Introduction to Computer Graphics

Marie-Paule Cani & Estelle Duveau

04/02 Introduction & projective rendering

11/02 Prodedural modeling, Interactive modeling with parametric surfaces

25/02 Introduction to OpenGL + lab: first steps & modeling

04/03 Implicit surfaces 1 + lecture/lab: transformations & hierarchies

11/03 Implicit surfaces 2 + Lights & materials in OpenGL

18/03 Textures, aliasing + Lab: Lights & materials in OpenGL

25/03 Textures in OpenGL: lecture + lab

01/04 Procedural & kinematic animation + lab: procedural anim

08/04 Physics: particle systems + lab: physics 1

22/04 Physics: collisions, control + lab: physics 2

29/04 Animating complex objects + Realistic rendering

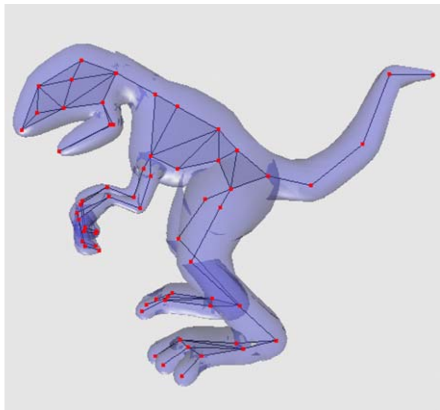
06/05 Talks: results of cases studies

Implicit Surfaces
Modeling complex shapes?

- Smooth surfaces
- Branching shapes
- Local details

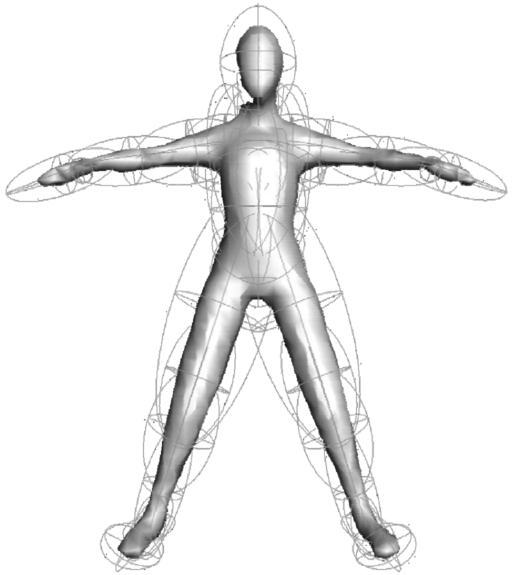
Three possible strategies

1. Lots of simple skeletons
2. Fewer, complex skeletons
3. Discrete scalar field



Implicit Surfaces
Modeling complex shapes?

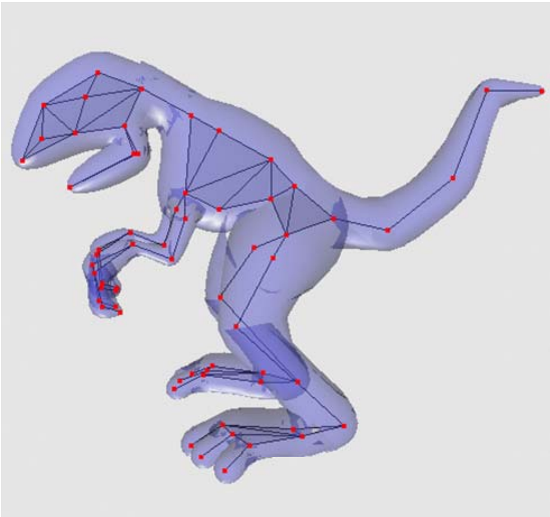
1. Lots of simple skeletons, additive field



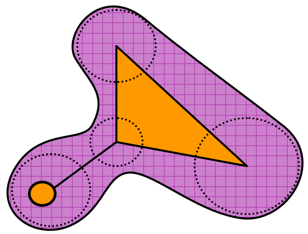
- Cost of field queries function of the number of skeletons
  Can be improved using local fields plus a query grid…
- Lack of smoothness ? Unwanted blending?

Implicit Surfaces
Modeling complex shapes?

2. Fewer, complex skeletons



- Intuitive
  - Skeleton graph of the shape's topology
  - Analogy with medial axis
- Major problems!
  - Bulges
  - Unwanted blending

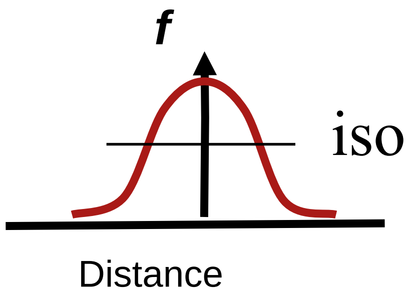


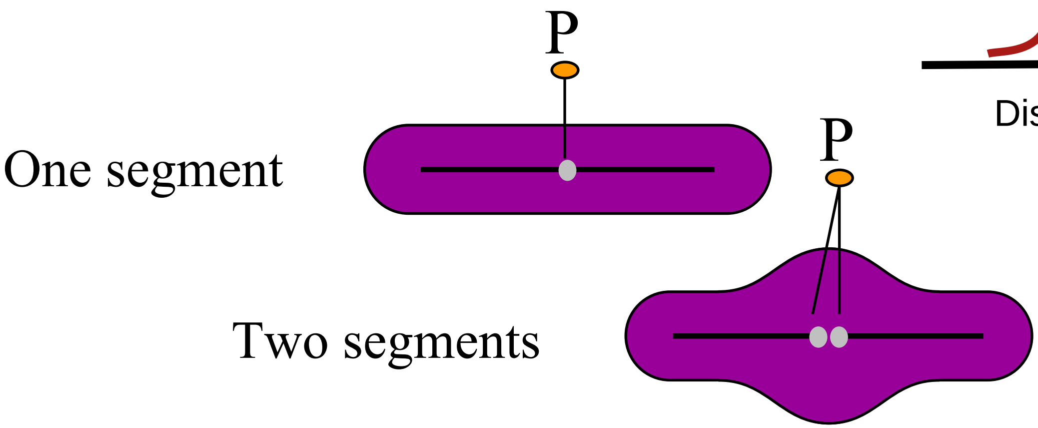
Medial axis

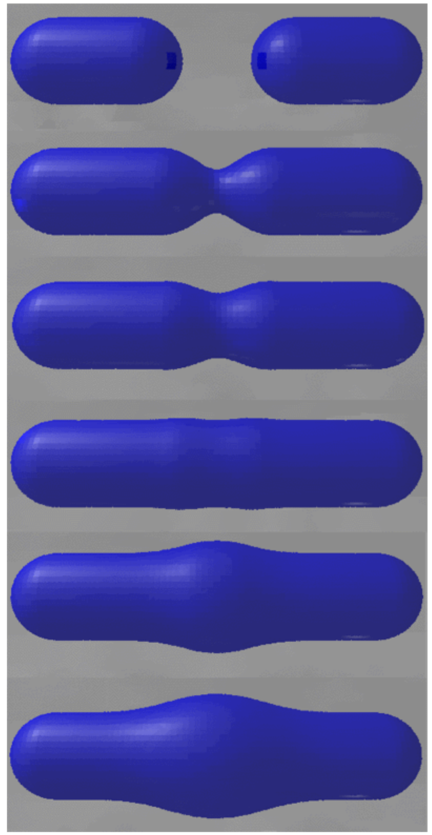
The bulges problem

Field values based on distance

- Distance to the closest point on S_i
- The shape changes if S_i is divided
- 3D bulge at all joints!

