Interactive Voxel based Cutting of Deformable Models at Arbitrary Resolution

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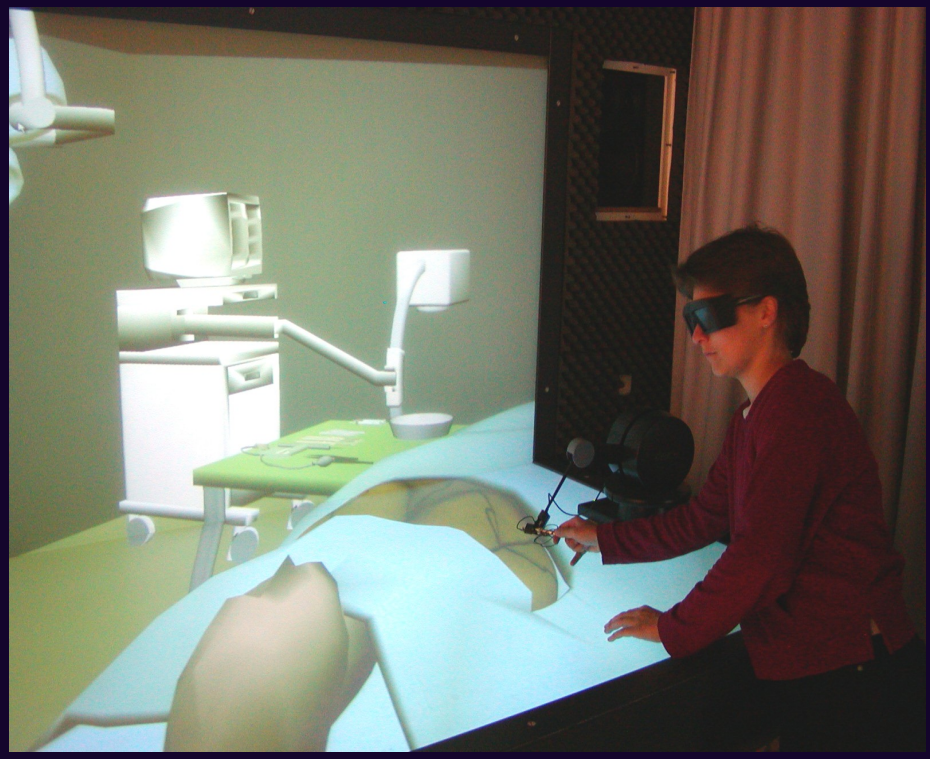
Motivation: Virtual Surgery

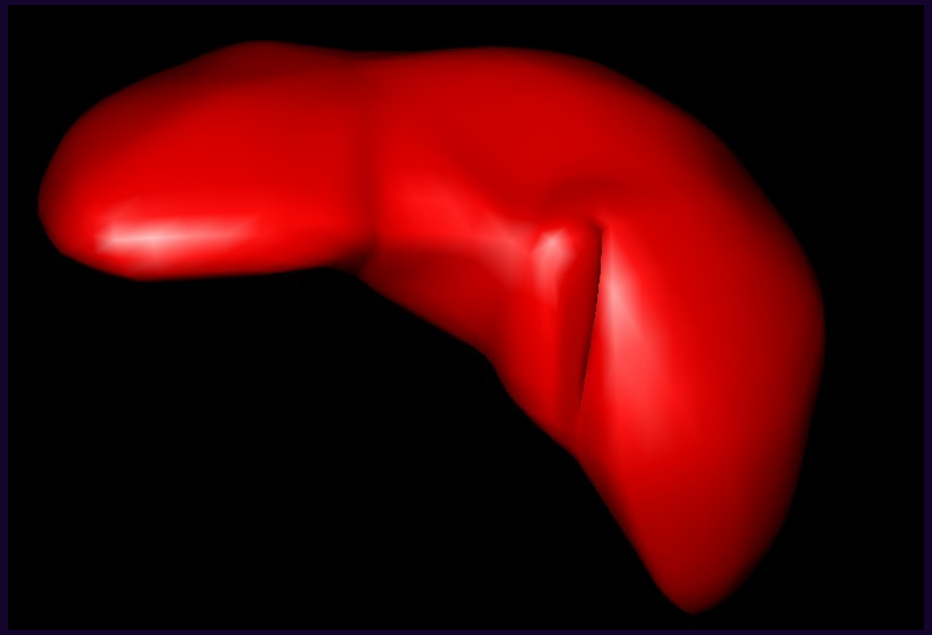
Requirements:

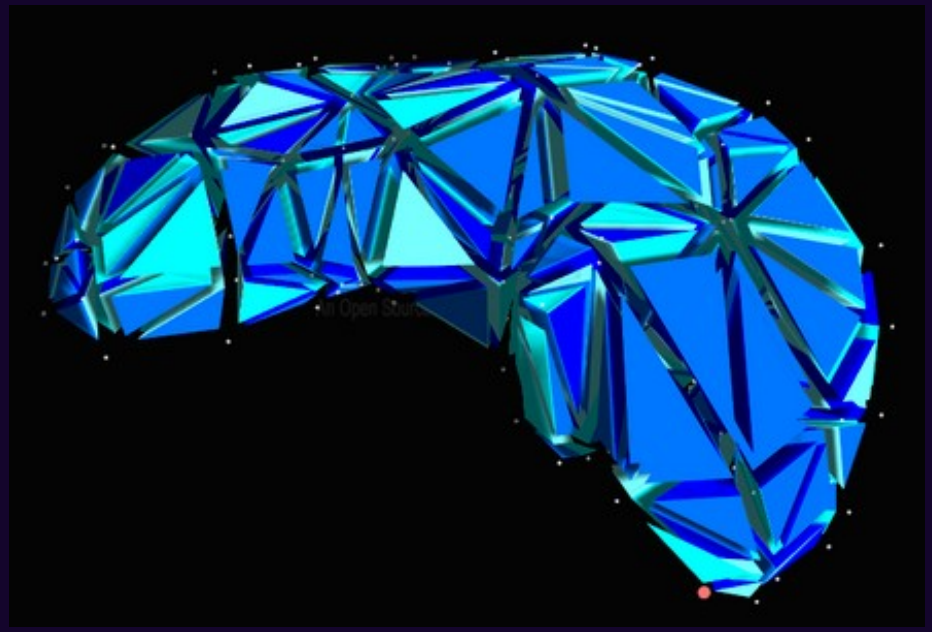
- patient specific data
  - mechanical properties
  - visualization
- interactive soft tissue deformation
- **stable interactive cutting of soft tissue**
- force feedback



State of the Art - Deformation

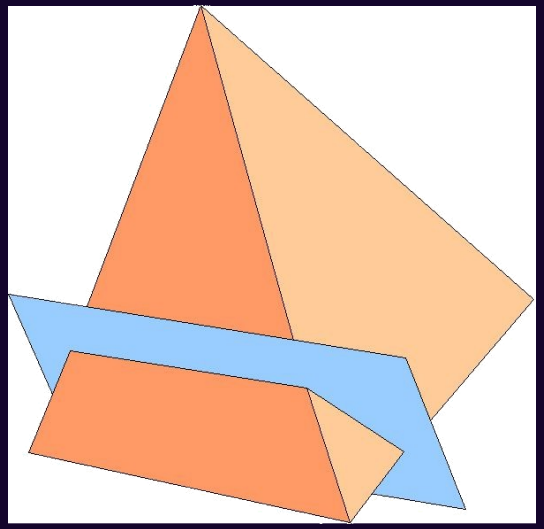
- The Finite Elements Method (FEM) approximates the object using a volumetric mesh of simple elements (e.g., tetrahedra) connected at nodes

