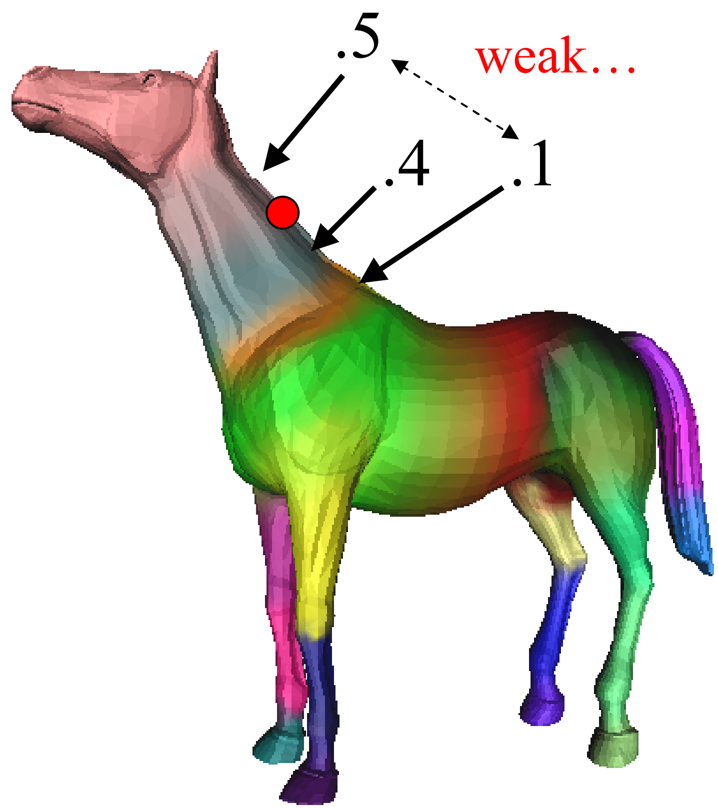
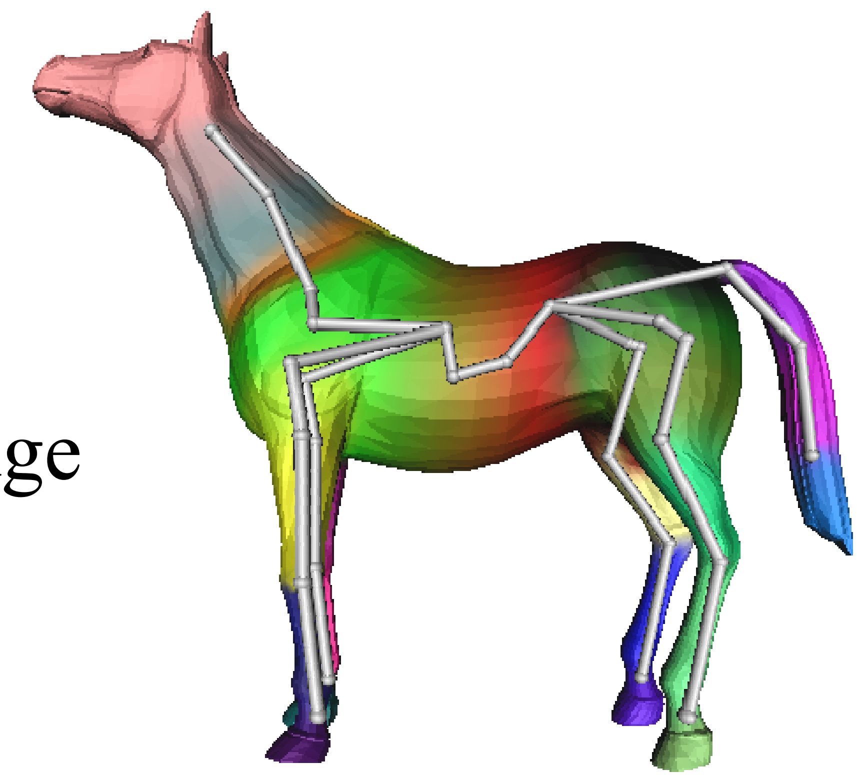
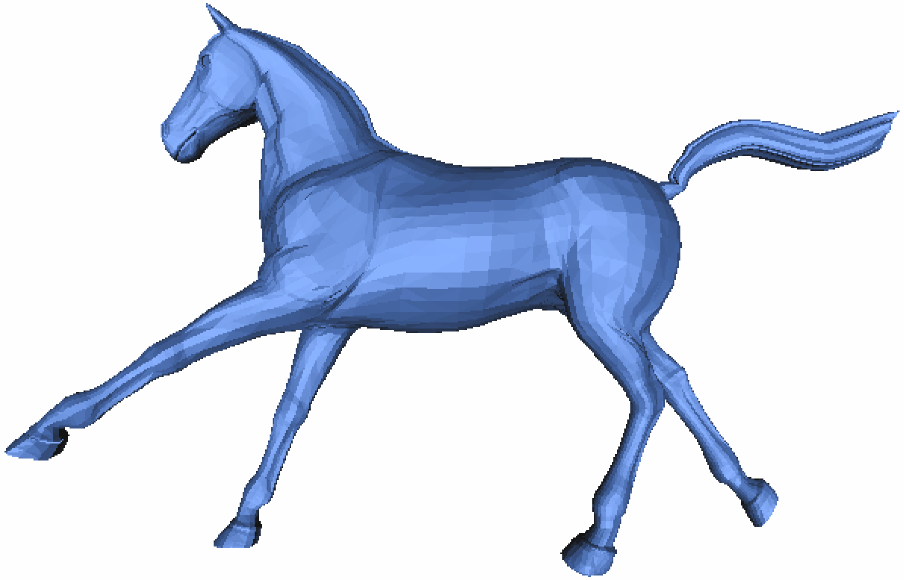