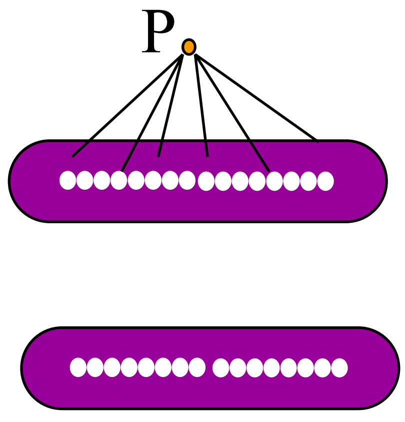






Avoid Unwanted Bulges?

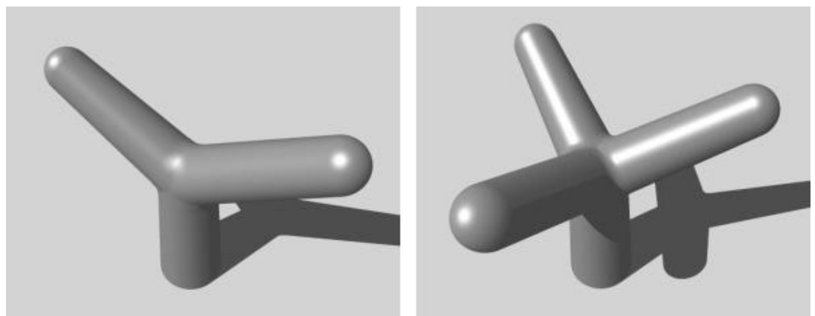
Convolution surfaces *[Bloomenthal Shoemake 91]*



- Integral along Si on point contributions

$$F(S,p) = \int_{s \in S} f(s,p)\,ds$$

= convolution of the skeleton with a “kernel” f



Convolution Surfaces

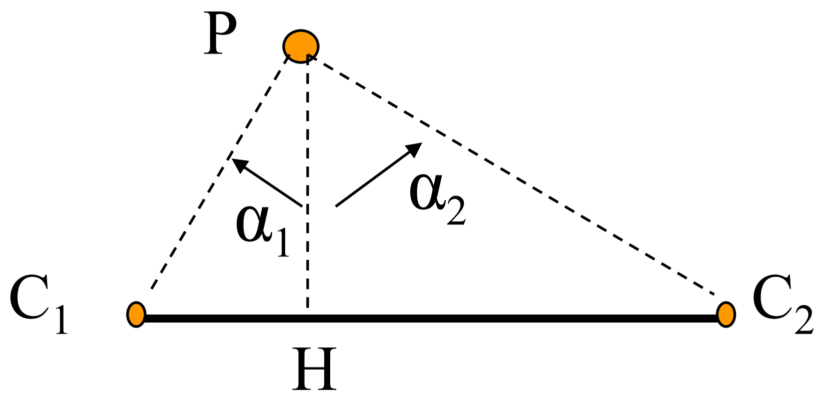
- *[Bloomenthal Shoemake 1991]*
  - Blinn’s exponential field
  - Discrete, approximate computation of the integral
- *[Sherstyuk 1998-1999]*
  - Some analytical solutions
  - Skeletons
    - segments
    - triangles
    - arcs of circles

Convolution surfaces

Example of analytical solution *[Cani Hornus 2001]*

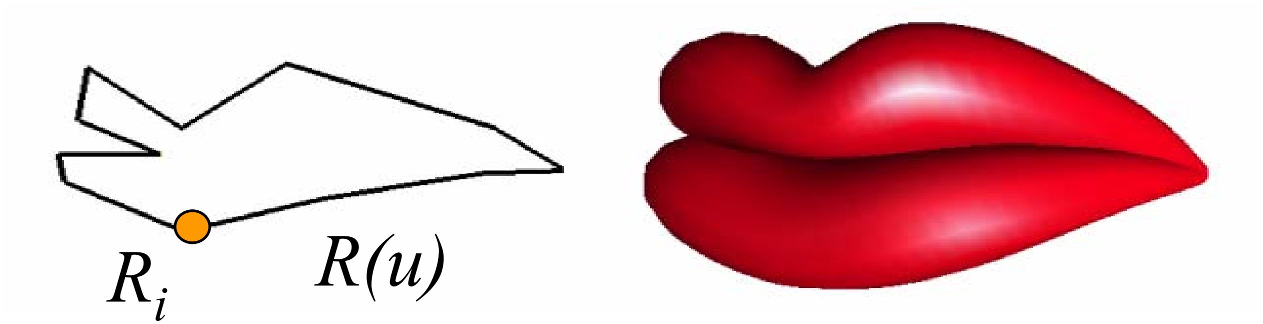
Along a line-segment

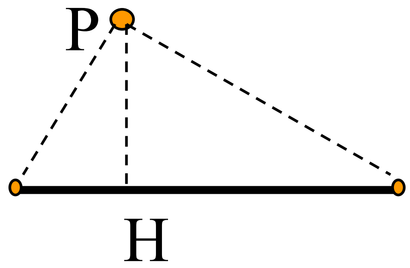
$$f(P) = \int_{r1}^{r2} \frac{1}{r^3} . dr$$



$$F(P) = \frac{\sin(\alpha_1) - \sin(\alpha_2)}{d^2(P, H)}$$

Convolution surfaces Non-constant radius?





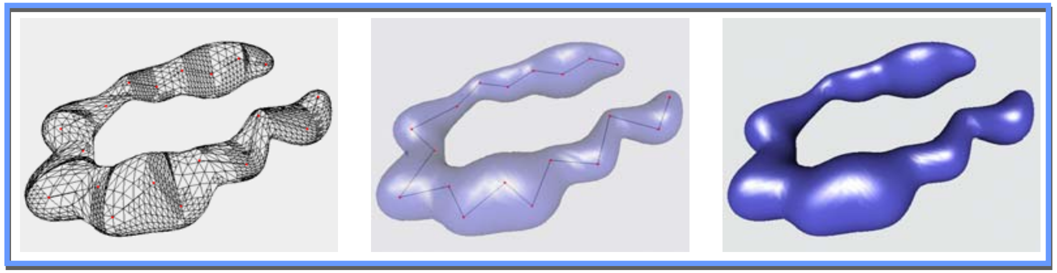
- R(u) computed by interpolation
- Modified convolution kernel (iso=0.5)

