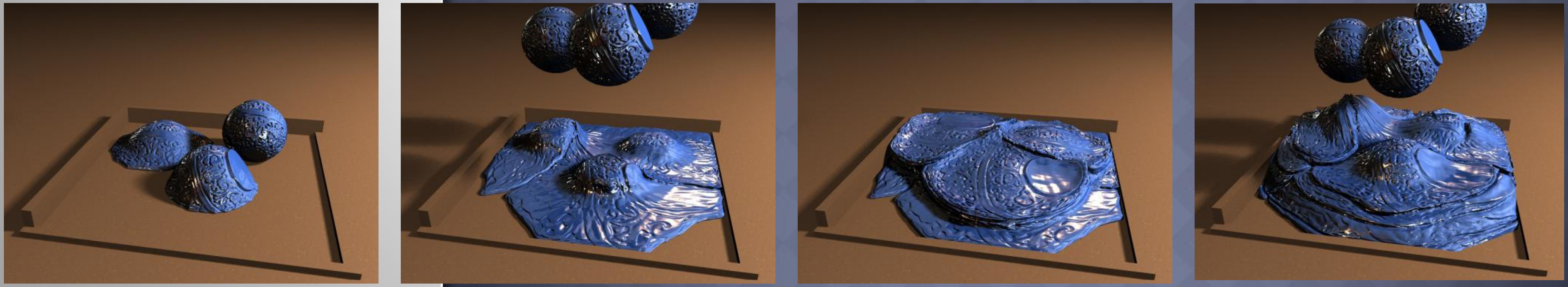
# DEFORMING MESHES THAT SPLIT AND MERGE

Alex Li 11/20/2009



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# OVERVIEW

- Introduction
- Overview of Approach
- Lagrangian Mesh Update
- Detection of Topological Events
- Altering the Mesh Topology
- Results
- Limitations
- Conclusion

# INTRODUCTION

- Presents a method for accurately tracking the moving surface of deformable materials that gracefully handles topological changes

- Why is this method useful:
  - Model materials → water, toothpaste, bread dough, peanut butter, taffy, tar, clay, etc.

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# INTRODUCTION CONTINUED

- Approach uses a triangular mesh to represent the surface of objects
  - *Benefit*: allows the surface to move in Lagrangian manner
  - *Drawback*: changing the topology of a mesh is very difficult
    - *Solution*: completely avoids the difficulties by replacing the parts of the mesh that has topology changes with a simplified surface generated by marching cubes

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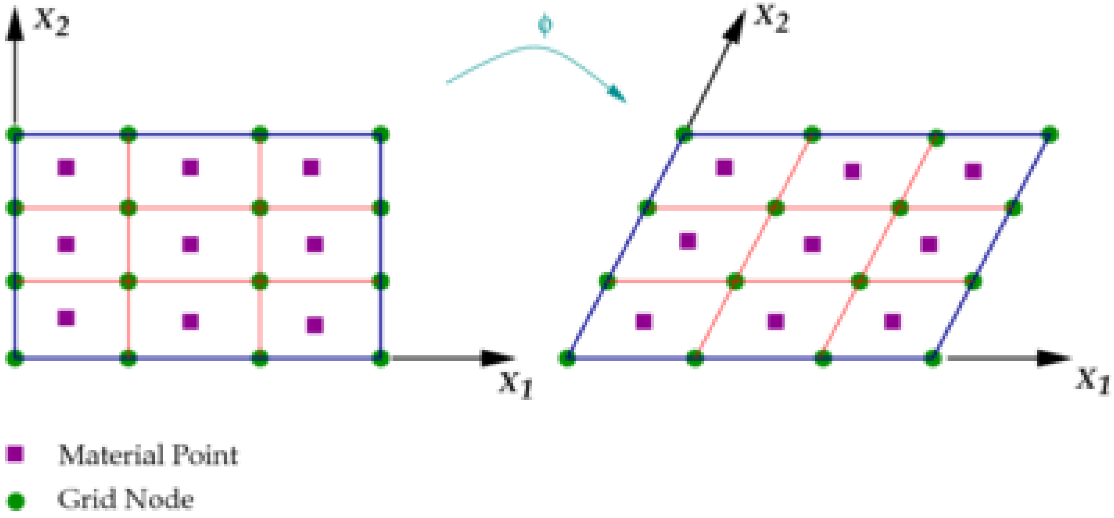
# KEY ATTRIBUTES OF THE METHOD