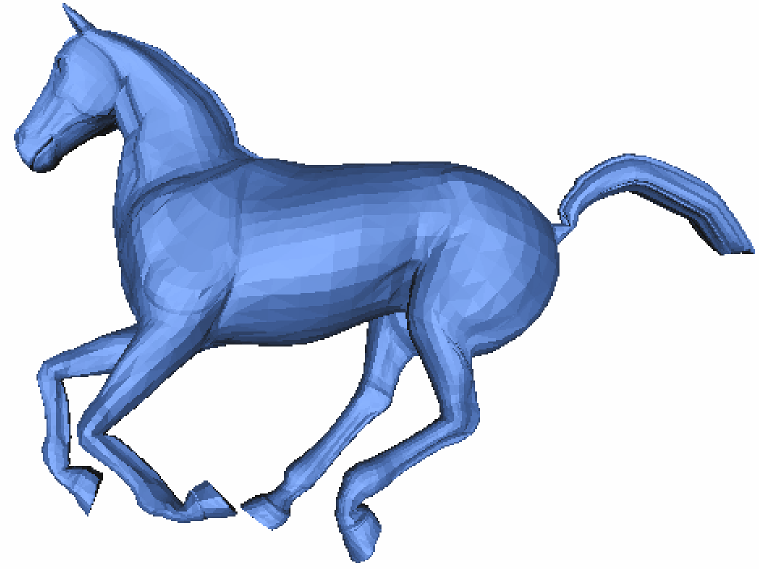
Bone Connectivity

- Extract maximal spanning tree to determine connectivity
- For each vertex
  - For each bone weight
    - Let α_{max} be the maximum weight
    - Add weight α_j to edge between (max, j)



