Fraunhofer Institut Graphische Datenverarbeitung

Real-Time Collision Detection for Dynamic Virtual Environments
-
Distance Fields

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Outline

- Introduction
- Distance Field Generation
- Collision Detection using Distance Fields
- Conclusion

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Introduction

- Physically based modeling
  - Cloth, hair, etc.
- Problem
  - Many contact points
- During Simulation
  - Detect Collision
  - Compute Collision Response
    - Proximity or penetration depth
    - Surface normal

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Distance Field Definition

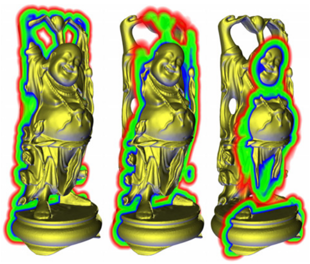
- Scalar function

$$D : \mathbb{R}^3 \rightarrow \mathbb{R}$$

- $dist(\mathbf{p})$ = distance to closest point on surface
- $sign(\mathbf{p})$ = negative if inside object

$$D(\mathbf{p}) = sign(\mathbf{p}) \cdot dist(\mathbf{p})$$

Example – Distance Field 2D-Slices



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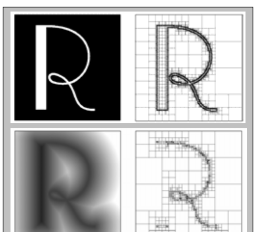
Distance Field Data Structures

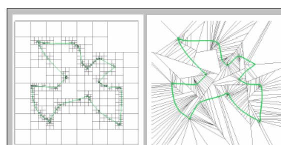
- Uniform 3D grid
  - Queries take *O(1)* time
  - Curved surfaces can be represented quite well
  - C^0 continuous
- Adaptively sampled distance fields (ADFs)
  - [Frisken et al. '00]
  - C^{-1} between different levels
    - can be resolved



Frisken et al. '00

Distance Field Data Structures

- BSP-tree
  - [Wu and Kobbelt '03]
  - Piecewise linear approximation
  - Generation computationally expensive
  - Discontinuities between cells
  - Compact!



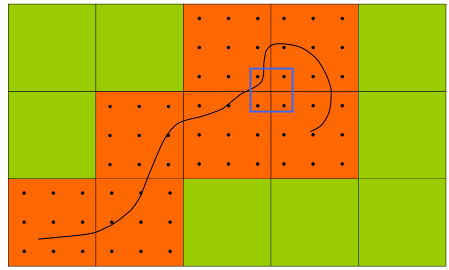
ADF 895 cells BSP-tree 254 cells

[Wu and Kobbelt '03]

Distance Field Data Structures

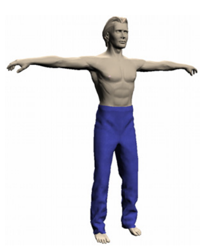
- Sparse Block Grids
  - [Bridson '03]
  - Distance values needed only for a small band
  - Divide the uniform grid into blocks
    - Coarse grid contains pointers to fine sub-grids
    - Not all sub-grids exist
  - Queries (in comparison to uniform grids)
    - More complex
    - Less efficient

Sparse Block Grid Example



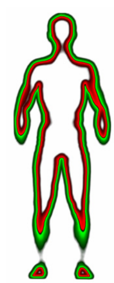
Sparse Block Grid – Memory Savings

- Uniform Grid
  - Resolution 378x396x81
  - 48.5 MB
- Sparse Block Grid
  - Same resolution
  - 3x3x3 sub-grids
  - 6.7 MB
  - 86% memory savings



Computation of Distance Fields

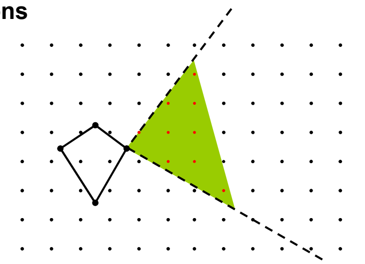
- Object representation
  - Triangular mesh
- Problem
  - Computing distances for all grid points
  - Naïve computation too costly
- Collision detection
  - Only a small band needed



Computation of Distance Fields

- Propagation methods
  - Fast Marching methods [Sethian '96]
  - Distance Transforms [Jones and Satherley '01]
- Rasterizing of distance functions
  - Full distance field
  - [Sud et al. '04], [Hoff et al. '99]
- Bounded Voronoi Regions
  - [Sigg et al. '03], [Breen et al. '01]
  - Bounding polyhedron around Voronoi regions of edges, faces and vertices

Scan Conversion of Bounded Voronoi Regions



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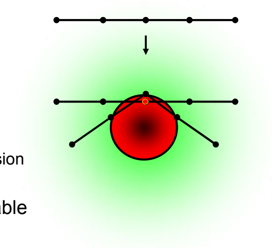
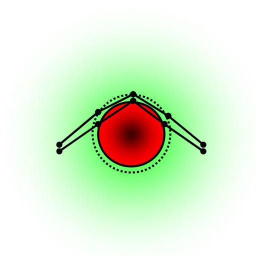
Collision Detection

- [Fuhrmann et al. '03]
- Scenario
  - Deformable object A
  - Static object B
- Collision Detection
  - Sample object A
  - Test sample points for collision with B
- If both objects are deformable
  - Swap and repeat



Collision Detection

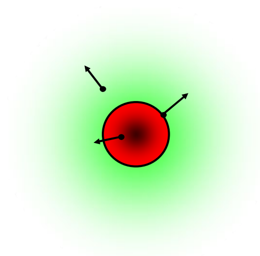
- Problem
  – Edges intersect object
- Solution
  – Preserve ε distance at vertices



Queries needed for collision detection

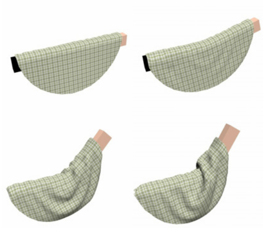
(On a uniform or sparse grid)

- Distance
  – Tri-linear interpolation
- Normal
  – Direction given by the gradient



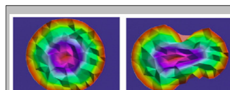
What about deforming collision objects?

- Multiple distance fields
- Linked rigid objects
  – One distance field per object
- Not possible yet
  - Soft objects like a bending human arm



Other approaches for deforming objects

- [Bridson et al. '03]
  – Clothing and animated characters
  – Pre-computed ADFs for the body parts
  – Can be used for several cloth simulations
- [Fisher and Lin '01]
  – Deforming geometries
  – Collision detection is done hierarchically
  – Partial DF updates only
  – Internal distance fields for collision response



[Fisher and Lin '01

Demo Video

- Captured directly from screen
- Simulation runs in java 1.4.1
- Rendering with OpenGL
- Tests made on a Intel Processor at 2.8 GHz
- Buddha model consist of 100k triangles

Real-Time Collision Detection using Distance Fields

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Summary

- Distance Fields Generation
  - Pre-Processing step
  - Duration: Some seconds
- Collision Detection using Distance Fields
  - Most useful for deformable against rigid objects
  - Efficient computation of
    - Penetration depth / proximity
    - Gradient (Normal)
  - Easy to implement
  - Robust algorithm

Thank You!

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