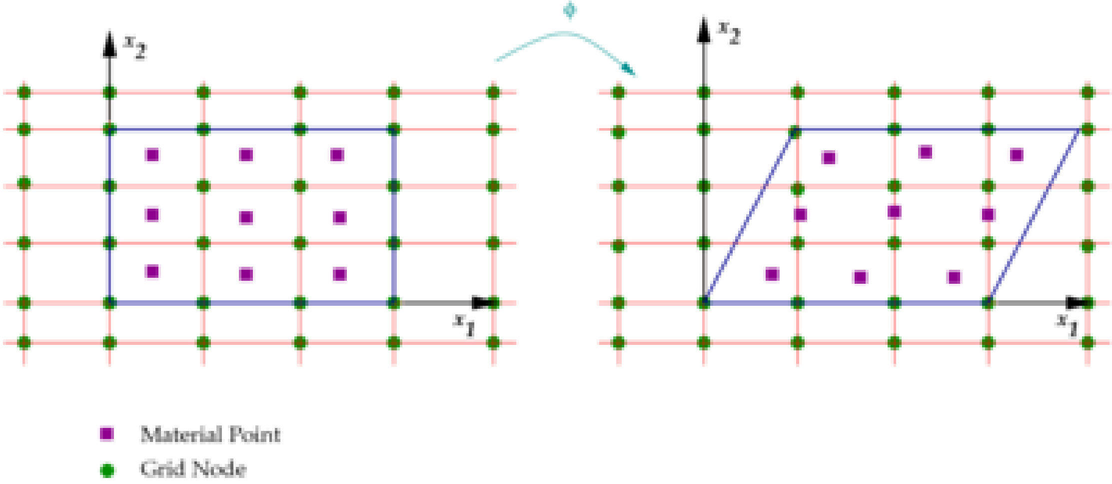
- Performs topological splits and merges
- Retains thin features and fine surface details
- Robust during complex topology changes
- Surface tracker can be tuned to allow/forbid particular kinds of topology changes
- Surface tracker does not depend upon any particular simulation technique
- Decouple physics, topological, and surface detail resolutions in simulator

# DEFINITIONS

- Lagrangian mesh:



- Eulerian mesh:



Referenced from: http://en.wikiversity.org/wiki/Nonlinear_finite_elements/Lagrangian_and_Eulerian_descriptions

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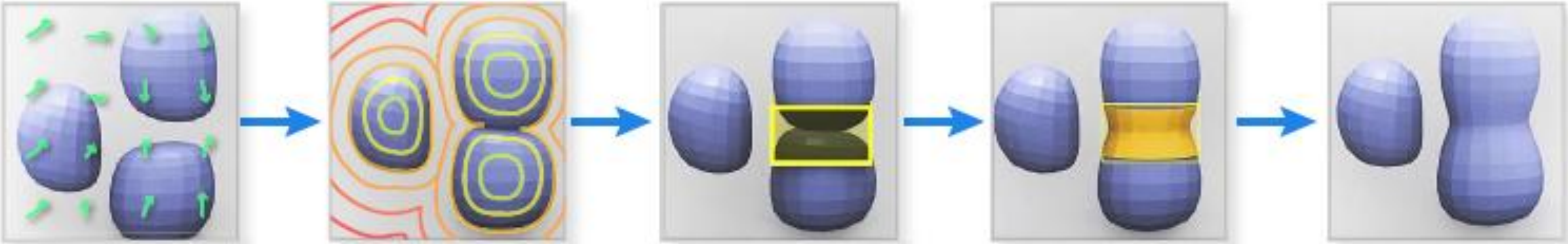
# APPROACH

Step 1 Step 2 Step 3 Step 4 Step 5



Advect Mesh Vertices | Compute Signed Distance Field | Detect Topological Events | Compute Corrected Mesh | Stitch Meshes Together

**Figure 2:** *Overview of our topology modification pipeline.*

Input: A closed manifold mesh M that represents the surface of the given material.

Output: A new mesh that has been modified in regions of topological change.

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# LAGRANGIAN MESH UPDATE

- Advantages:
  - Inherently preserves surface details

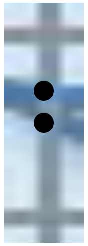
- Other Methods:
  - Level set method : leads to numerical smoothing of surface features, and impossible to represent a surface with details smaller than grid resolution
  - Combined Eulerian and Lagrangian: difficult to retain sub-grid resolution surface details

# DETECTION OF TOPOLOGICAL EVENTS

- Signed Distance Field Calculation
  - Calculate and place a signed distance function on a regular grid that encloses the mesh M
- Topological Event Detection Mechanisms
  - Complex cell test
- Deep Cell and Self-Intersection Tests

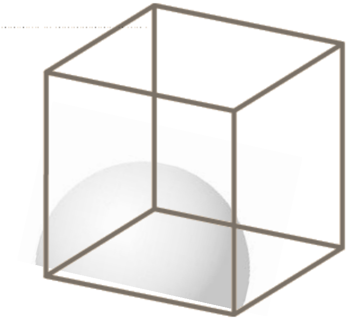
# WHAT IS A COMPLEX CELL?

- *Complex edge*: edge in distance function D that intersects M, the surface mesh, more than once



- *Complex face*: square face in D that intersects M in the shape of a closed loop or touches a complex edge

- *Complex cell*: cubic cell in D that has any complex edges or complex faces, or any cell that has the same sign of D at all of its corners while also having explicit geometry from M embedded inside of it



