Progressive Isocontouring

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Lawrence **L**ivermore **N**ational **L**aboratory

Outline

- Motivation (large data visualization)
- Core Visualization Technologies
- The isosurface computation problem (definition and prior work)
- Time-critical isocontouring
- Conclusions

Motivation

- Large data-sets
  - multi-resolution data-structures
  - parallel/out-of-core computation
  - for dynamic settings little or no preprocessing
- Data analysis available for a wide class of inputs
  - dimension-independent algorithms (unified techniques that apply to data of different dimensions)
- Guaranteed interactivity and scalability
  - highly flexible adaptivity (progressive computation)
- Distributed computing resources
  - loose coupling between successive computation stages

Motivation

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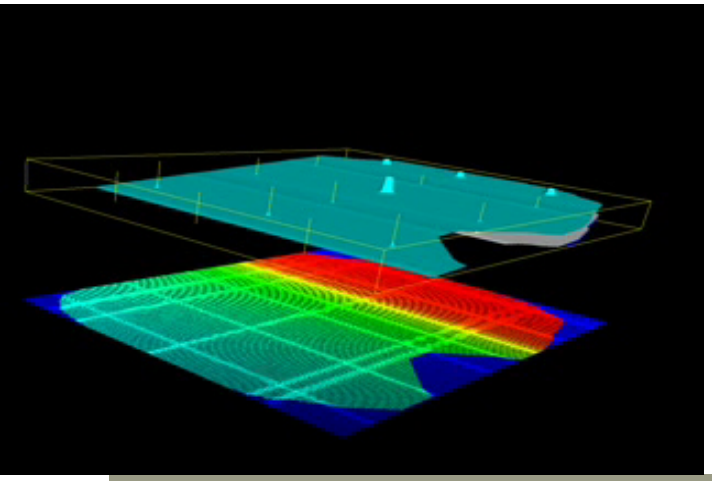
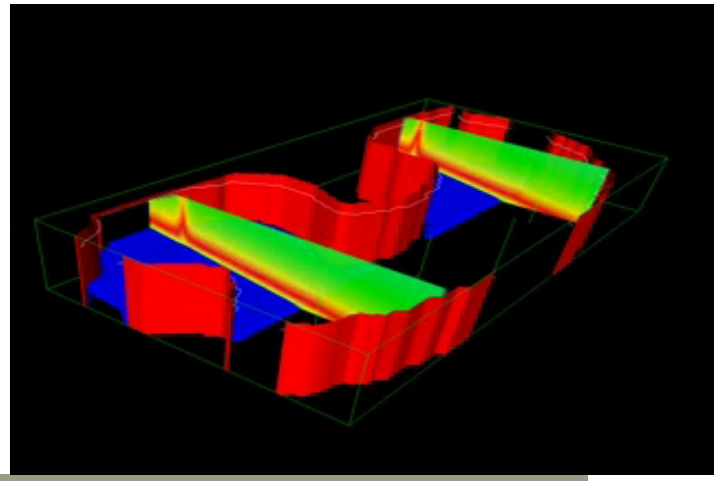
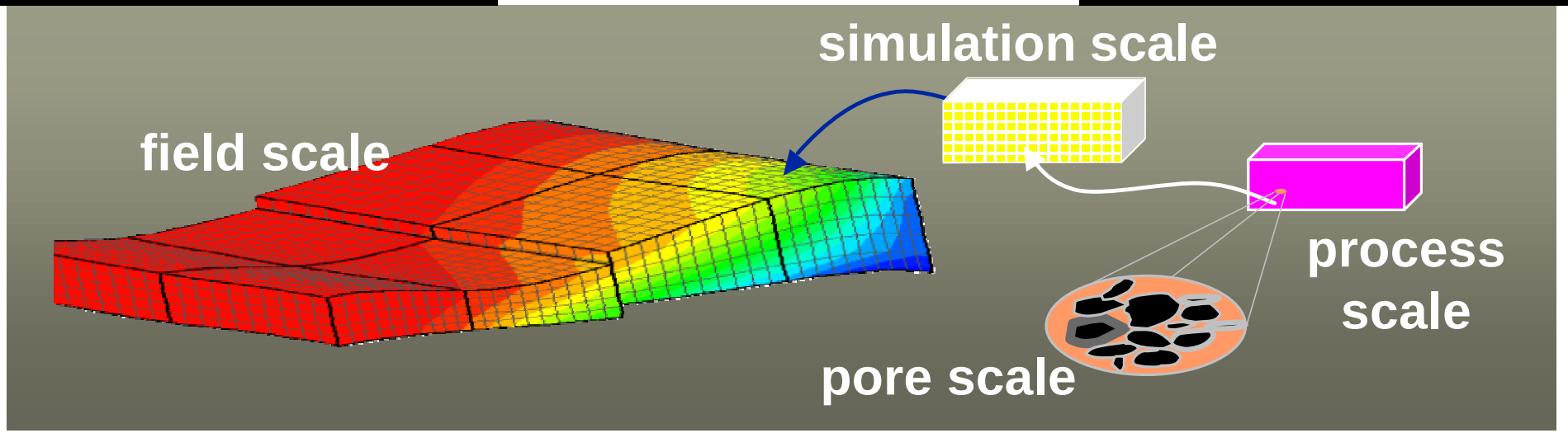
  - **multi-resolution data-structures**
  - **parallel/out-of-core computation**
  - **for dynamic settings little or no preprocessing**
- **Data analysis available for a wide class of inputs**
  - **dimension-independent algorithms (unified techniques that apply to data of different dimensions)**
- **Guaranteed interactivity and scalability**
  - **highly flexible adaptivity (progressive computation)**
- **Distributed computing resources**
  - **loose coupling between successive computation stages**

