Grid Adaptation by Deformation in 2D and 3D

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Outline

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Objects in a numerical simulation

Objects in Featflow

- Circles, spheres, boxes, rectangles or compound objects of these primitives
- Goal: Use of multiple arbitrary shaped objects
- Represent objects by closed NURBS curves or NURBS surfaces

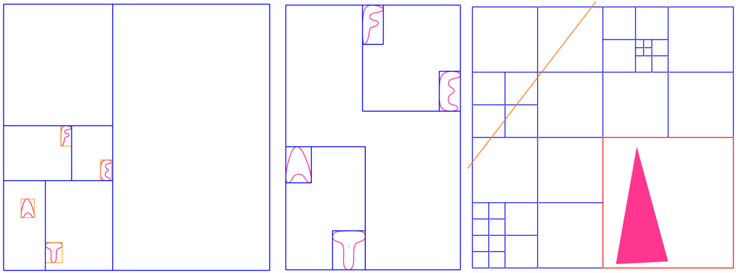
Requirements for ficticious boundary methods and grid adaptation

- Solve the containment problem
- Compute the minimum distance between a grid point and an arbitrary shaped object

Strategy for minimum distance computation

Ray tracing methods in distance computation

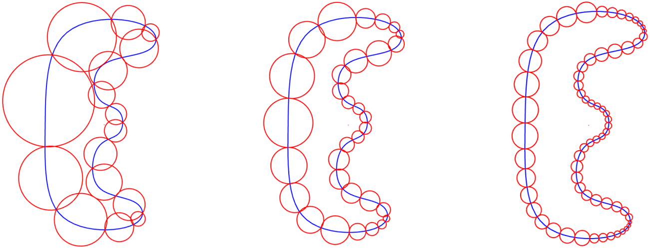
- Use of hierarchical data structures to subdivide search space
- Quadtrees, octrees, k-d-trees, bounding volume hierarchies(spheres, circles, rectangles, AABBs)
- Quickly reject objects/regions that are not part of the solution



Dynamic Hierarchical Data Structures

Choice of acceleration structures

- Hierarchy of axis aligned bounding rectangles (AABR tree) of the objects
- Quickly reduce the candidates on the bounding rectangle level
- Hierarchy of circles to further decompose the objects
- Structures can be updated quickly without rebuilding them
- Reuse data structures for collision detection

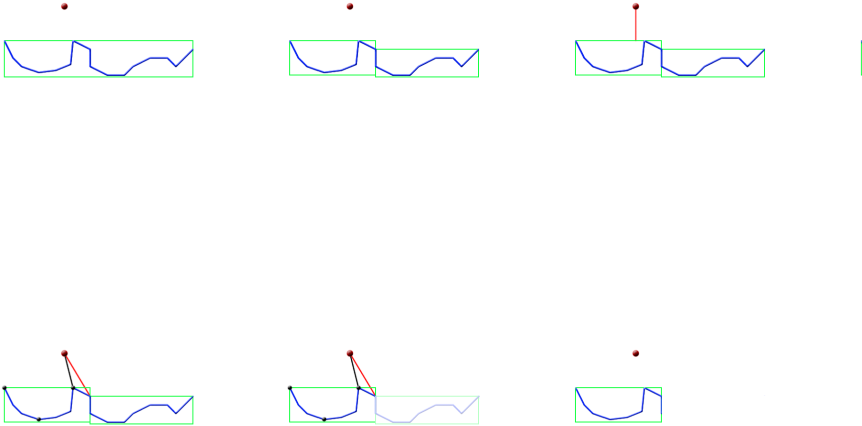


Rejection criterion for distance computation

Lower bound / upper bound principle

- Elements (nodes) in a hierarchy supply methods to compute lower and upper bounds for the distance
- For each level in the hierarchy an upper bound is computed
- When a node's lower bound is worse than the upper bound it can be pruned

Lower bound / upper bound search example



Further acceleration methods

Incorporating time and space coherency

- A global upper and lower bound for the current grid point can be constructed from the preceding grid point
- Lazily update the bounding rectangle hierarchy
- Make use of information from the last time step (point inside, long distances,...)