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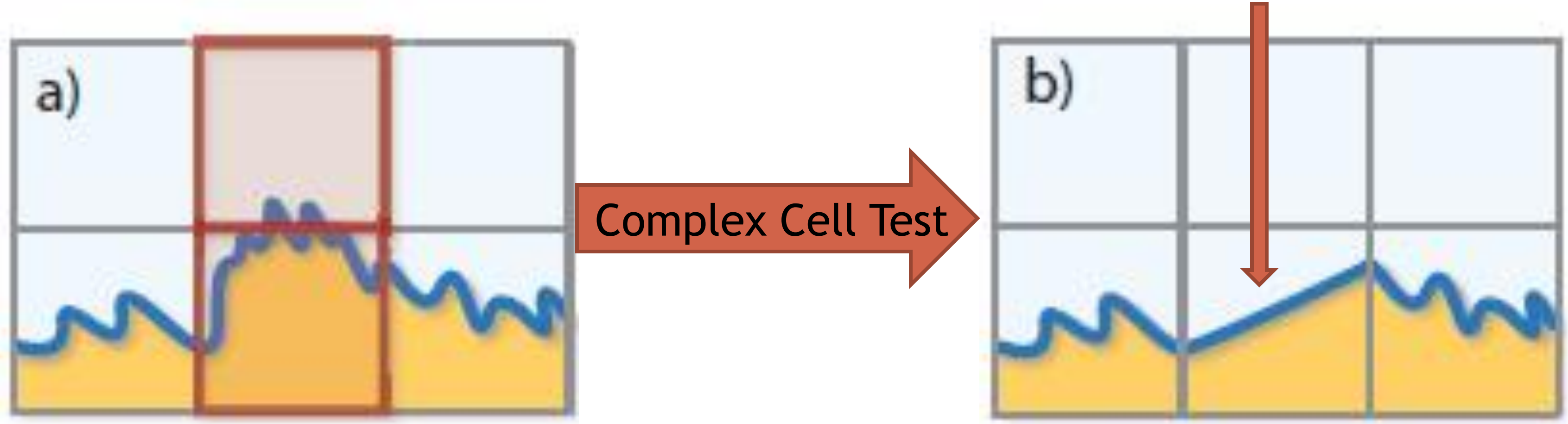
# WHY IS THE COMPLEX CELL TEST NOT SUFFICIENT?



Complex Cell Test

Does not preserve sharp corners

A straight-forward application of the complex cell test will also mark detailed surfaces as topologically complex, and will not preserve surface details like sharp corners.

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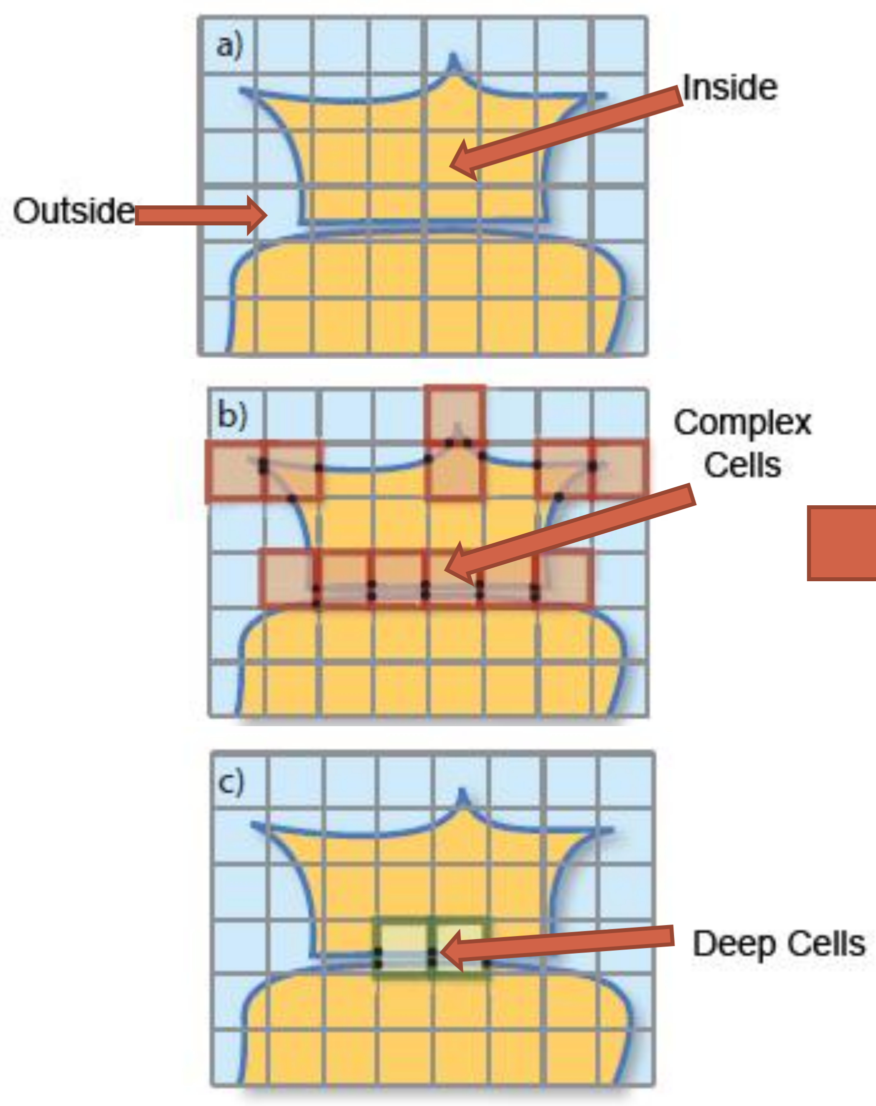
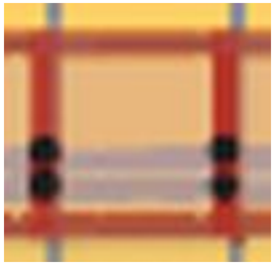
# DEEP CELLS