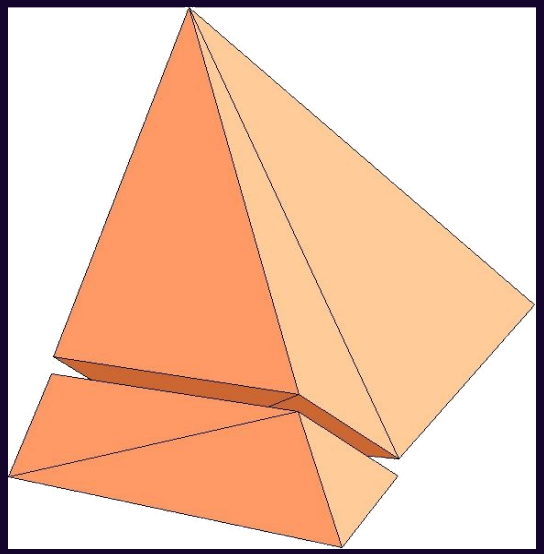




State of the Art - Cutting

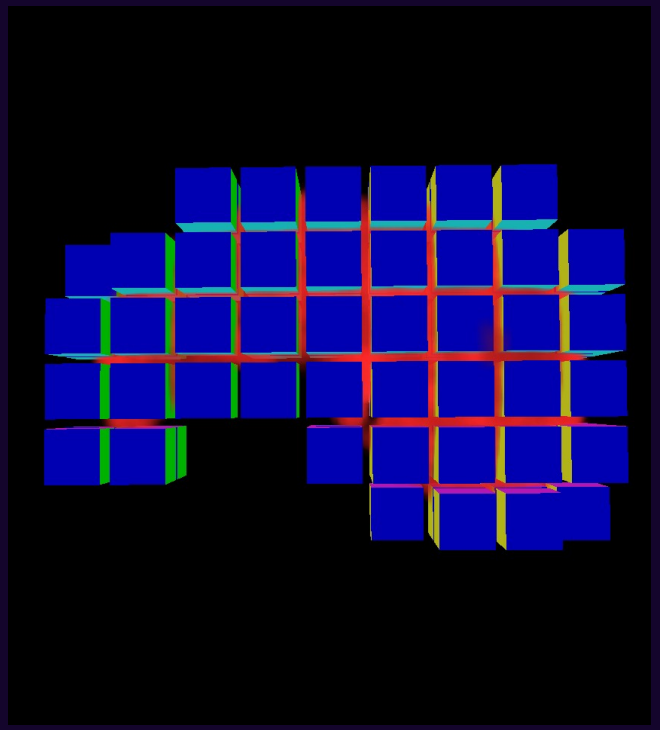
- A cut is modeled by subdividing the elements (local remeshing)
- Problems
  - Increasing number of elements
  - Simulation instability due to small and ill shaped elements





Voxel based Approach

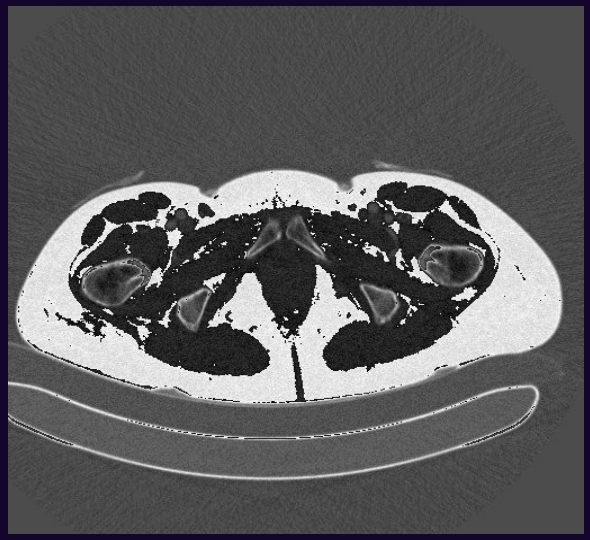
Interactive liver surgery using hexahedral finite elements



Why voxels?

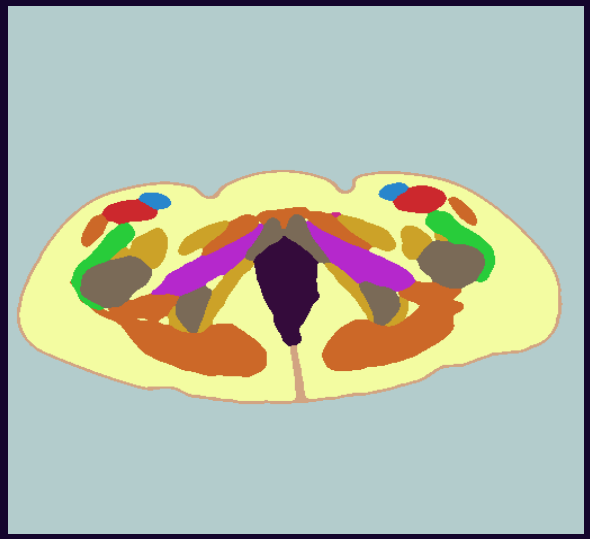
Medical data are voxels

- no loss of information due to conversions



Regular grid

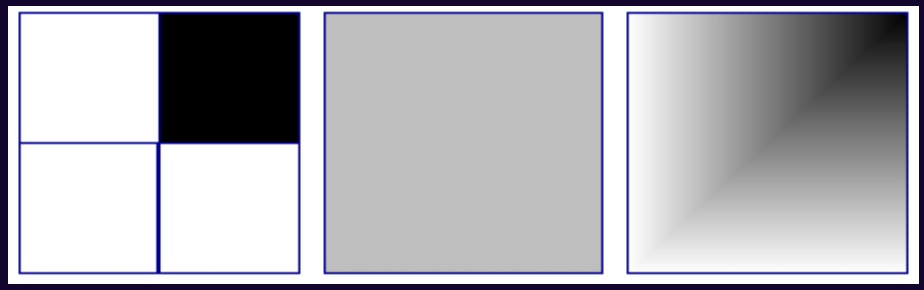
- straight forward hierarchies (octree)
- 3D texture (convenient for GPU implementations)

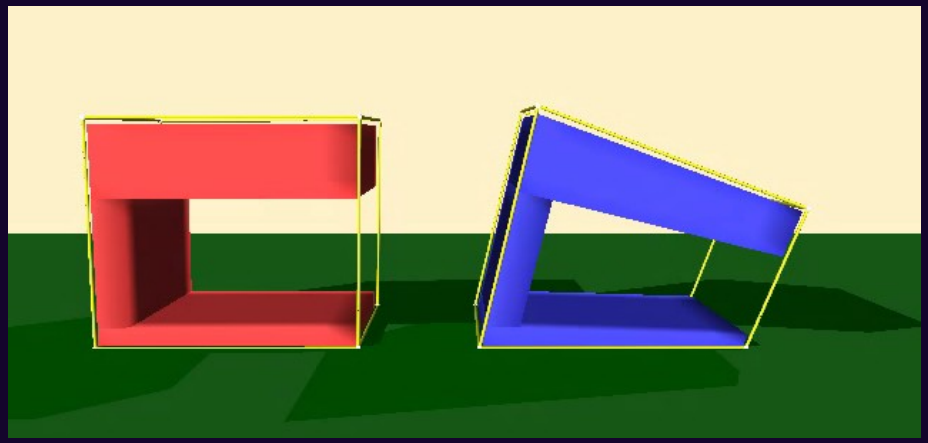


Voxel based Approach - Deformation

Nonuniform stiffness

- M. Nesme et al. (2006), *Animating Shapes at Arbitrary Resolution with Non-Uniform Stiffness*. In: Eurographics Workshop in Virtual Reality Interaction and Physical Simulation (VRIPHYS'06)

