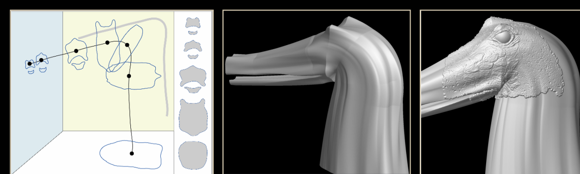
Designing with Distance Fields

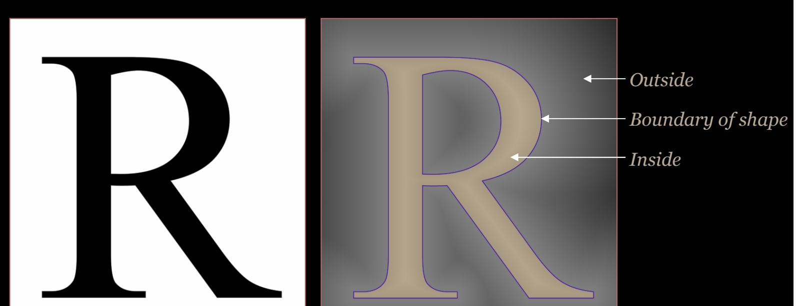
From Concept Modeling to Detailed Carving



Sarah F. Frisken, Tufts University
Ronald N. Perry, Mitsubishi Electric Research Labs

Distance Fields

- An object's distance field represents, for any point in space, the distance from that point to the object
  - The distance can be signed to distinguish between the inside and outside of the object



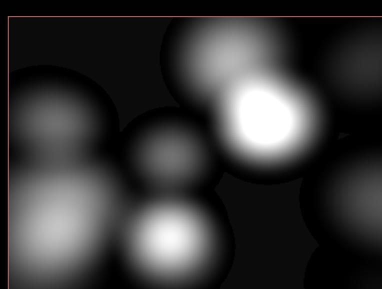
2D Shape *Shape's distance field*

Distance Fields

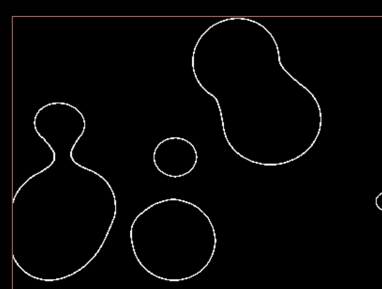
- Distance fields are <u>implicit representations</u> of shape …
  - See *Introduction to Implicit Surfaces* (J. Bloomenthal, ed.), 1997
- The surface of the shape is an <u>implicit surface</u>
  - An implicit surface is an iso-contour of an implicitly defined scalar function

Distance Fields

- An example of an implicit representation, $F(\underline{x})$, where $\underline{x} \in \Re^3$



A 2D cross section of $F(\underline{x})$



An iso-contour of $F(\underline{x})$ *where* $F(\underline{x}) = 0.28$

Distance Fields

- Typically, for a shape represented by a distance field, the shape's boundary, Ω, is the zero-valued iso-surface of the distance function
  - i.e., for an implicitly defined distance function, $dist(\underline{x})$, Ω is the set of all points where $dist(\underline{x}) = 0$

Distance Fields

- General distance function

  $dist(\underline{x}) = Norm(\underline{x} - \underline{S}(\underline{x}))$, where $Norm(\underline{u})$ is a metric that decreases monotonically with $||\underline{u}||$, and $S(\underline{x})$ is a point on the boundary Ω

- Minimum distance

  $\underline{S}(\underline{x}) = \underline{s}^*$, where $\underline{s}^*$ is on Ω and

  $|Norm(\underline{x}-\underline{s}^*)| \leq |Norm(\underline{x} - \underline{S})|, \ \forall \underline{S} \in \Omega$

- Euclidean norm
  - Minimum Euclidean distance

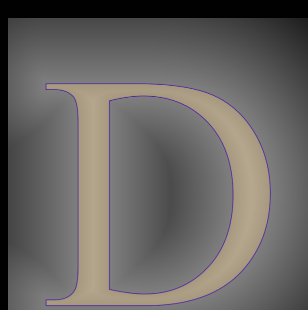
$$
\begin{aligned}
dist(\underline{x}) &= \pm\sqrt{(\underline{x} - \underline{s}^*) \bullet (\underline{x} - \underline{s}^*)^T)} \\
&= \pm\sqrt{(x - s_x^*)^2 + (y - s_y^*)^2 + (z - s_z^*)^2}, \ \text{for } \underline{x} = (x, y, z) \\
&= \text{the signed magnitude of the vector from } \underline{x} \text{ to } \underline{s}^*
\end{aligned}
$$

General Properties

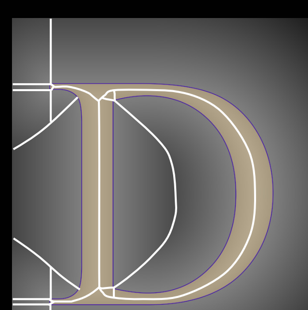
- Distance fields are defined every where in space
  - Not just on the surface like boundary representations
- It is trivial to determine whether a point is inside, outside or on the boundary of a shape
  - Evaluate F(x) and compare it to the value of the iso-surface
- Gradients of the distance field provide geometric information
  - On the surface
    - The gradient is normal to the surface
  - Off the surface
    - The gradient points in the direction of the closest surface point

Continuity Properties

- Distance fields are C^0 continuous everywhere
- Euclidean distance fields are C^1 continuous except at boundaries of Voronoi Regions
  - C^1 near smooth sections of the boundary
    - Distance field is linear near linear sections of the boundary
  - Not C^1 near corners or the medial axis



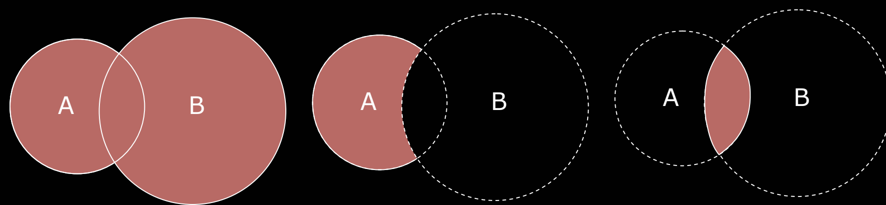
Distance field is C^0 continuous



C^1 continuous except at Voronoi boundaries

Operations on Distance Fields

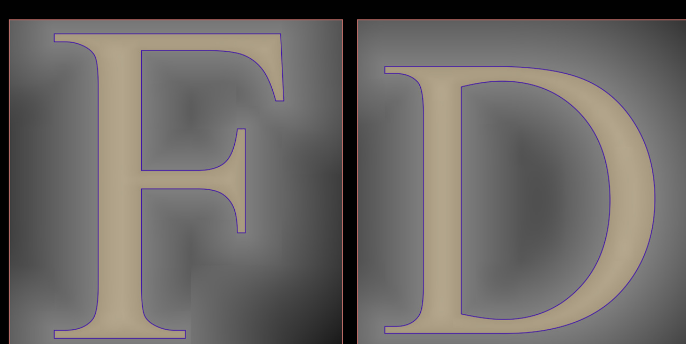
- *Constructive Solid Geometry* or CSG is the result of a Boolean operations applied to primitive, aggregate, or CSG objects
  - Boolean operations on distance fields are fast and simple