Distancefield

3D search algorithm

problems in existing implementation

- slow & inaccurate raytracing
- ray-quad intersection was calculated by projecting the quad into the plane
- raytracing failed quite often, especially for non-planar faces
- fallback to brute-force search caused unacceptable time complexity

Search with distance information

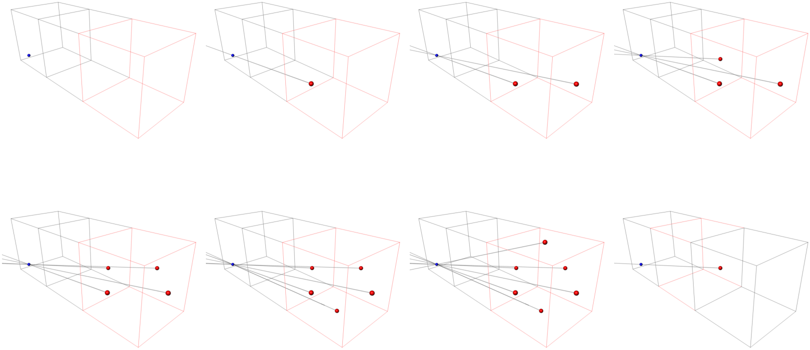
general idea

- no expensive raytracing
- only cheap calculation of distances
- next element is found by calculating the smallest distance to the search point

Algorithm one

- check if point is within element
- distance from search point to the center of each face
- only cheap calculation of distances for six faces
- next element is adjacent element to the face with smallest distance

Algorithm one

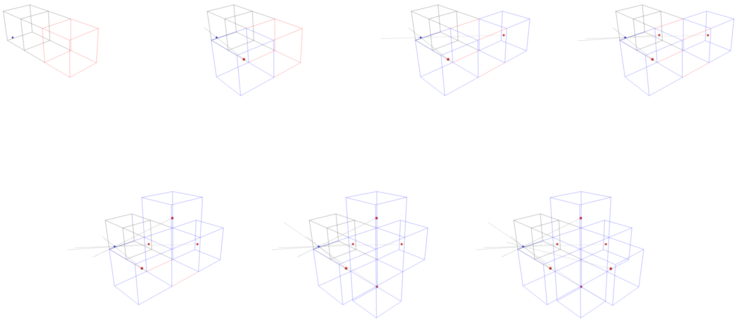


Search with distance information

Algorithm two

- check if point is within element
- distance from searchpoint to the center of the element
- distance calculation for six adjacent elements
- go to the element with smallest distance

Algorithm two



Search with distance information

Algorithm three, combination of cheap distance search and raytracing

- go to element with smallest global distance
- check if point is within element
- if not, start raytracing search

Search with distance information

Conclusion for distance-searches

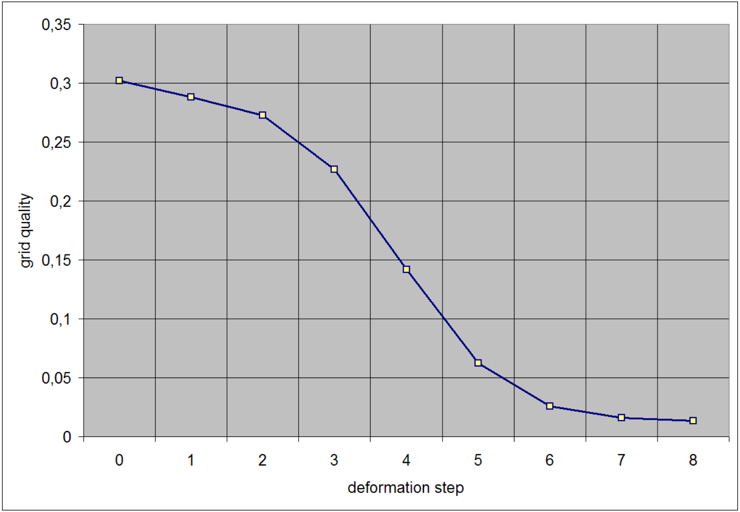
- for quite regular elements distance search is an option
- problems arise as soon as the grid contains distorted elements
- every distance-search had an Achilles heel
- pure raytracing is not slower then combination

New raytracing implementation

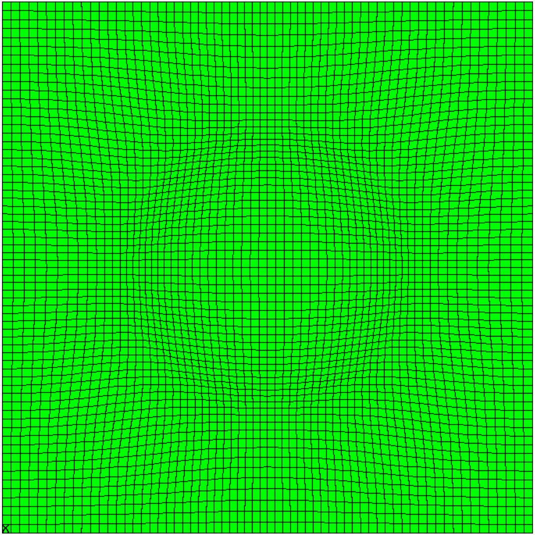
New raytracing implementation

- separate the quad faces into two triangles
- calculate ray-traingle intersection
- fast and accurate, fails only for heavily distorted elements