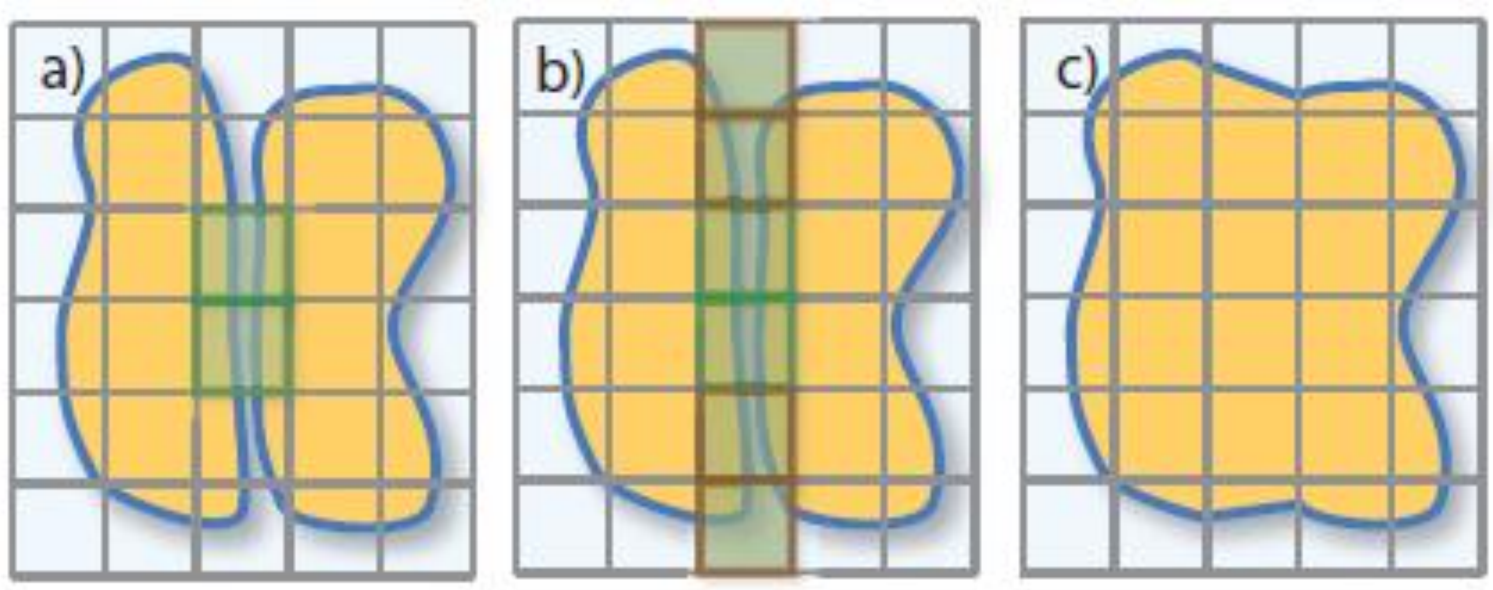
Examples of complex cells:



# DEEP CELL AND SELF-INTERSECTION TESTS

- Method to preserve thin features: only allow merging and never split the topology
- Mark cells that indicate significantly large self-intersections in the mesh