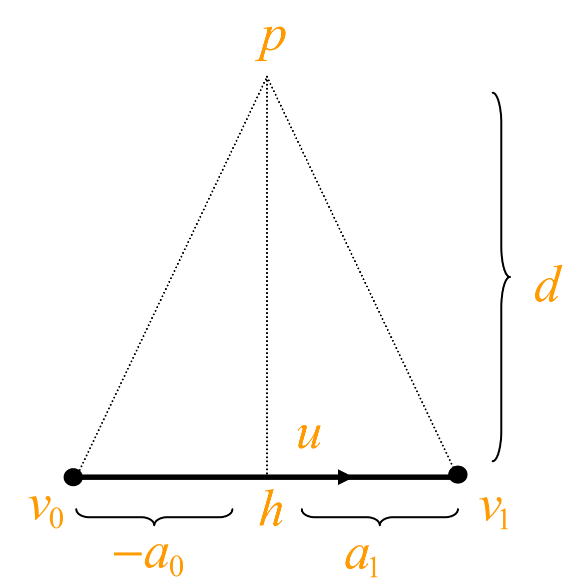
$$F(P) = \frac{\sin(\alpha_1) - \sin(\alpha_2)}{D^2(P,H)} \quad \text{where} \quad D(P,H) = \sqrt{2}\,\frac{d(P,H)}{R(H)}$$

Surfaces of non-constant radius
Exact solution *[Hornus Cani Angelidis 2002]*

- interpolation linéaire de r
- convolution de $f(s,p) = \frac{r^2}{d^2(p,s)}c$

$$F(S,p) = \frac{((dC - D^2/d)A + (r_0 - r_1)DB + (a_0 - a_1)C)}{(a_0 - a_1)^2}c$$





$A = \arctan(a_1/d) + \arctan(-a_0/d)$
$B = \log((a_1^2 + d^2)/(a_0^2 + d^2))$
$C = (r_0 - r_1)^2$
$D = r_0 a_1 + r_1 a_0$

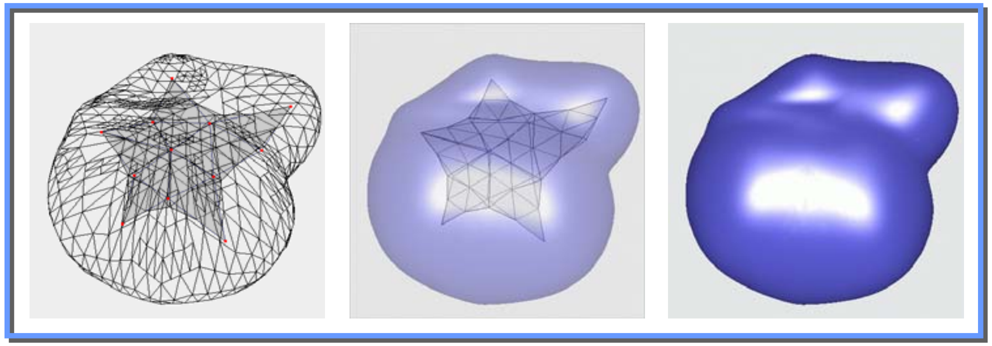
Surfaces of non-constant radius
Not exact on triangles *[Angelidis Cani 2002]*

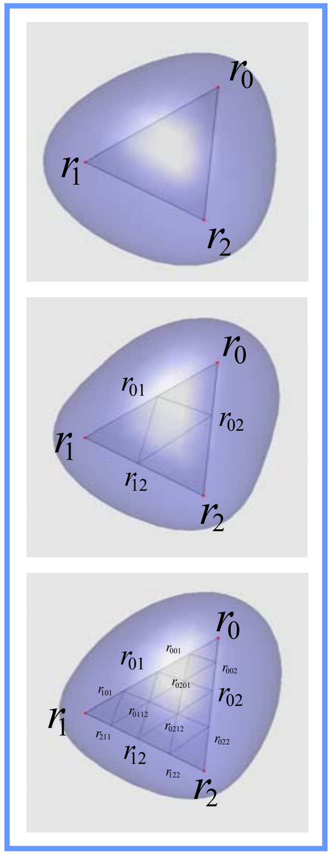
- Sherstyuk' field [She98]

$$F(S,p)=\int_{s\in S}\frac{1}{(1+s^2d^2(p,s))^2}\,dS$$

- Practical solution to varying radius

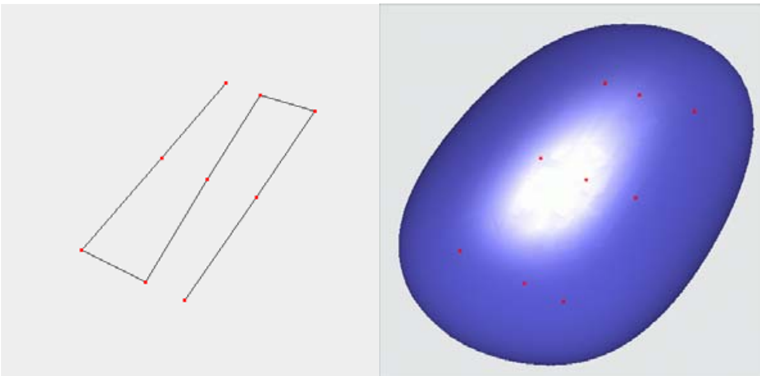
$$\frac{r_0+r_1+r_2}{3}F(S,p)$$

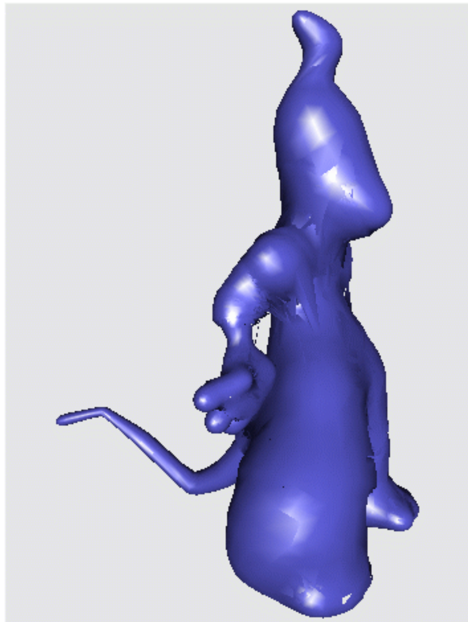




The unwanded Blending problem

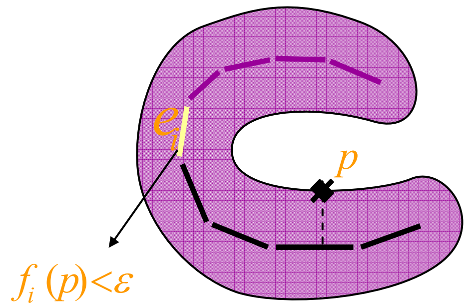
- Primitives blend according to their distance!

