



SIGGRAPH2007

Harmonic Coordinates for Character Articulation



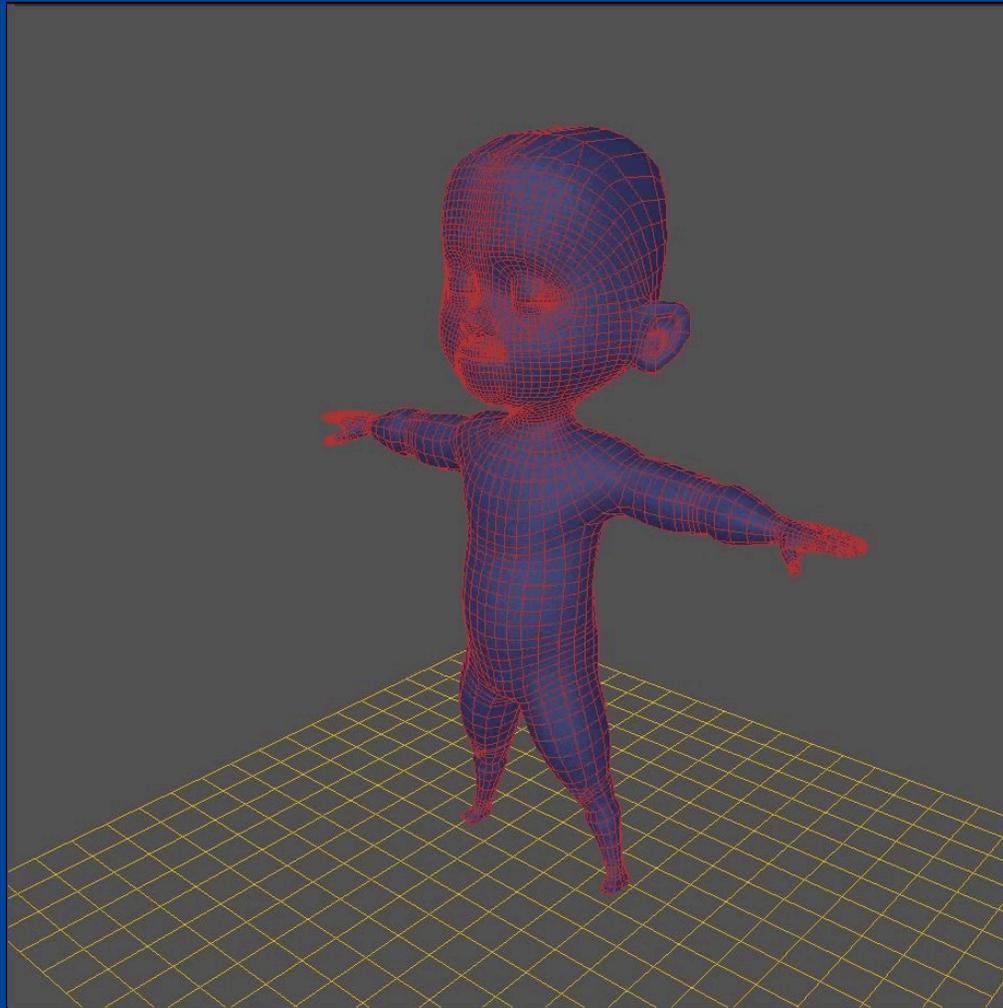
SIGGRAPH2007

Pixar Animation Studios

Pushkar Joshi, Mark Meyer, Tony DeRose,

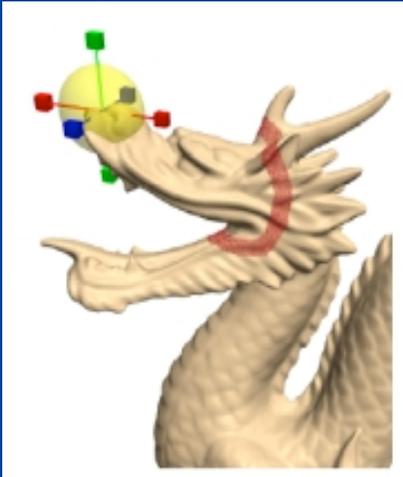
Brian Green, Tom Sanocki

Character Articulation

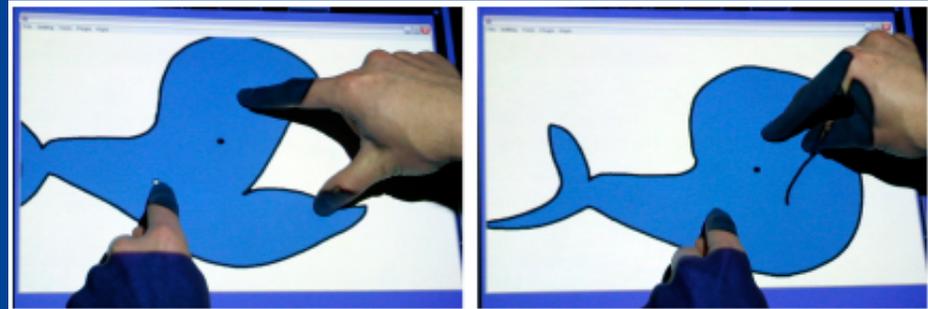


Direct Mesh Manipulation

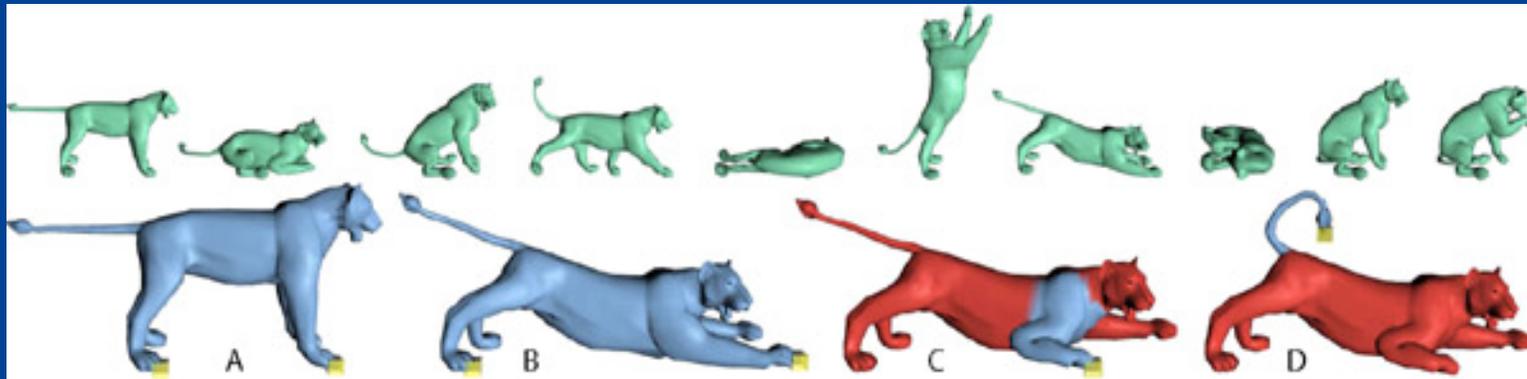
Sorkine et al. 2004



Igarashi et al. 2005



Sumner et al. 2005

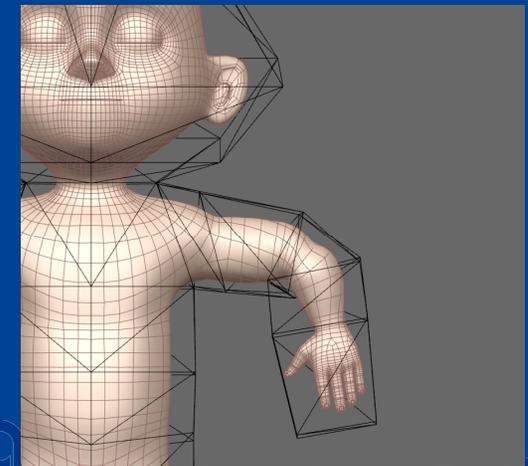
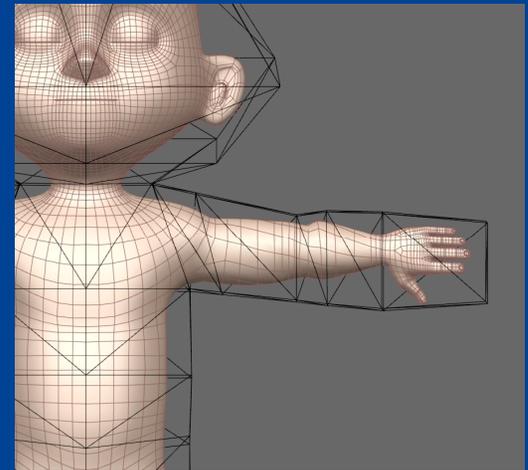