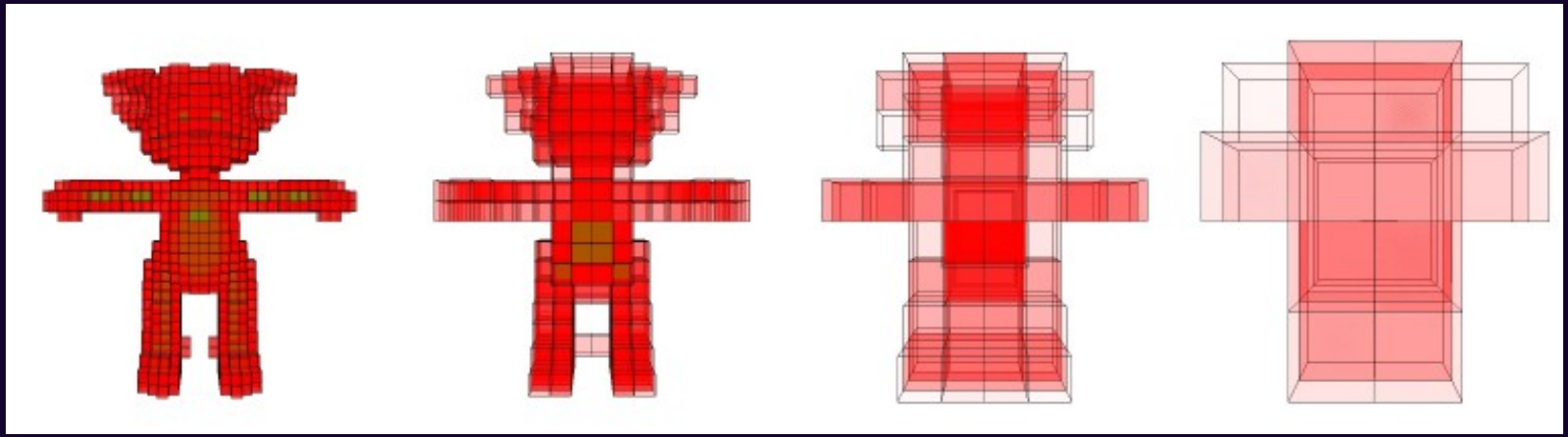




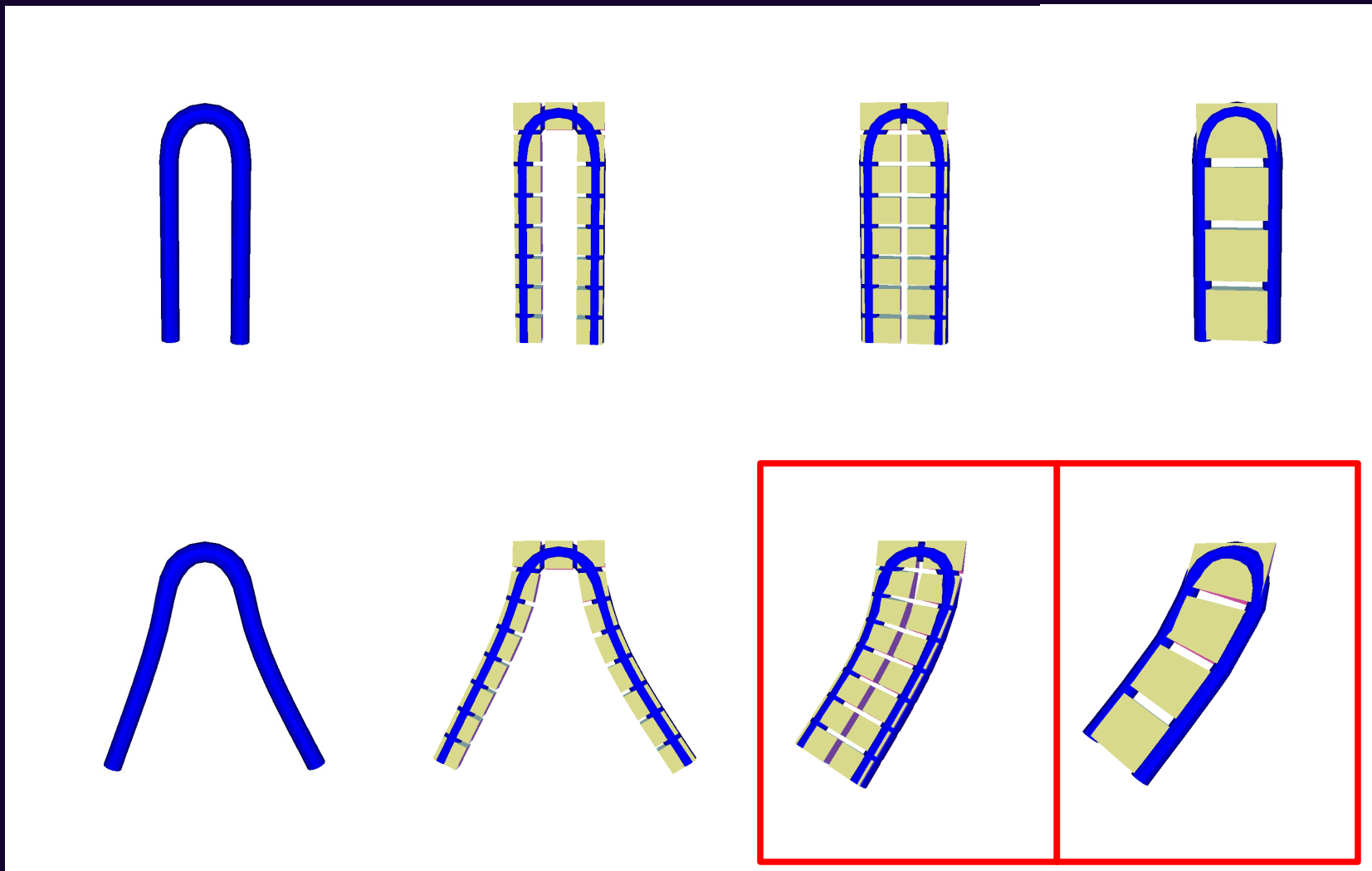
Nonuniform Stiffness

Simulation at arbitrary resolution

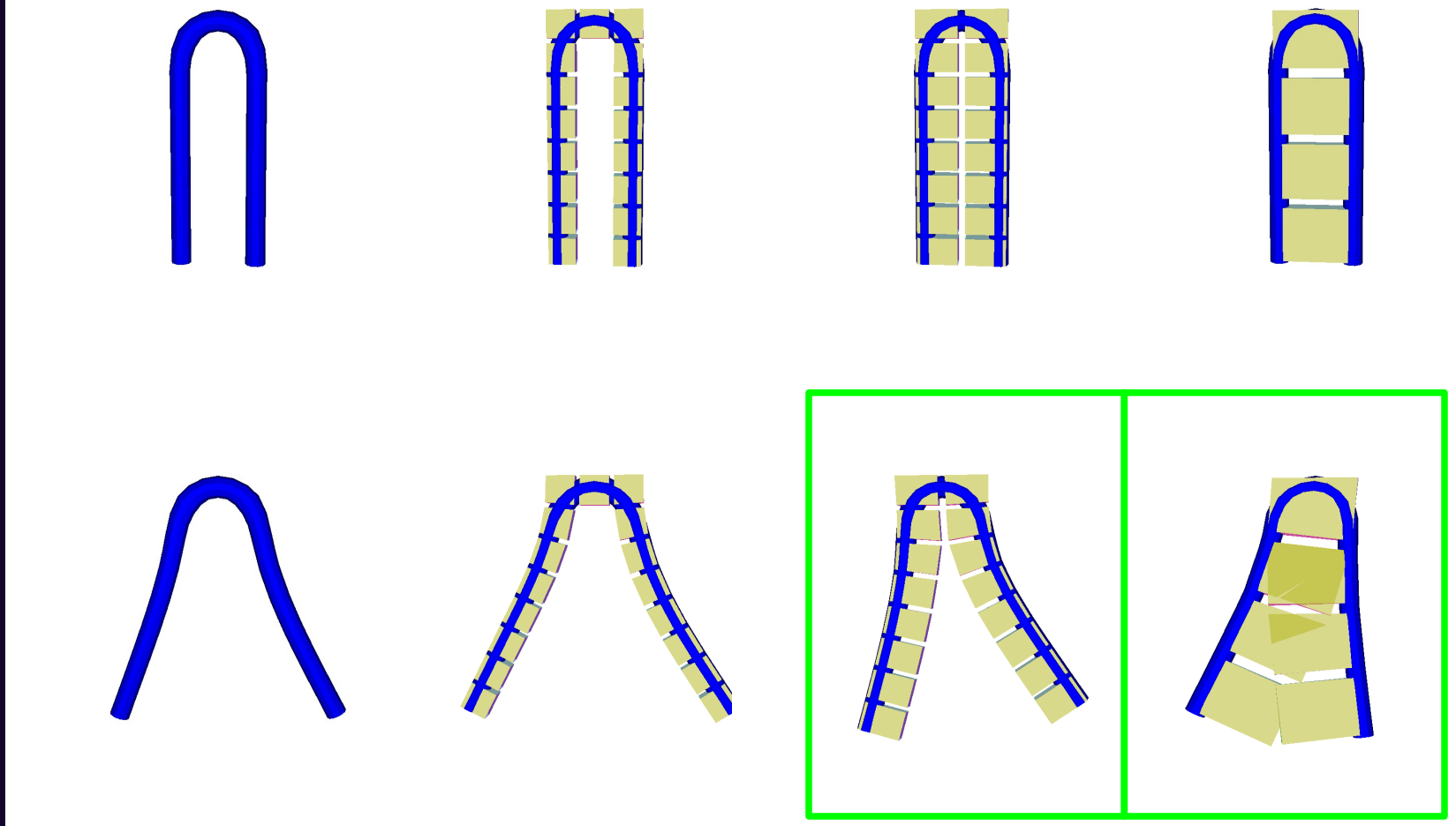
- a small number of coarse finite -> efficient simulation
- preservation of fine details for visualization
- BUT: problems with branched objects