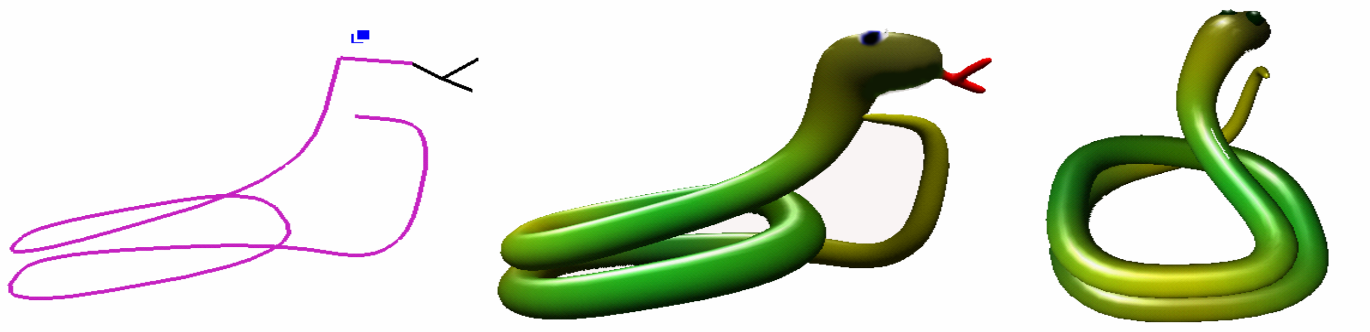




Solution to Unwanded Blending
Blending graph expressing the topology

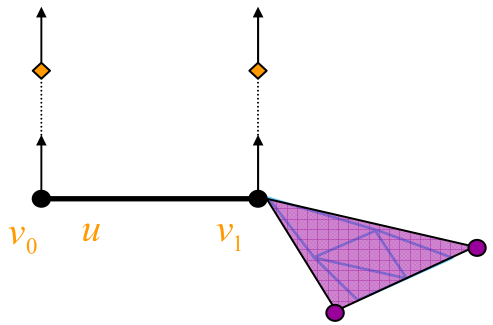
- *[Guy Wyvill 1995]*
  Field at P: Find skeleton with main influence
  Add its immediate neighbors : discontinuous!!
- *[Cani Hornus 2001]*
  Blend until the contribution is small enough
  Only works in specific cases!

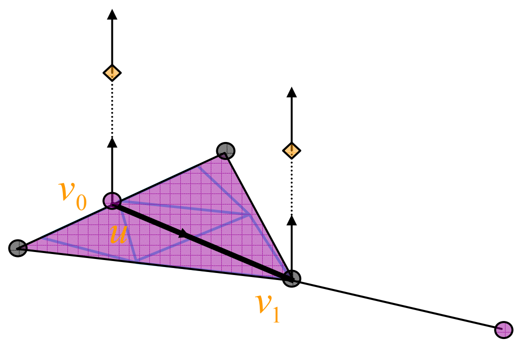


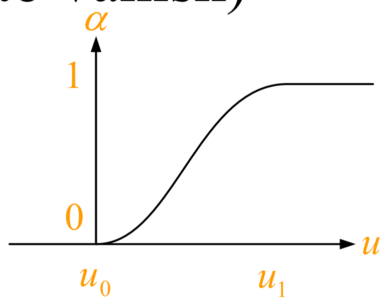


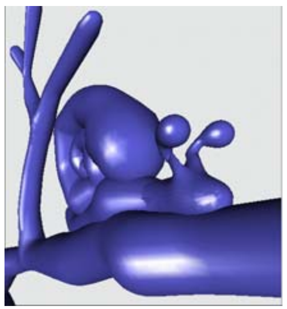
Solution to Unwanded Blending
Blending graph expressing the topology

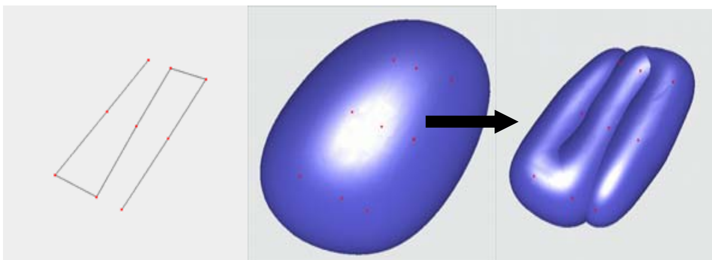
- *[Angelidis Cani 2002]*
  - decay functions (force the field contributions to vanish)