Union: $A \cup B$ *Difference:* $A - B$ *Intersection:* $A \cap B$

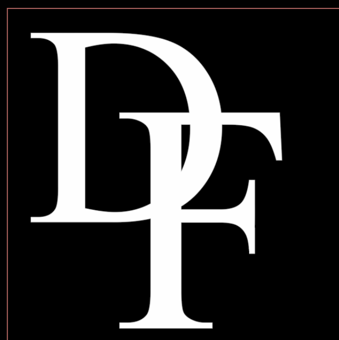
Operations on Distance Fields

- Boolean operations are fast and simple
  - *Intersection:* $dist(A \cap B) = min\ (dist(A), dist(B))$
  - *Union:* $dist(A \cup B) = max\ (dist(A), dist(B))$
  - *Difference:* $dist(A - B) = min\ (dist(A), -dist(B))$

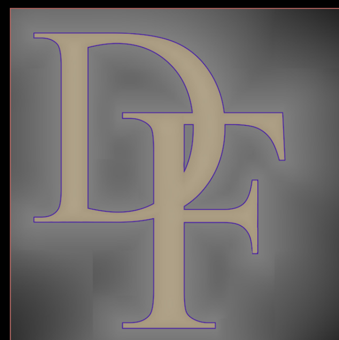


Operations on Distance Fields

- Boolean operations are fast and simple



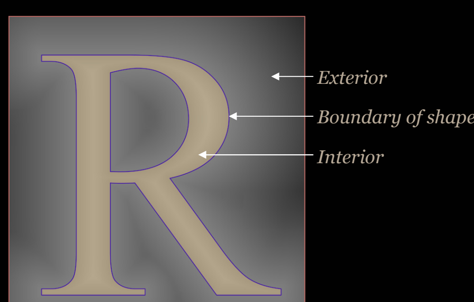
Union of two shapes



Union of two distance fields

Advantages

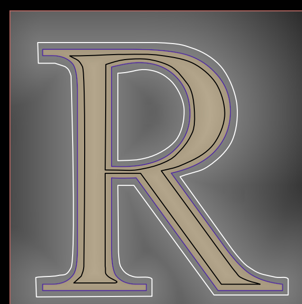
- Conceptual advantages over outlines
  - Distance fields represent more than just the object outline
    - Represent the object interior, exterior, and its boundary (useful for CSG operations and physical simulation)



Shape's distance field

Advantages

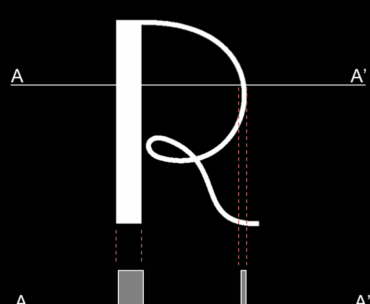
- Conceptual advantages over outlines
  - Distance fields represent more than just the object outline
    - Represents an infinite number of offset surfaces



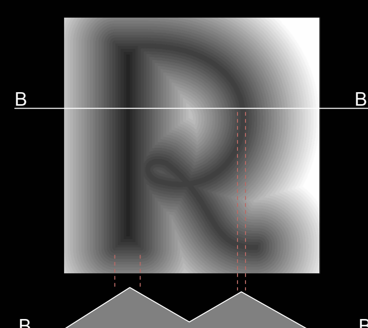
Boundary offsets

Advantages

- Conceptual advantages over outlines
  - Gains in efficiency and quality because distance fields vary smoothly (C^0 continuous) and throughout space



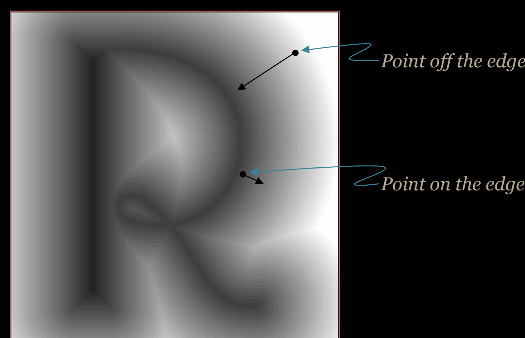
Intensity profile of the standard representation is discontinuous at boundaries



Intensity profile of the distance field is C^0 continuous throughout space

Advantages

- Conceptual advantages over outlines
  - Gradient of the distance field yields
    - Surface normal for points on the edge
    - Direction to the closest edge point for points off the edge



History – Rendering and Processing

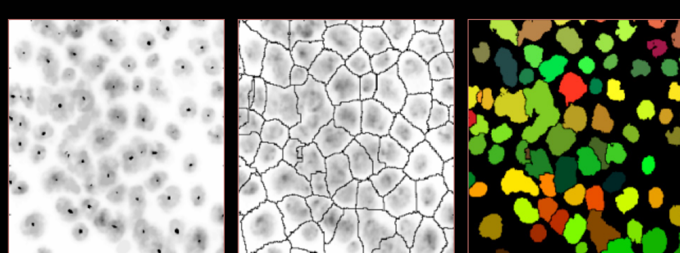
- Distance fields are a specific example of implicit functions (see "Introduction to Implicit Surfaces", ed. Bloomenthal, 1997)
- Rendering and processing
  - Tessellation
    - Bloomenthal, "Polygonization of Implicit Surfaces", Computer Aided Geometric Design, 1988
    - Szeliski and Tonnesen, "Surface modeling with oriented particle systems", SIGGRAPH, 1992
    - Heckbert and Witkin, "Using particles to sample and control implicit surfaces", SIGGRAPH, 1994
  - Ray tracing
    - Zuiderveld et al., "Acceleration of Ray-Casting using 3D Distance Transforms", Vis. In Biomedical Computing, 1992
    - Yagel and Shi, "Accelerating Volume Animation by Space-Leaping", IEEE Vis. 1993

History – Applications

- CAD
  - Offsetting
    - Ricci, "A Constructive Geometry for Computer Graphics", Computer, 1973 (CSG of implicit representations of solids
    - Breen, "Constructive Cubes: CSG Evaluation for Display Using Discrete 3D Scalar Data Sets", Eurographics, 1991
  - Tolerancing
    - Requicha, "Towards a Theory of Geometric Tolerancing", J. Robotics Research, 1983
  - Rounds and filets
    - Rockwood, "The Displacement Method for Implicit Blending in Solid Models", Transactions on Graphics, 1989
  - Swept surfaces and volumes
    - Schroeder, Lorensen, and Linthicum, "Implicit Modeling of Swept Surfaces and Volumes", IEEE Vis. 1994
  - Simulation
    - Biswas and Shapiro, "Approximate distance fields with non-vanishing gradients", Graphical Models, 2004

History – Applications

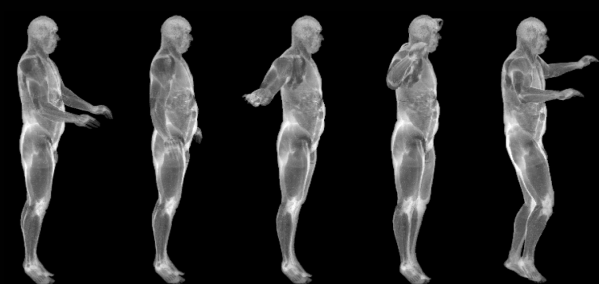
- Image processing
  - Image segmentation
    - Yang , Staib, and Duncan, " Neighbor-Constrained Segmentation with Level Set Based 3D Deformable Models," IEEE Trans Med Imaging, 2004
    - e.g., watershed segmentation
  - Shape matching
    - Lavalle and Szeliski, "Recovering the Position and Orientation of Free Form Objects from Image Contours Using 3D Distance Maps", IEEE PAMI, 1995