Volumetric Deformation

Character embedded in volume

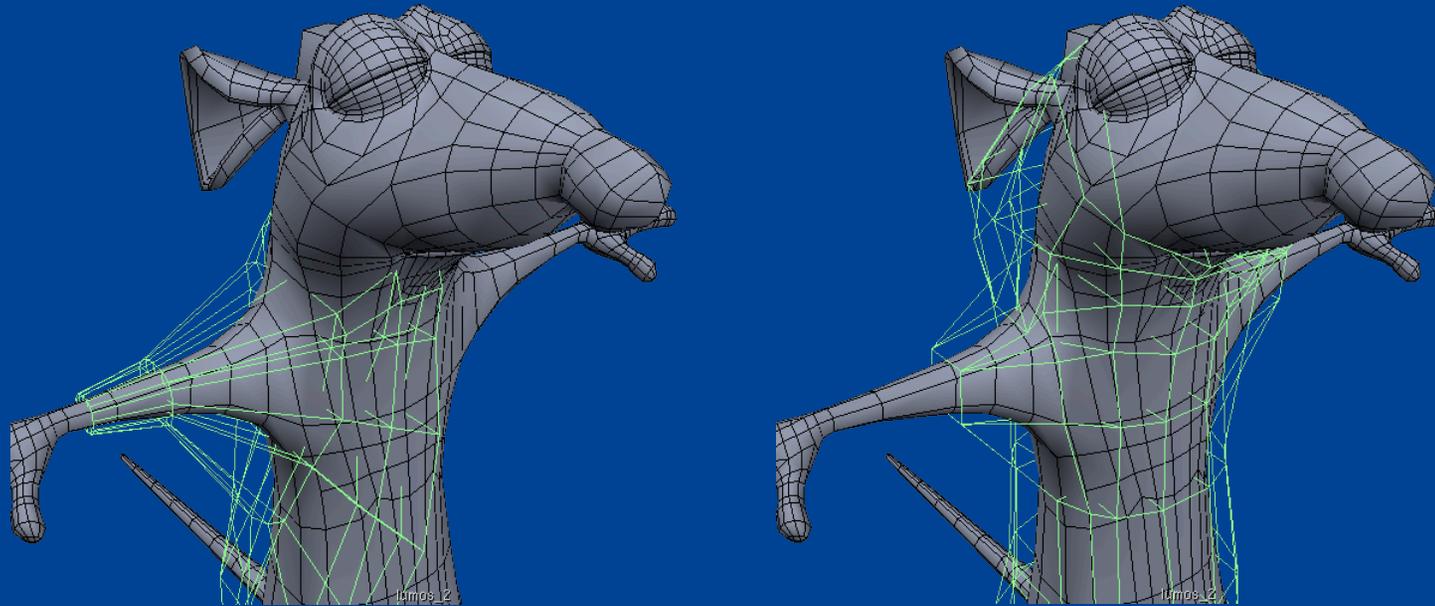
Deform character by
deforming volume

Decouple character geometry
from articulation



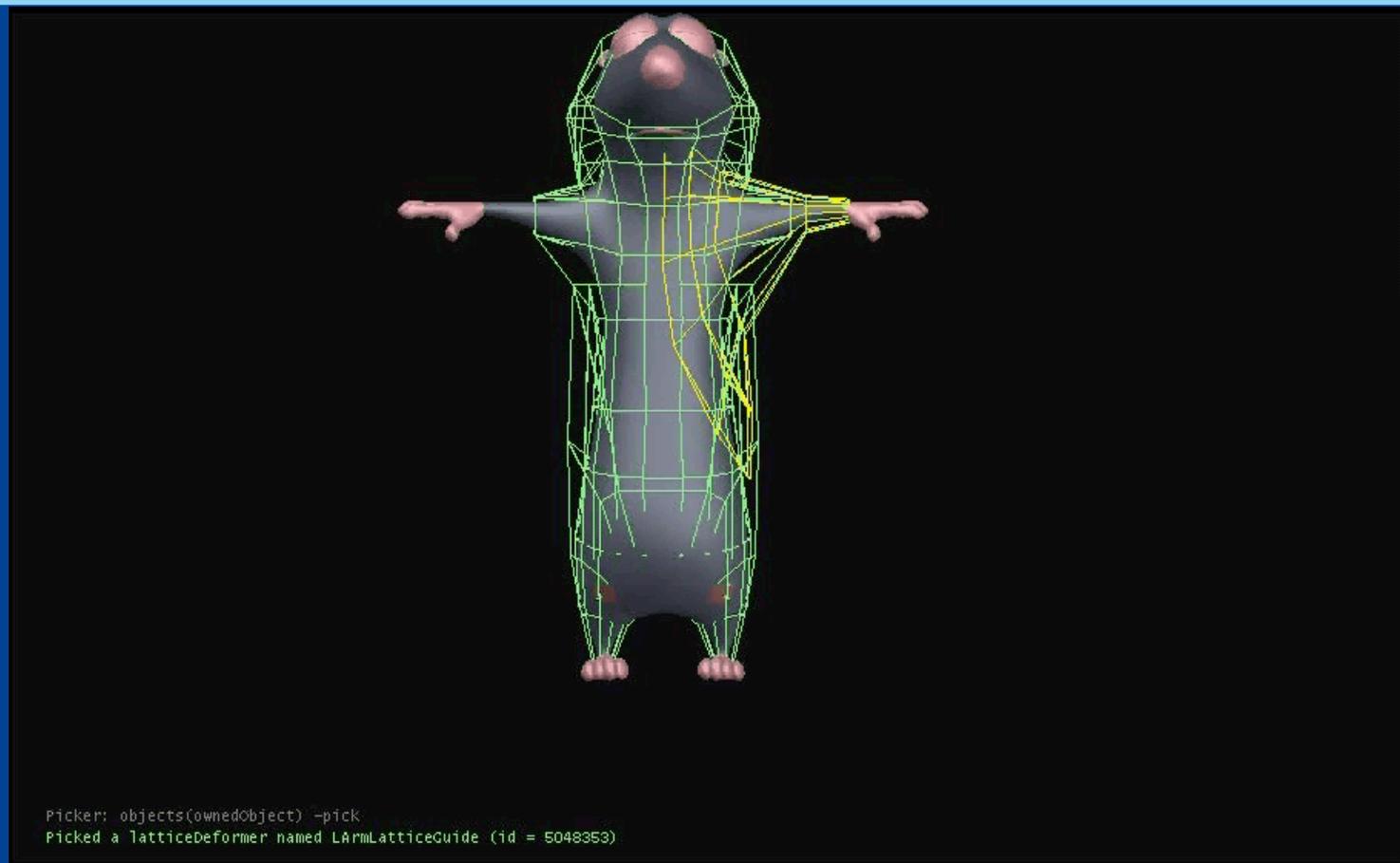
Freeform Deformation

Barr 1984, Sederberg and Parry 1986



Cubical Grid: Topological Restrictions!

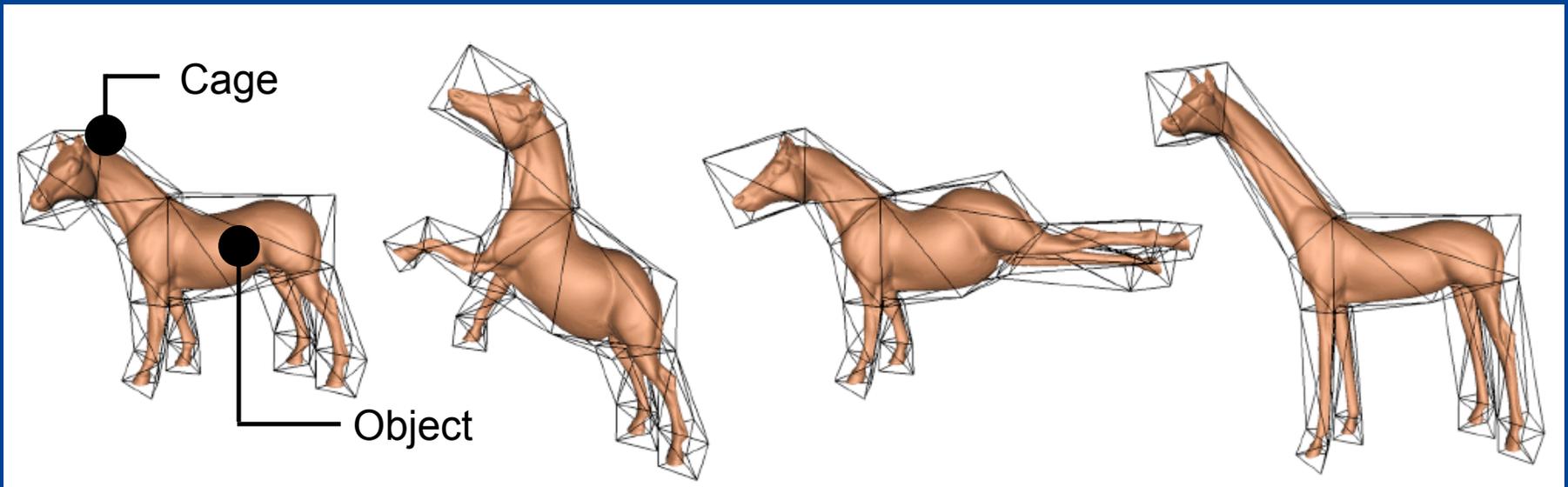
Freeform Deformation



Cubical Grid: Topological Restrictions!

Mean Value Coordinates

Ju, Schaeffer, Warren. SIGGRAPH 2005



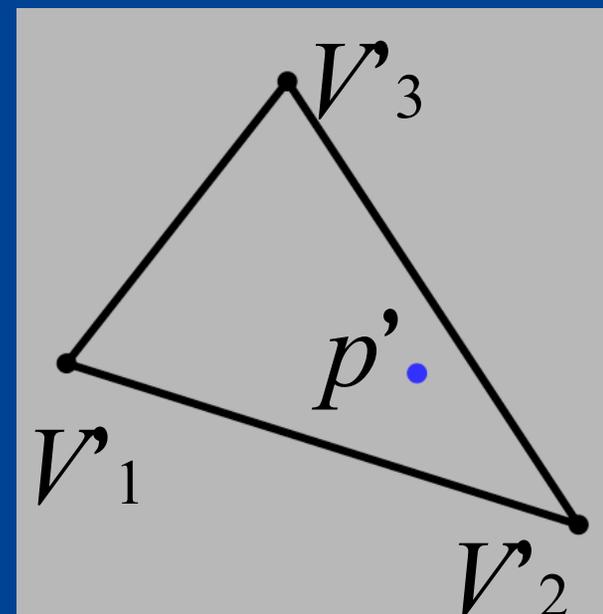
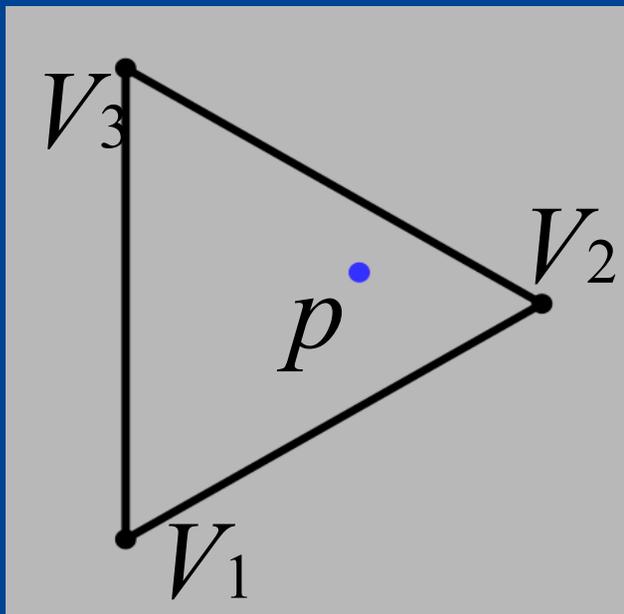
Topologically Flexible Deformation System