# CELL-MARCHING STEP



Deep cells are marked

March outward along complex edges and faces

Topological change after re-sampling

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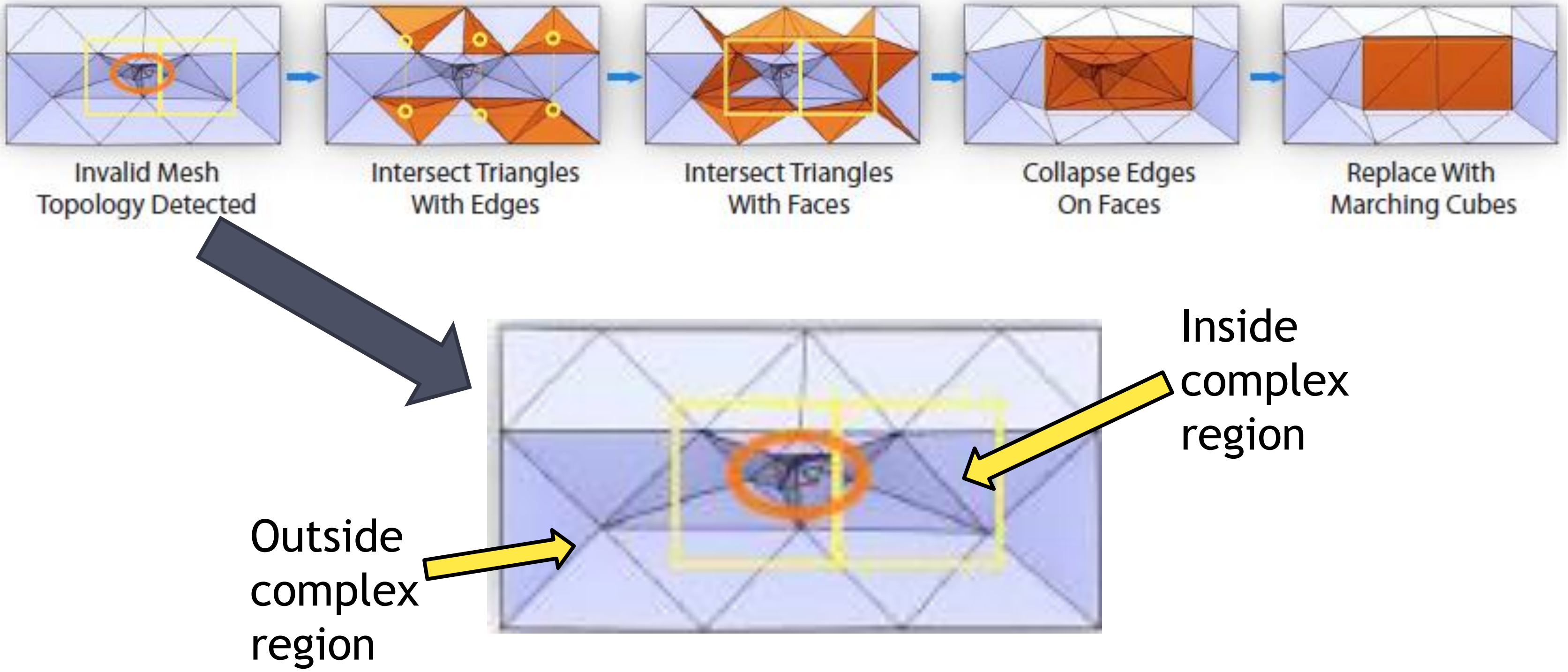
# ALTERING MESH TOPOLOGY - STEP1



Inside complex region

Outside complex region

Mark the topologically complex cells

# ALTERING MESH TOPOLOGY – STEP2

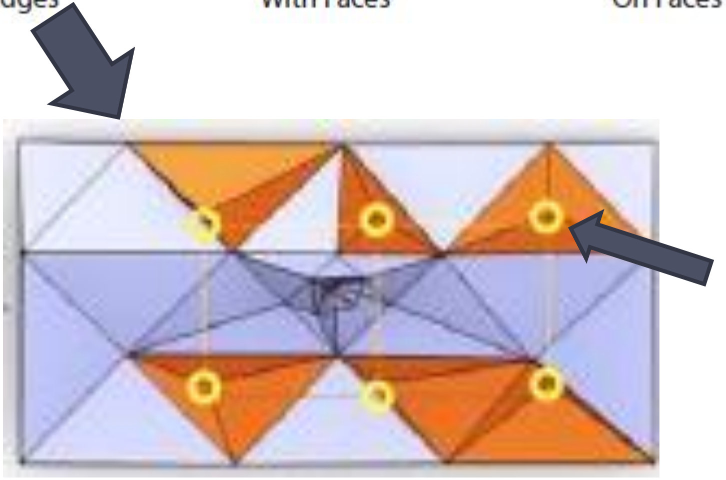

Invalid Mesh Topology Detected

Intersect Triangles With Edges

Intersect Triangles With Faces

Collapse Edges On Faces

Replace With Marching Cubes


Type 1 vertex

Find each triangle that intersects a cell edge on the boundary of the marked region. Calculate the intersection point between the triangle and edge and subdivide the triangle into 3 new triangles that share a vertex at the intersection point (type 1 vertex).

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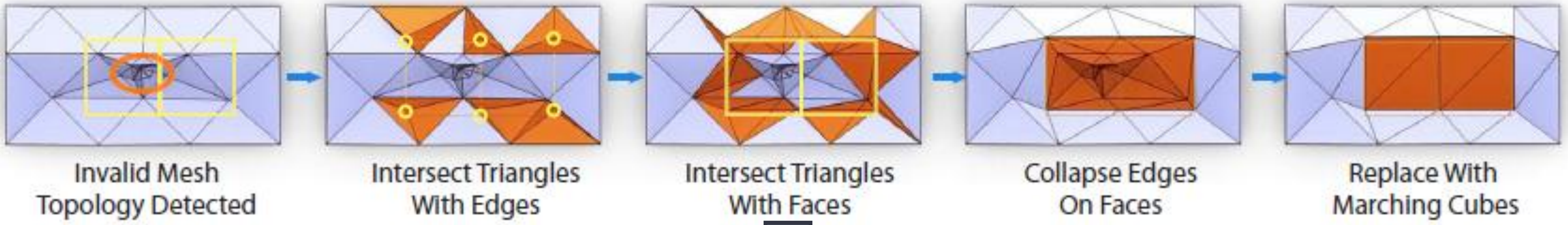
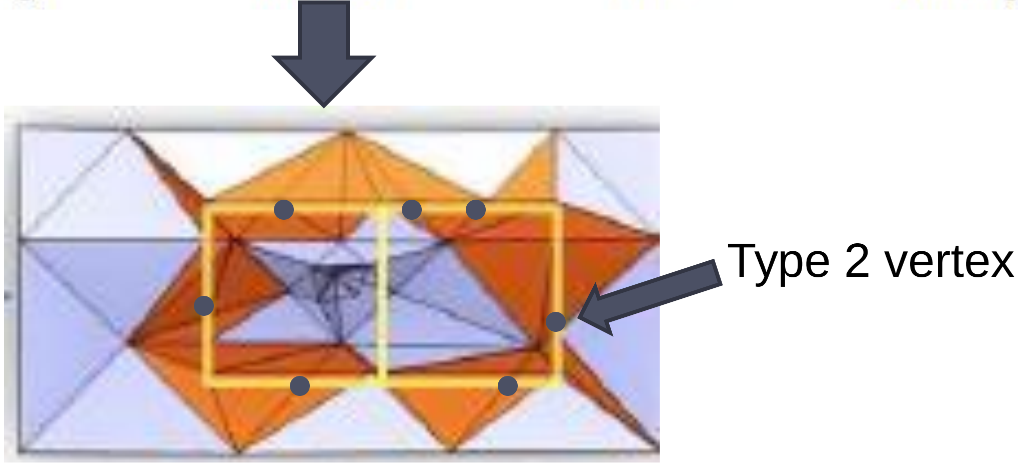
# ALTERING MESH TOPOLOGY – STEP3