Original image, watershed segmentation, and segmented cells: from www.cellprofiler.org

History – Applications

- Medical
  - 3D surface reconstruction from cross sections
    - Raya and Udupa, "Shape-based Interpolation of Multi-dimensional Objects", IEEE Trans. Med. Imaging, 1990
  - Navigation during virtual surgery
    - Hong, et. al, "Virtual Voyage: Interactive Navigation in the Human Colon", SIGGRAPH 1997
  - Medial axis representation for animation of the Virtual Human
    - Gagvani and Silver, Animating volumetric models, Graphical Models, 2001



Animating the Virtual Human: from Gagvani and Silver, 2001

History – Applications

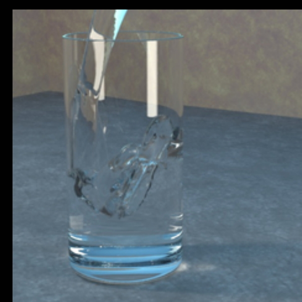
- Robotics
  - Path planning
    - Lengyel et al., "Real-time Robot Motion Planning Using Rasterizing Computer Graphics Hardware", SIGGRAPH 1990
  - Collision detection
    - Fisher and Lin, "Deformed Distance Fields for Simulation of Non-Penetrating Flexible Bodies", Eurographics Wkshop on Comp Anim and Modeling, 2001
  - Haptics
    - Gibson et al, "Simulating Arthroscopic Knee Surgery using Volumetric Object Representations, Real-time Volume Rendering, and Haptic Feedback", CVRMed, 1997

History – Applications

- Simulation
  - Modeling continually varying heterogeneous materials
    - Biswas, Shapiro, and Tsukanov. Heterogeneous Material Modeling with Distance Fields. Technical Report, 2002-4.
  - Level sets
    - Osher and Sethian, "Fronts Propagating with Curvature-Dependent Speed, Algorithms Based on Hamilton-Jacobian Formulation", J. Computational Physics, 1988

Fedkiw, Stam, and Jensen

Neuyen, Fedkiw, and Jensen



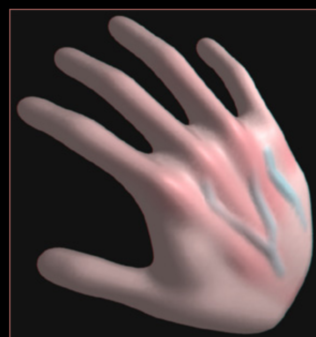
Enright, Marschner, and Fedkiw

History – Applications

- Reconstructing 3D models from range data
  - Unorganized points, projected distances, 3D distance fields
    - Hoppe et al., "Surface Reconstruction from Unorganized Points", SIGGRAPH, 1992
    - Bajaj, Bernardini, and Xu, "Automatic Reconstruction of Surfaces and Scalar Fields from 3D Scans", SIGGRAPH 1995
    - Curlass and Levoy, "A volumetric Method for Building Complex Models from Range Images", SIGGRAPH 1996
    - Carr et al., "Reconstruction and Representation of 3D Objects with Radial Basis Functions", SIGGRAPH 2001
    - Hilton et al., "Reliable Surface Reconstruction from Multiple Range Images", European Conf. on Computer Vision, 1996
    - Wheeler et al., "Consensus Surfaces for Modeling 3D Objects from Multiple Range Images", Int. Conf. on Computer Vision, 1998
    - Whitaker, "A Level-set Approach to 3D Reconstruction from Range Data", International J. Computer Vision, 1998
    - Boissonnat and Cazals, "Smooth Surface Reconstruction via Natural Neighbor Interpolation of Distance Functions", ACM Symposium on Computational Geometry, 2000
    - Sagaawa, Nishino, and Ikeuchi, "Robust and Adaptive Integration of Multiple Range Images with Photometric Attributes", 2001
    - Frisken and Perry, "Efficient Estimation of 3D Euclidean Distance Fields from 2D Range Images", Symposium on Volume Visualization, 2002

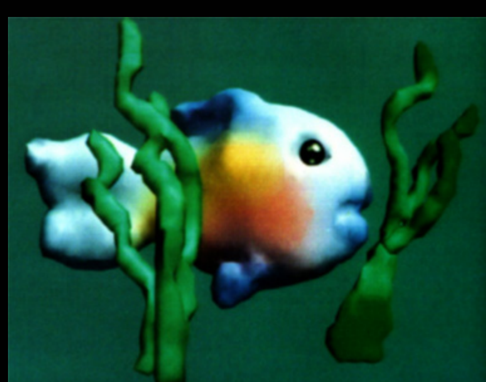
History – Applications

- Distance Fields for Design
  - Bloomenthal and Wyville, Interactive Techniques for Implicit Modeling", Computer Graphics, 1990



History – Applications

- Distance Fields for Design
  - Gaylean and Hughes, "Sculpting: an Interactive Volume Modeling Technique", SIGGRAPH 1991



History – Applications

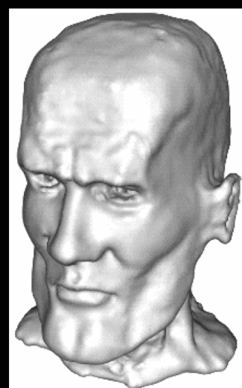
- Distance Fields for Design
  - Avila and Sobierajski, "A Haptic Interaction Method for Volume Visualization, IEEE Visualization 1996

History – Applications

- Distance Fields for Design
  - Wang and Kaufman, "Volume Sculpting", Interactive 3D Graphics, 1995.

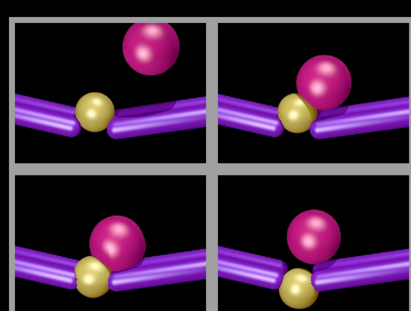
History – Applications

- Distance Fields for Design
  - Baerentzen, "Octree-based Volume Sculpting, IEEE Symposium on Vol. Vis., 1998



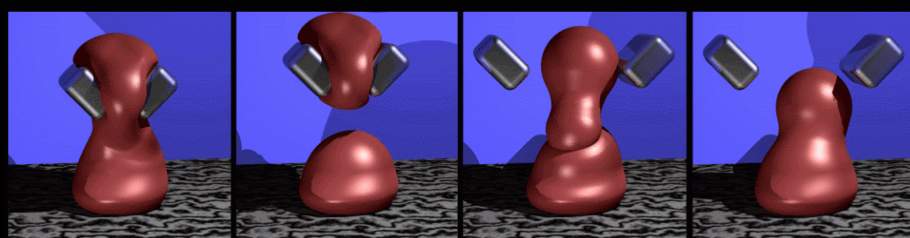
History – Applications

- Distance Fields for Design
  - Cani (Gascuel), "An Implicit Formulation for Precise Contact Modeling Between Flexible Solids", SIGGRAPH 1993



History – Applications

- Distance Fields for Design
    - Desbrun and Cani, “Active Implicit Surface for Animation”, Graphics Interface, 1998