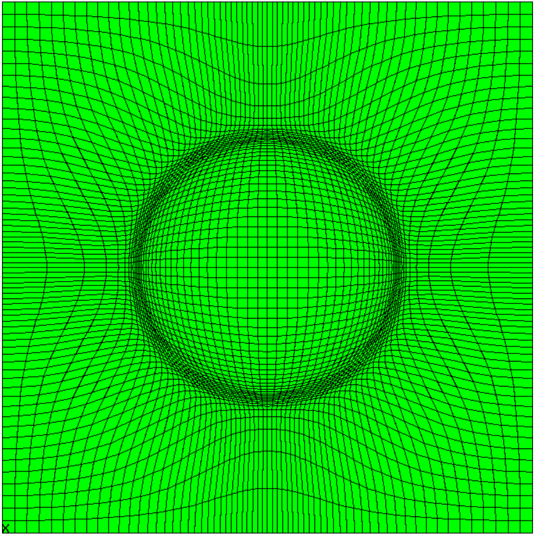
Numerical results



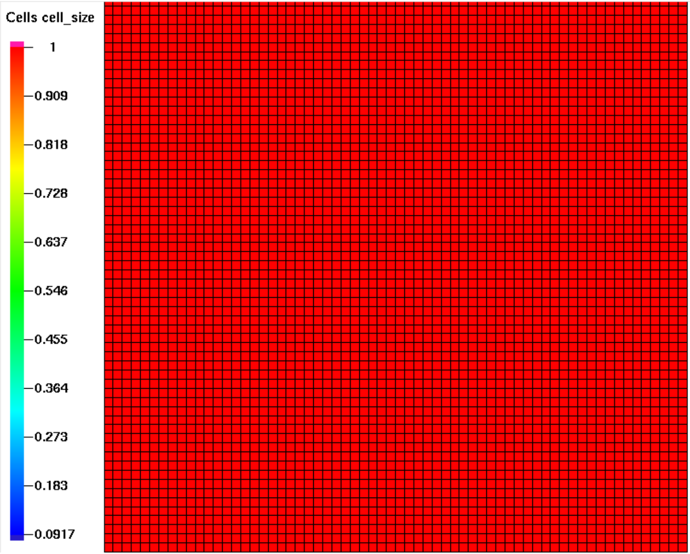
Numerical results



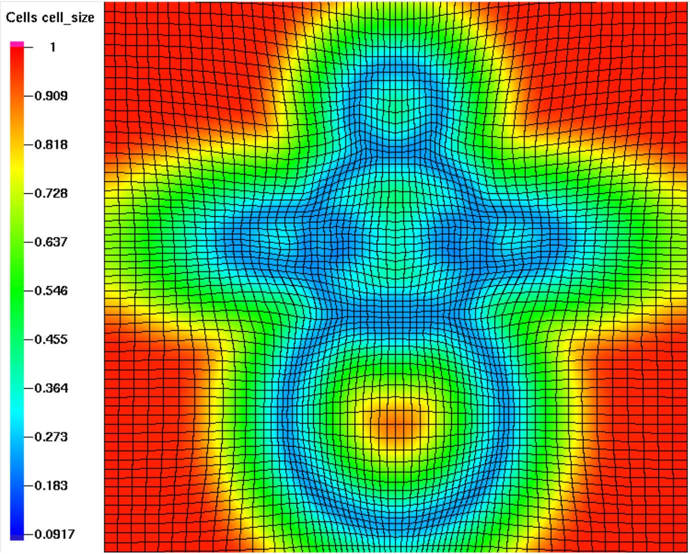
Numerical results



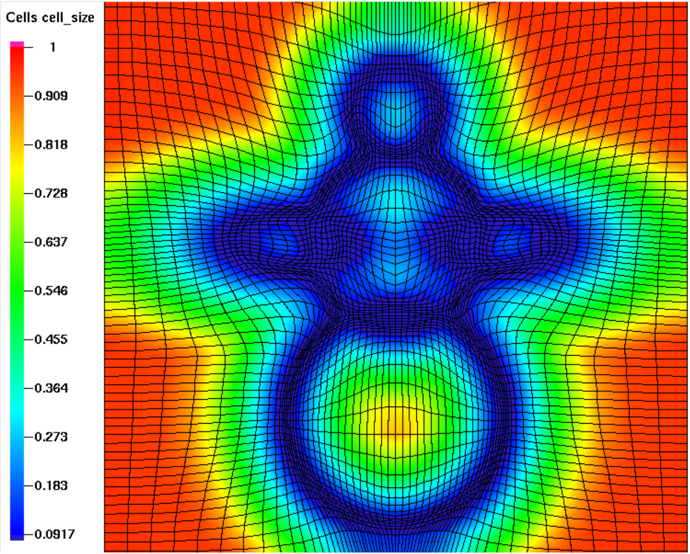
Numerical results



Numerical results



Numerical results