Motivation

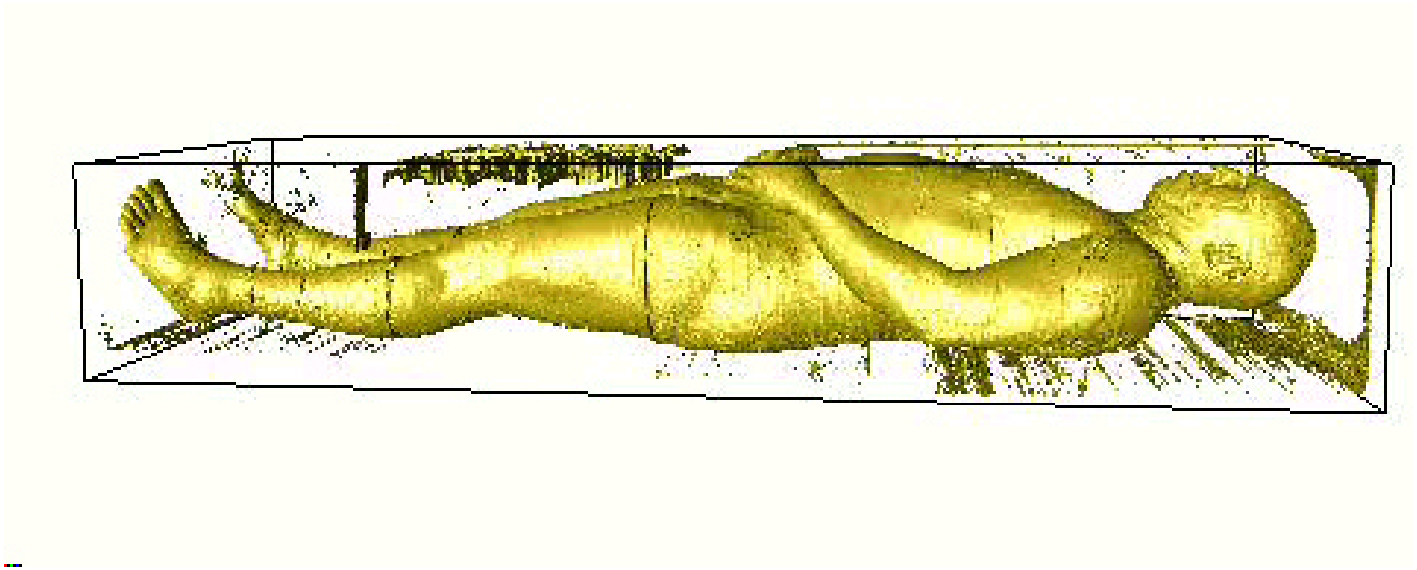
Multi-scale Oil Reservoir Modeling, Simulation, Visualization