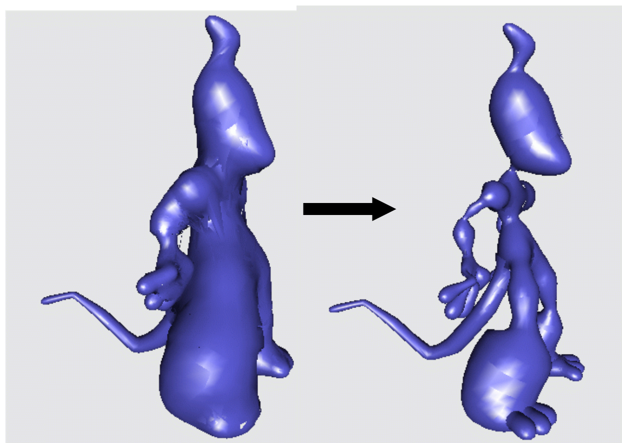






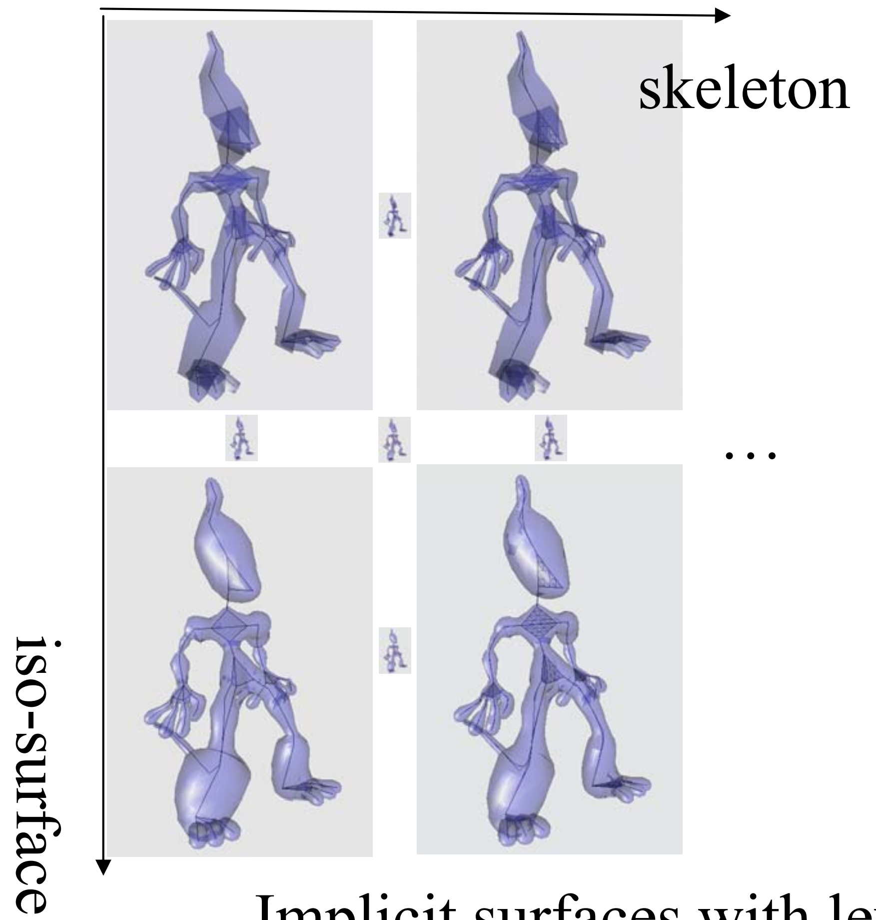


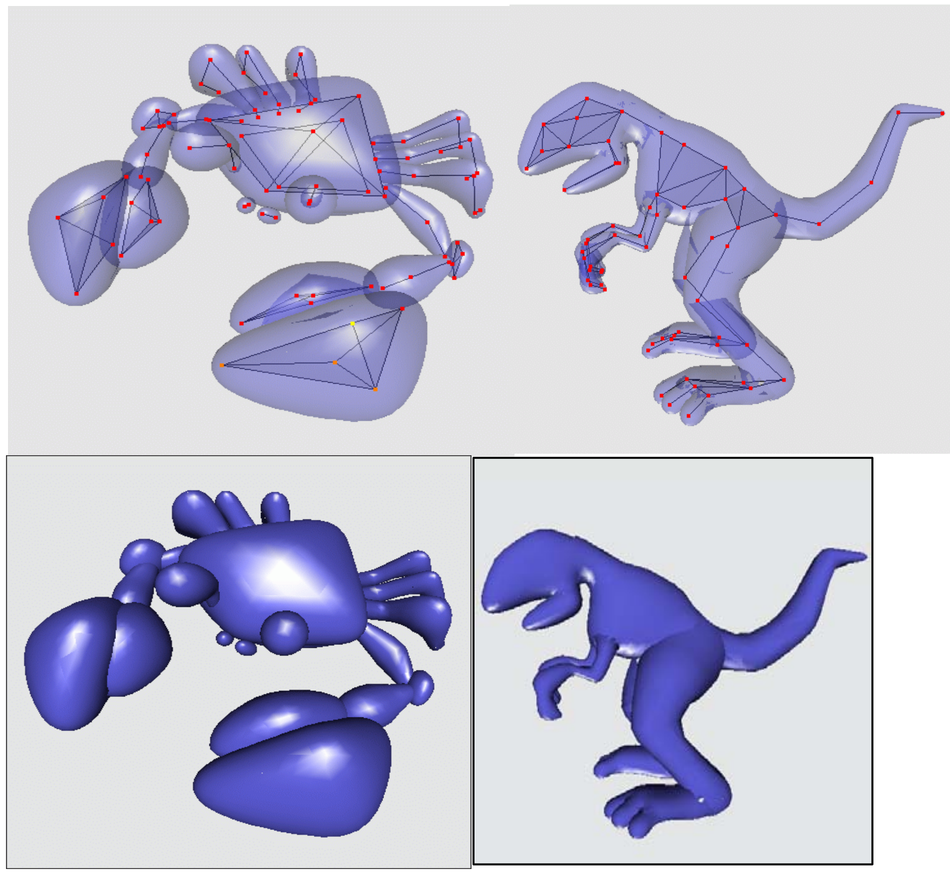




Example of use *[Angelidis Cani 2002]*

Subdivision curves & surfaces as skeletons

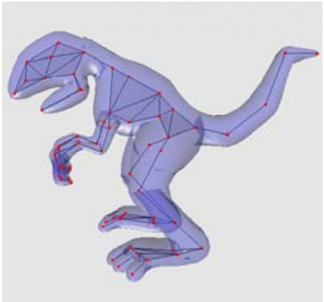




Implicit surfaces with levels of detail!

Implicit Surfaces
Modeling complex shapes?

1. Lots of simple skeletons
2. Fewer, complex skeletons

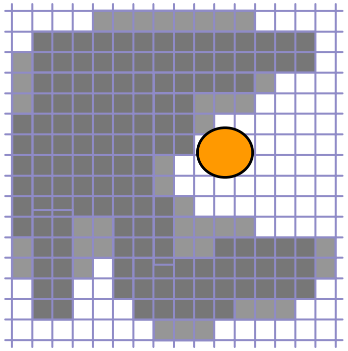


3. **Discrete scalar field**

   Discrete field, stored in a grid

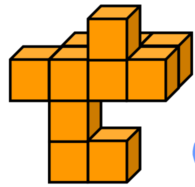
   Smooth interpolation

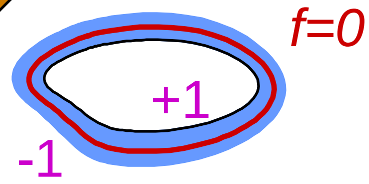
   → Constant time field queries



Discrete scalar field: data structures

Unbounded grid?





- H-table storage of non-empty cells
  – Created or deleted when and where needed
  – Field values clamped to [Max, 0], where iso = max/2

3 structures

  – non-empty cells, surface cells, surface vertices (on edges)