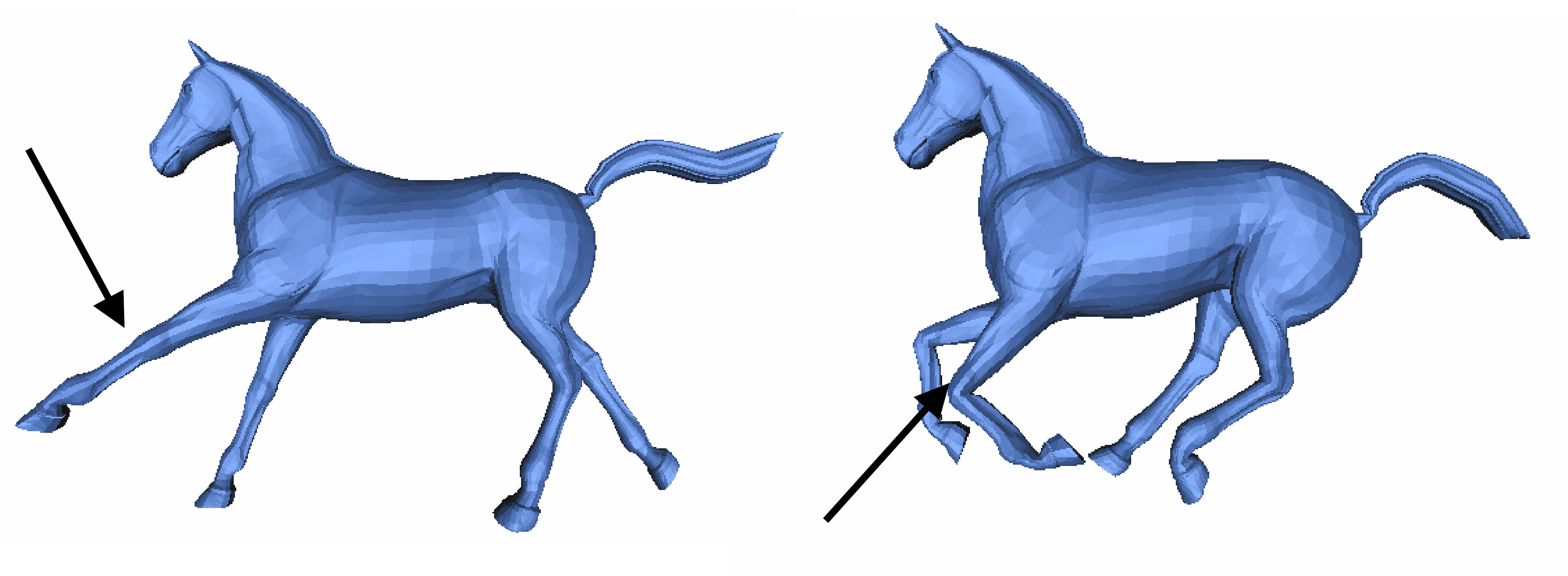
Joint Locations





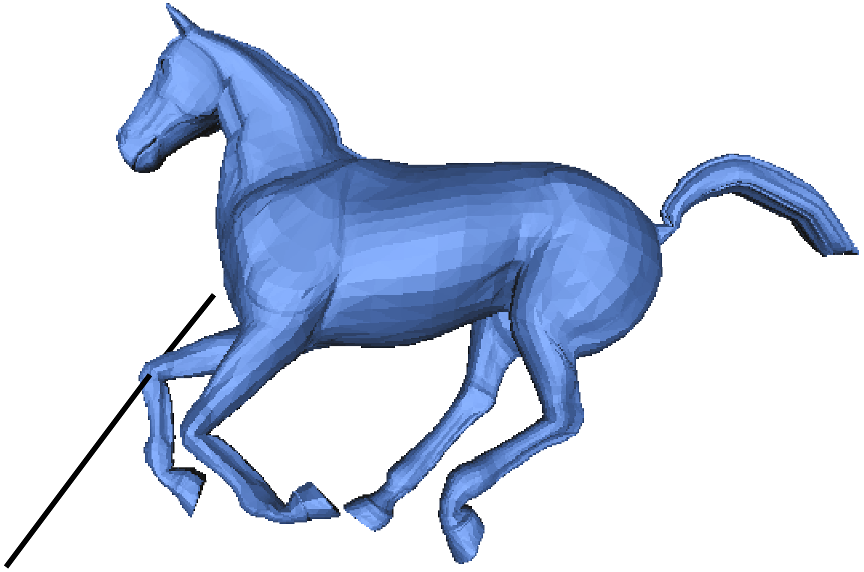
Joint Locations

- Joint has same position with respect to both bone transformations



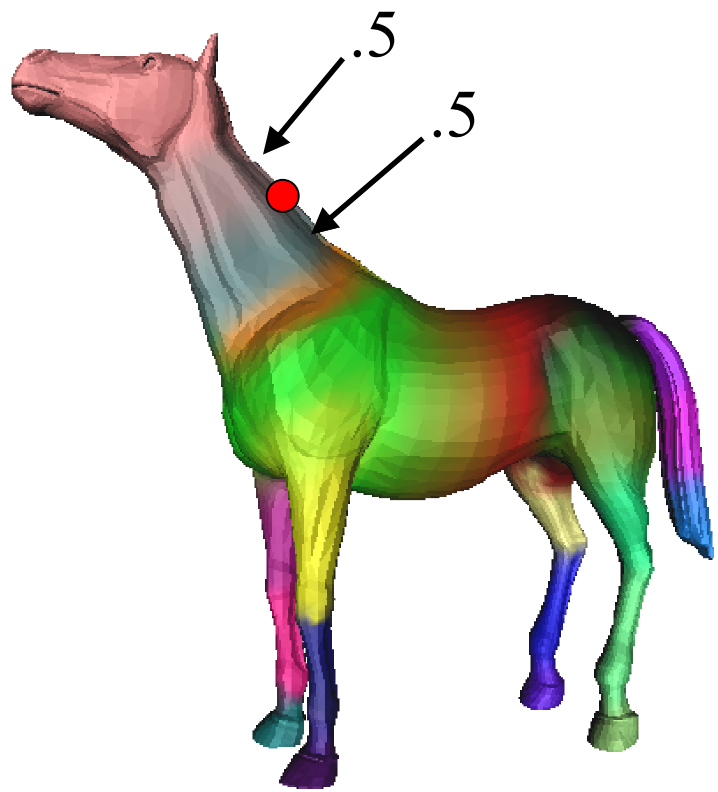
Joint Locations

- Many joints act as hinges and bend along an axis
- Yields infinite number of solutions to minimization!!!



Joint Locations

- Vertex weights indicate information about joint locations!!!



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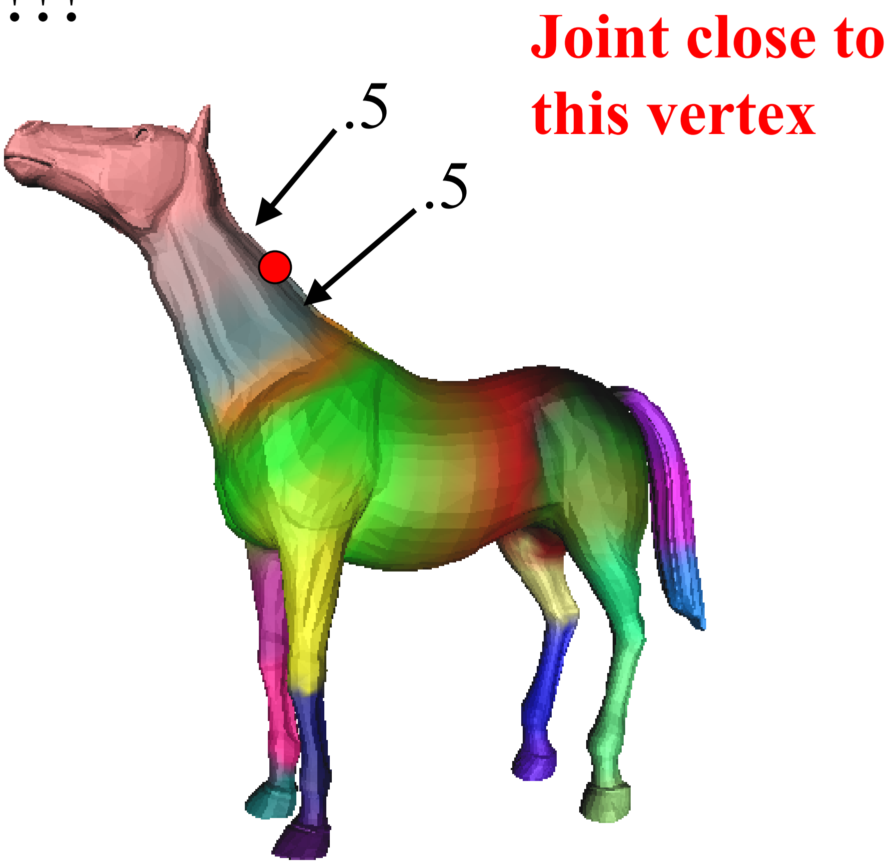

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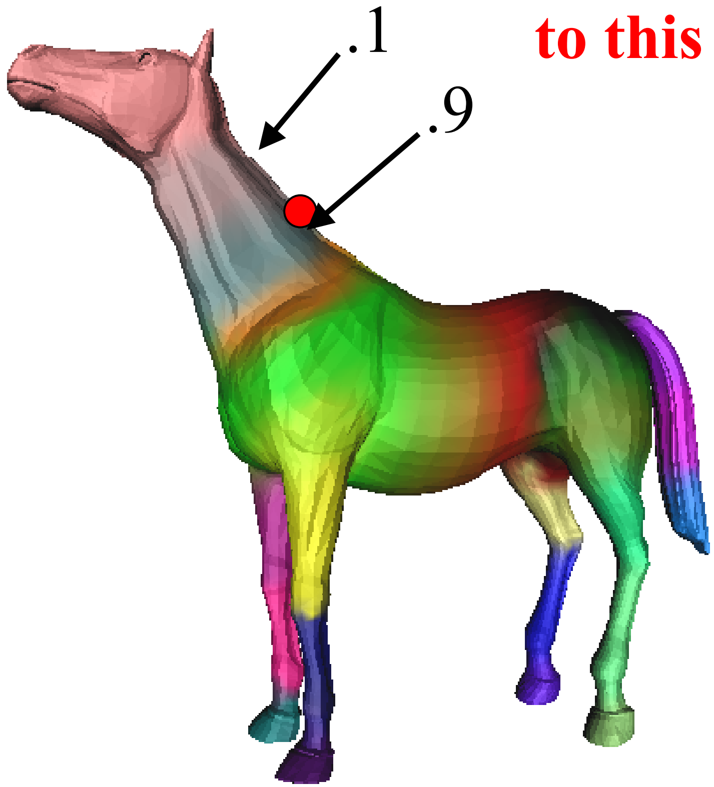
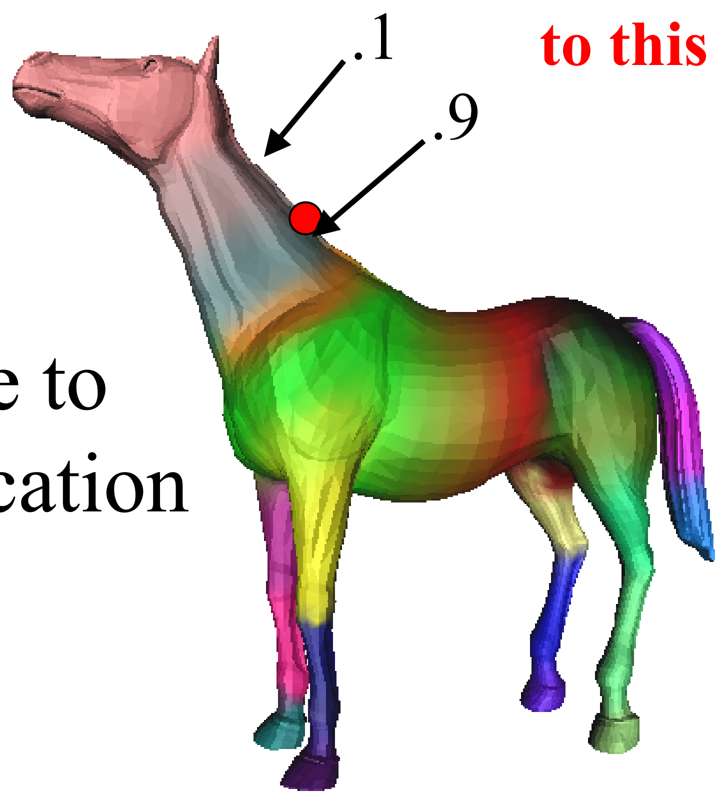