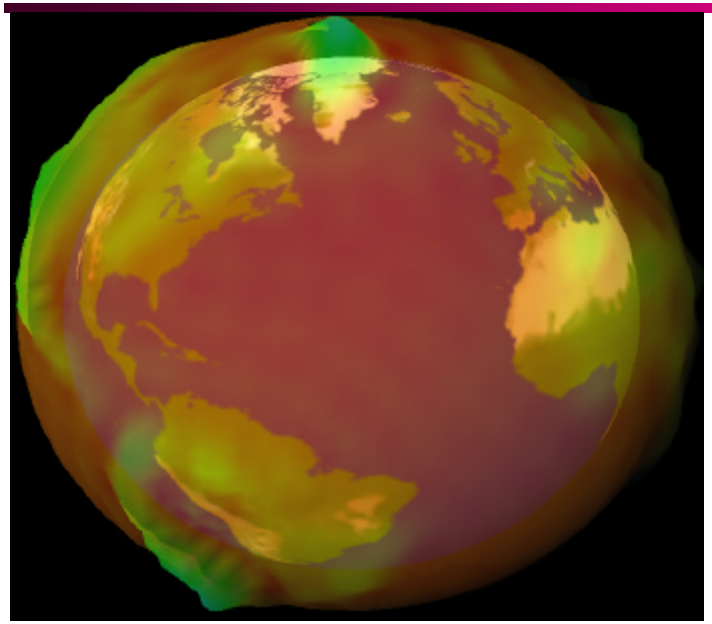


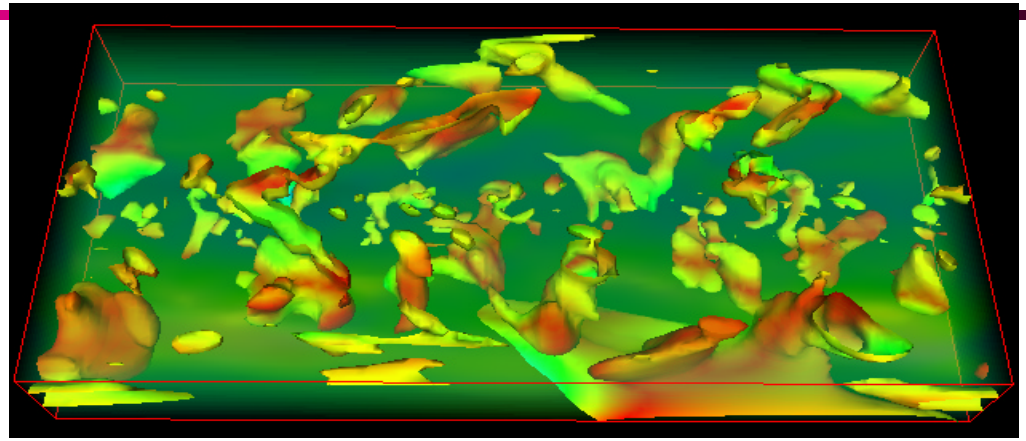
Motivation



Visible Human

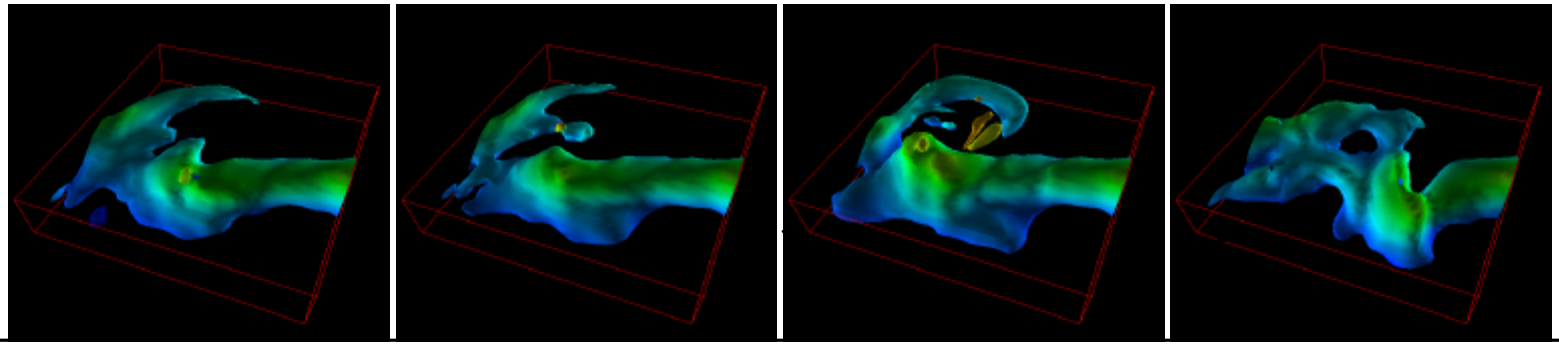
Motivation



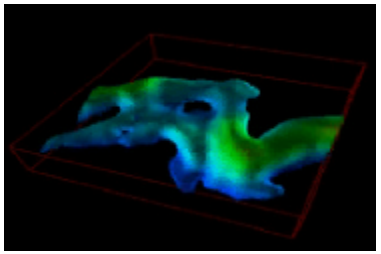


Regional Simulation