non-empty cells   surface cells   iso-surface

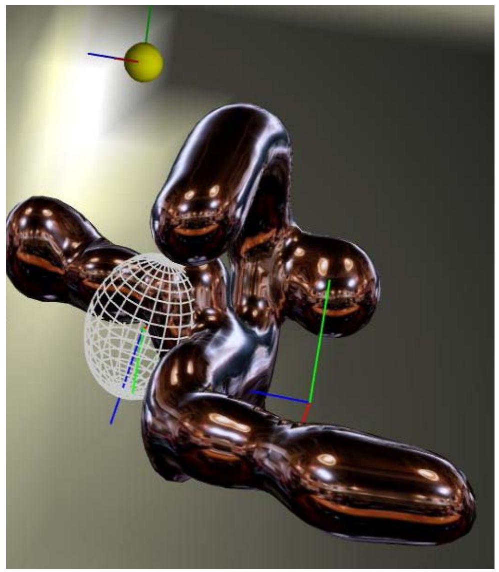
Sculpting tools

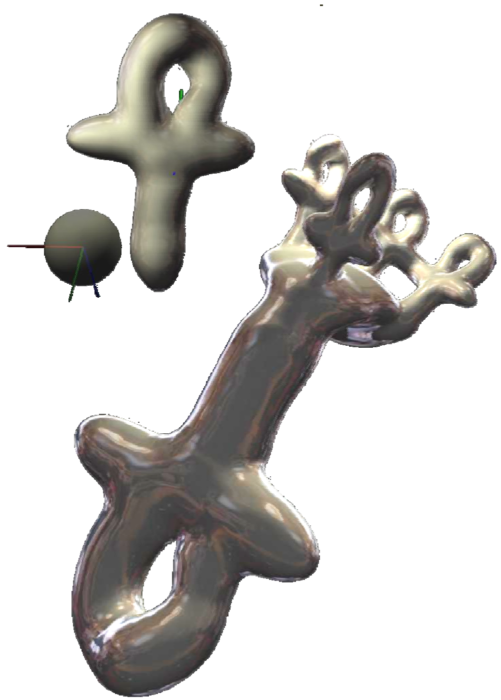
Analytical or discrete tools defined by

1. A continuous field function = Tool's contribution
2. An action = The blending operation to apply

Possible actions

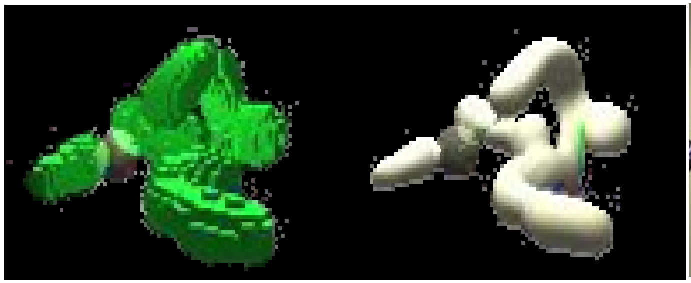
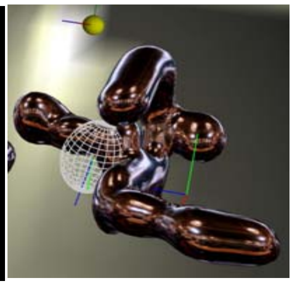
- Add material (+)
- Remove material (-)
- Paint
- Smooth (low band filter)





Visualization

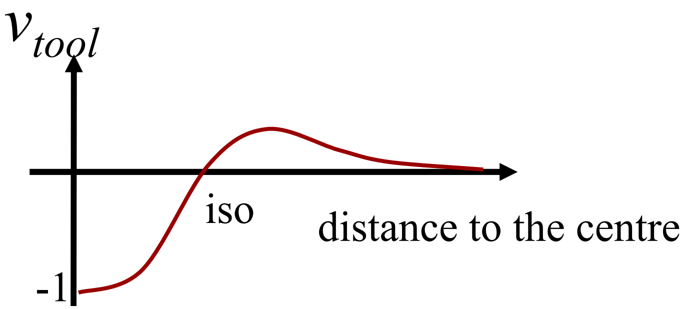
- Real-time, incremental marching cubes
  - Re-compute triangle data only where needed
- Environment textures
  - good perception of the shape

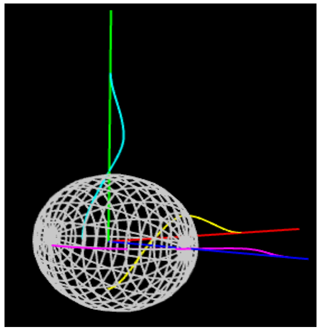



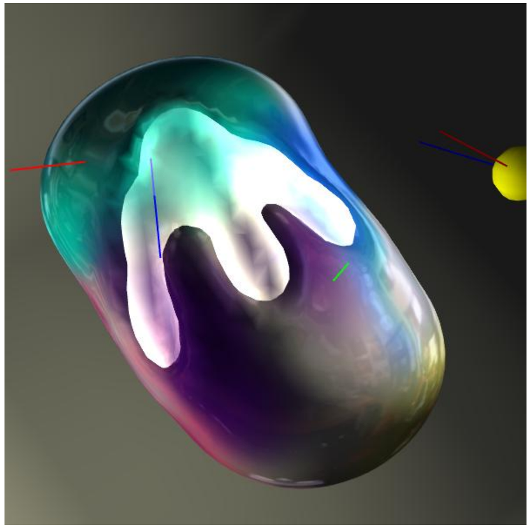
But clay also deforms!

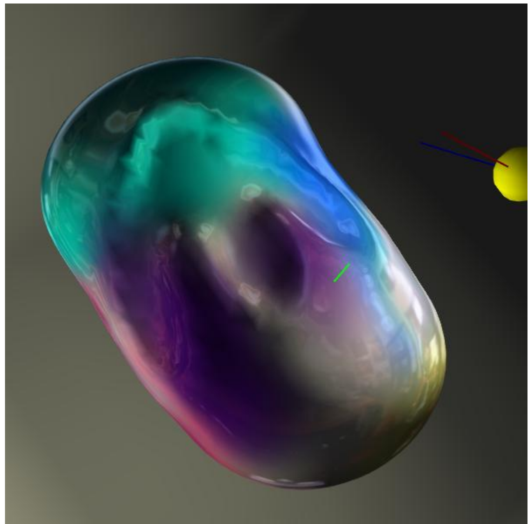
"Push" the material with a rigid tool ?

– Geometric deformation mimicking physics



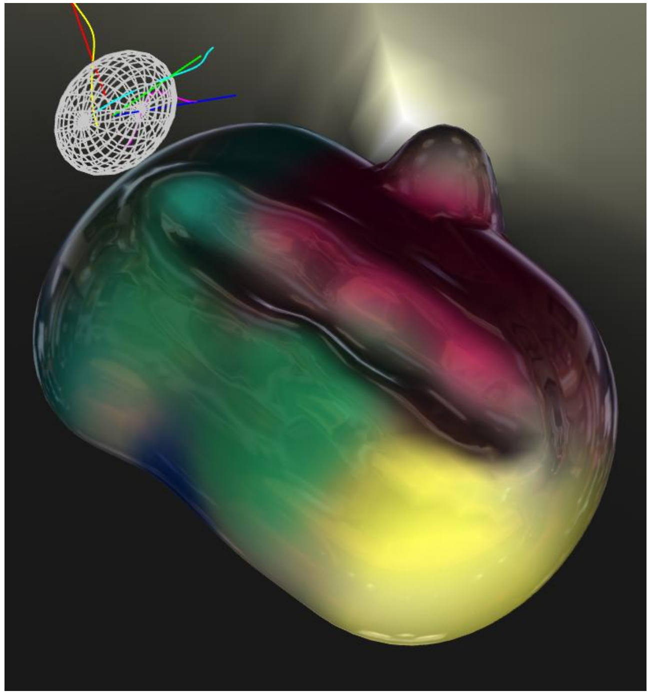


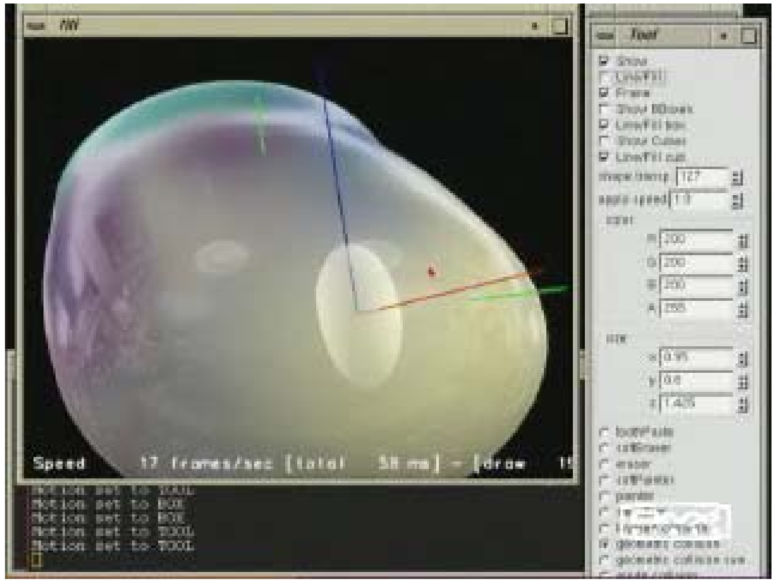




Addition of local deformations

- Push material with a rigid tool *[Ferley Cani Gascuel, 2001]*
  - User controlled bulge : no exact volume preservation





“Feel” the material: Force Feedback

Two forces are available

- Viscous friction from the tool’s speed and field value
- Contact force along the field’s gradient at the tool center

Phantom desktop
(1000 Hz)

Force feedback: Best combination of forces?