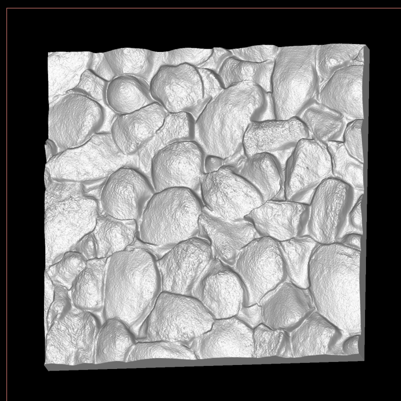


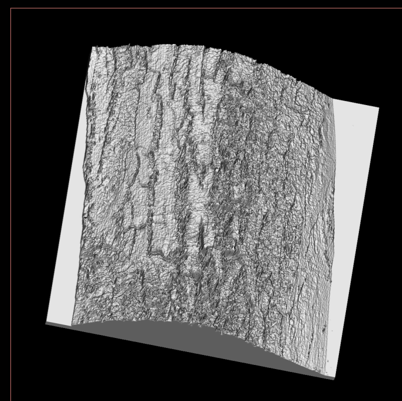
History – Applications

- Distance Fields for Design
    - Blanch, Ferley, Cani, Gascuel “Non-Realistic Haptic Feedback for Virtual Sculpture”, Rapport de recherche RR-5090, 2004

History – Applications

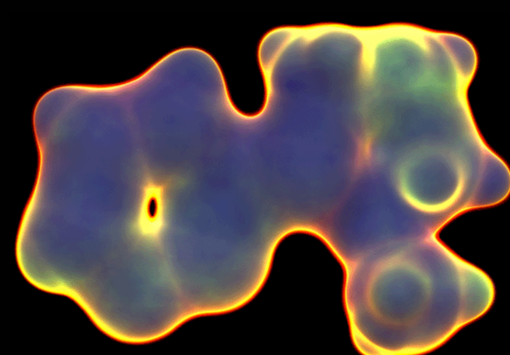
- Distance Fields for Design
    - Perry, Frisken, "Kizamu: a system for sculpting digital characters", SIGGRAPH 2001





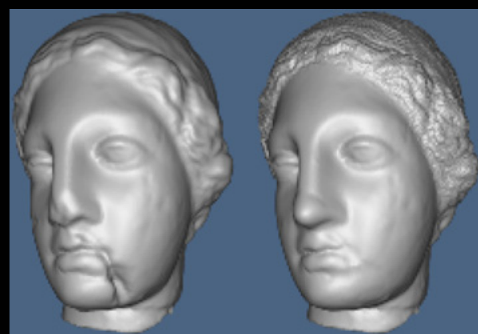
History – Applications

- Distance Fields for Design
    - Perry, Frisken, "Kizamu: a system for sculpting digital characters", SIGGRAPH 2001



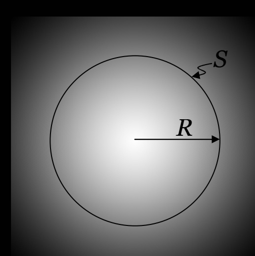
History – Applications

- Distance Fields for Design
  - Museth et al. "Level Set Surface Editing Operators", SIGGRAPH 2002



Representing Distance Fields

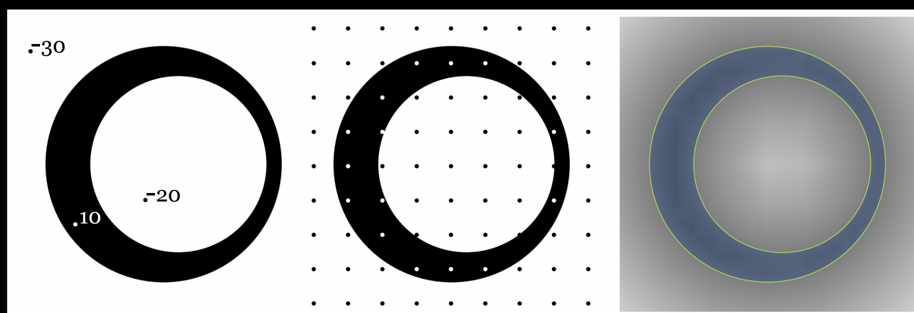
- Implicit representation
  - e.g., sphere, dist(x,y,z) = R - $\sqrt{(x - c_x{}^*)^2 + (y - c_y{}^*)^2 + (z - c_z{}^*)^2}$



  - Distances are computed at query points as needed for rendering or processing
  - Complex models can be represented via CSG
    - Precise but slow for complex models

Representing Distance Fields

- Sampled volumes
  - Distances are computed and stored in a regular 3D grid
  - Distances at non-grid locations are interpolated
    - Payne and Toga, "Distance Field Manipulation of Surface Models", IEEE Computer Graphics and Applications, 1992



A 2D shape and three signed distance values — *A regularly sampling of the distance field* — *A 2D image depicting the distance field*

Representing Distance Fields

- Sampled volumes
  - Smooth surfaces are well represented by a relatively small number of samples
    - Frisken (Gibson), "Using Distance Maps for Smooth Surface Representation in Sampled Volumes", IEEE Symposium on Vol Vis, 1998

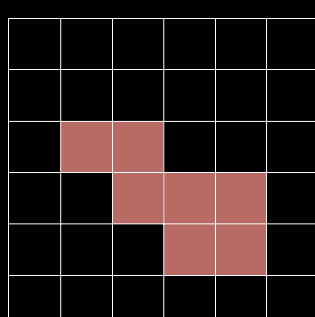
Radius = 30 voxels 100 x 100 x 100 — *Radius = 3 voxels 10 x 10 x 10* — *Radius = 2 voxels 10 x 10 x 10* — *Radius = 1.5 voxels 10 x 10 x 10*

Representing Distance Fields

- Sampled volumes
  - For detailed models, the distance field must be sampled at high enough rates to avoid aliasing during reconstruction and rendering
  - Regularly sampled volumes have
    - Slow processing times
    - Large memory requirements
    - Limited resolution

Representing Distance Fields

- Addressing memory requirements and processing speed
  - Speed up distance computation using approximating distance transforms
    - Jones and Satherley "Voxelisation: Modeling for Volume Graphics", in *Vision, Modeling, and Visualization, 2000*



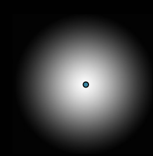
Binary 2D shape

3	2	2	3	4	4
2	1	1	2	2	3
1	0	0	1	1	2
2	1	0	0	0	1
3	2	1	0	0	1
4	3	2	1	1	2

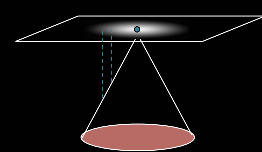
Chessboard distance

Representing Distance Fields

- Addressing memory requirements and processing speed
  - Speed up distance computation using hardware
    - Hoff et al, "Fast Computation of Generalized Voronoi Diagrams Using Graphics Hardware", SIGGRAPH 1997
      - E.g., points



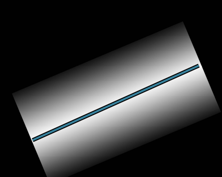
2D distance field of a point



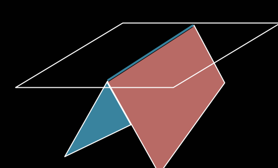
A 3D cone with its apex at the point has z-coordinates that correspond to the point's distance field

Representing Distance Fields

- Addressing memory requirements and processing speed
  - Speed up distance computation using hardware
    - Hoff et al, "Fast Computation of Generalized Voronoi Diagrams Using Graphics Hardware", SIGGRAPH 1997
      - e.g., lines