Combined Analysis



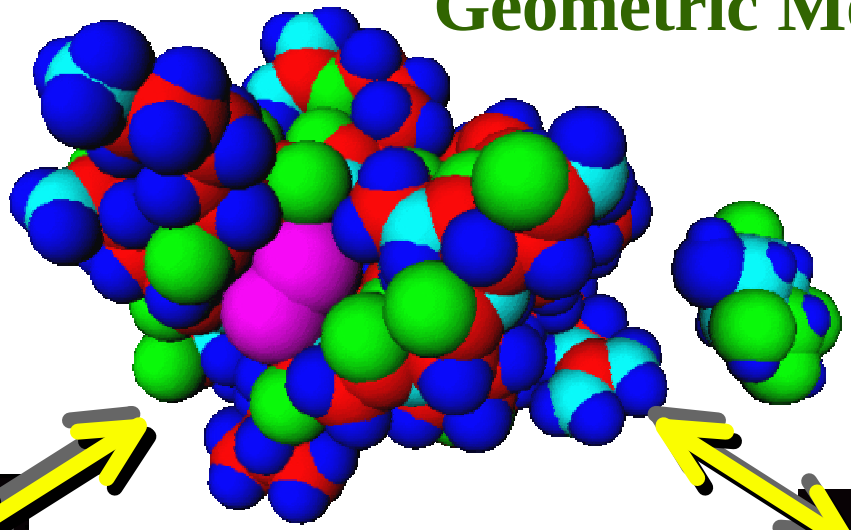
Time Evolution

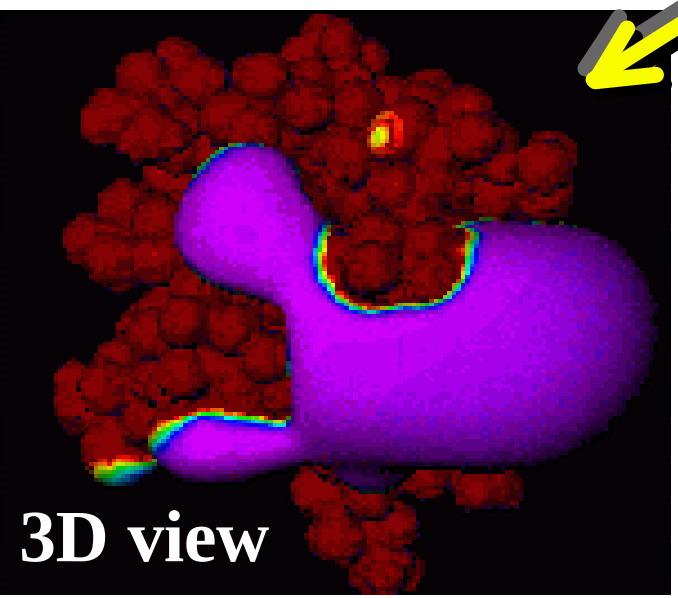


Community Climate Model

Motivation

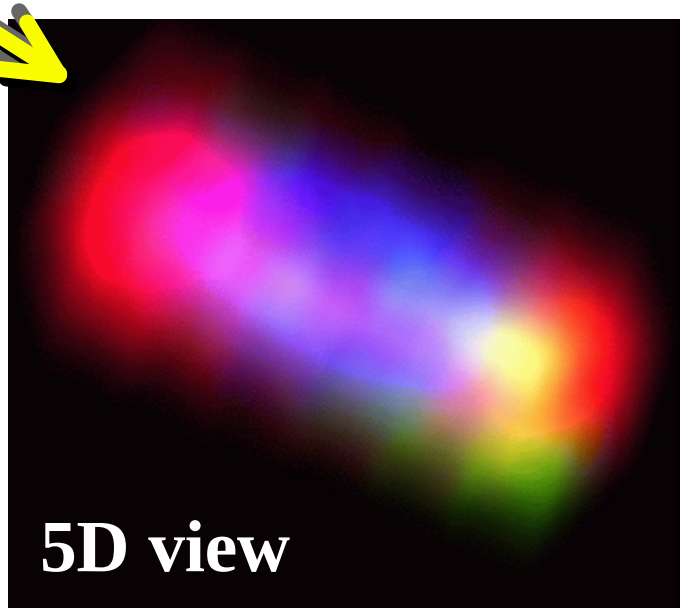
Geometric Model