Objects with Branches - Problem



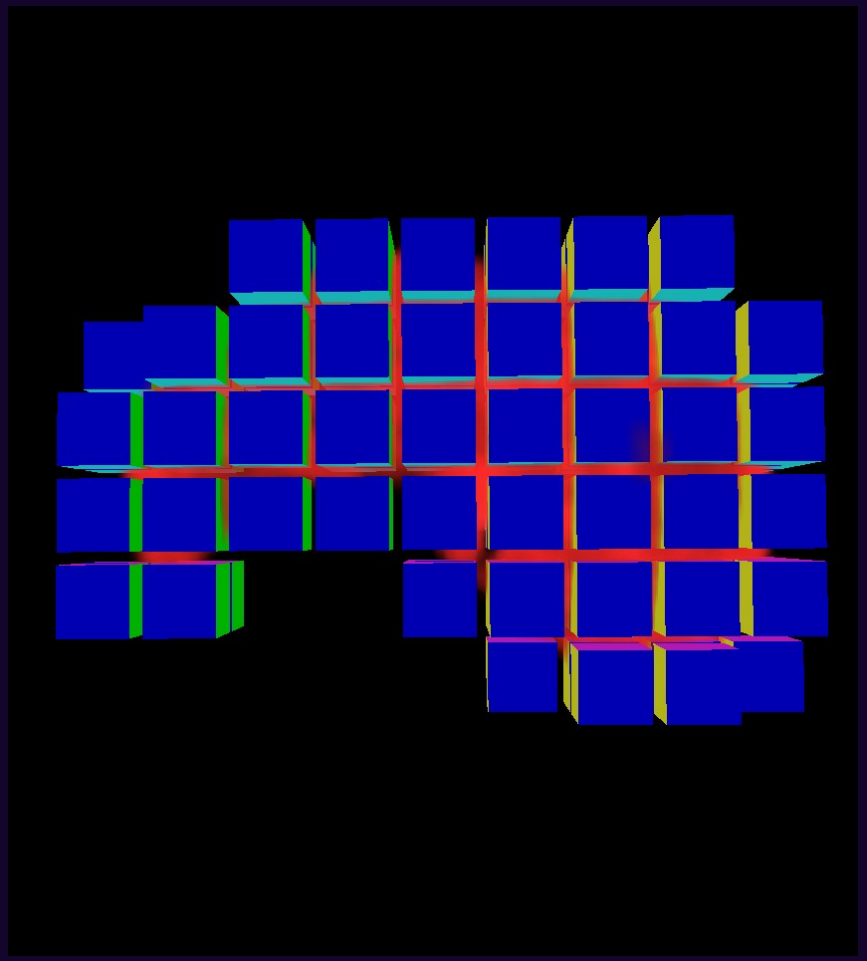
Objects with Branches - Solution



Cutting

Cutting = creation of branches during the simulation by removing fine voxels

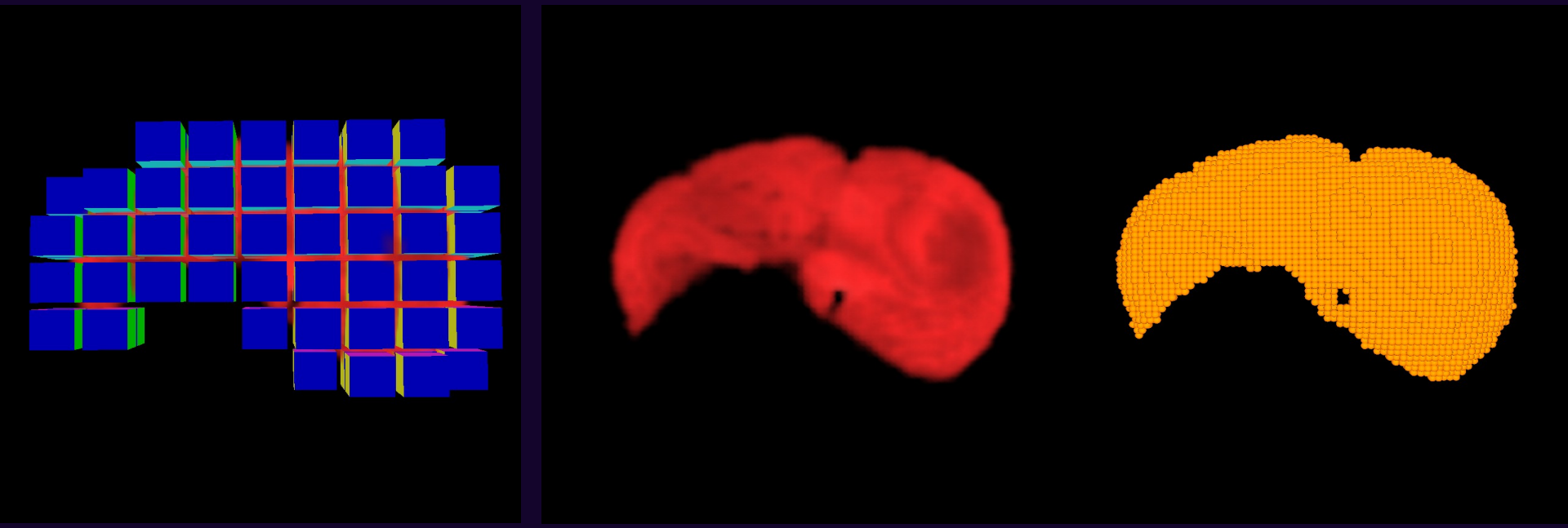
Topological changes must be propagated to all components