Joint Locations

- Vertex weights indicate information about joint locations!!!

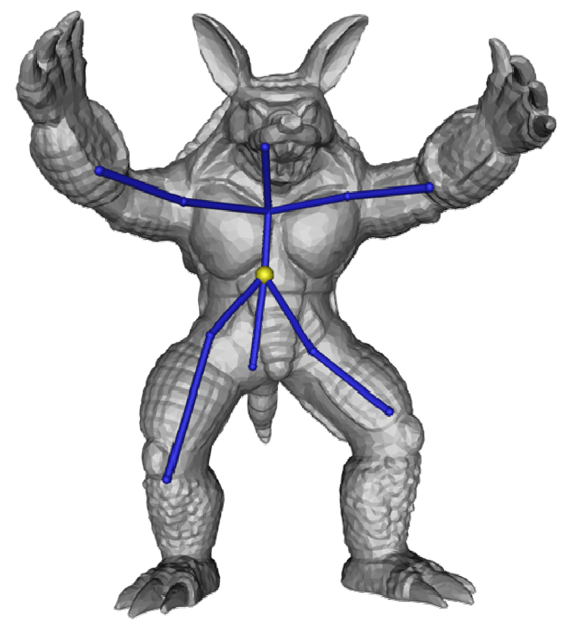
Joint not close to this vertex



Minimize distance to estimated joint location

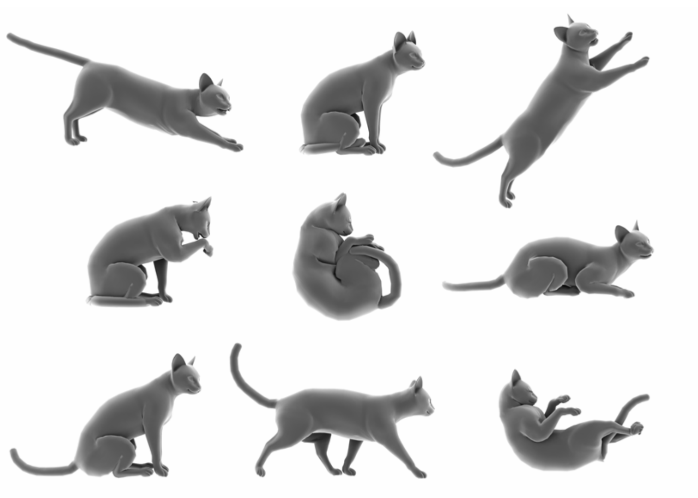
Root of Skeleton

- Very arbitrary…
- We choose bone closest to center of mass
- Center of mass important in physical calculations so makes sense to set root there



Results

Examples



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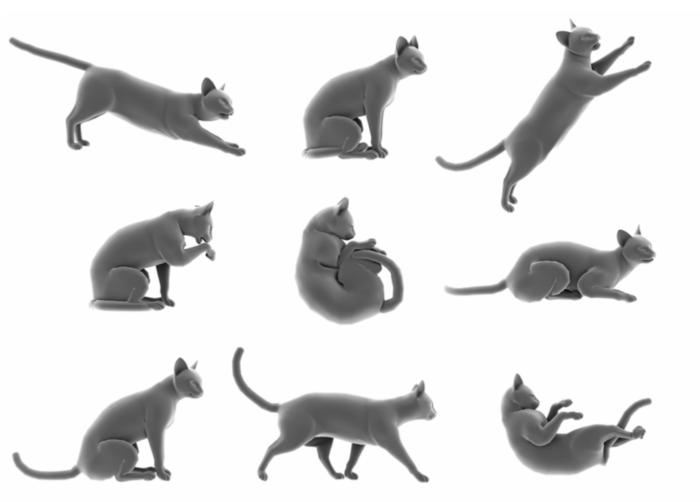