3D view

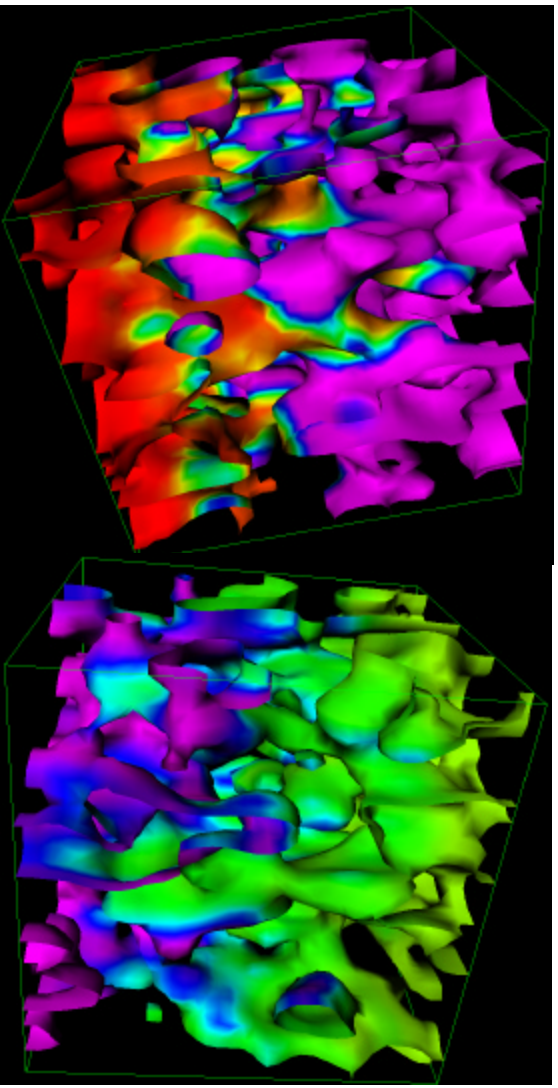
Molecular Interaction

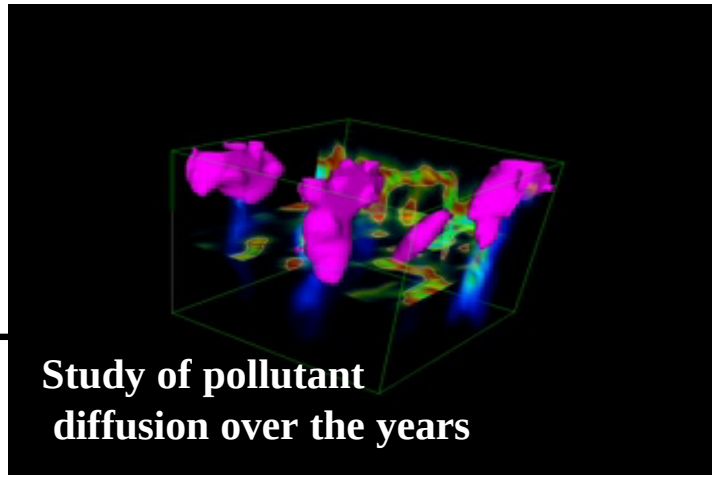


5D view

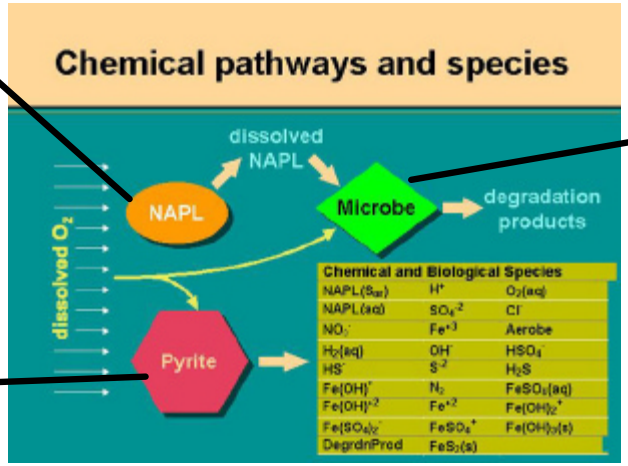
Motivation

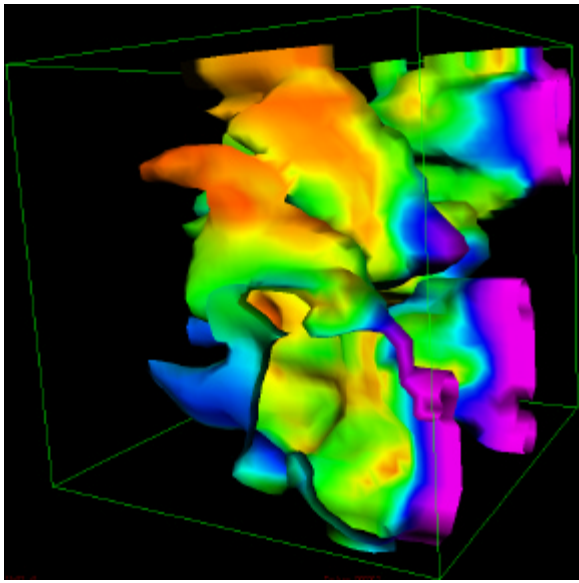
