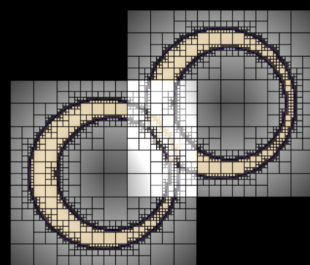
A Computationally Efficient Framework for Modeling Soft Body Impact



Sarah F. Frisken and Ronald N. Perry
Mitsubishi Electric Research Laboratories

Modeling Soft Body Impact

- Detect collisions between interacting bodies
- Model global motion changes (e.g., position and velocity)
  - Apply a dynamic simulation method
- Model local shape changes (i.e., deformation)
  - Apply a deformation method that may be
    - Non-physical (e.g. control point-based)
    - Physically plausible (e.g., FFD)
    - Physically realistic and dynamic (e.g. FEM)

Modeling Soft Body Impact

- Wide range of applications and goals
  - e.g., editing tools in Maya deform surfaces by moving nearby control points
  - e.g., computer simulation for games may approximate or exaggerate physics
  - e.g., protein docking for molecular modeling requires accurate modeling

An Observation

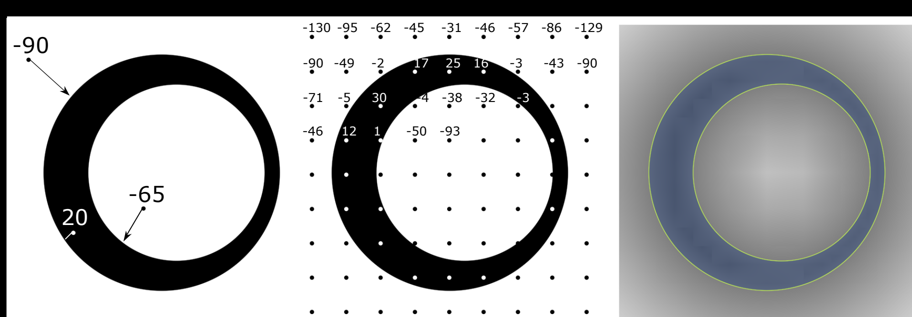
- Common requirements for modeling soft body interactions
  - Detect collisions between interacting soft bodies
  - Compute impact forces
  - Compute deformation forces and/or contact deformation

A Proposal

- Represent Objects with Adaptively Sampled Distance Fields (ADFs)
  - Compact representation of detailed shape
  - Efficient collision detection
  - Straightforward force computation
  - A means for estimating contact deformation

Distance Fields

- Specify the (possibly) signed distance to a shape



2D shape with sampled distances to its edge

Regularly sampled distance values

2D distance field

Distance Fields

- Advantages
  - Provide trivial inside/outside and proximity tests for collision detection
  - Penalty-based contact forces can be computed for penetrating bodies using the distance field and its gradient
  - Implicit nature of the distance field provides a means for estimating contact forces

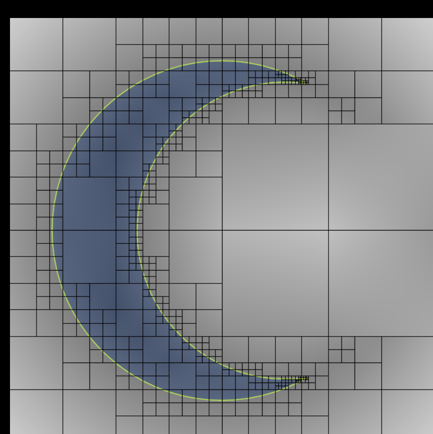
Distance Fields

- Disadvantages of regularly sampled distance fields
  - High sampling rates are required to representing objects with fine detail without aliasing
  - For regularly sampled volumes, high sampling rates require large volumes which are slow to process and render
  - Detail is limited by the fixed volume resolution

Adaptively Sampled Distance Fields

- Detail-directed sampling
  - High sampling rates only where needed
- Spatial data structure (e.g., an octree)
  - Fast localization for efficient processing
- Reconstruction method (e.g., trilinear interpolation)
  - For reconstructing the distance field and its gradient from the sampled distance values

Advantages of ADFs

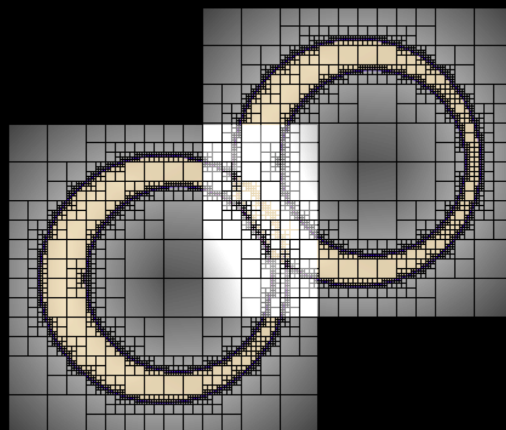


ADFs consolidate the data needed to represent complex objects

ADFs provide

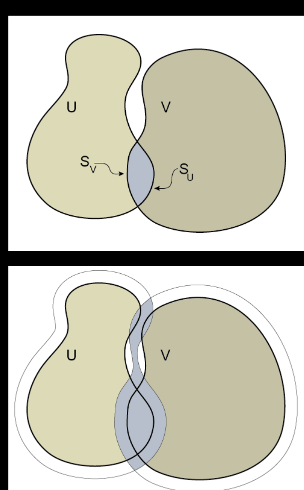
- Spatial hierarchy
- Distance field
- Object surface
- Object interior
- Object exterior
- Surface normal (gradient at surface)
- Direction to closest surface point (gradient off surface)