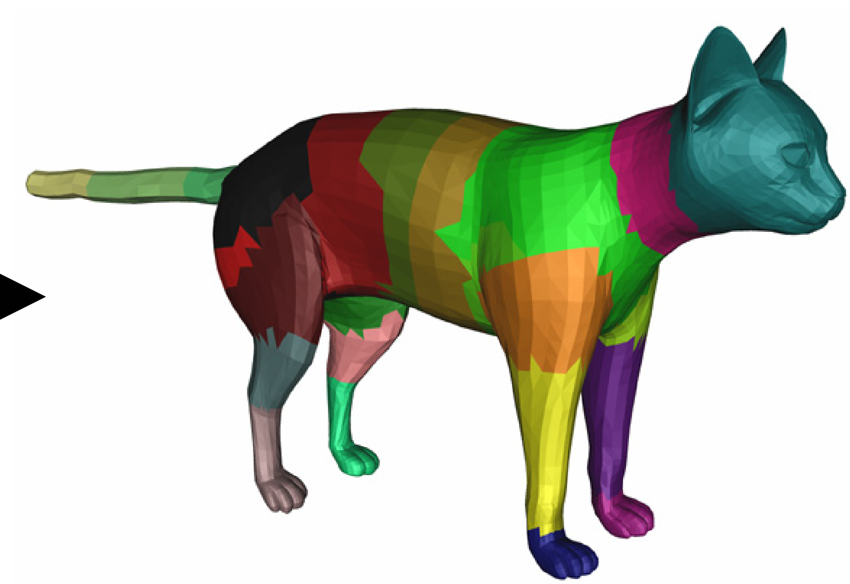

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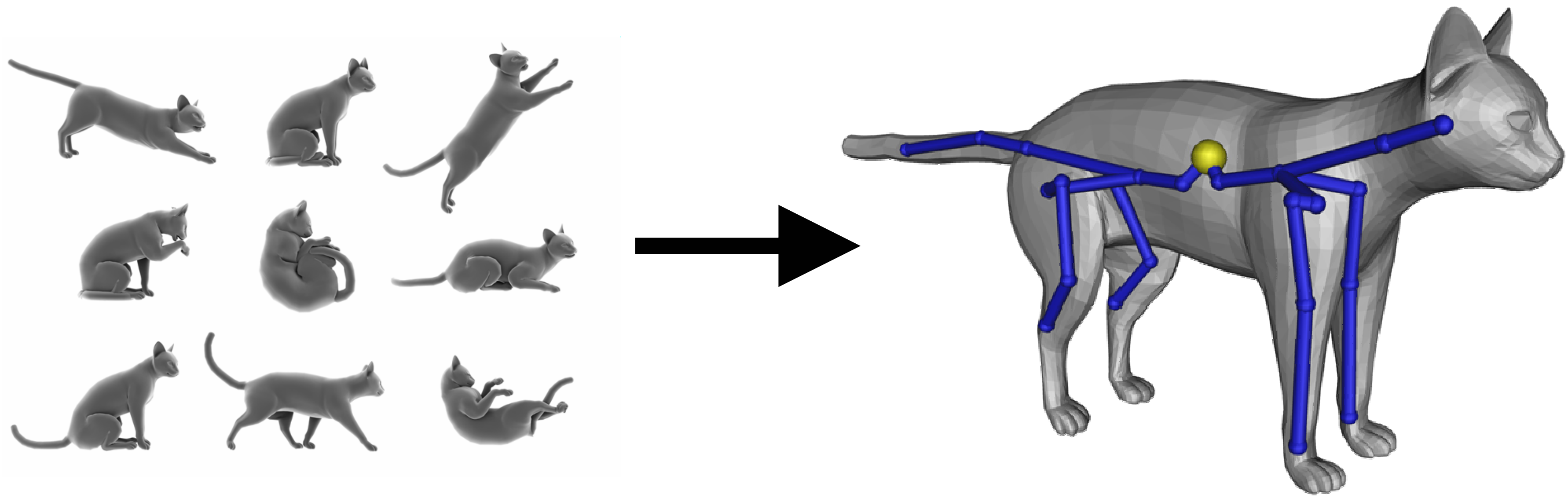

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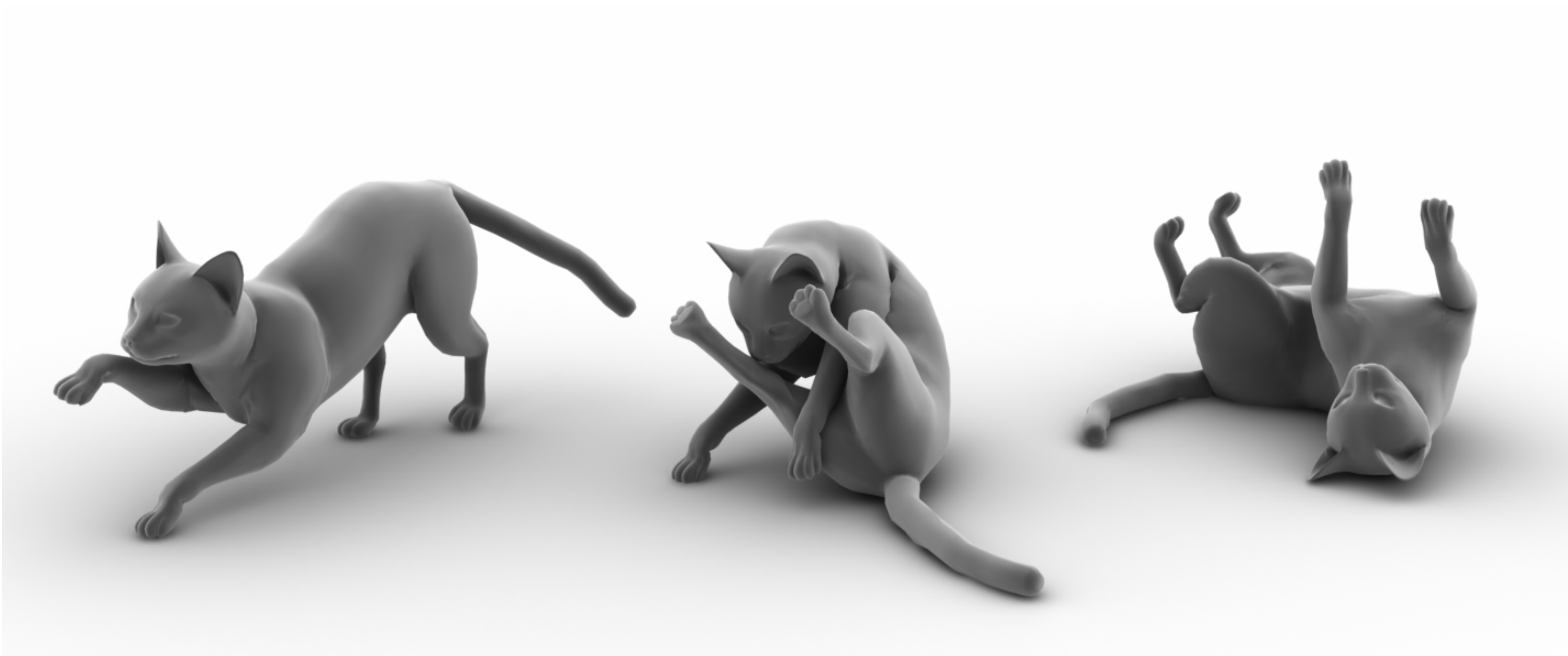