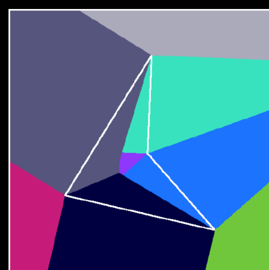
2D distance field of a line



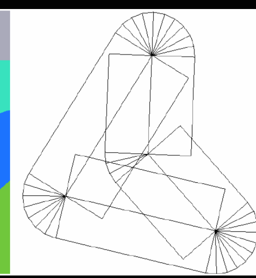
A 3D folded plate with its apex along the line has z-coordinates that correspond to the line's distance field

Representing Distance Fields

- Addressing memory requirements and processing speed
  - Fast distance computation using hardware
    - Hoff et al, "Fast Computation of Generalized Voronoi Diagrams Using Graphics Hardware", SIGGRAPH 1997



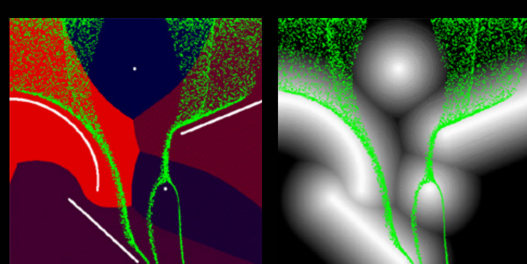
Hardware-generated Voronoi diagram of a chevron shape



Projected 3D geometry used to approximate the 2D distance field of the chevron

Representing Distance Fields

- Addressing memory requirements and processing speed
  - Fast distance computation using hardware
    - Hoff et al, "Fast Computation of Generalized Voronoi Diagrams Using Graphics Hardware", SIGGRAPH 1997



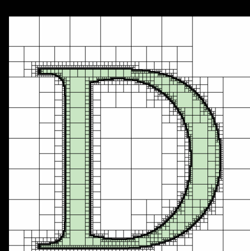
Using hardware generated distance fields to control particle dynamics

Representing Distance Fields

- Addressing memory requirements and processing speed
  - Reducing the number of distance samples
    - Distance shells (compute accurate distances in a narrow region near the boundary)
      - Jones, "The Production of Volume Data from Triangular Meshes Using Voxelisation", *Computer Graphics Forum*,1996
      - Sramek and Kaufman, "Alias-free voxelization of geometric objects", IEEE Trans on Vis and Computer Graphics, 1999
    - Level sets for propagating accurate distances throughout the volume
      - Kimmel and Sethian, "Fast Marching Methods for Computing Distance Maps and Shortest Paths", Tech report, U.C. Berkeley, 1996
      - Breen, Mauch, and Whitaker, "3D Scan Conversion of CSG Models into Distance Volumes", IEEE Symposium on Vol Vis, 1998

Representing Distance Fields

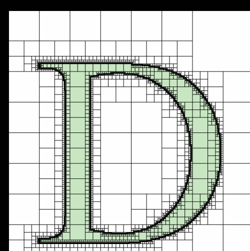
- Addressing memory requirements and processing speed
  - Reducing the number of distance samples
    - Boundary-limited Octrees
      - Jones and Satherly, "Shape Representation using Space Filled Sub-Voxel Distance Fields", IEEE International Conf. on Shape Modeling and Apps, 2001
      - Strain, "Fast Tree-based Redistancing for Level Set Computations", J. Computational Physics, 1999
    - ADFs
      - Frisken, Perry, Rockwood, Jones, "Adaptively Sampled Distance Fields: a General Representation of Shape for Computer Graphics", SIGGRAPH 2000



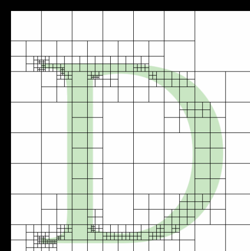
Boundary-limited quadtree

Representing Distance Fields

- Addressing memory requirements and processing speed
  - Reducing the number of distance samples
    - Boundary-limited octrees and quadtrees
      - Jones and Satherly, "Shape Representation using Space Filled Sub-Voxel Distance Fields", IEEE International Conf. on Shape Modeling and Apps, 2001
      - Strain, "Fast Tree-based Redistancing for Level Set Computations", J. Computational Physics, 1999
    - ADFs
      - Frisken, Perry, Rockwood, Jones, "Adaptively Sampled Distance Fields: a General Representation of Shape for Computer Graphics", SIGGRAPH 2000



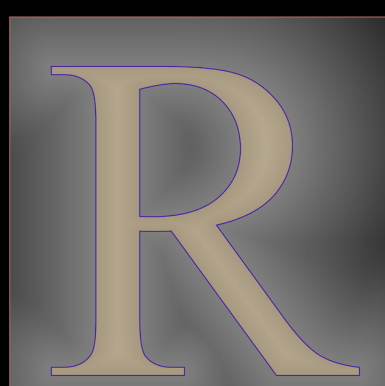
Boundary-limited quadtree



Detail-directed ADF

Adaptively Sampled Distance Fields

- Detail-directed sampling of the distance field



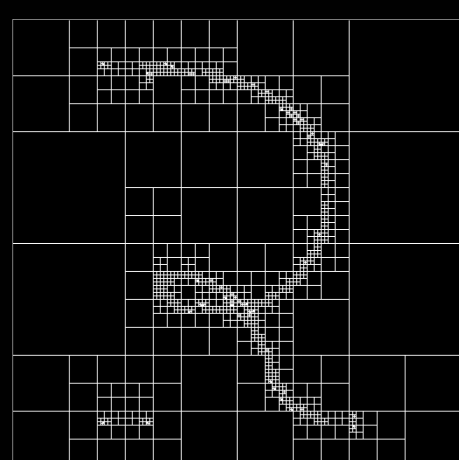
Sample at low rates where the distance field is smooth. Sample at higher rates only where necessary (e.g., near corners).

Adaptively Sampled Distance Fields

- Detail-directed sampling of the distance field
  - High sampling rates only where needed
    - Fewer distance samples to compute
    - Less memory required
    - Faster to process
- Spatial data structure
  - Fast localization for efficient processing
- ADFs are defined very generally: they consist of
  - Adaptively sampled distance values ...
  - Organized in a spatial data structure ...
  - With a method for reconstructing the distance field from the sampled distance values