Find all triangle edges that intersect a cell face on the boundary of the marked region. Split each triangle edge at the point where it intersects the face, subdividing the 2 original triangles into 4 and inserting a new vertex on the face (type 2 vertex).

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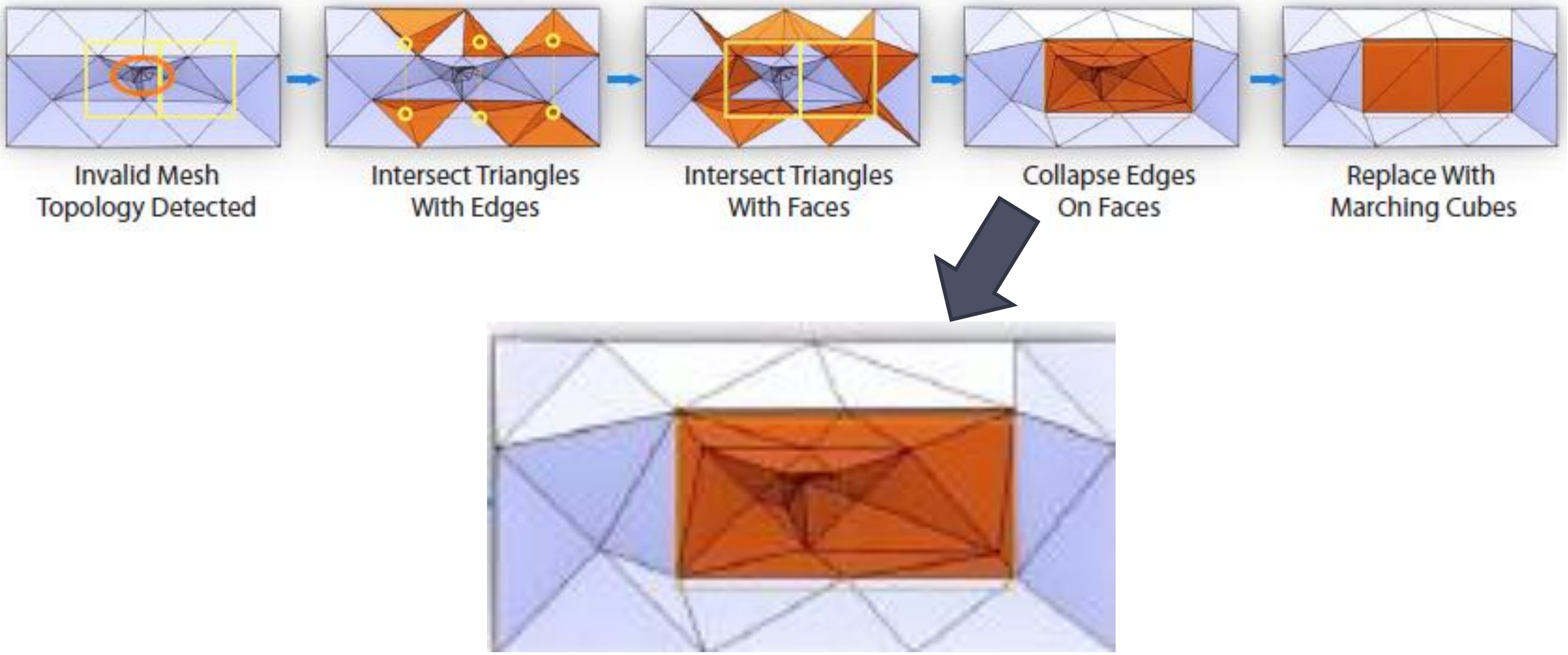
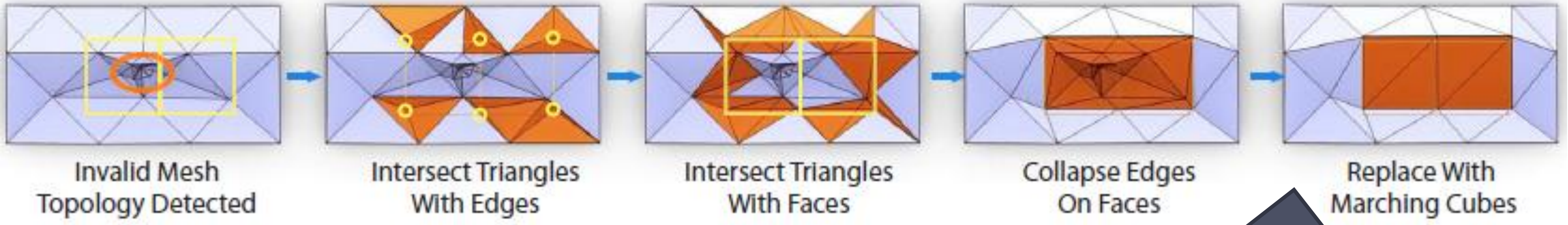
# ALTERING MESH TOPOLOGY – STEP4