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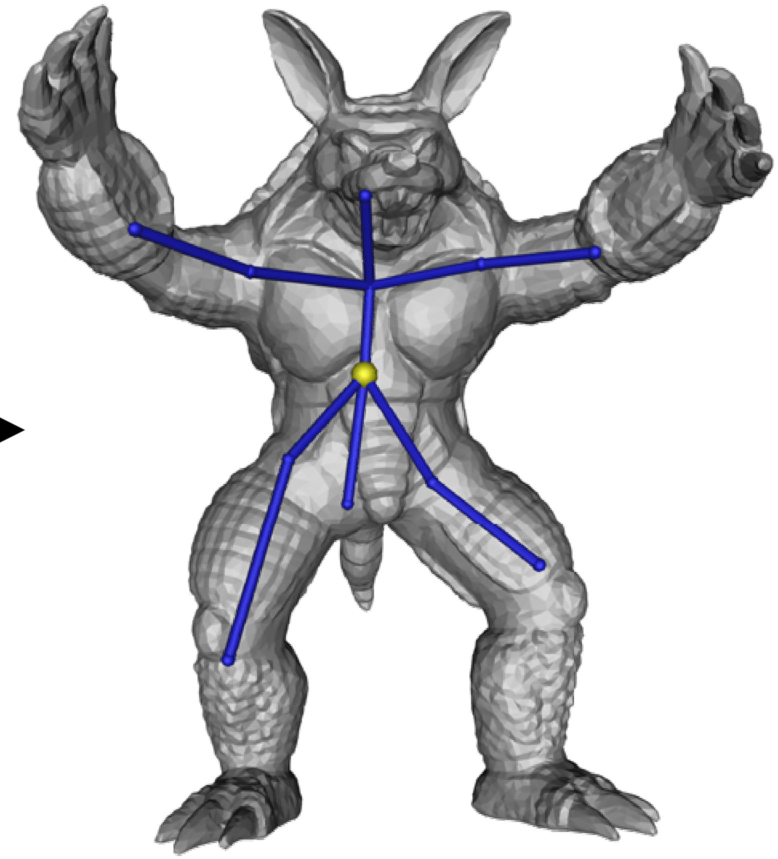

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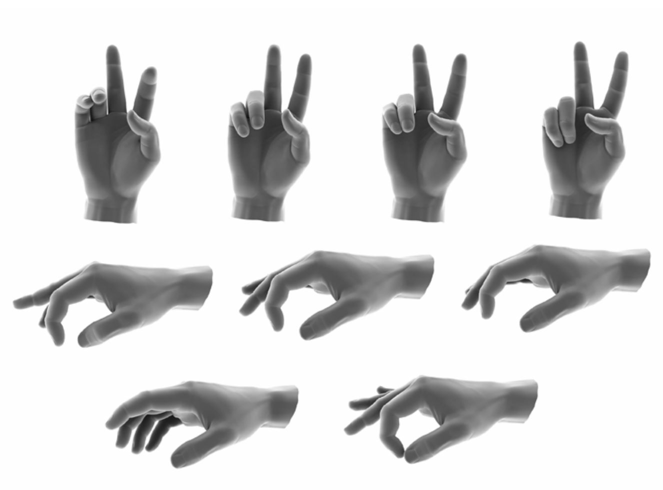

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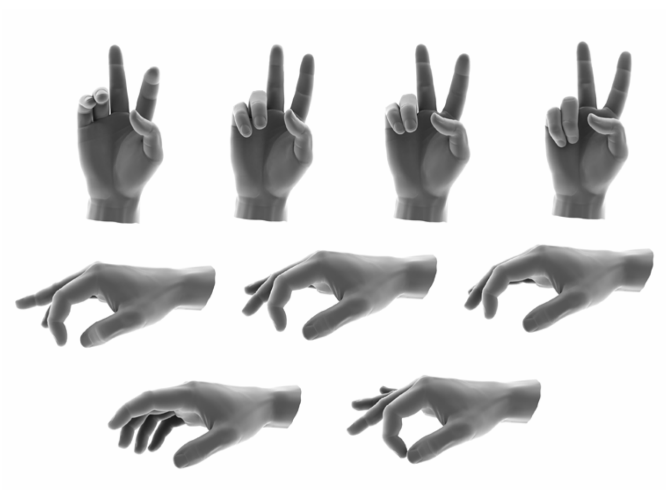

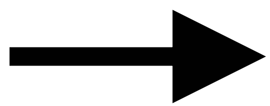

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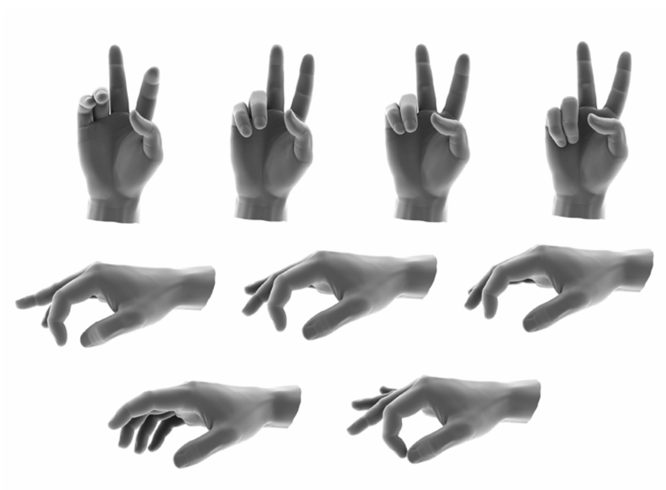