face tomorrow

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Barycentric Coordinates

Piecewise linear on boundary, Smooth, Sum to 1

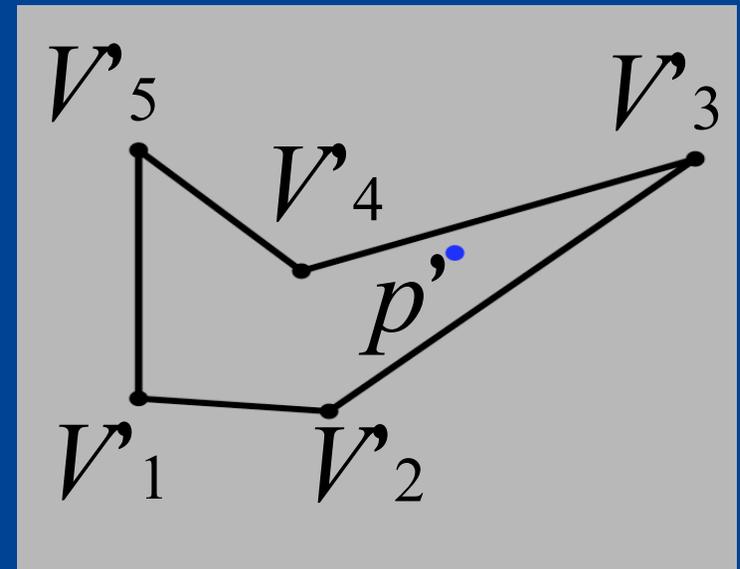
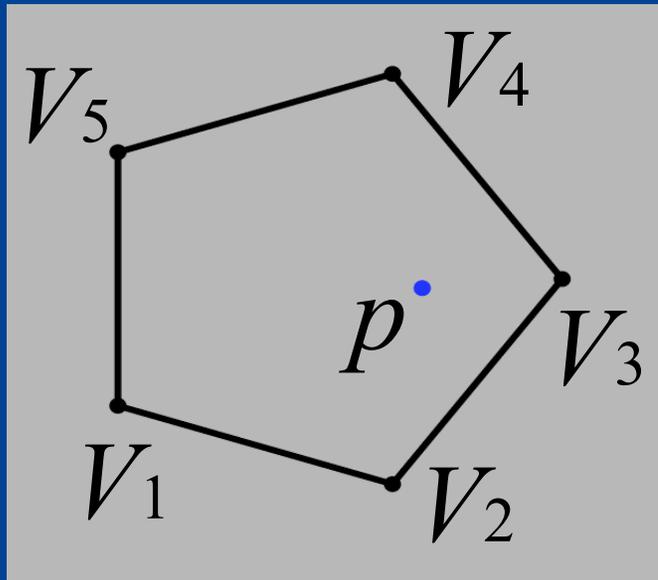


$$p = \sum_{i=1,2,3} \beta_i(p) V_i$$

$$p' = \sum_{i=1,2,3} \beta_i(p) V'_i$$

Generalized Barycentric Coordinates

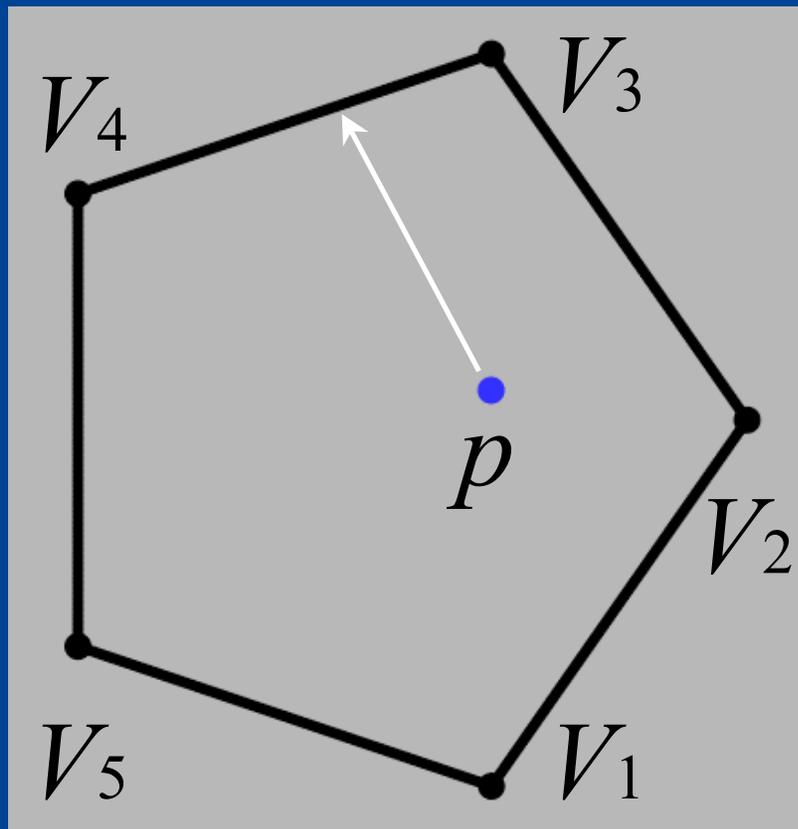
Piecewise linear on boundary, Smooth, Sum to 1



$$p \stackrel{?}{=} \sum_{i=1, \dots, n} \beta_i(p) V_i$$

$$p' = \sum_{i=1, \dots, n} \beta_i(p) V'_i$$

Mean Value Coordinates



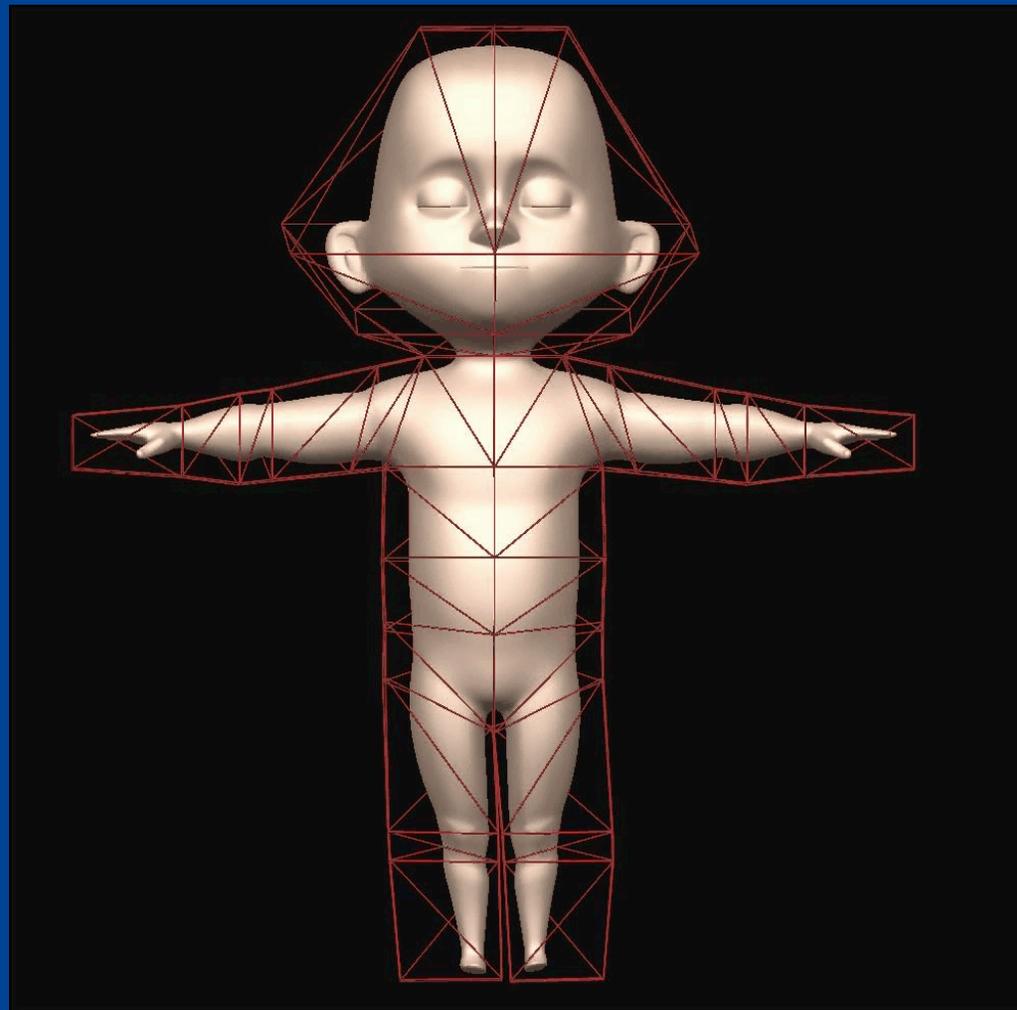
Floater 2003, Ju et al. 2005

Piecewise linear on boundary

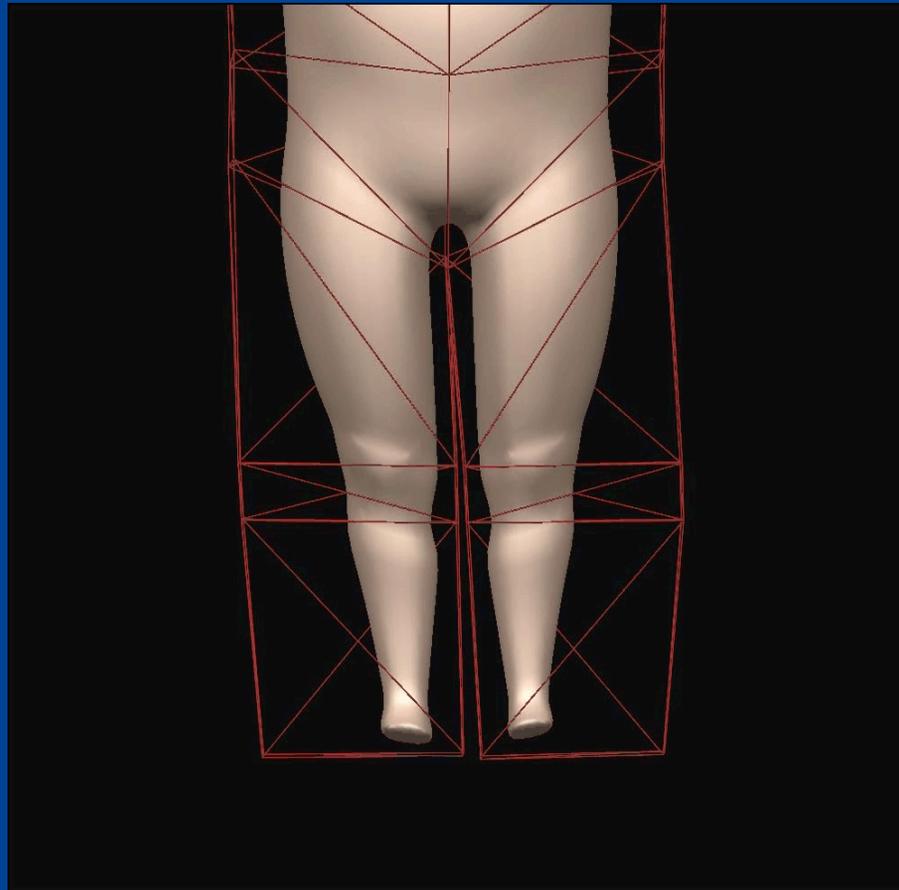
Straight line distance from
boundary for interpolation