Collision Detection



Use ADF spatial hierarchy for efficient localization of potential collision

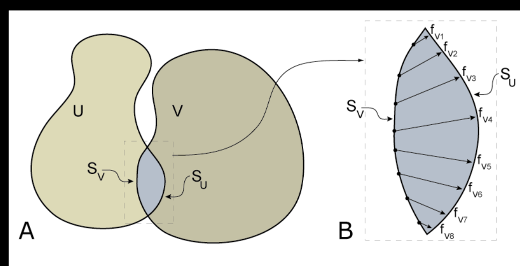
Collision Detection



- Collision occurs in the overlap region of the ADFs
  - Overlap region is determined using simple CSG operations
  - Full geometry of the overlap region is available
- Can use the overlap region of ADF offset surfaces for proximity tests

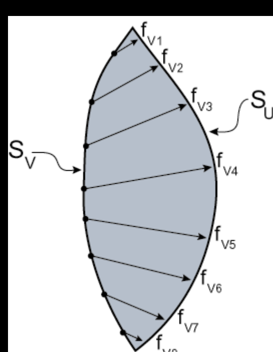
Contact Forces

- Compute contact forces in the overlap region
- Derive force vectors acting on *penetrating* body from distance field of the *penetrated* body



Forces are computed in the overlap region

Contact Forces



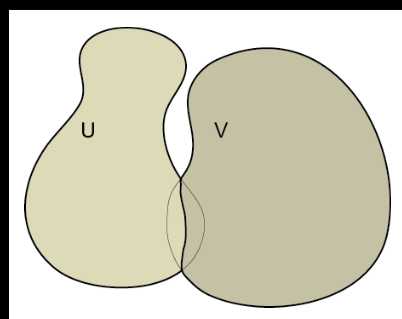
Deformation forces on the surface S_V due to penetration of U by V

- $\mathbf{f}_V(\mathbf{p}) = \alpha\, d_U(\mathbf{p})\, \nabla d_U(\mathbf{p})$
- Compute contact forces
  - At surface points (shown here) *OR*
  - Over the entire overlap region (more accurate?)
- Apply a deformation method (e.g. FEM)
- Derive impact forces
  - From contact forces and surface normals
  - Apply a dynamic simulation method

Modeling Deformation using Implicit Functions

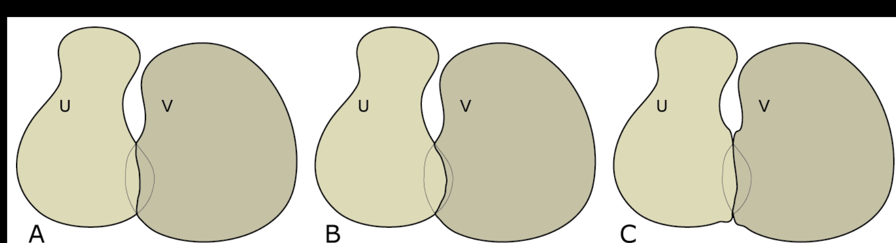
- Approximate contact deformation by combining distance fields in the overlap region

$$d_{U'}(\mathbf{p}) = \min(d_U(\mathbf{p}), \alpha\, d_U(\mathbf{p}) - (1 - \alpha)\, d_V(\mathbf{p})),\ \alpha \in (0,1)$$



Modeling Deformation using Implicit Functions

- Achieve different effects depending on method for combining distance fields



Material compression with similar materials

Material compression with V softer than U

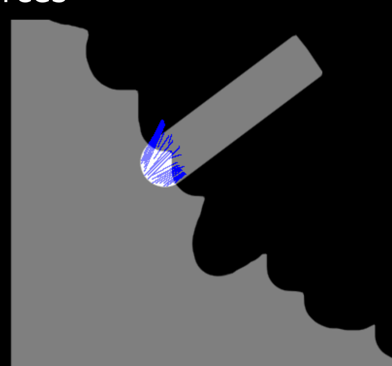
Volume preservation (after Cani, Graphics Interface '98)

Summary

- ADFs
  - Use distance fields to represent shape
  - Adaptive sampling provides efficient memory usage and reduced computation so we can represent very detailed shapes
  - Spatial data structure provides fast localization and processing
- An efficient framework for soft body impact
  - Fast collision detection
  - Straightforward force computation
  - A means for estimating contact deformation

Preliminary Results

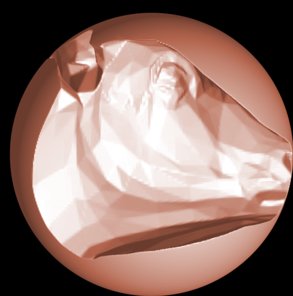
- Interactive computation and display of 2D contact forces



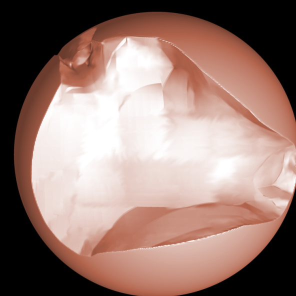
Interactive force computation
on complex shapes

Preliminary Results

- Can achieve detailed 3D contact deformation



A soft sphere after impact with a 'hard' ADF model



A soft sphere after impact with a 'soft' ADF model

The End