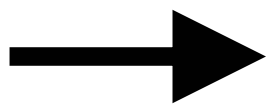

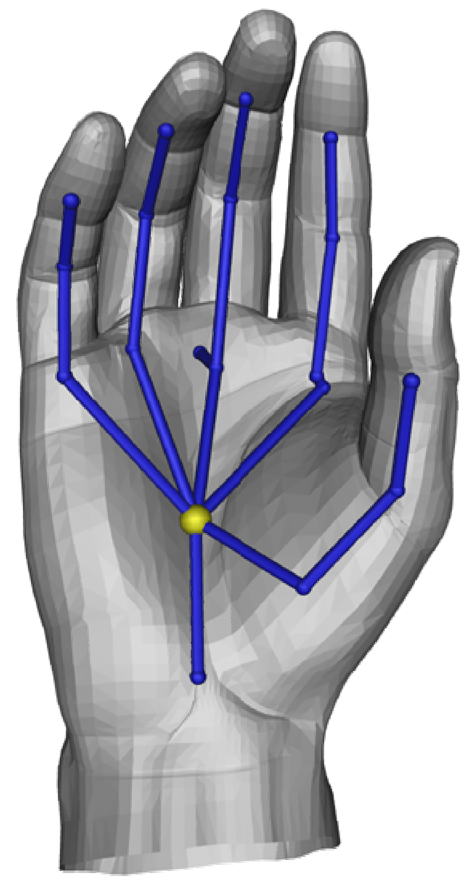

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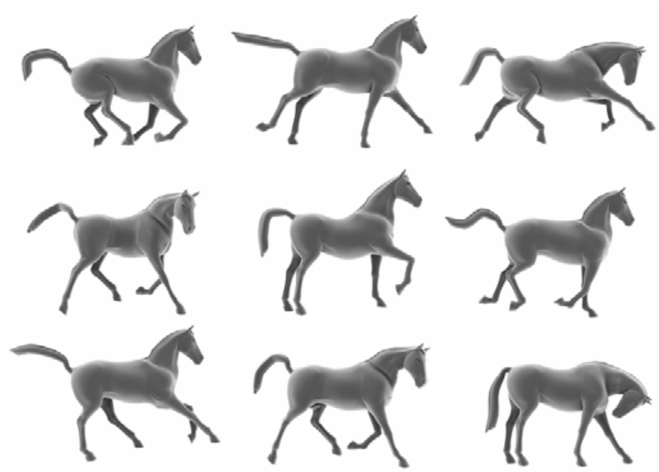

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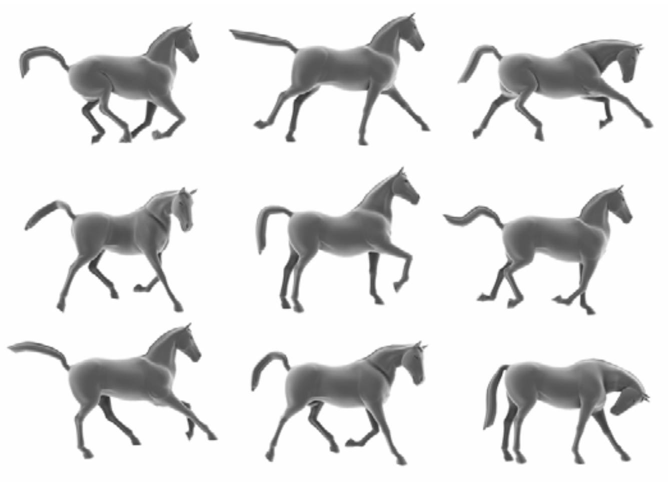

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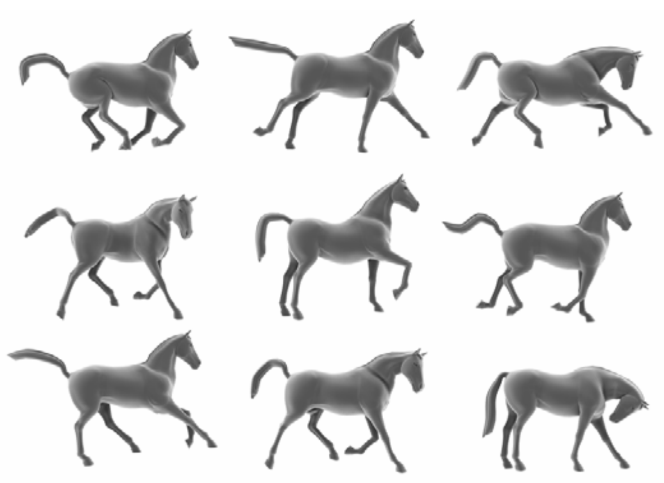