Closed form formula

Mean Value Coordinates

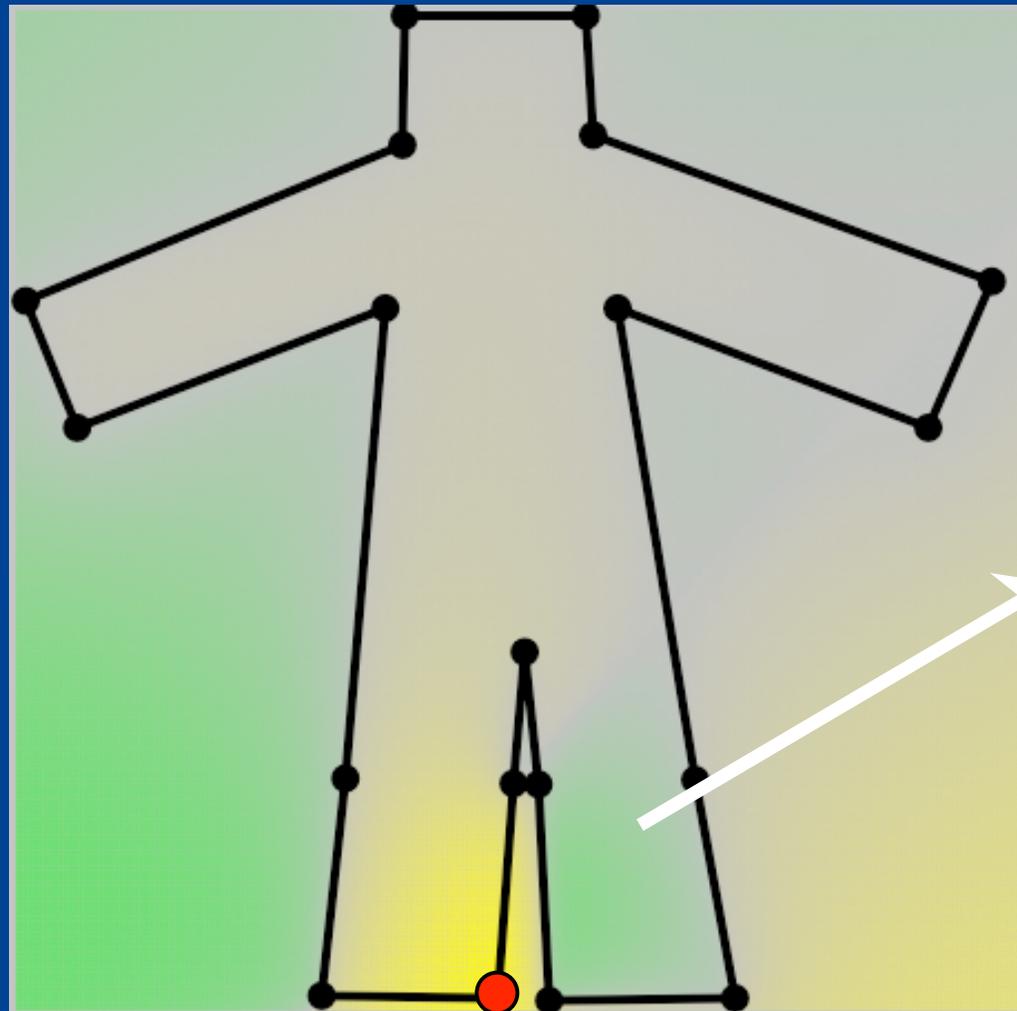


Mean Value Coordinates



large concavity produces non-local motion in opposite direction

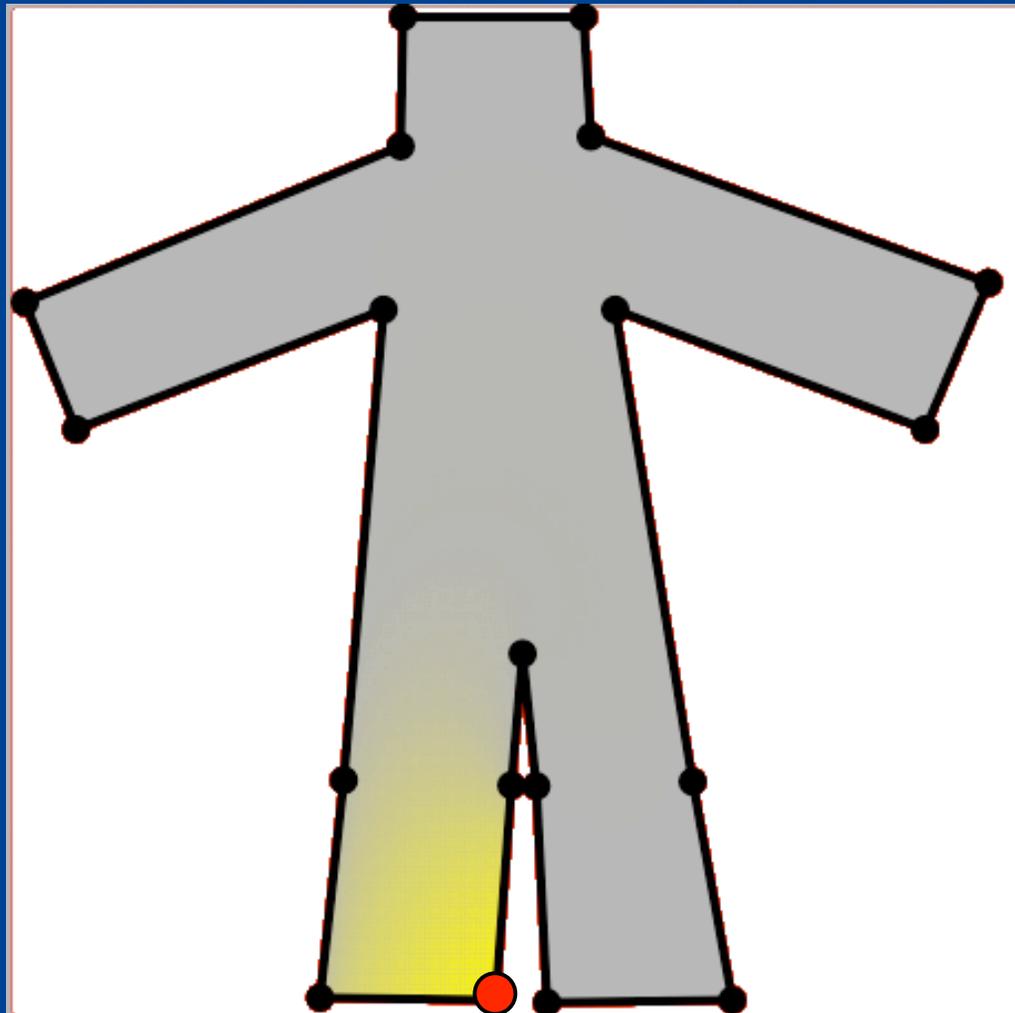
Mean Value Coordinate Field



Significant
negative weight

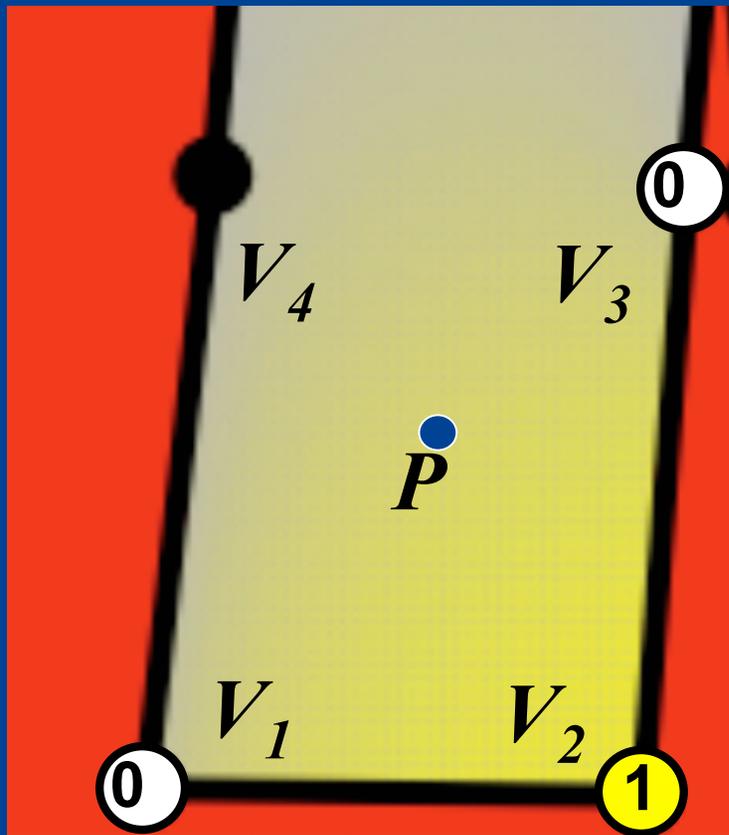
Positive
Negative

Desired Coordinate Field



-  Positive
-  Undefined

Laplace Equation for Interpolation



Harmonic coordinate
field for V_2

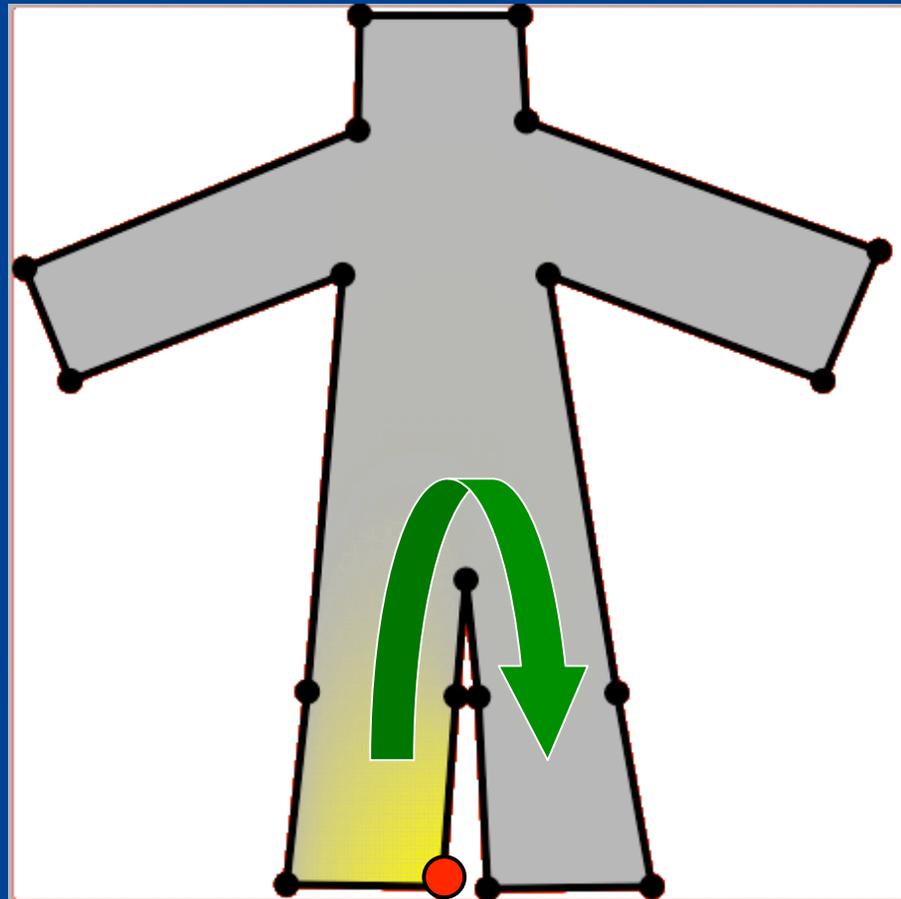
Steady-state heat equation

For every cage vertex V_i
solve Laplace Equation

$$\Delta h_i(P) = 0$$

$h_i(P)$ is harmonic coordinate
of vertex V_i at point P

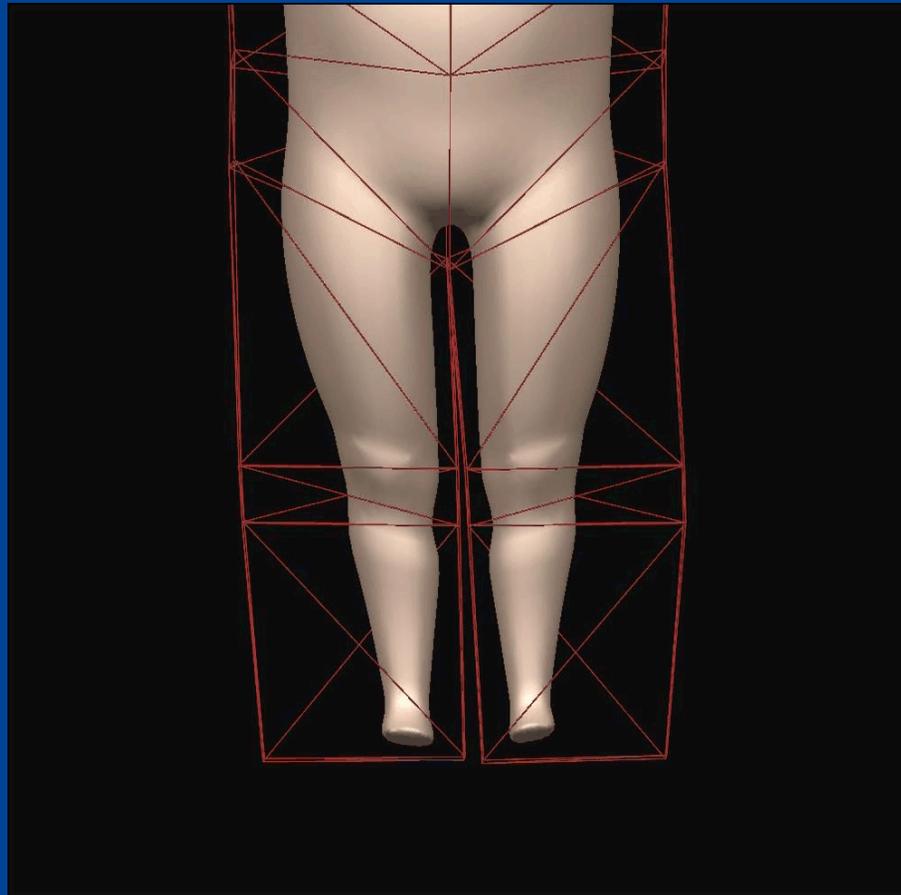
Harmonic Coordinate Field