Different Models for Different Tasks

coarse level

fine level



mechanical model

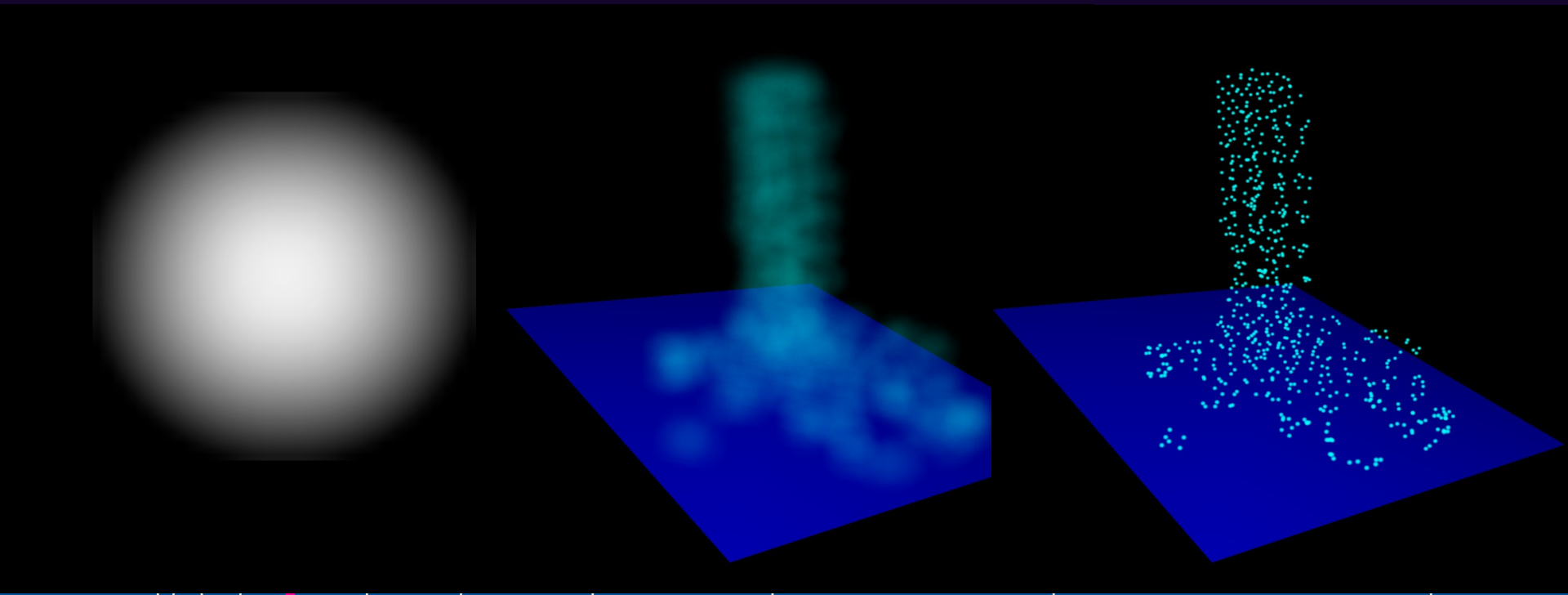
visual model

collision model

Visual Model

Billboarding

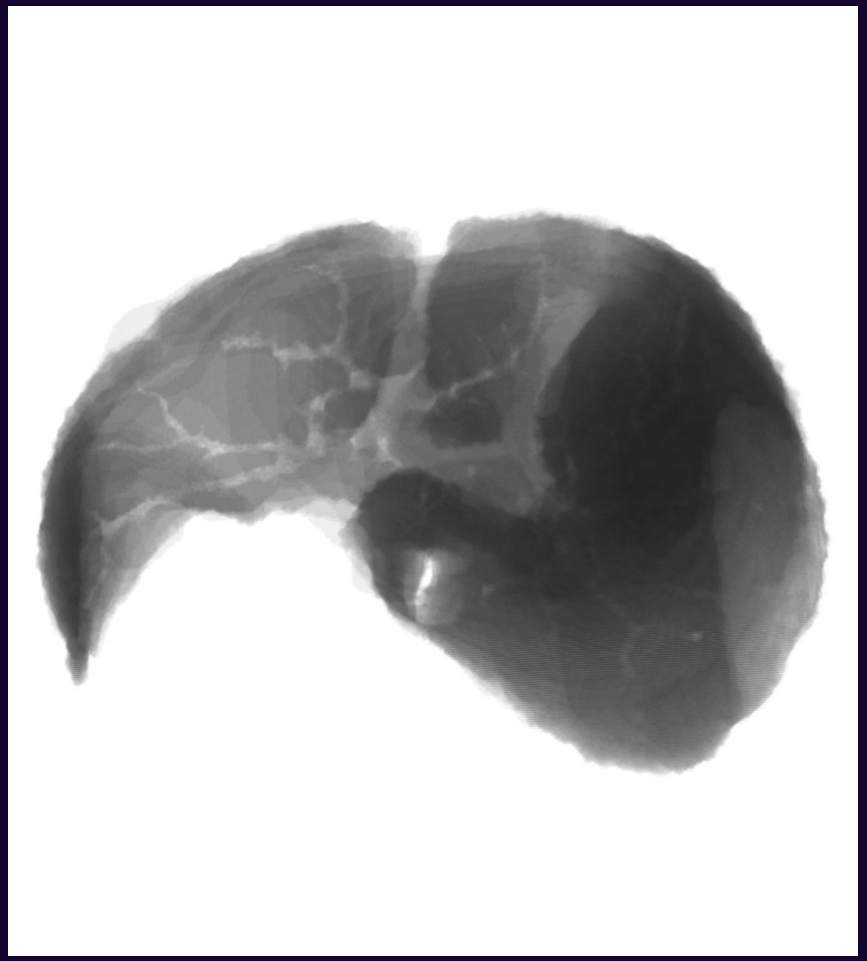
- efficient visualization of many particles
- each “sphere” consists of 1 textured quad oriented towards the camera



Visual Model - cont.

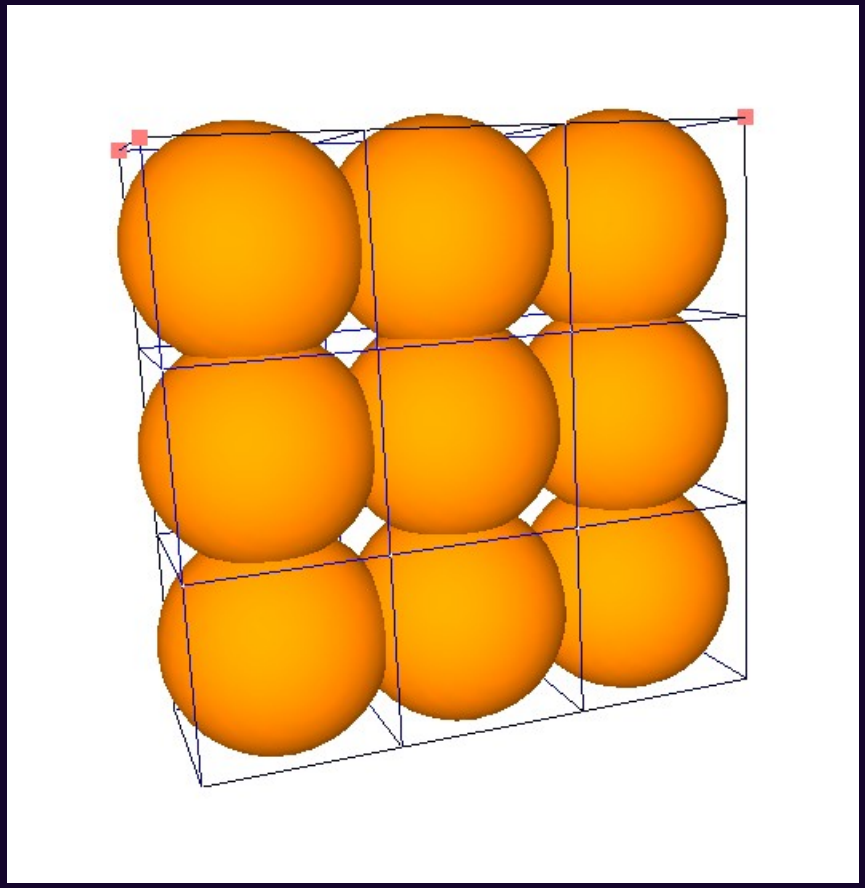
For medical data

- use segmentation as a mask in the non-segmented dataset
- modulate color by the data