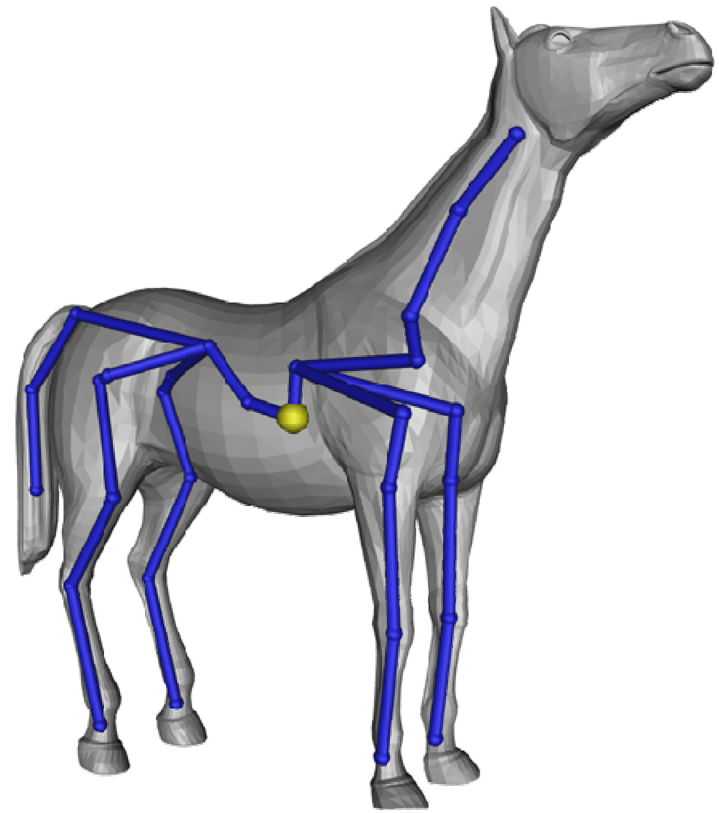

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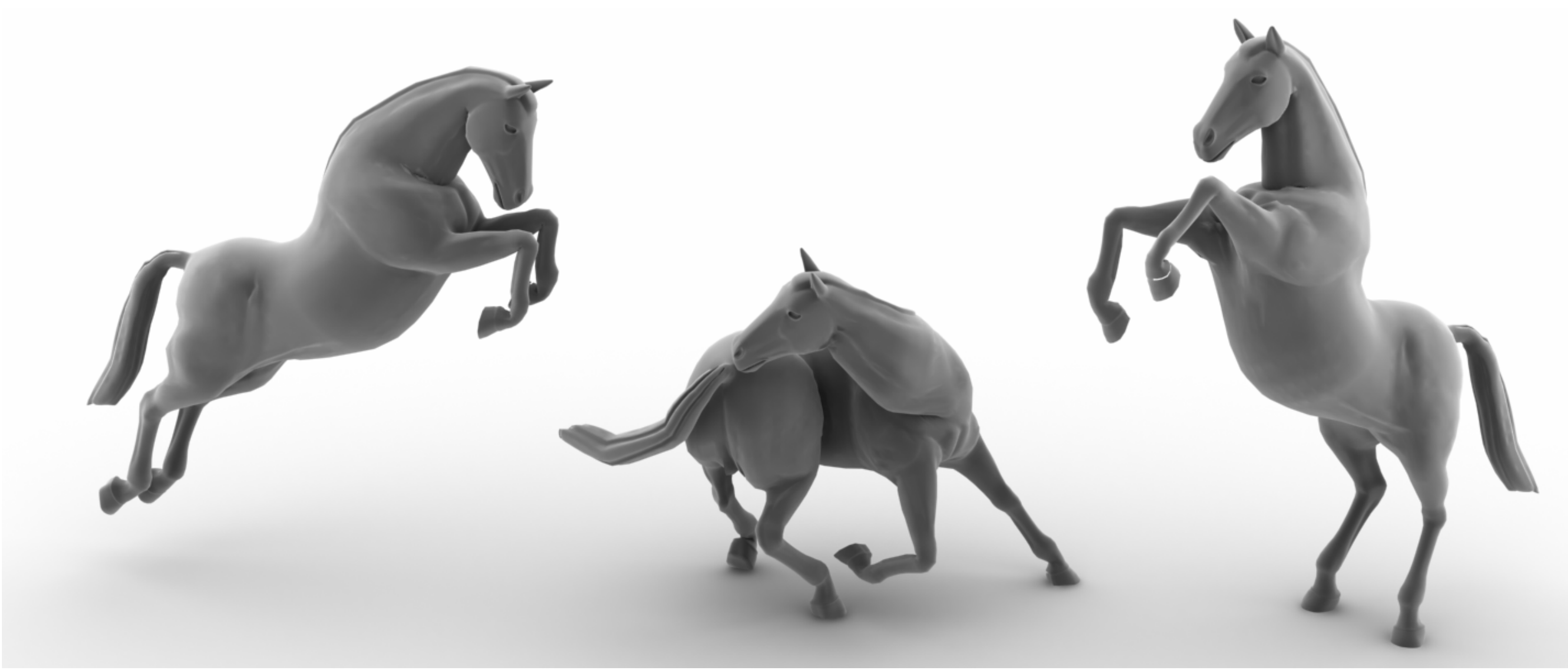

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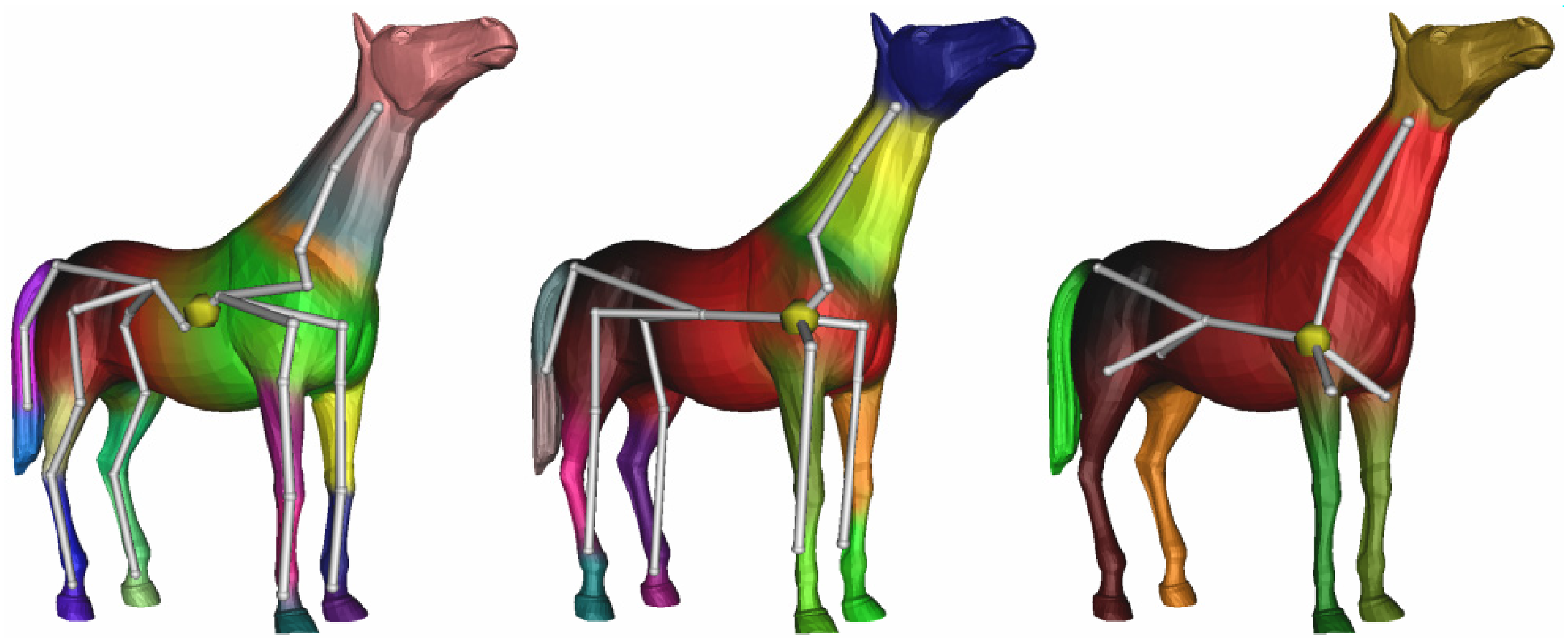

29 bones 19 bones 9 bones

Performance

Model	Faces	Example Poses	Bones	Face Clustering	Skinning	Skeleton Extraction
Hand	15789	46	19	9.96s	6.46s	0.00s
Horse	16843	23	29	5.53s	11.14s	0.00s
Cat	14410	9	24	2.11s	4.01s	0.00s
Armadillo	30000	9	12	5.21s	2.53s	0.00s
Elephant	84638	23	22	32.29s	32.23s	0.02s
Lion	9996	9	19	1.57s	1.85s	0.00s

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Face Clustering 10x-50x faster than Mean Shift Clustering [James, Twigg 2005]

Importing Skeletons

- Maya-script importer
- Manipulate directly in Maya
- No plugins/special software needed
- Works with existing production pipelines

Future Work

- Skeletons are good but not perfect
- Improve weight fitting
- Add user feedback to create an intelligent system