Simplify curve connecting type 1 and 2 vertices until it’s a straight line between type 1 vertices. Repeatedly collapse all type 2 vertices until they are removed. Afterwards, no triangles will cross the faces of any marked cell. Each triangle will lie completely inside or outside of the region.

# ALTERING MESH TOPOLOGY – STEP5



Delete all triangles that lie completely inside the marked region. Use marching cubes to generate a triangle mesh in the marked region, and connect the meshes together at the type 1 vertices.

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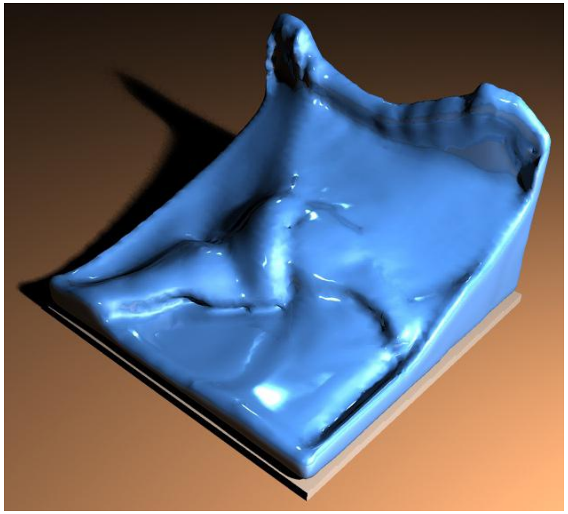
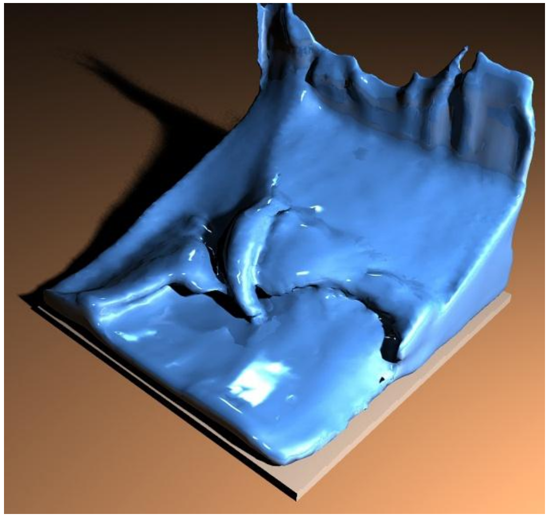
# ROBUSTNESS

- Ensure triangles are well-shaped
  - Adaptively subdivide triangle edges when they get too long, and collapse edges when they become too short or possess a bad aspect ratio
  - Perform edge flips after creating type 1 vertices if any newly created triangle has particularly small angles
- Maintain simple topology along boundary faces before sewing meshes together
  - Delay edge collapses if it will prematurely connect other type 1 vertices
- Gridlock: where no safe edge collapse can be performed