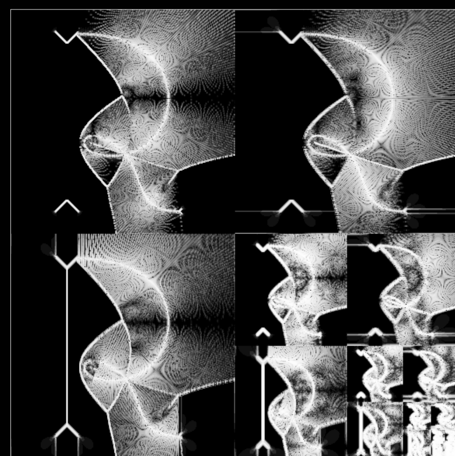
Various Instantiations of ADFs

Example of a quadtree-based 2D ADF



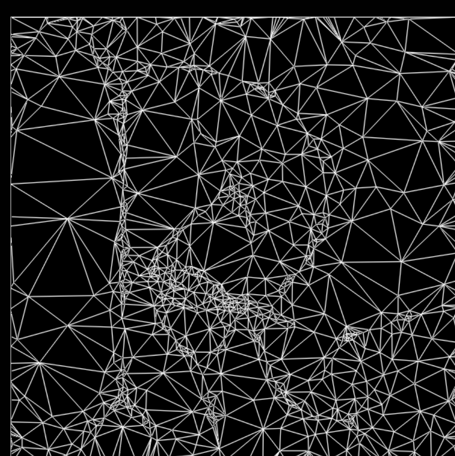
Various Instantiations of ADFs

Example of a wavelet-based 2D ADF



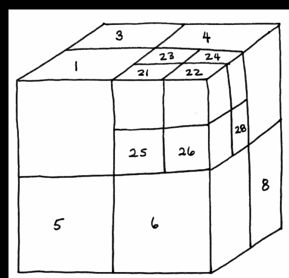
Various Instantiations of ADFs

Example of a multi-resolution triangulation-based 2D ADF

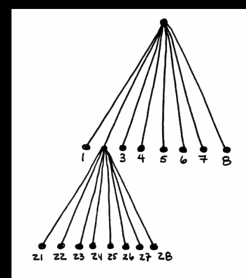


Octree-based ADFs

- A set of distance values is stored for each leaf cell in the octree
- Distances and gradients between the sample points are reconstructed by interpolating the stored values



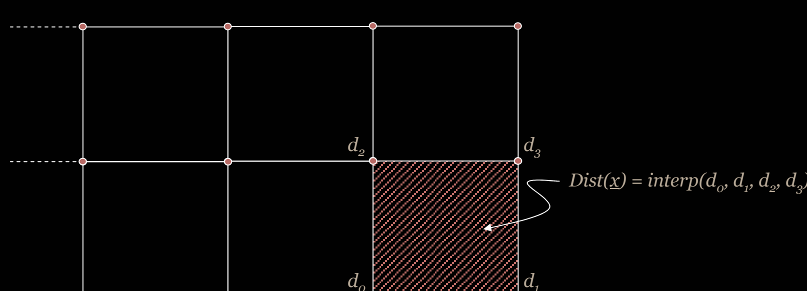
Spatial structure of an octree



Tree structure of an octree

Locally Implicit Representation

- Reconstruction from samples
  - Distances at positions between sample points are reconstructed from sampled distances
    - The sampling breaks the distance field into a set of spatially-limited local implicit representations



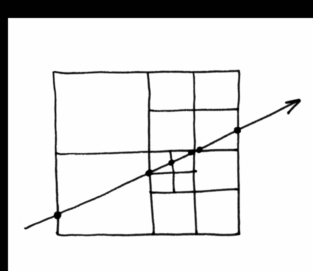
Sampling on a rectilinear grid with a bi-linear reconstruction function breaks the distance field into locally implicit fields

Adaptively Sampled Distance Fields

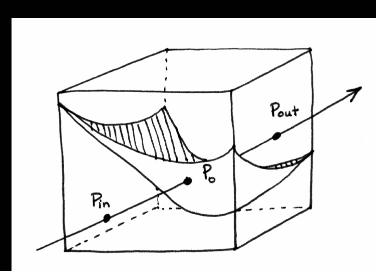
- Rendering
  - There are three basic approaches
    - Ray tracing
    - Tessellation
    - Point models

Ray Casting ADFs

- For each pixel
  - Cast ray(s) into the ADF octree
  - Locate intersection of ray with the object surface
  - Shade the image pixel according to the gradient of the distance field at the intersection point



Cast each ray into the ADF Octree



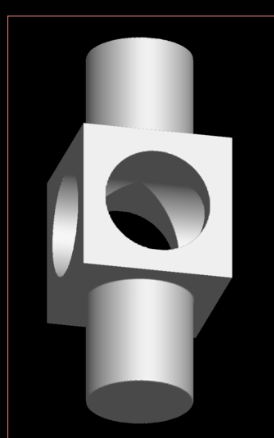
Determine ray-surface intersections analytically assuming a bilinear surface

Ray Casting ADFs

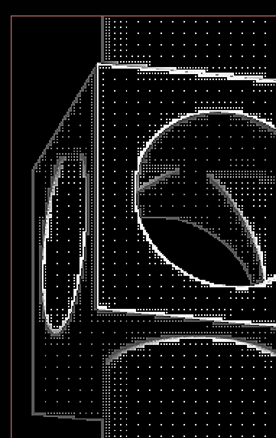
- To improve rendering times
  - Render from coarse to fine resolution
  - Local redraw during editing
  - Use adaptive ray casting
    - Subdivide the image into a hierarchy of tiles according to perception-based predicates
    - Pixels in tiles greater than 1x1 are bilinearly interpolated
    - Achieve 6x speedup (10x when supersampling)

Ray Casting ADFs

- Adaptive ray casting



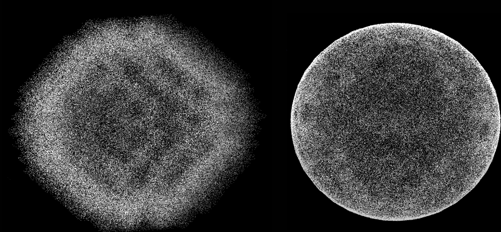
Rendered via adaptively ray casting



Rays cast to render part of the image on the left

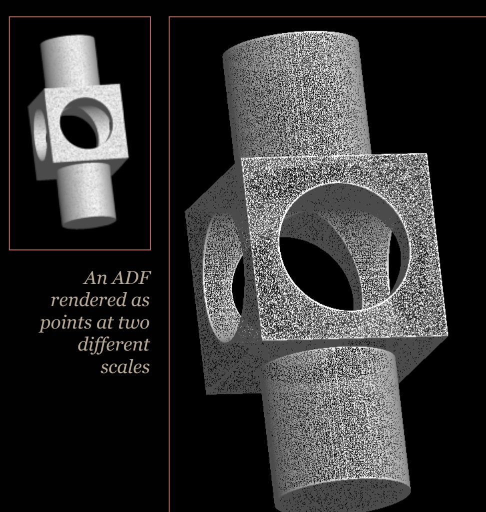
Point-based Rendering of ADFs

- Generate points on the surface and render the points
  - Seed each boundary leaf cell with randomly placed points, number of points proportional to cell size
  - Relax the points onto the ADF surface using the distance field and gradient
  - Optionally shade each point using the distance gradient
  - Can generate 800,000 Phong-shaded points in 0.2 seconds



Original points seeded in boundary leaf cells *Points after relaxation onto the surface*

Point-based Rendering of ADFs



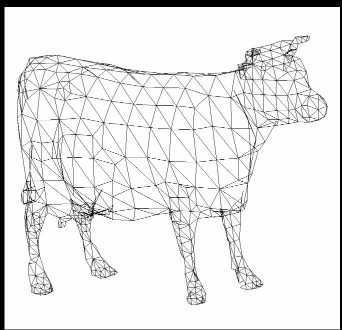
An ADF rendered as points at two different scales

Tessellating ADFs

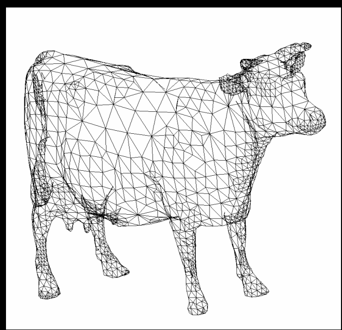
- Convert ADFs to triangle models and render interactively with hardware
- Use the SurfaceNets triangulation algorithm to create triangle models on-the-fly
  - Frisken (Gibson), *"Constrained Elastic SurfaceNets: Generating Smooth Surfaces from Binary Segmented Data", Proc. MICCAI, 1998*
  - Topologically consistent
  - Good-quality triangles
  - Fast – 200,000 triangles in 0.37 seconds (in 2001)
  - LOD models