Non-applied tool

- **More contact force**
  - The user feels the surface
  - He can place the tool from it

Applied tool

- **More viscous friction**
  - The tool can penetrate inside
  - The user feels the density of clay

→ *«Expressive» haptic feedback!*

Sculpted in 1 hour

Multi-resolution?

- Both coarse and fine features at interactive rates?
- Internal representation still transparent to the user

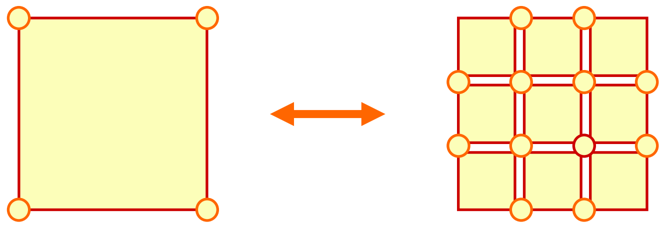
Multi-grid, two options

1. Store average + delta contributions at finer levels

   Elegant but extra cost for coherency

2. Store extra field samples at finer levels

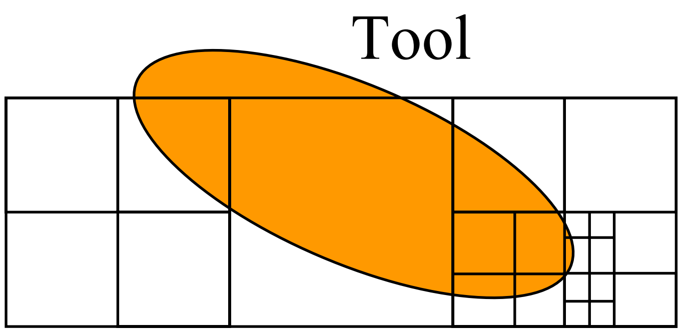
   Levels can be updated independently



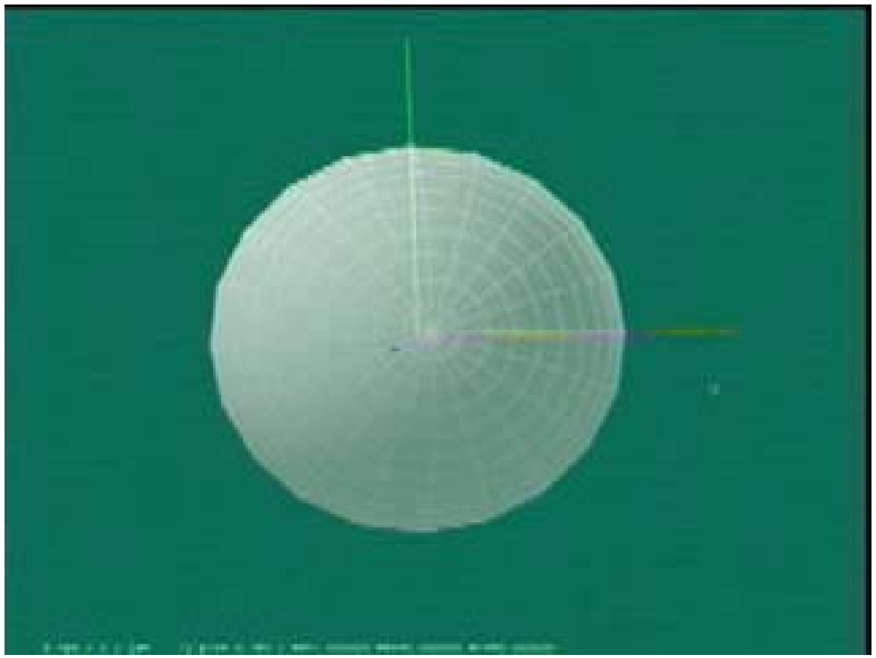
→ *option 2*

Multi-Resolution

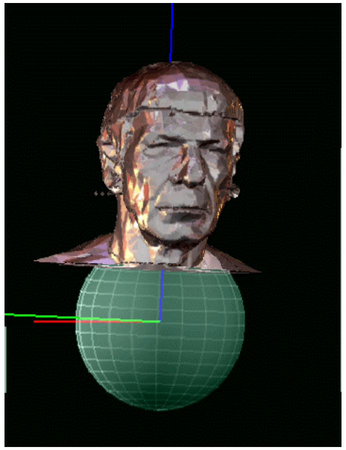
- Multi-grid of un-bounded resolution (H-table)
- The tools' sharp features guide local resolution
- Progressive action of tools : update from coarse to fine levels
- LODs for surface display

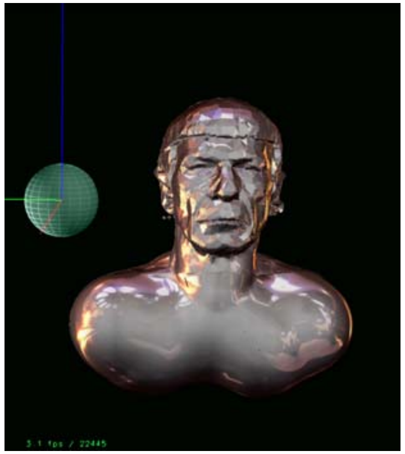


[Ferley Cani Gascuel, GMOD 2002]