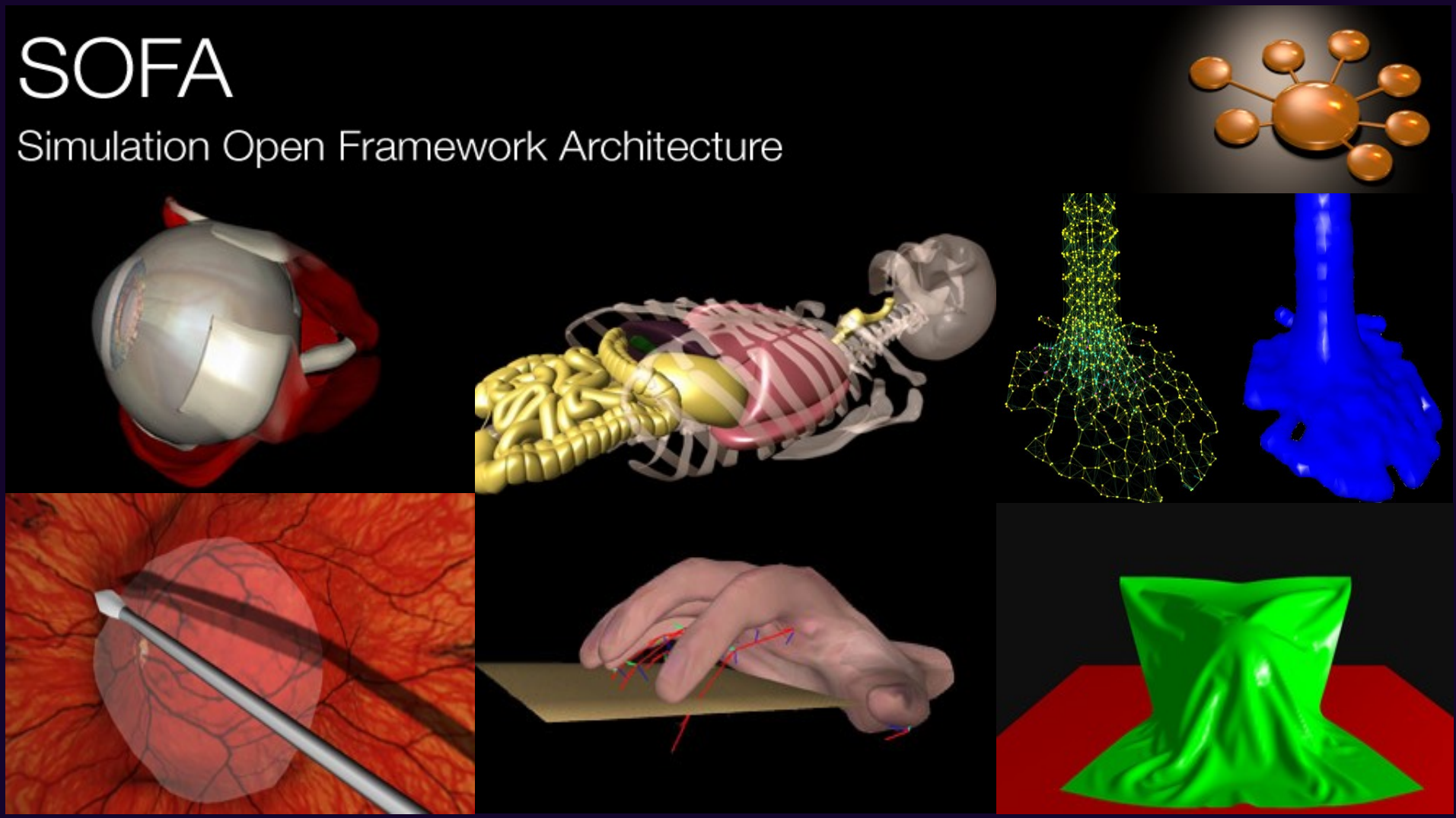
Collision Model

A sphere in the center of each voxel

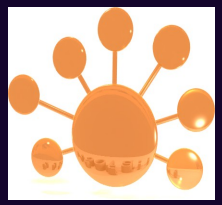


SOFA

Simulation Open Framework Architecture



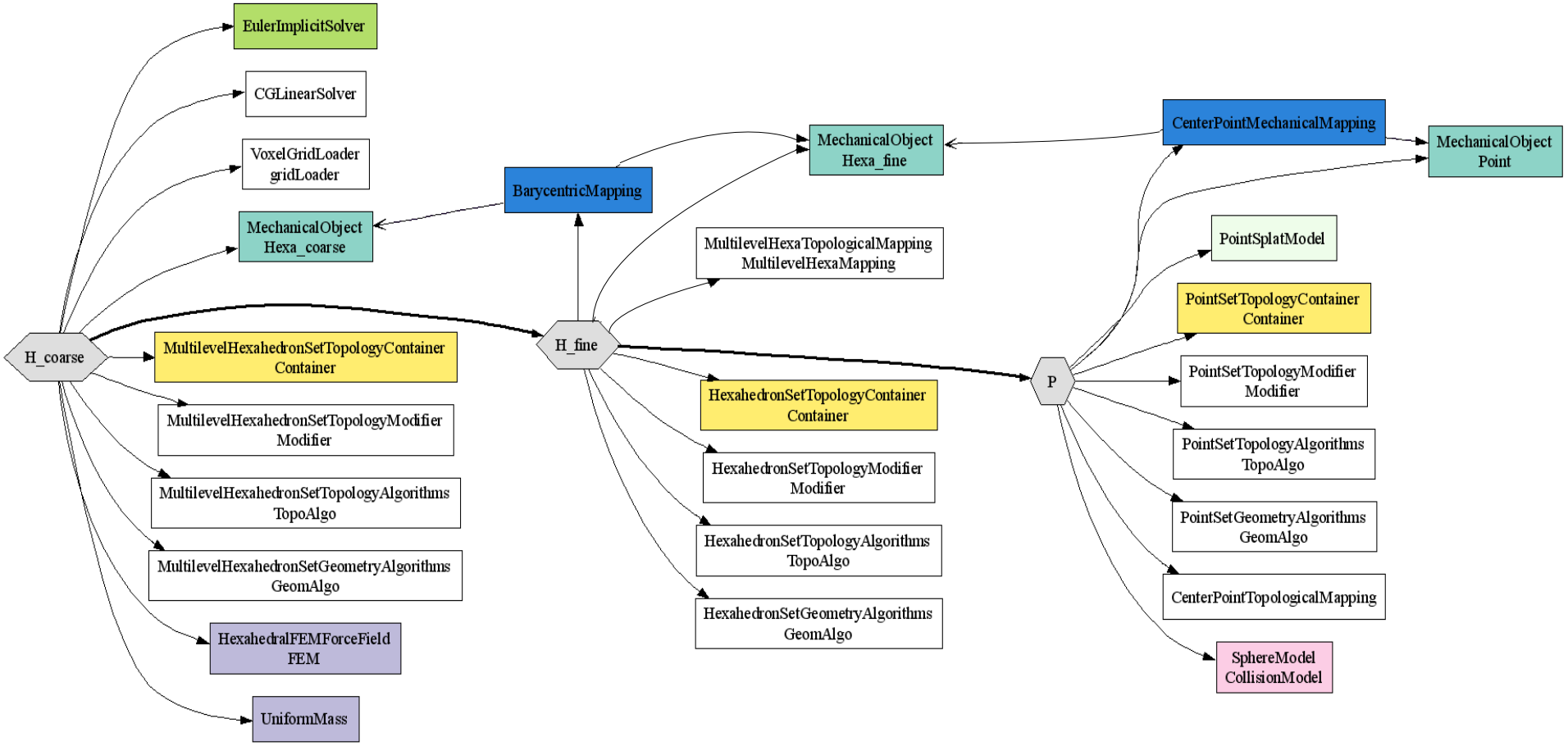
www.sofa-framework.org



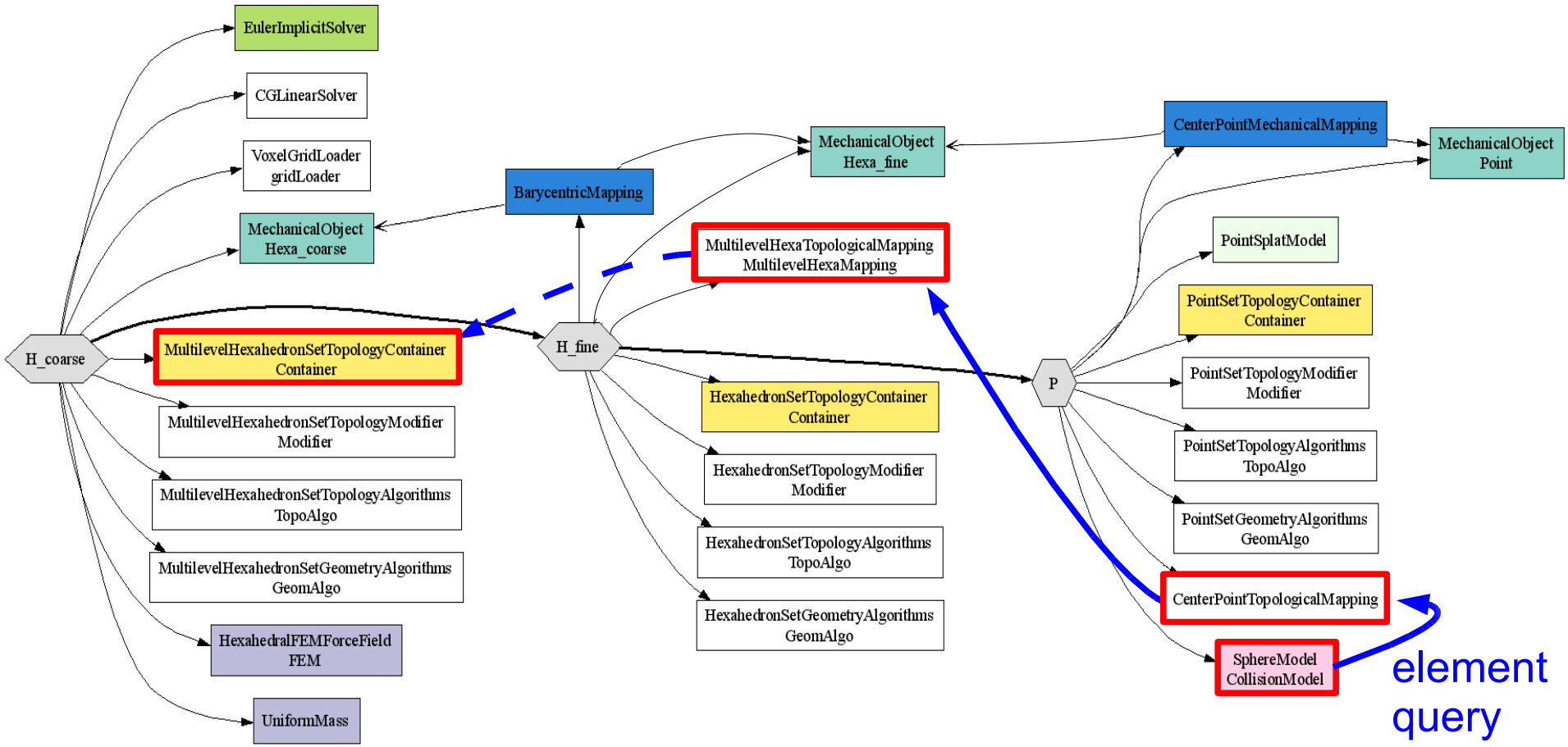