- Positive
- Undefined

Weights drop-off with distance *within* cage

Harmonic Coordinates



intuitive motion due to interior locality and non-negativity

Harmonic Coordinates

- Linear precision
- Sum to 1
- Reduce to barycentric coordinates for simplices

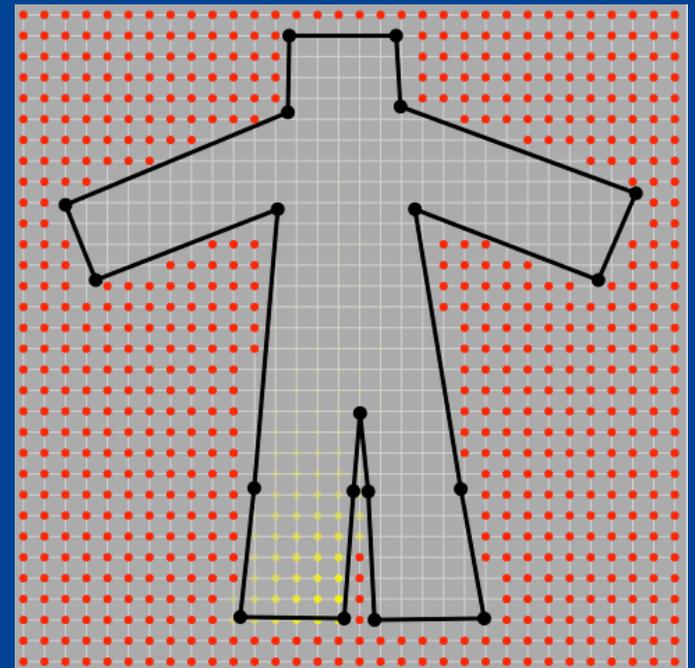
- Non-negative
- Interior locality
- Extended to nD

Numerical Solution

- No closed form: need numerical solution

OK for character articulation!

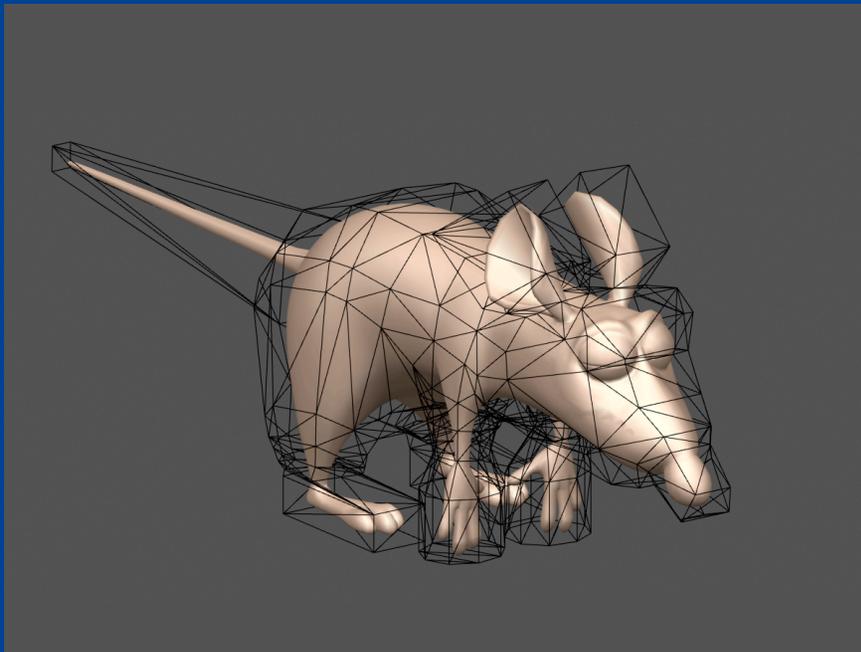
- Finite Difference solution
- Regular grid
- Irregular Laplacian stencil near boundary



Linear System Solver

- Sparse linear system solve
- Many different solution techniques
 - Multigrid Solver (used for this talk)
 - Direct Solver (SuperLU)