Tessellating ADFs

- LOD triangle models
  - The octree hierarchy provides a natural structure for creating level-of-detail triangle models



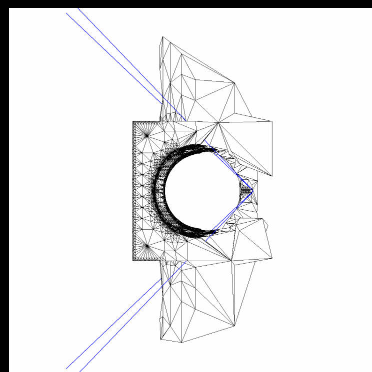
Low resolution model



Medium resolution model

Tessellating ADFs

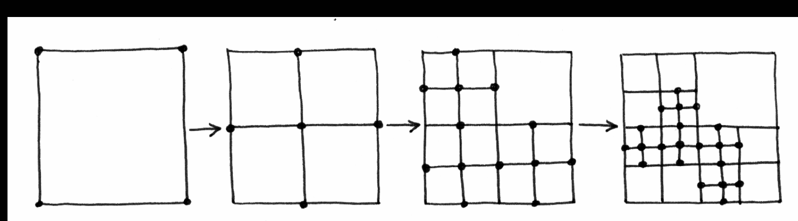
- View-dependent triangle generation
  - Pope, Frisken and Perry, *"Dynamic Meshing Using Adaptively Sampled Distance Fields", SIGGRAPH Sketch, 2001*



Very large data models can be tessellated dynamically according to viewing parameters

ADF Generation

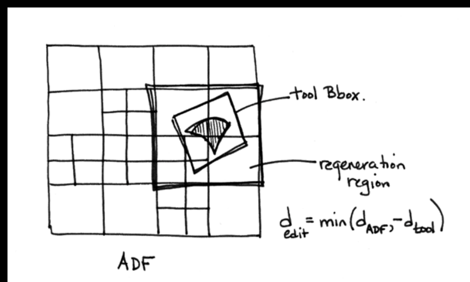
- ADF Generation
  - Requires a means for computing the distance to the shape at arbitrary points
  - Top-down generation
    - Compute distances to the shape from each corner of the root cell
    - Compute a representation error for the cell
    - Recursively subdivide cells if they contain a boundary and their representation error is larger than a specified threshold



Initialize root cell *Recursively subdivide*

ADF Editing

- Editing is localized generation
  - The ADF is regenerated inside cells that are overlapped by the tool's bounding volume
  - Regeneration blends the distance fields of the ADF and the tool using CSG operations

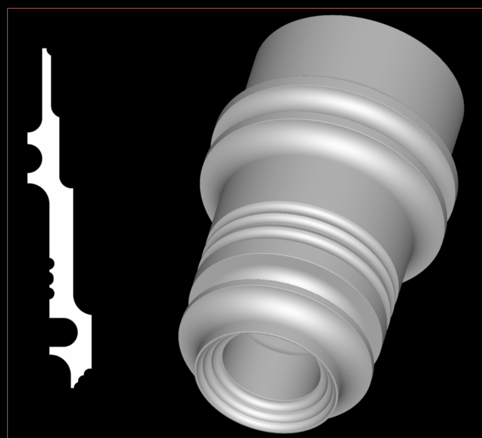


During editing, the ADF within a region near the tool's bounding box is regenerated using the appropriate CSG operation to blend the distance fields of the tool and the object

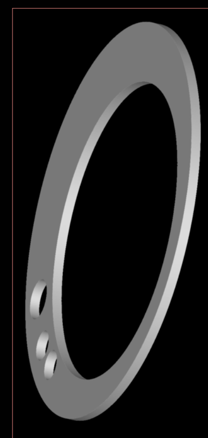
Detailed Carving

- Kizamu
  - Perry and Frisken, *"Kizamu: A System for Sculpting Digital Characters", SIGGRAPH 2001*
  - Provides
    - Generation of parts
      - From stock distance functions (spheres, cubes, cones, cylinders, offsets of 3D Bezier curves)
      - Using CSG of stock parts
      - Via a scripting interface
      - From height fields and range data
      - Extrusion and revolution of 2D ADFs
    - Detailed carving using a variety of brushes and brush paradigms
      - Surface following
      - Pressure sensitive pen input
      - Lathing tools
    - Various rendering methods
      - Ray tracing (surface and volume)
      - Point-based rendering
      - Tessellation
    - History
    - Infinite undo and redo

Detailed Carving



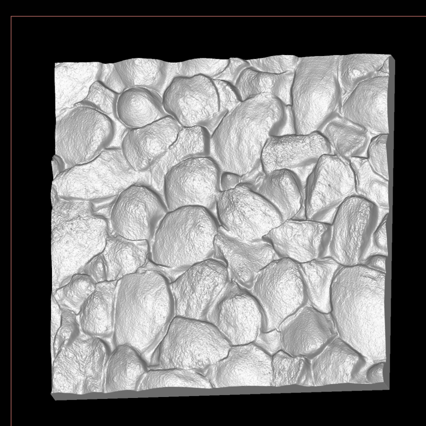
Surface of revolution



Extruded shape

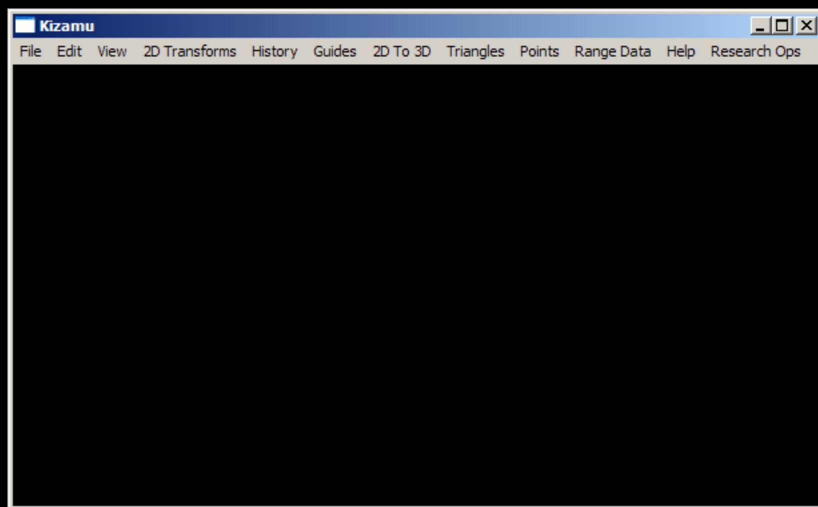
Detailed Carving

Freeform model carved from a sphere



Detailed model of stones from range data

Kizamu Demo

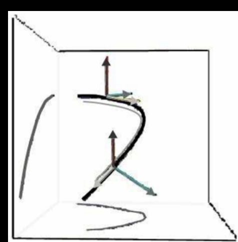


Concept Modeling

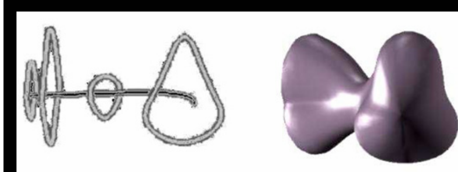
- Input from various sources
  - ADFs can be generated from existing 3D models
    - E.g., from triangle models or Bezier patches
  - ADFs can be generated from range data
    - Data from 3D scanners, pseudo-depth cameras
    - Elevation maps
    - Synthetic range data (e.g., from a texture generator)
- Preliminary construction in Kizamu
  - Stock distance functions can be combined via CSG
    - Spheres, rectangular solids, cylinders, cones, etc.
- Need a way to generate concept models that can be imported into Kizamu
  - Fast
  - Intuitive
  - Expressive