Multi-Scale Physical Simulation





Study of pollutant diffusion over the years

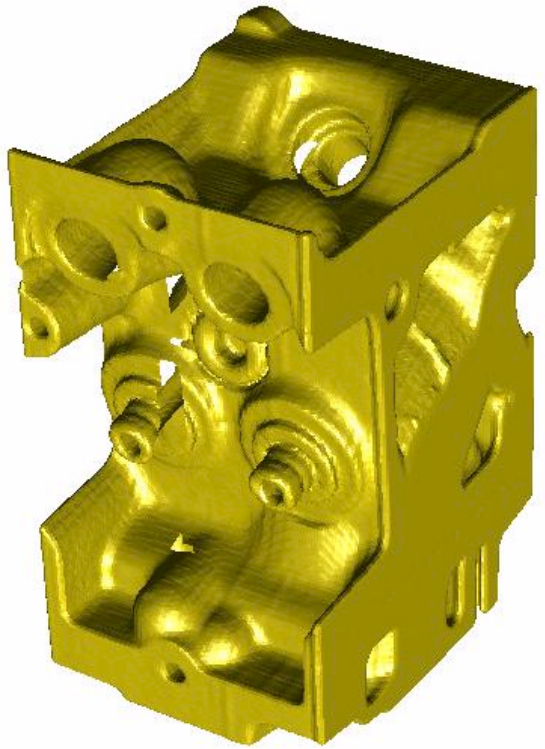




Core Technologies

Visualization/analysis techniques

- **Isocontouring**