Articulation of Production Character



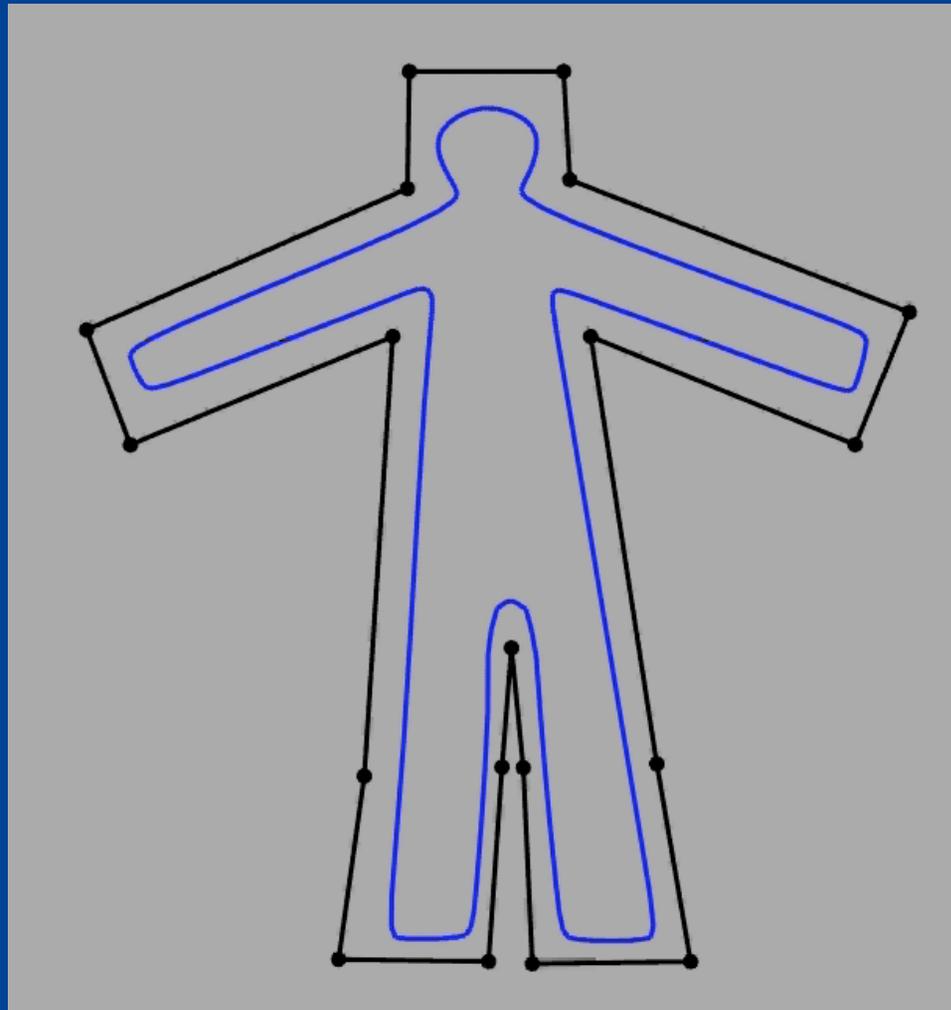
Articulation of Production Character



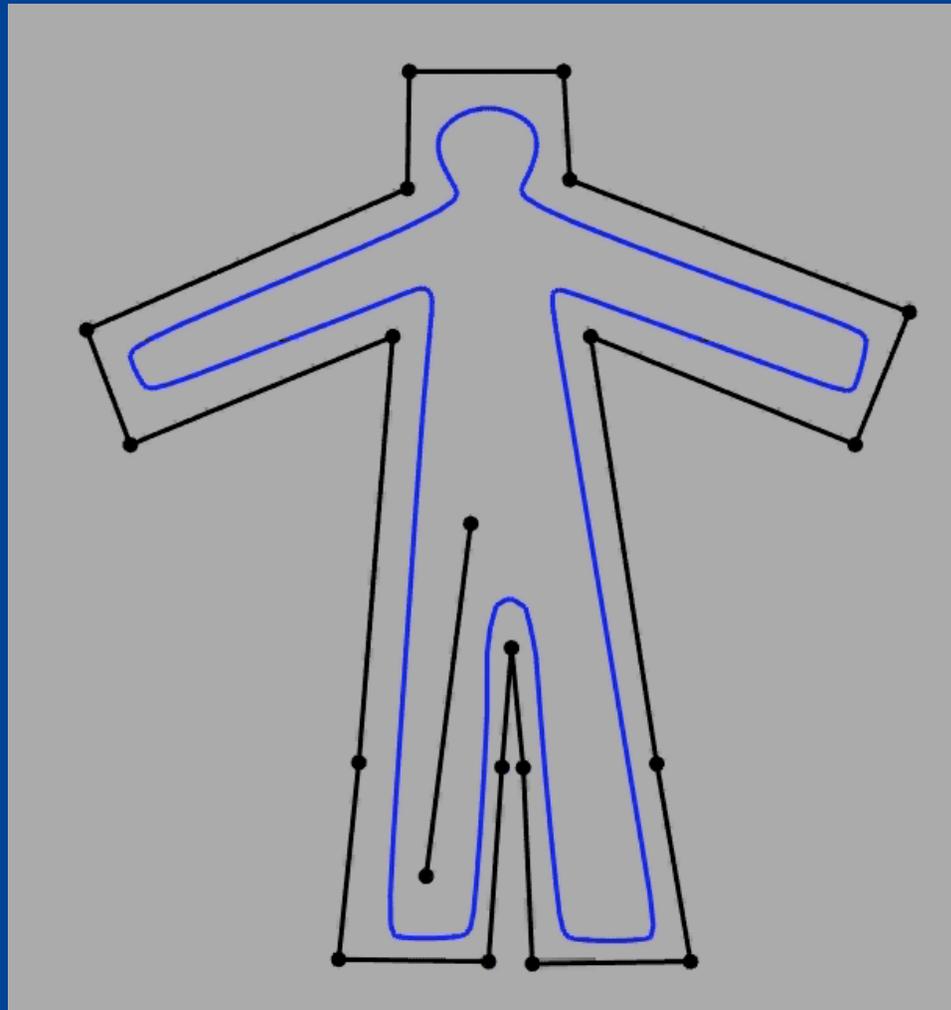
Extensions for Additional Control

- Interior Control
- Dynamic Binding

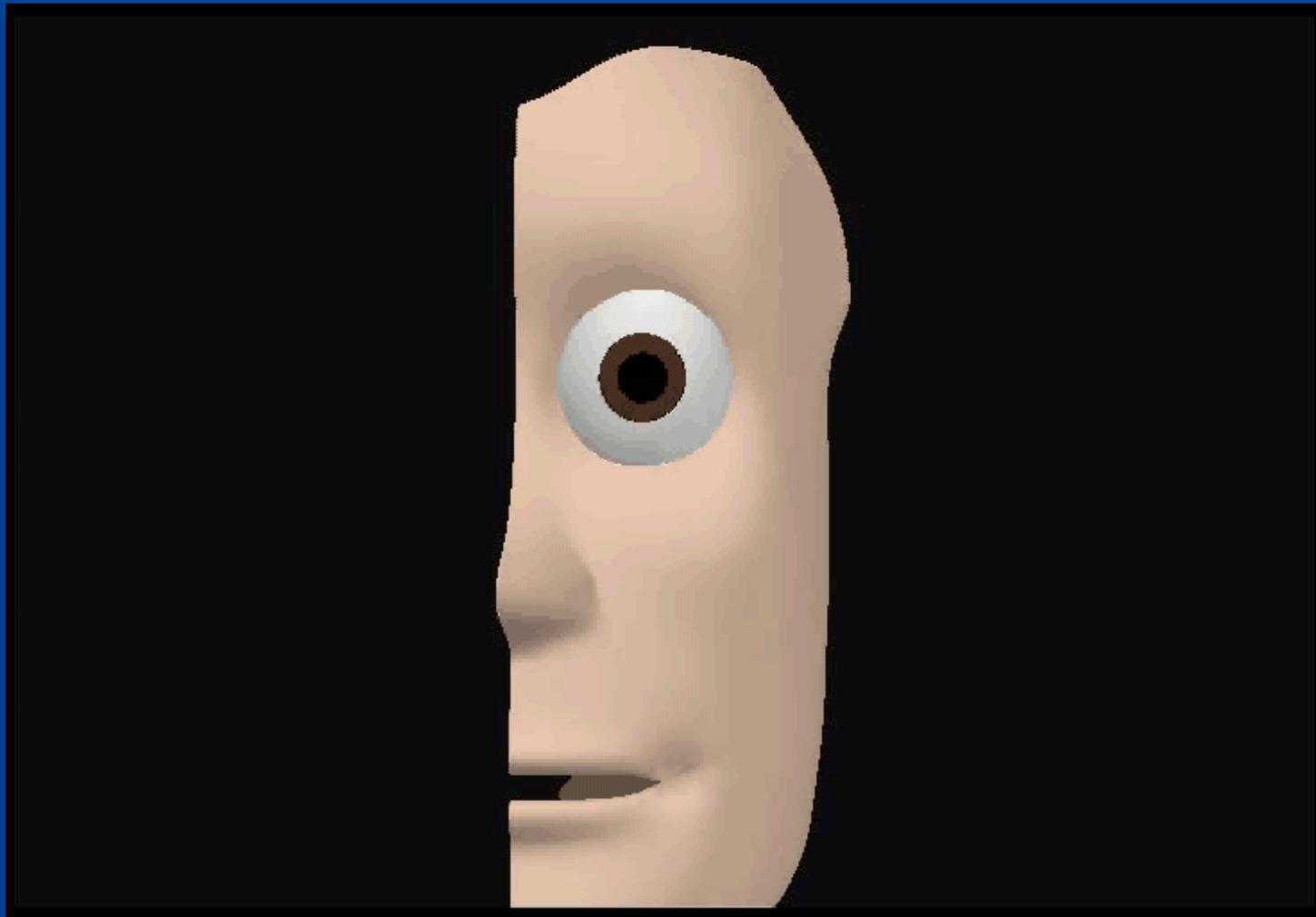
Interior Control – Need for Blockers



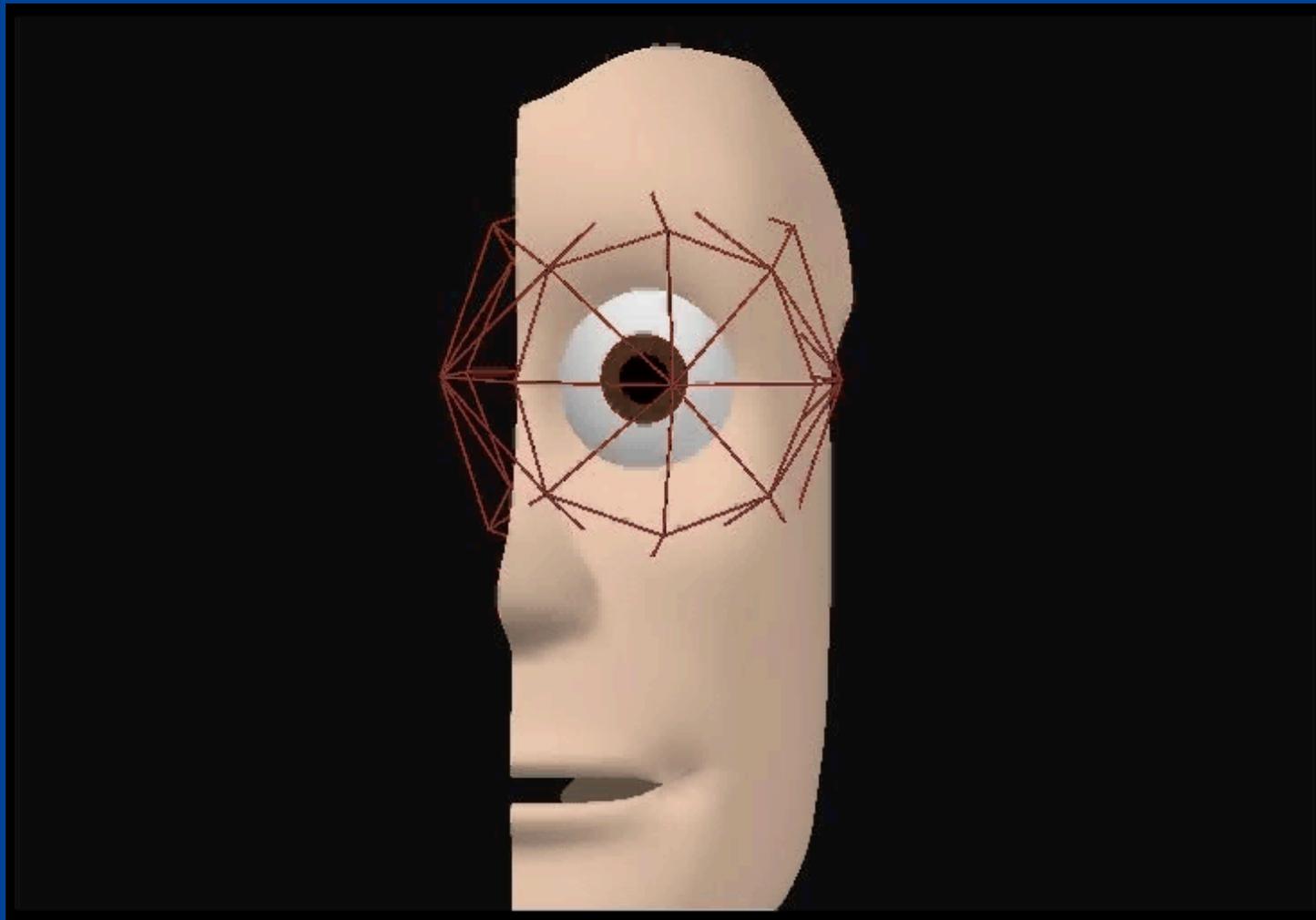
Interior Control – With Blockers



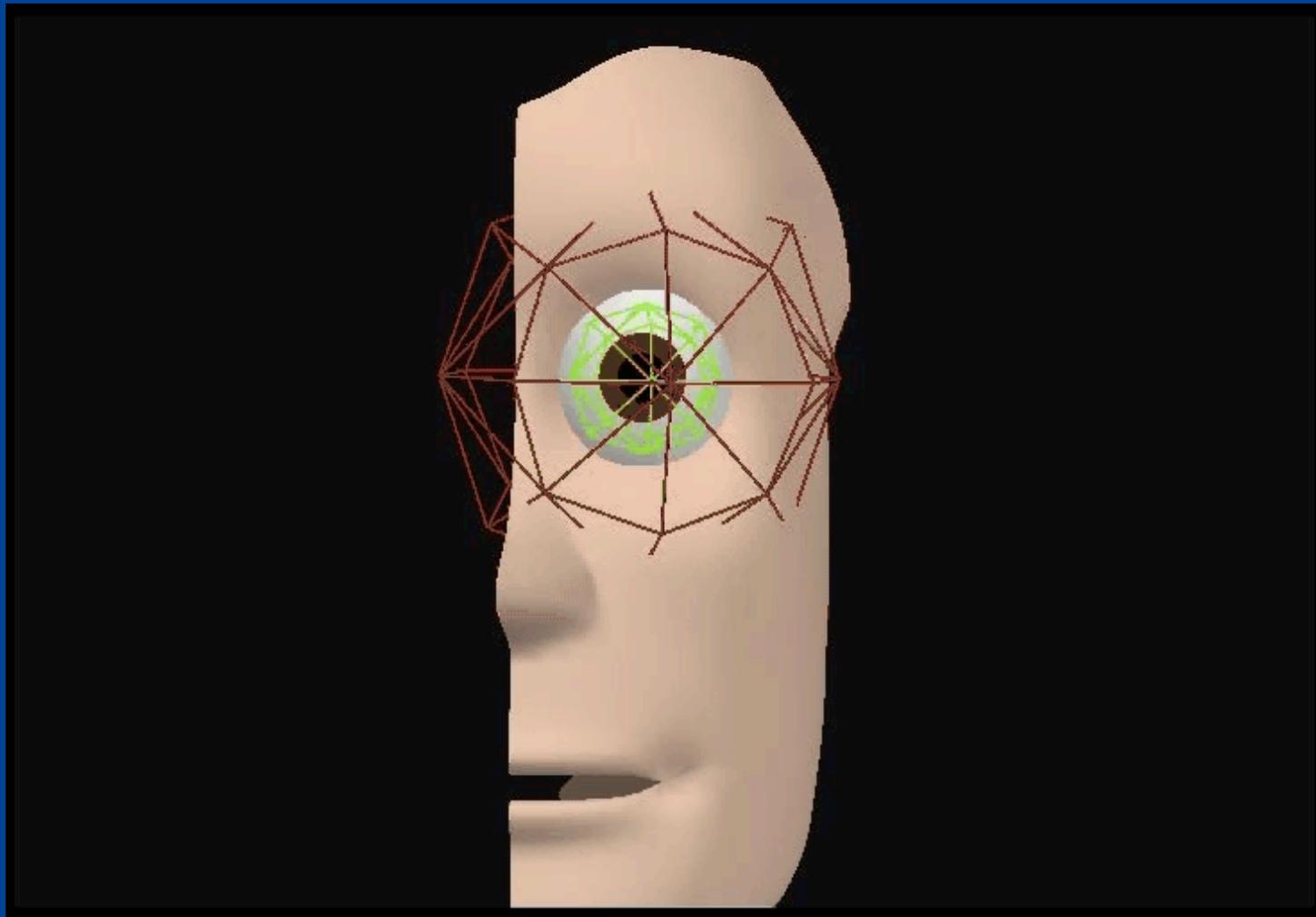
Interior Control – Need for Subcage



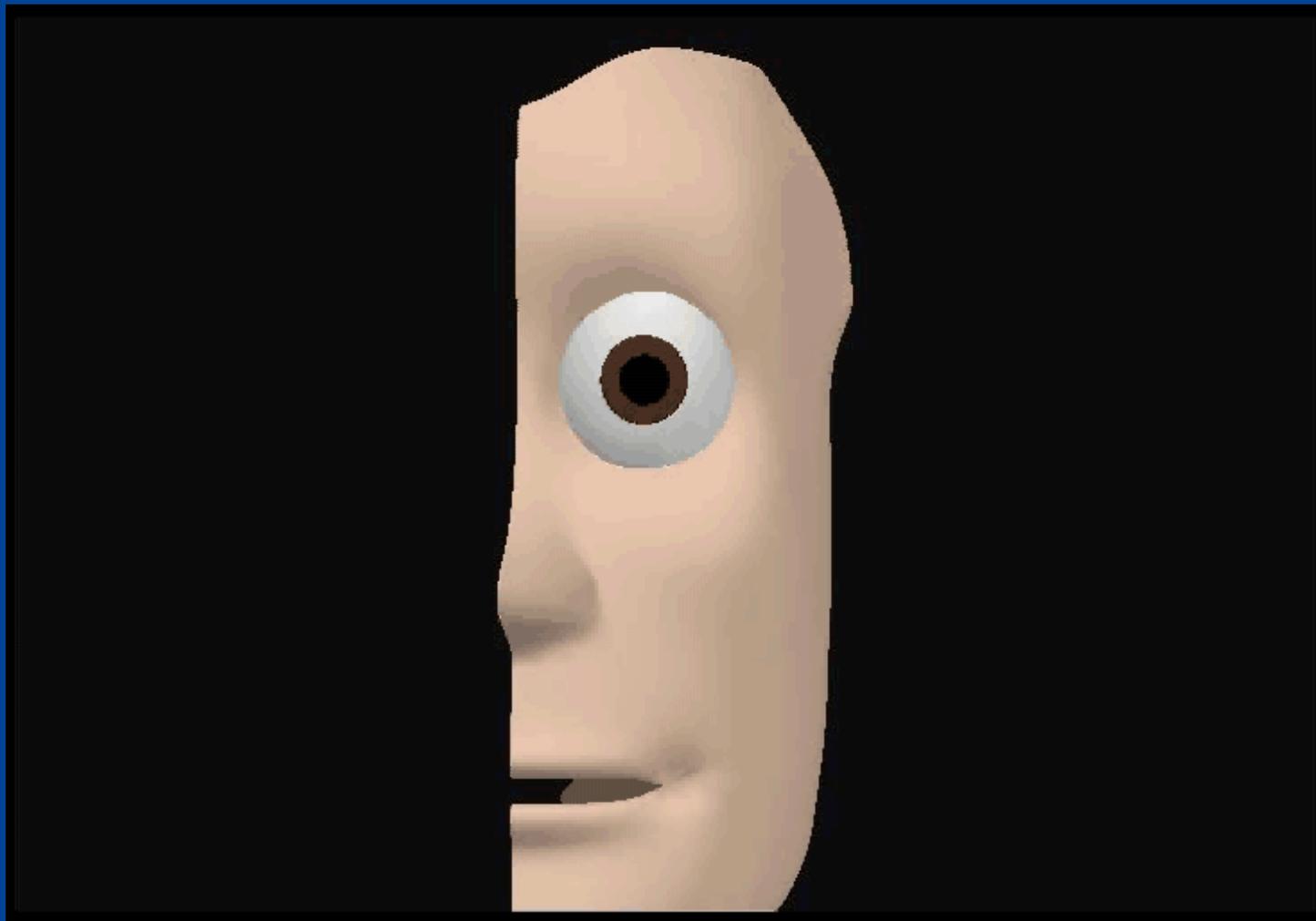
Interior Control – Need for Subcage



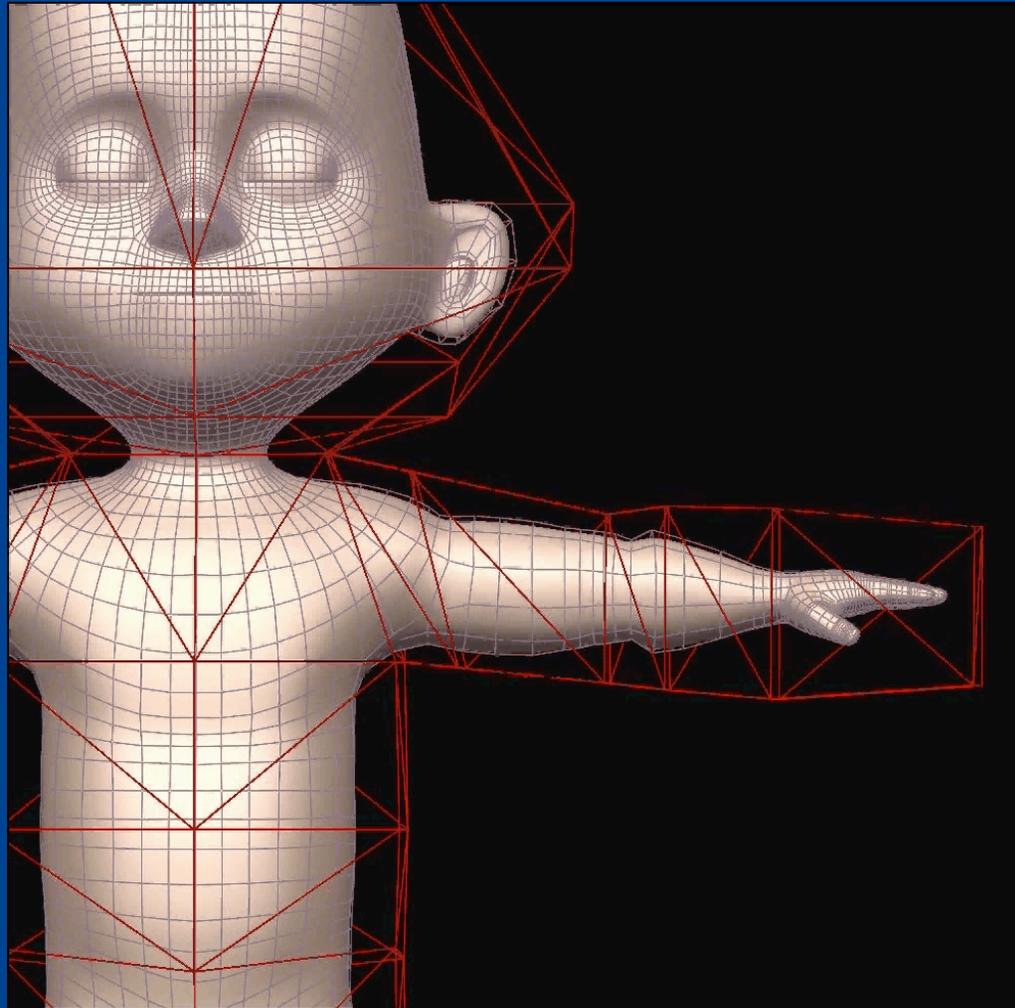
Interior Control – With Subcage



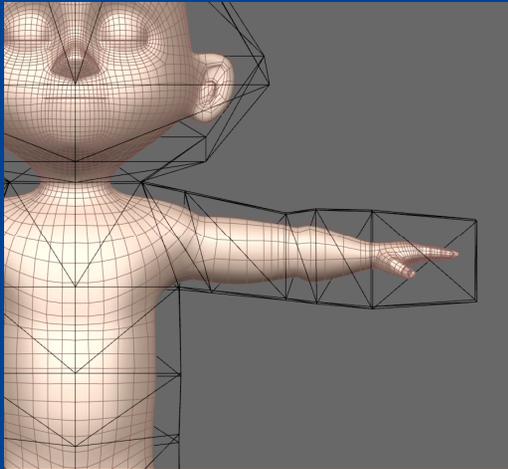
Interior Control – Final



Dynamic Binding