Concept Modeling

- Creature Feature
  - A prototype system for creating organic concept models
    - Shapes are based on a curved skeleton with cross-sections along the skeleton defined by 2D curves
    - Interface for creating the skeleton and profiles were inspired by previous work
      - Cohen et al., "An Interface for Sketching 3D Curves", Interactive 3D Graphics, 1999.
      - Grimm, "Implicit Generalized Cylinders using Profile Curves", Implicit Surfaces, 1999

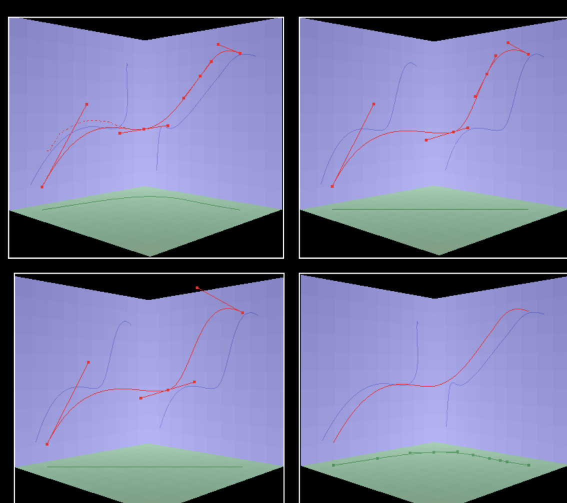


Skeleton sketching (Grimm, 1999)



Cross-sectional profiles (Grimm, 1999)

Creature Feature

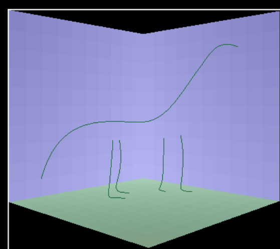


Add or delete points on the skeleton curve

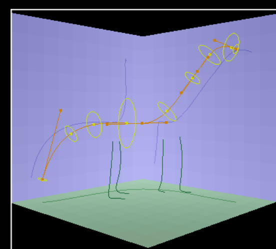
Drag control points on the curve or on its shadows to edit the shape of the curve

Curve overdrawing is provided

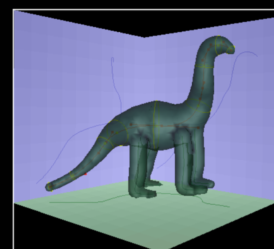
Creature Feature



Multiple curves are supported

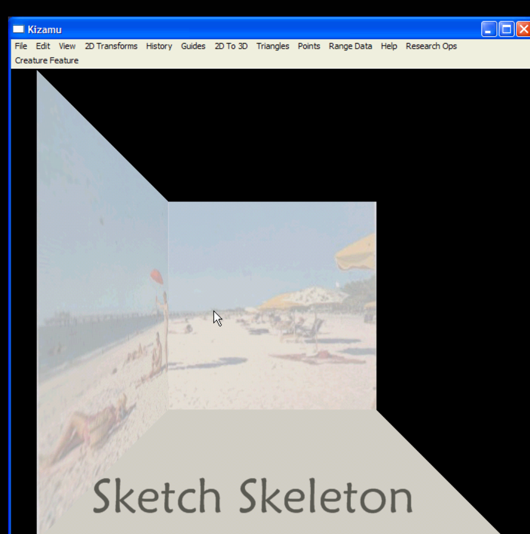


The current prototype uses circular profiles



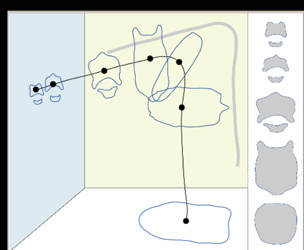
The lofted creature

Creature Feature

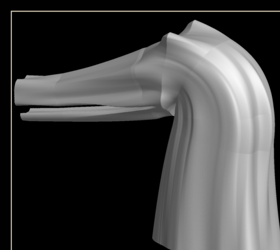


Creature Feature

- Next steps
  - Use more complex profiles to define cross sections along the skeleton
  - Provide an interface for sketching and editing the 2D profiles as 2D ADFs and/or curves



Skeleton curve and more complex profiles



Creature generated by lofting the profiles along the skeleton

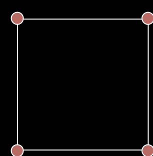
Lofted creature with detail added using Kizamu

Enhancements

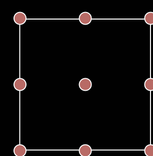
- Accurate representations for analysis and re-tessellation
  - Feature sensitive surface extraction from volume data, Proceedings of the 28th annual conference on Computer graphics and interactive techniques, p.57-66, August 2001
    - Ju et al., "Dual Contouring of Hermite Data", SIGGRAPH 2002
    - Huang et al., "A Complete Distance Field Representation", IEEE Visualization 2001
- Coloring and texturing
    - DeBry et al., "Painting and rendering textures on unparameterized models", SIGGRAPH, 2002
    - Benson and Davis, "Octree textures", SIGGRAPH, 2002

Enhancements

- Improved representation to reduce memory requirements and improve processing speeds
  - Biquadratic ADF cells for more compact representation of curved surfaces and edges
    - US patent 6,396,492, “Detail-directed Hierarchical Distance Fields”



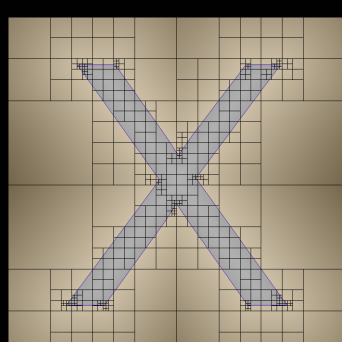
Bilinear cell
- 4 distance samples
- Bilinear interpolation
- Represents distance to lines exactly



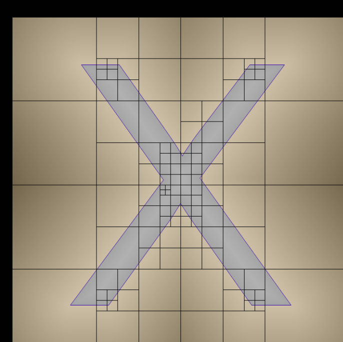
Biquadratic cell
- 9 distance samples
- Biquadratic interpolation
- Represents distance to curves more accurately

Enhancements

- Improved representation to reduce memory requirements and improve processing speeds
  - Special cells for thin structures, exact corners and edges
    - US patent application “Method for Generating an Adaptively Sampled Distance Field of and Object with Specialized Cells”



Biquadratic ADF



Special Cell ADF

Next Steps

- There are many directions to go
  - Complete Creature Feature and integrate it into Kizamu
  - Take Kizamu beyond the research prototype stage
    - Add more brushes (e.g., smoothing) and features
    - Design and build a reasonable user interface
    - Add coloring and texturing
    - Add high quality rendering
  - Explore deformation and modeling other physical phenomena using ADFs
  - Explore applications in CAD, entertainment, medicine, …
  - …

Many Thanks

- Ronald Perry
- Elena Jakubiack
- SMI conference organizers