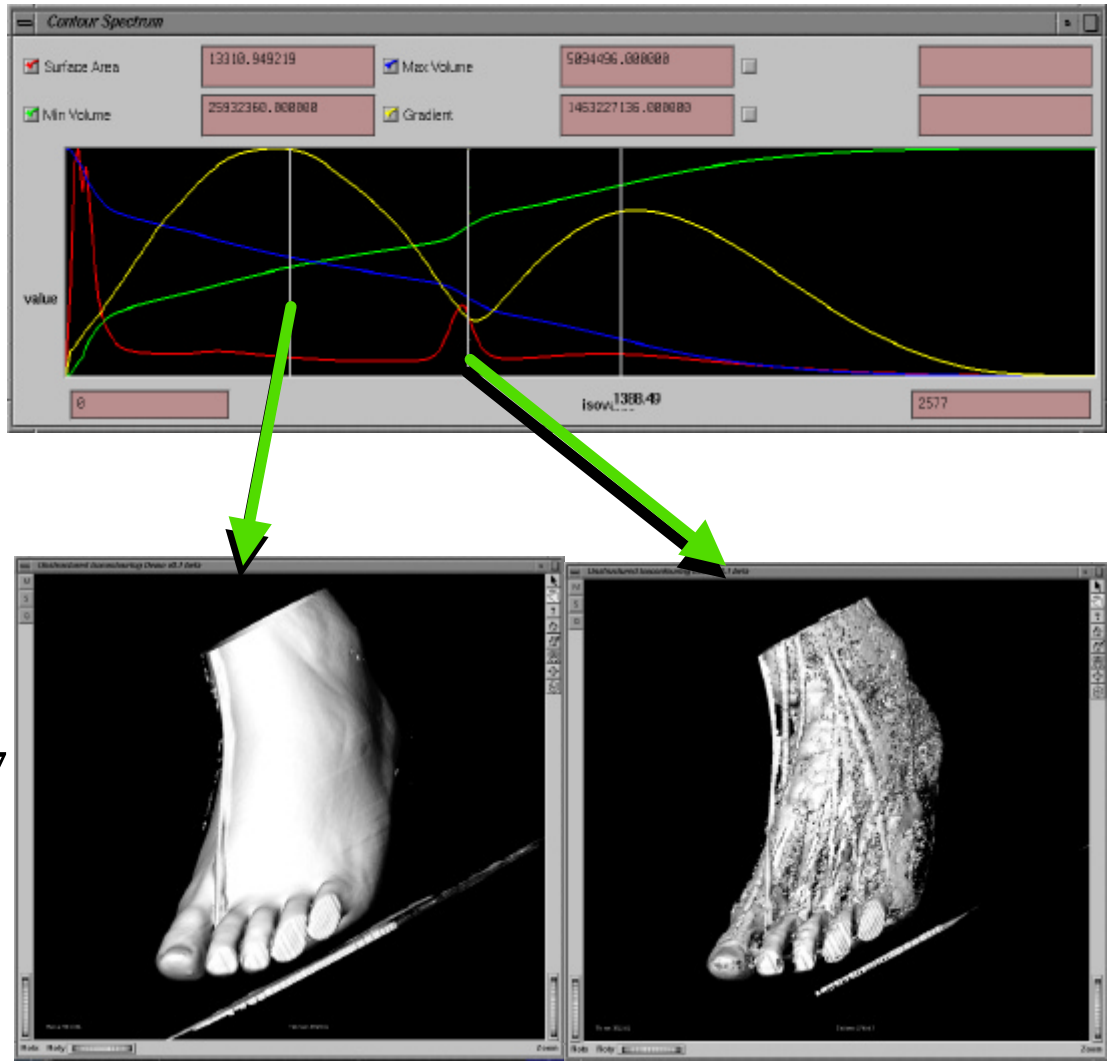


- IEEE Symposium on Volume Visualization, ‘96
- ACM Symposium on Computational Geometry, ‘97
- IEEE Symposium on Parallel Visualization and Graphics. ‘99
- IEEE Symposium on Volume Visualization, ‘00