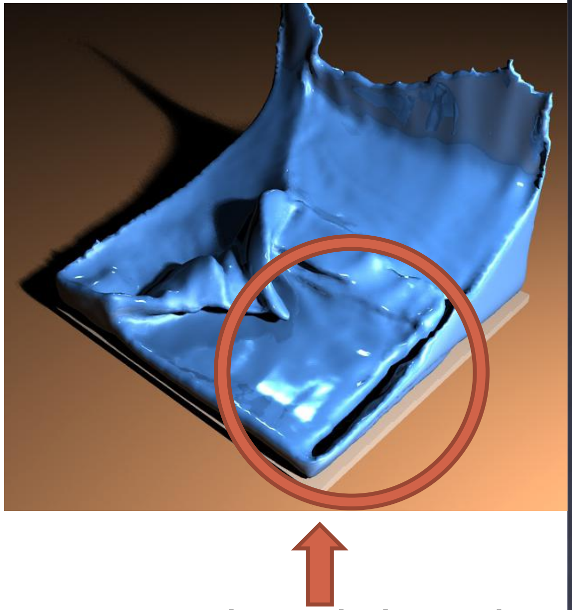
# RESULTS



Level set: most of the surface details are lost with this method



Particle level set: more surface details are kept



Proposed mesh-based tracker: detailed folding over on flat region of the liquid

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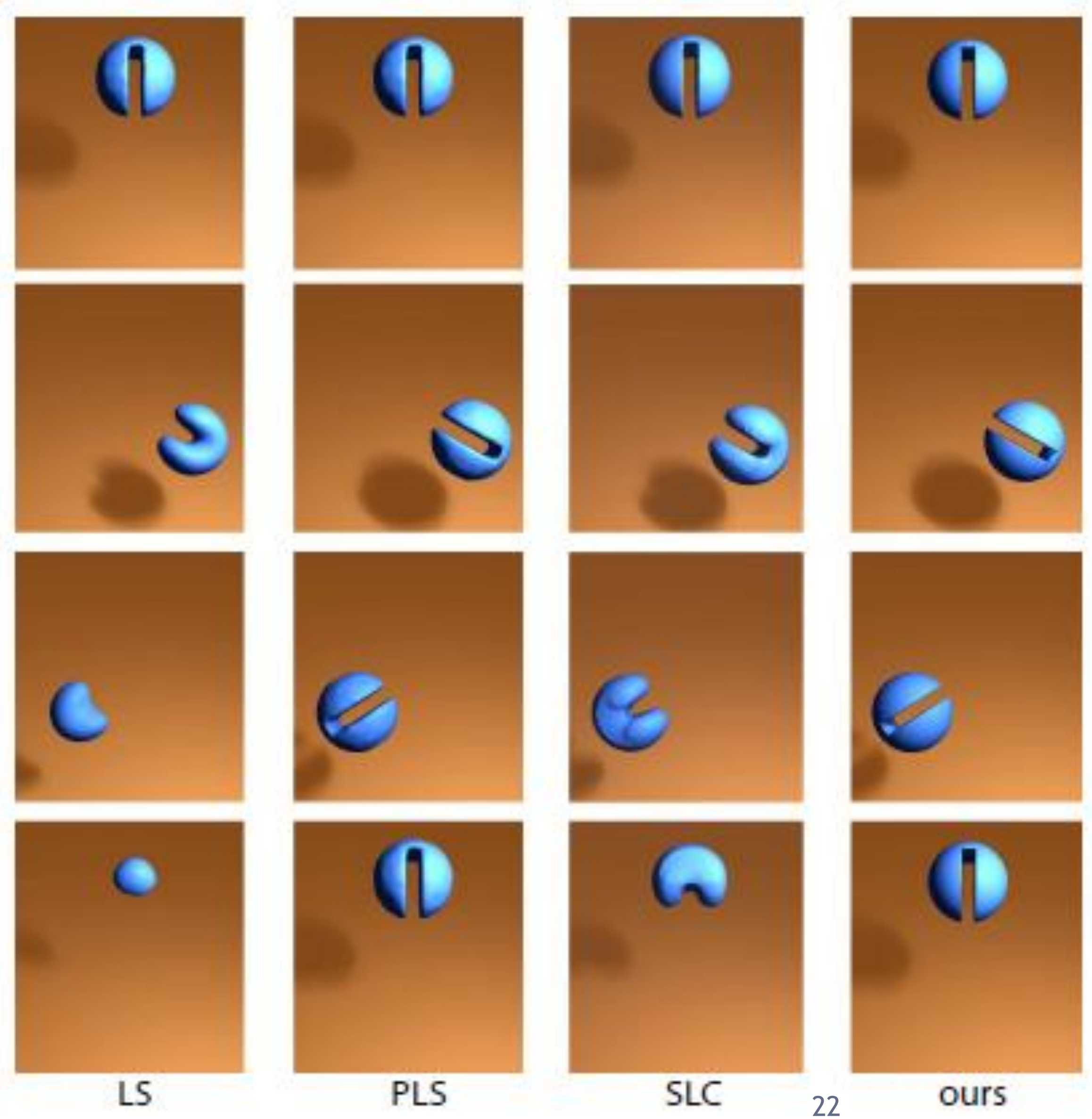
# RESULTS

Results from Zalesak Sphere example:

- Level set
- Particle level set
- Semi-Lagrangian contouring
- Paper's method



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- topogoop.mov

# LIMITATIONS

- Identifies topological events based on particular cell size of the distance field
- Topological classification will ignore small features that lie completely within a cell
- Extracted isosurface may not match the surface mesh at ambiguous marching cubes faces, leaving a quadrilateral hole in the mesh
- Proposed strategy for maintaining thin sheets doesn’t preserve complicated regions that have both splitting and merging behavior
- Re-meshing depends only on the sampled distance field, and ignores the actual geometry of the mesh
- Changes to the mesh may result in changes to the volume of the material

# FUTURE WORK

- Couple surface tracking method to other kinds of simulators: smoothed particle hydrodynamics, or lattice Boltzmann method
- Use other isosurface creation methods besides marching cubes: dual contouring method of isosurface creation
- Using local mesh operations: edge collapses that recognize and preserve sharp features
- Other rules for triggering topology changes that can be used for additional materials

# CONCLUSION

- Provides a technique for updating the surface of a deforming mesh that allows topological changes
- Surface tracker is the perfect balance between level set and deforming meshes that do not allow topological changes
- Robust: topology changes are carried out using marching cubes that only uses the sampled distance field
- Method many handle many different situations
- Motion of surface mesh can be guided by any velocity field/physics simulator