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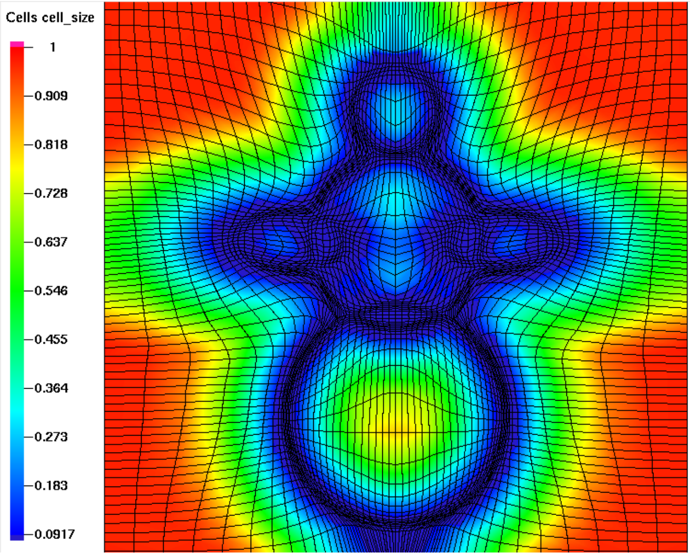

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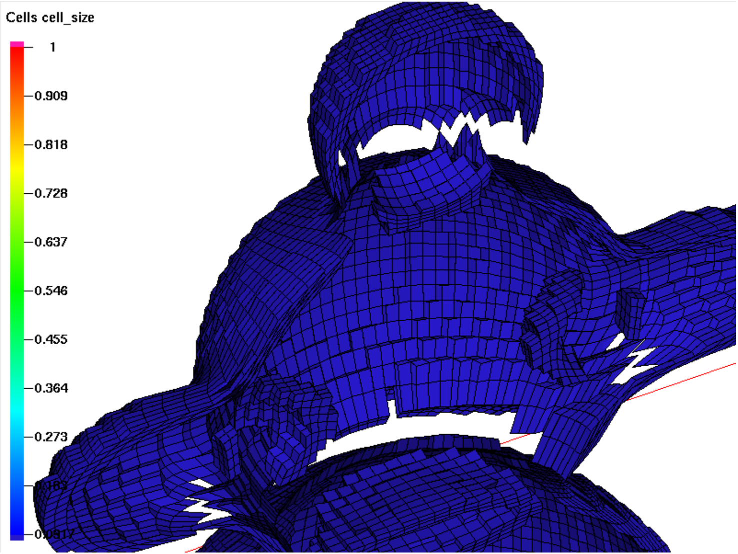

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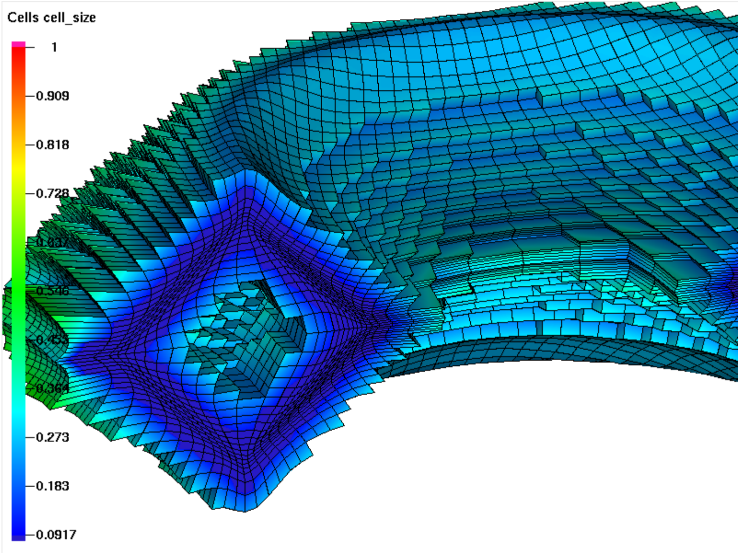