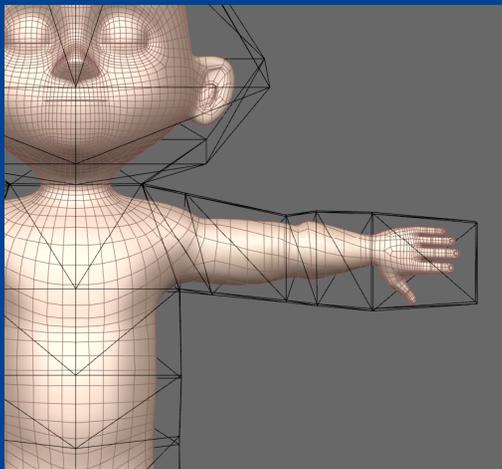


Dynamic Binding



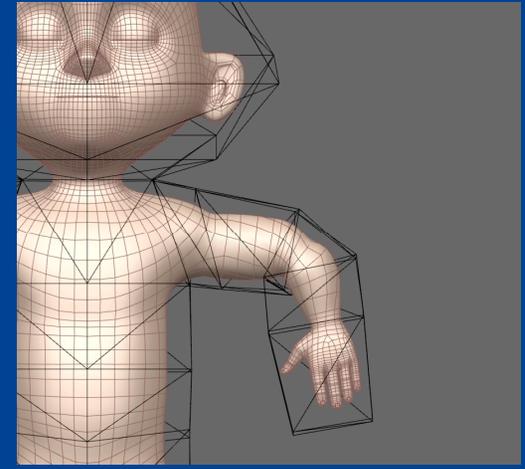
Initial Pose

Pose Object
within Cage



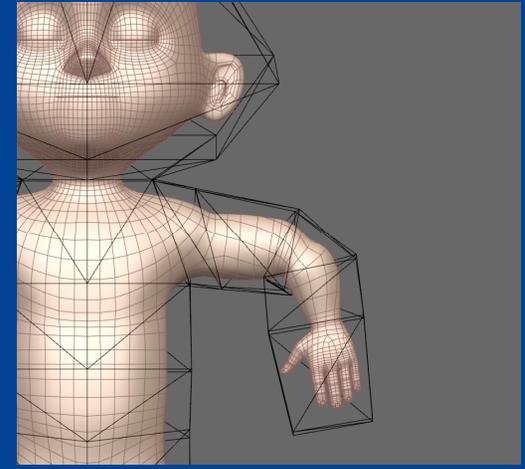
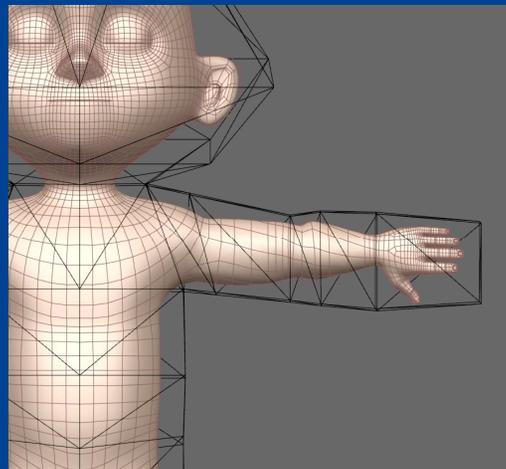
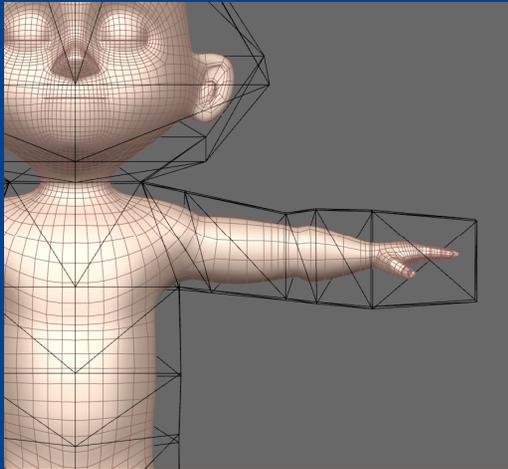
Bind

Pose Object by
moving Cage



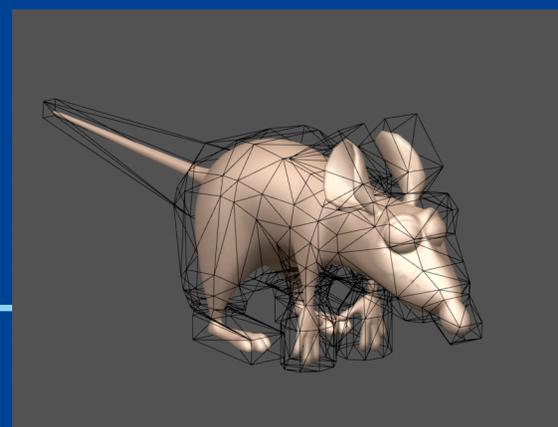
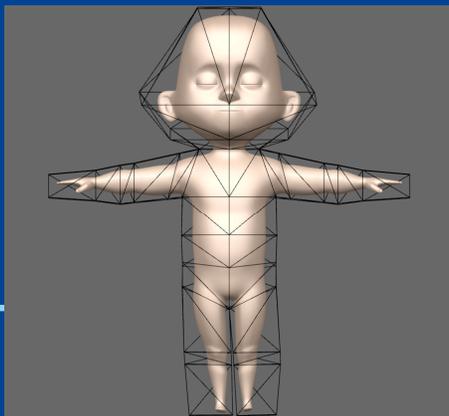
Final Pose

Dynamic Binding – Memory Costs



| | |
|--------|-------|
| Naive | 100MB |
| Sparse | 3MB |

Statistics



| | | |
|--|--------|--------|
| # of cage vertices | 112 | 325 |
| # of object vertices | 8019 | 9775 |
| Grid Resolution | 32^3 | 32^3 |
| Solve Time (sec.) <i>(a preprocess)</i> | 17.6 | 57.4 |