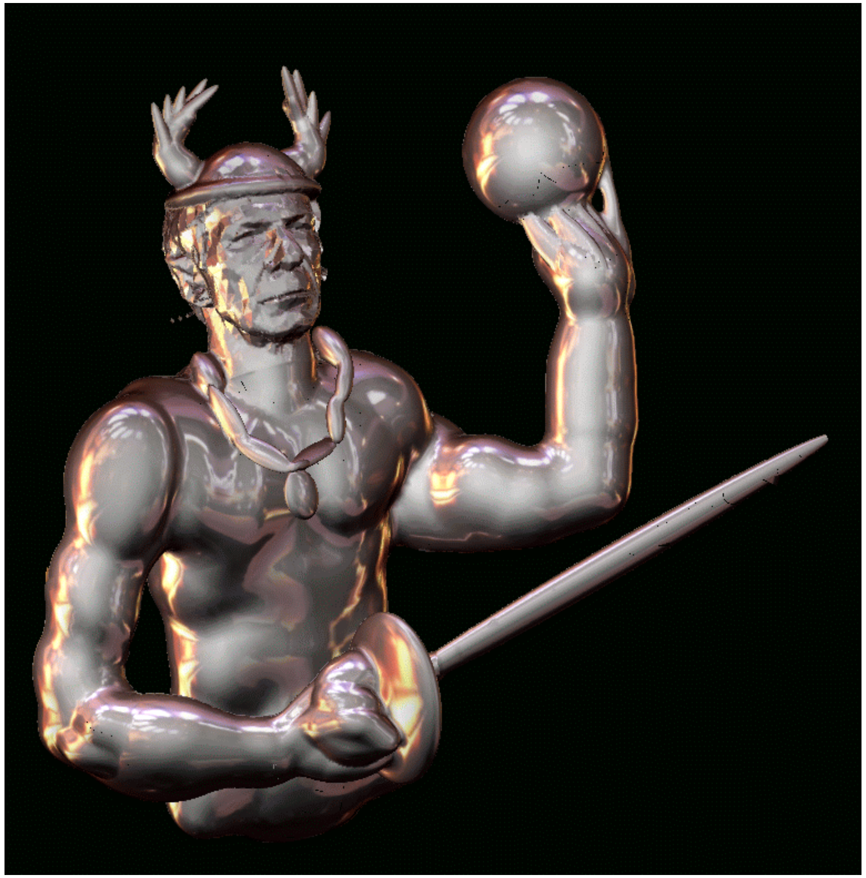


Multi-Resolution





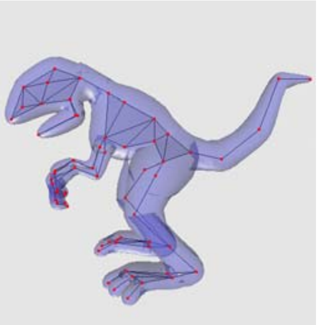
Sculpted in 1,5 hour



Best implicit representation?

Constructive representation (tree)

- Lots of very simple primitives?
  → objects breaking into pieces
- Fewer, complex skeletons?
  → skeleton-based animation



Discrete field, with smooth interpolation?

- Constant time field queries
- No limitation of complexity!

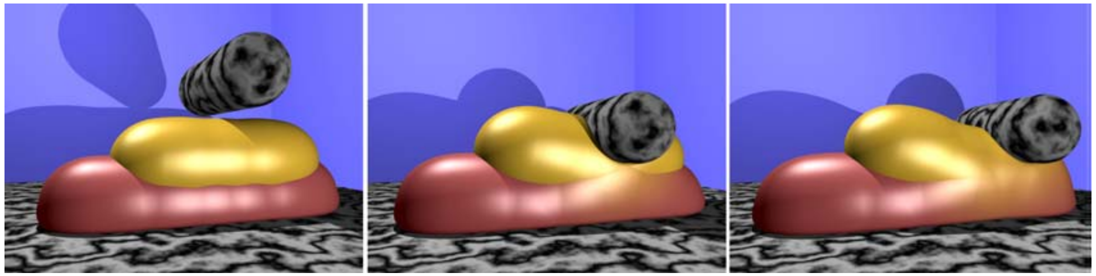
→ cannot be deformed easily

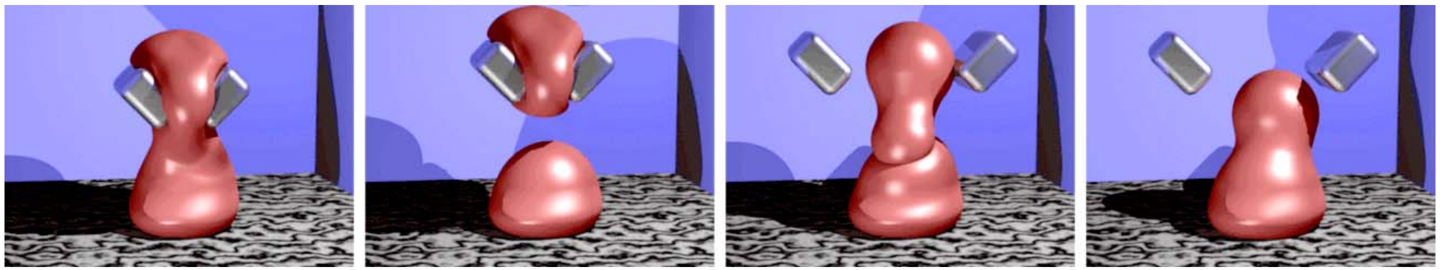
Advanced bibliography

Animation of Deformable Models Using Implicit Surfaces

[Cani Desbrun 1997] (SIGGRAPH 93/95]

- Precise contact modeling
- Constant volume
- Controlled blending

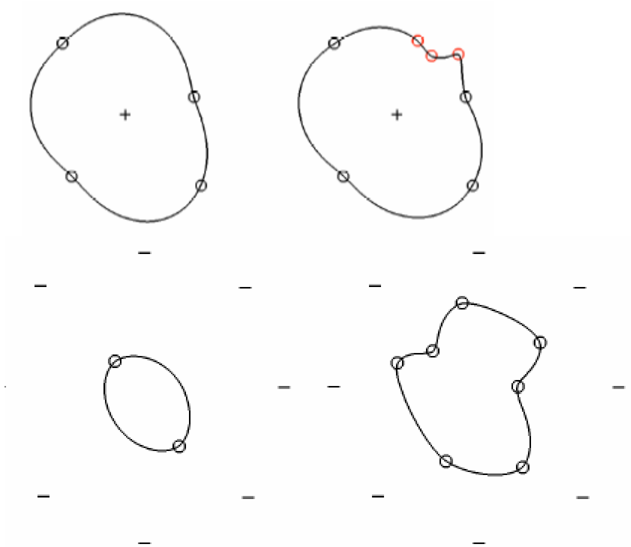


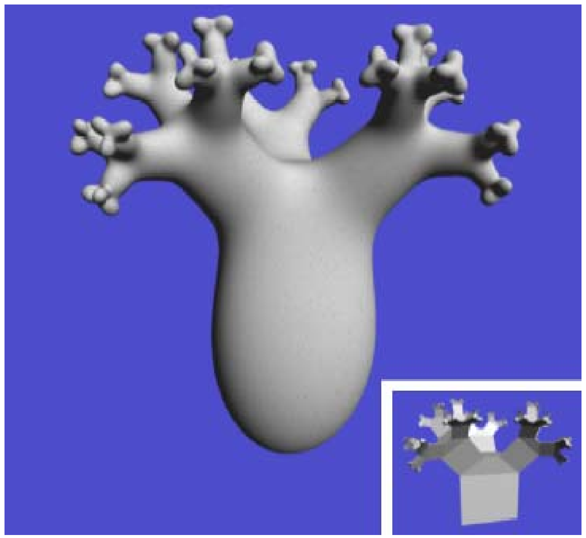


Advanced bibliography
Modeling with Implicit Surfaces that Interpolate

[Turk, O'Brien, SIGGRAPH 2002]

- Introduction of *Variational implicit surfaces*
  - Defined by solving a linear system of position constraints
  - Now widely used for reconstructing/re-sampling point sets





Advanced bibliography
2D potential fields for advanced implicit modeling

[Barthe, Dodgson, Sabin, Wyvill Computer Graphics Forum 2003]

- Controllable blending defined by a free-form curve $G(f_1, f_2)$
- Unifies CSG operators & smooth blending