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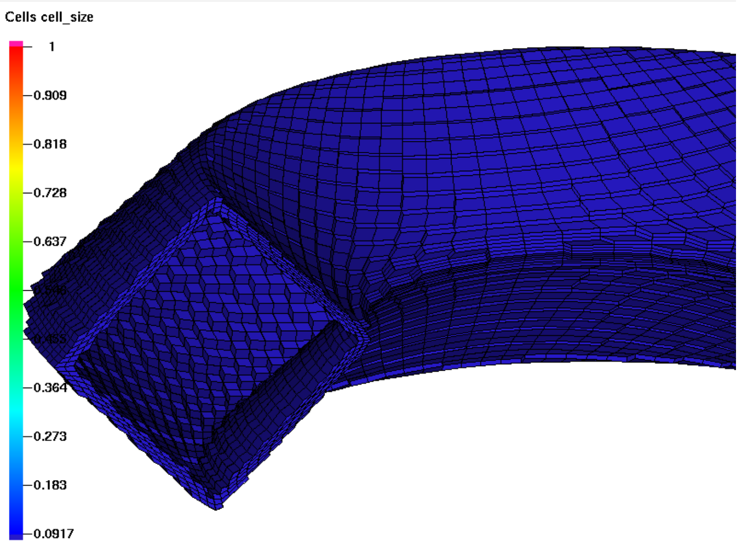


Future work

Future Work: Numerical analysis (Raphael)

- comparison with numerical methods (eikonal equation)
- extensive performance tests
- error estimation

Future work

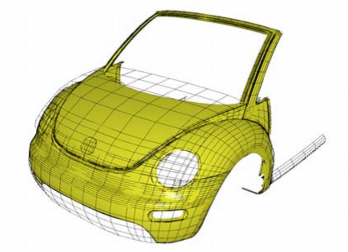
Possible Todo's

- Laplace and Umbrella-Smoothing (work in progress)
- parallel calculation of monitor function (OpenMP?)
- work on memory usage, for larger problems
- fix multigrid solver

Future work

Complex geometries (Diploma thesis Michael)

- Objects described by NURBS-surfaces and NURBS-patches
- Requirement: Efficient method for distance calculation
- Requirement: Efficient data structures
- Example below: 1578 patches (original data from Volkswagen)[1]

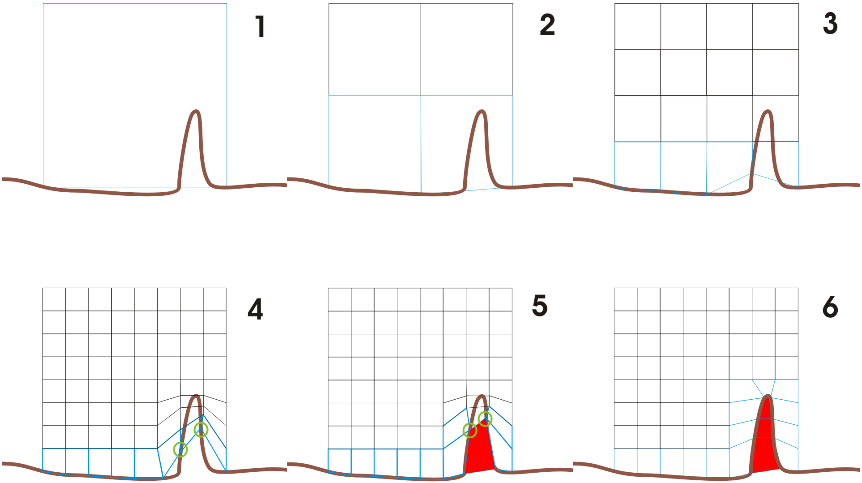


Future work

Diploma thesis (Matthias)

- Objects described by surface triangulation
- grid deformation with fictitious boundary
- versus
- exact grid deformation and refinement on the boundary of the simulated object
- or
- combination of both methods

future work



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