| Pose Time (sec.) | 0.026 | 0.111 |
| Grid Size (MB) | 3.7 | 9.2 |

Summary

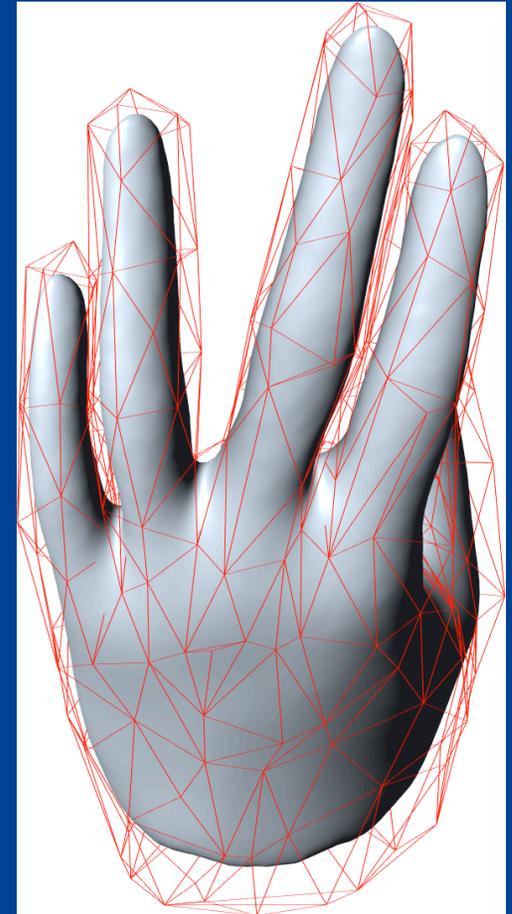
- Harmonic Coordinates – a new form of *generalized barycentric coordinates*
- Especially suitable for character articulation
 - Interior Locality
 - Non-negative
- Extensions for additional control in character animation pipeline

Harmonic Coordinates – Drawbacks

- No closed form formulation
 - *Interior locality and non-negativity are more important for character articulation.*
- Coordinates undefined on cage exterior
- Cage must be a bounded volume

Future Work

- Adaptive grids
- Moving cages
- Incremental solves
- “Positive Mean Value Coordinates”
(Lipman et al. SGP 2007)



Thank you!