SOFA scenegraph

coarse level

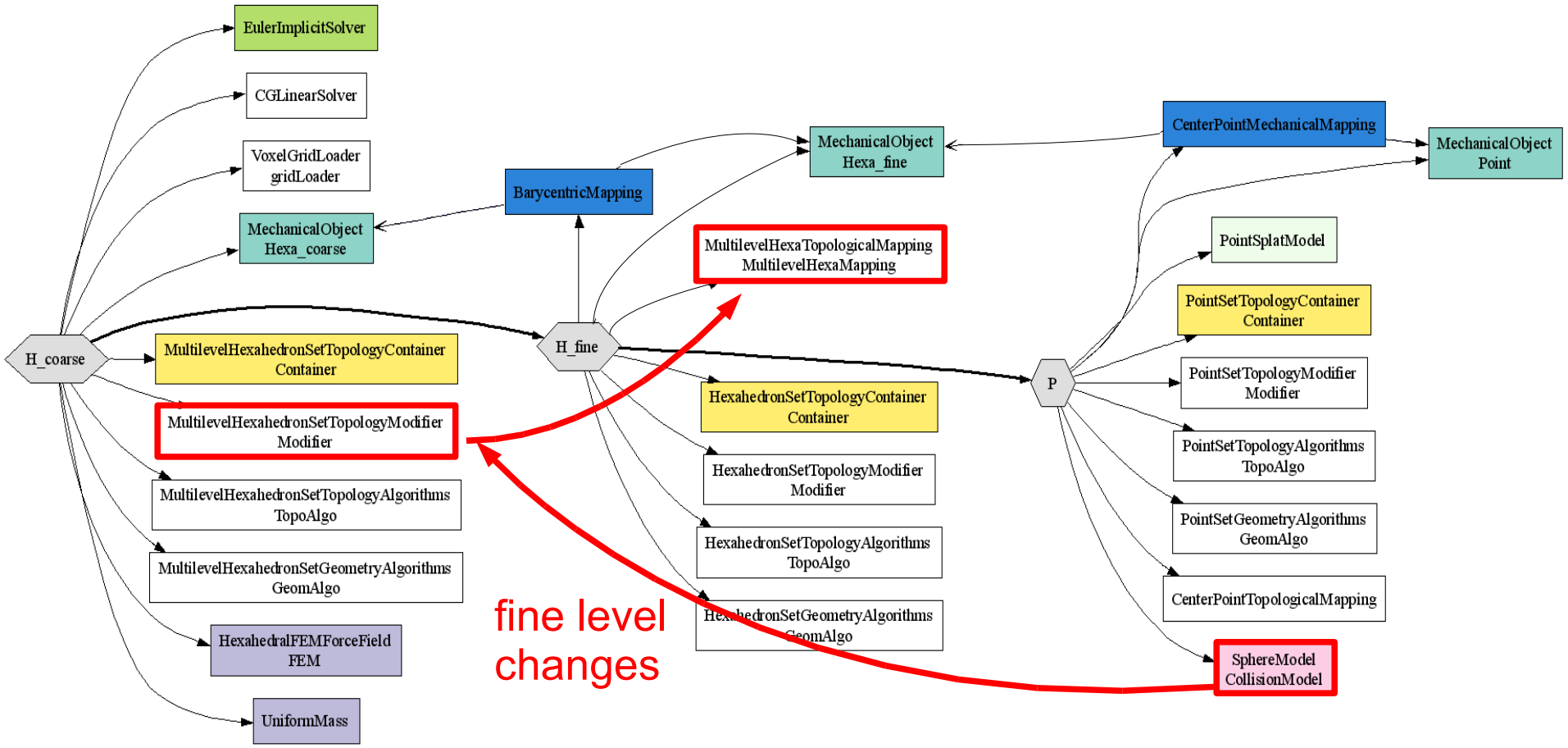
fine level



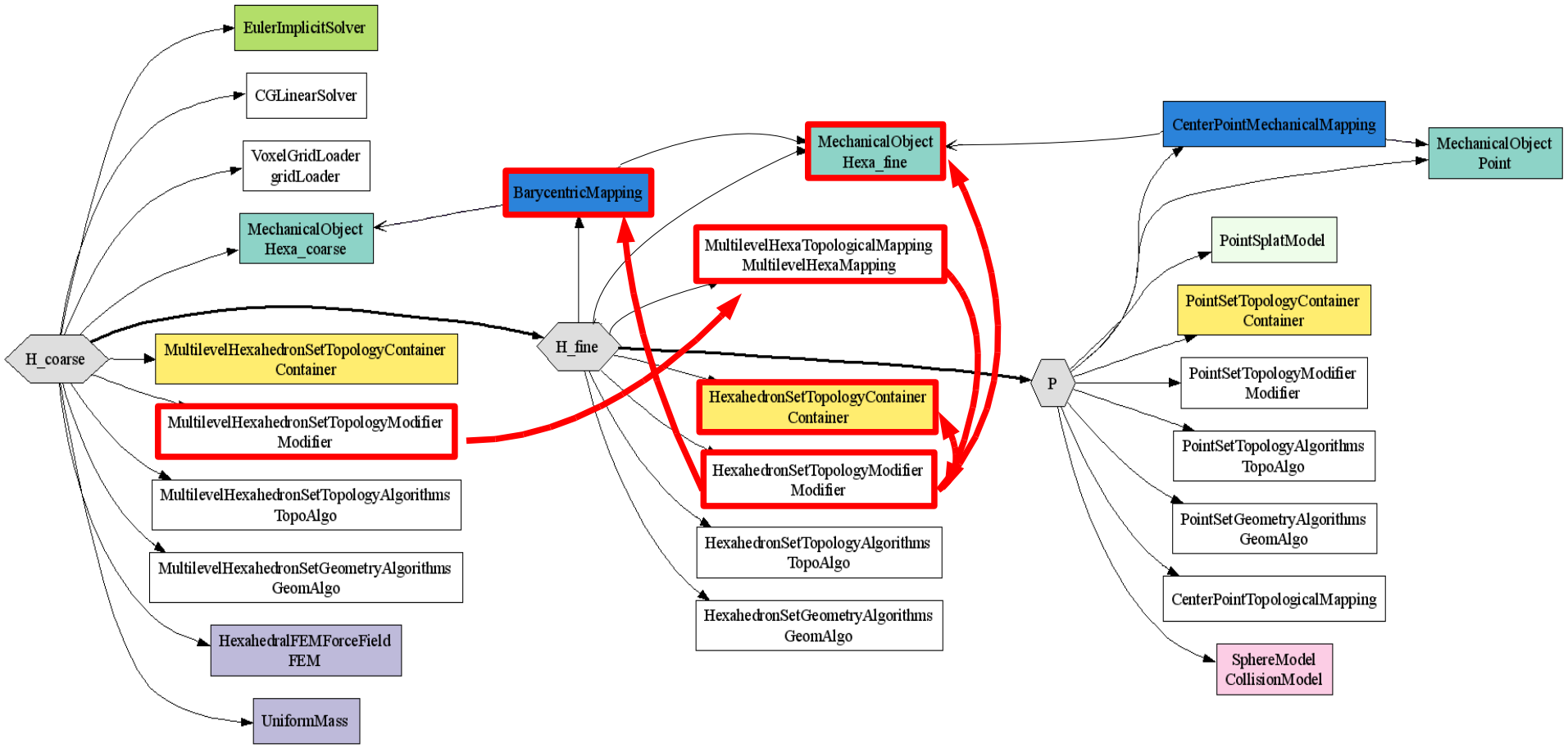
Propagation of Topological Changes (I)



Propagation of Topological Changes (II)



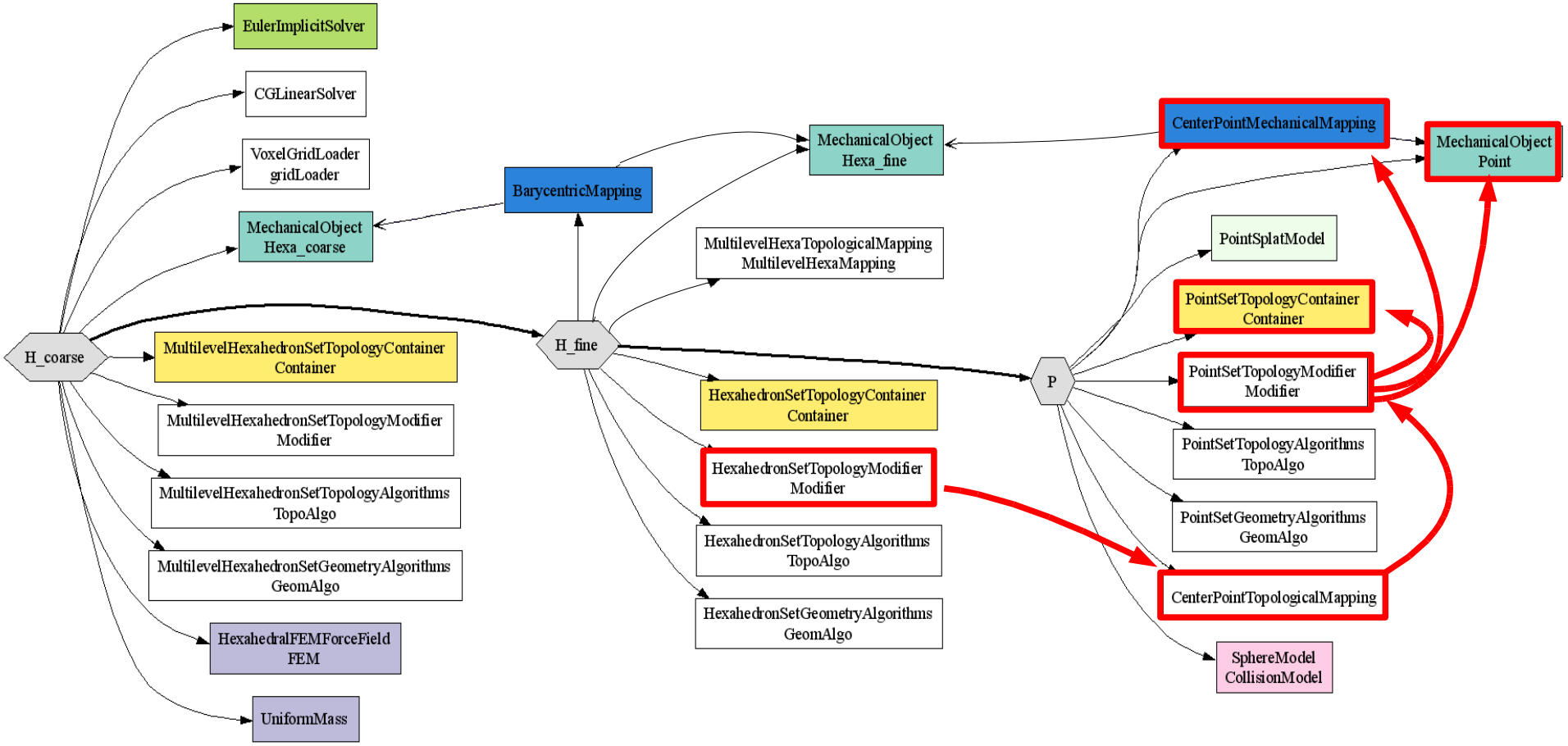
Propagation of Topological Changes (III)



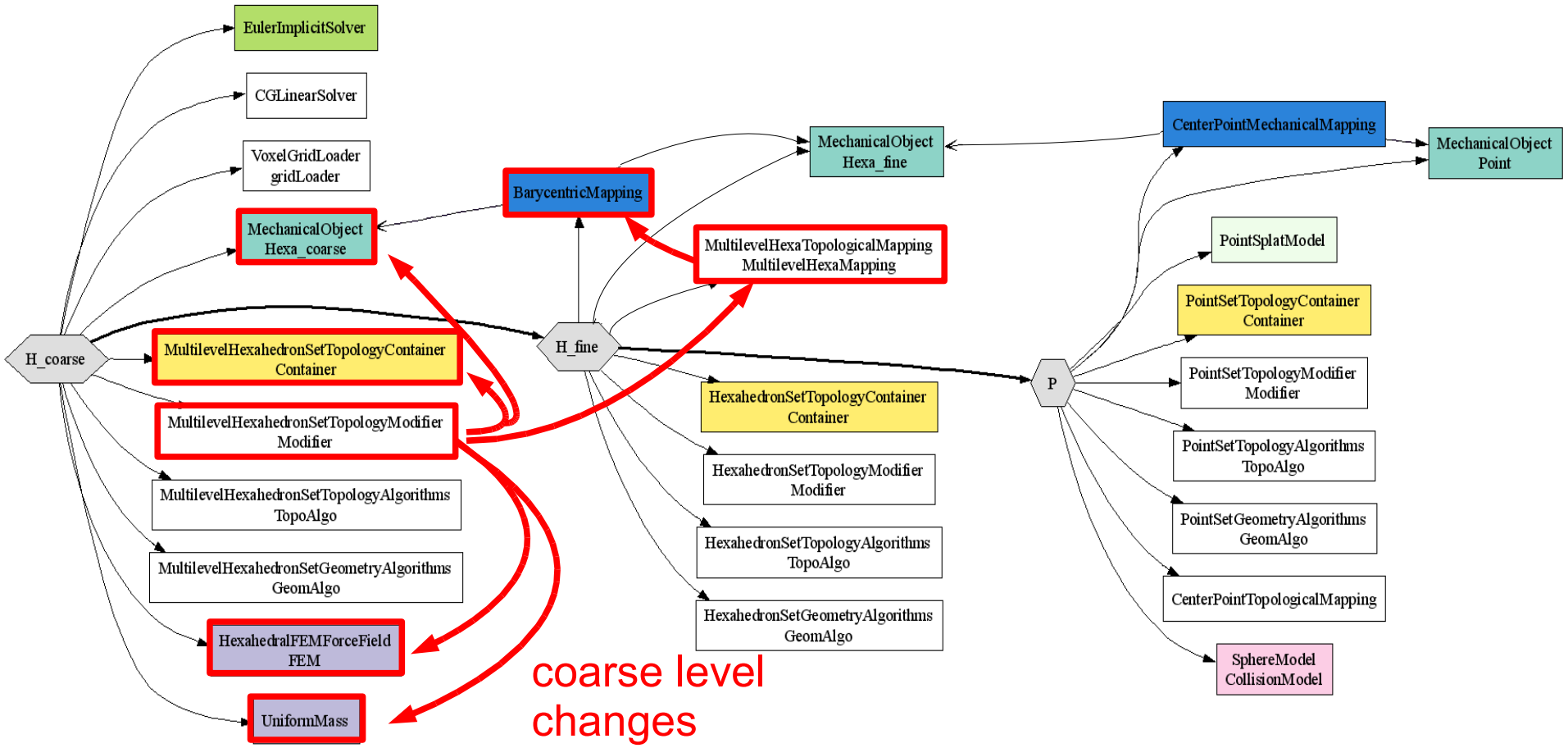
Propagation of Topological Changes (IV)

coarse level

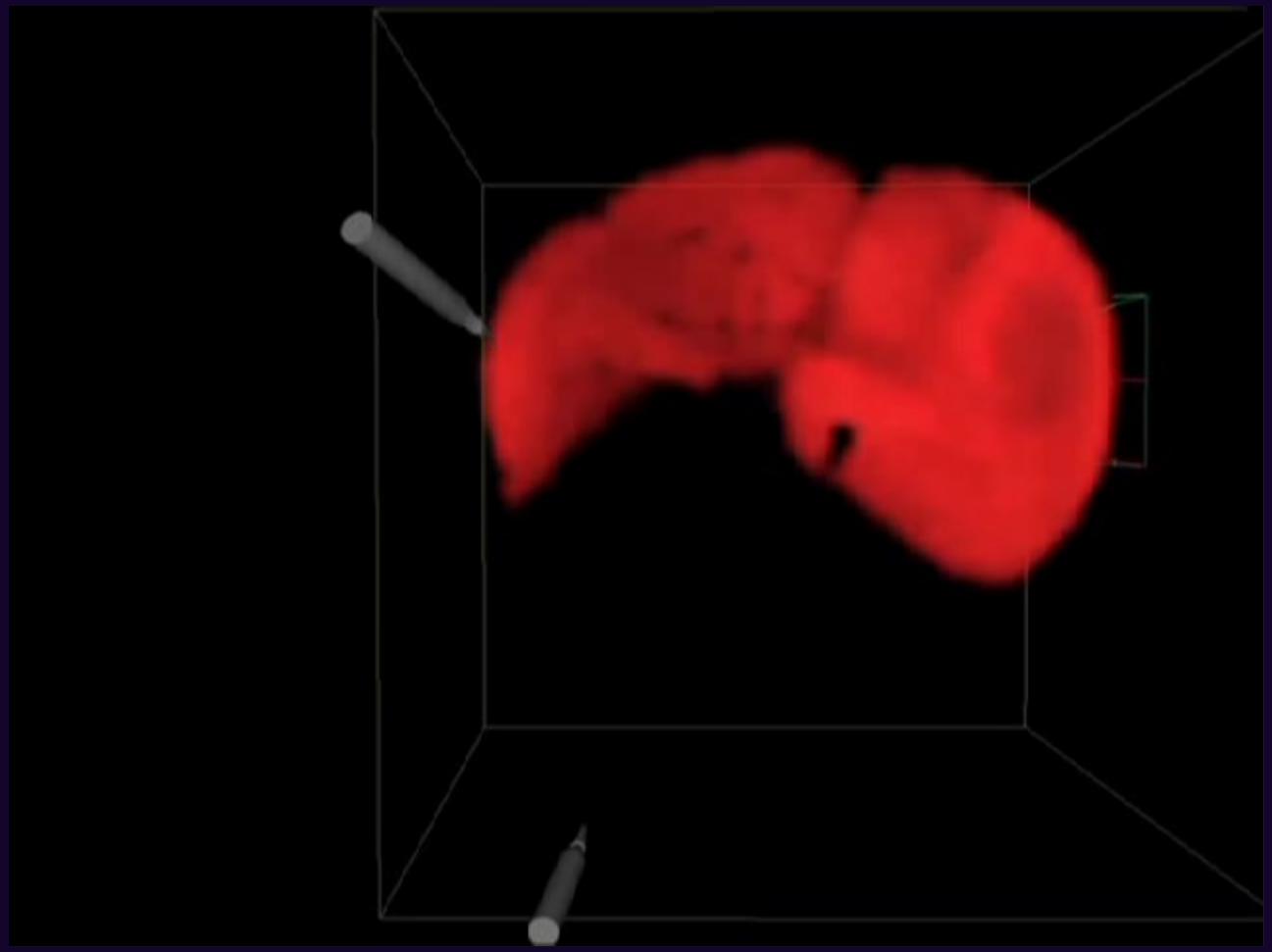
fine level



Propagation of Topological Changes (V)



Video



Conclusion

First prototype is working

- two level simulation
  - coarse level for physics
  - fine level for visualization and collision detection
- meshless visual and collision models
  - no connectivity problems
- efficient propagation of topological changes during the simulation
- direct use of medical data
  - patient specific simulation
- bi-manual interaction using Phantom devices