Core Technologies

Visualization/analysis techniques

- Isocontouring
- Spectral analysis



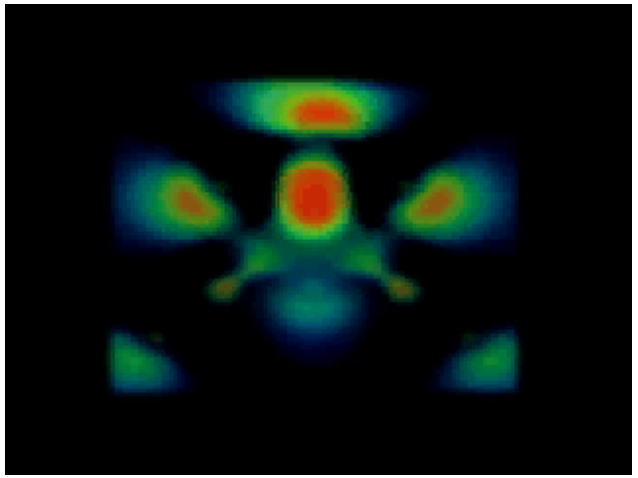
•IEEE Conference on Visualization, ’97

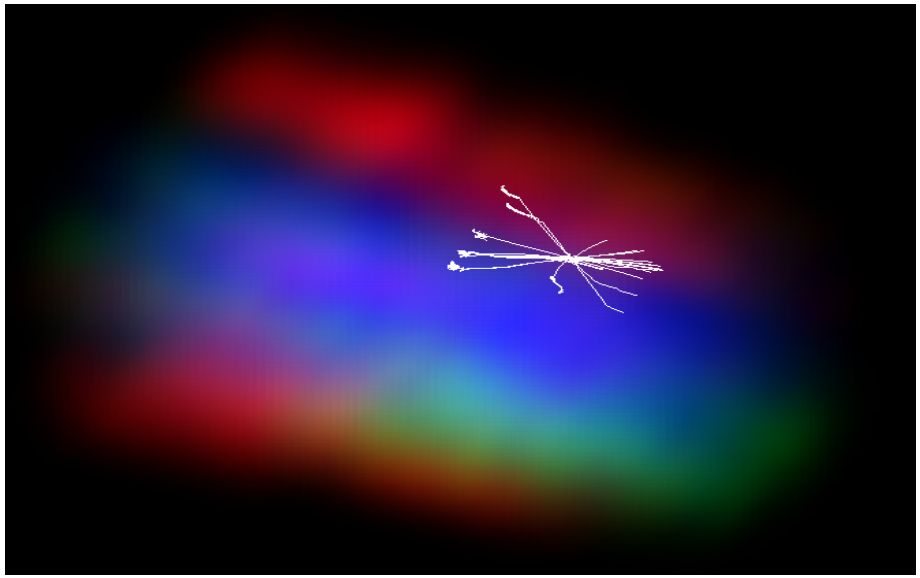
Core Technologies

Visualization/analysis techniques

- **Isocontouring**
- **Spectral analysis**
- **(Hyper)Volume rendering**

IEEE Symposium
on Volume Visualization, ‘98



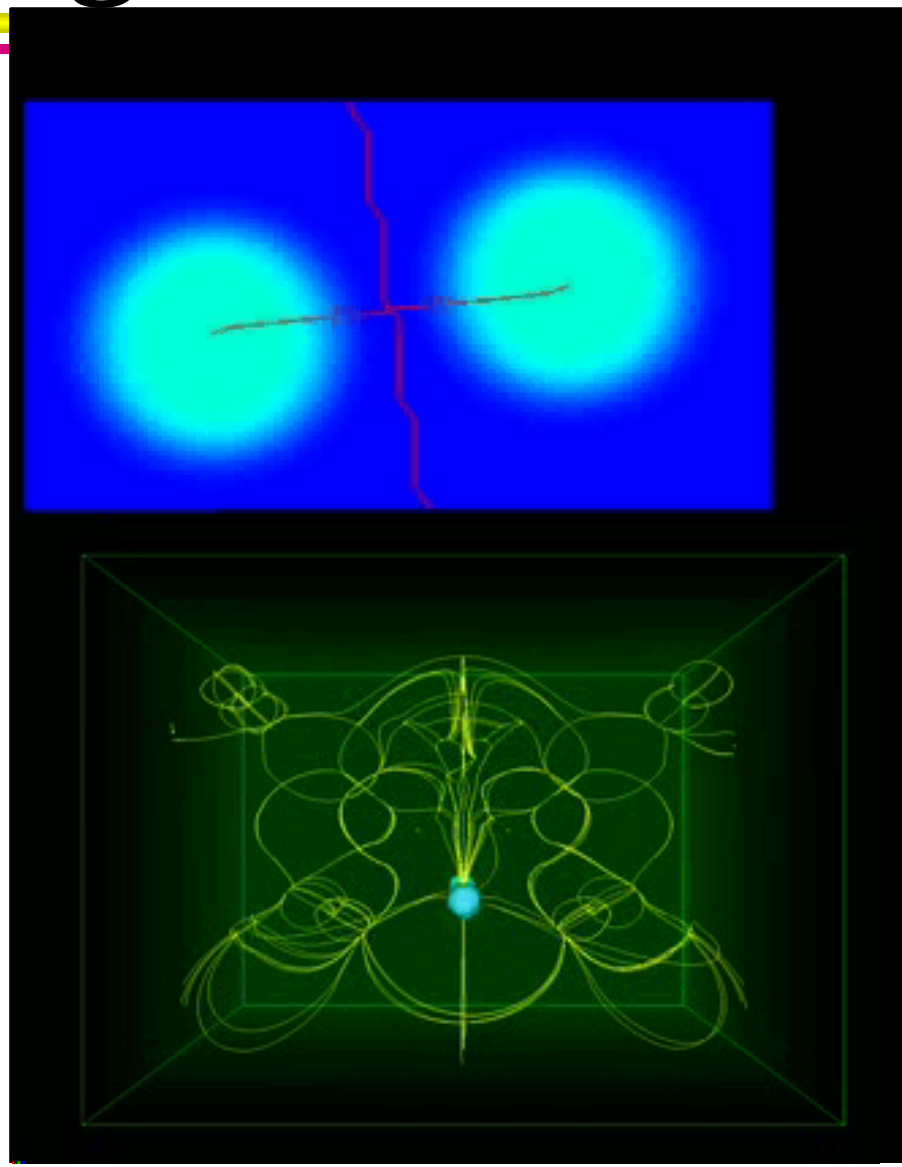


Core Technologies

Visualization/analysis techniques

- Isocontouring
- Spectral Analysis
- (Hyper)Volume Rendering
- Scalar Topology

IEEE Conference on Visualization, ‘98



Core Technologies

Visualization/analysis techniques

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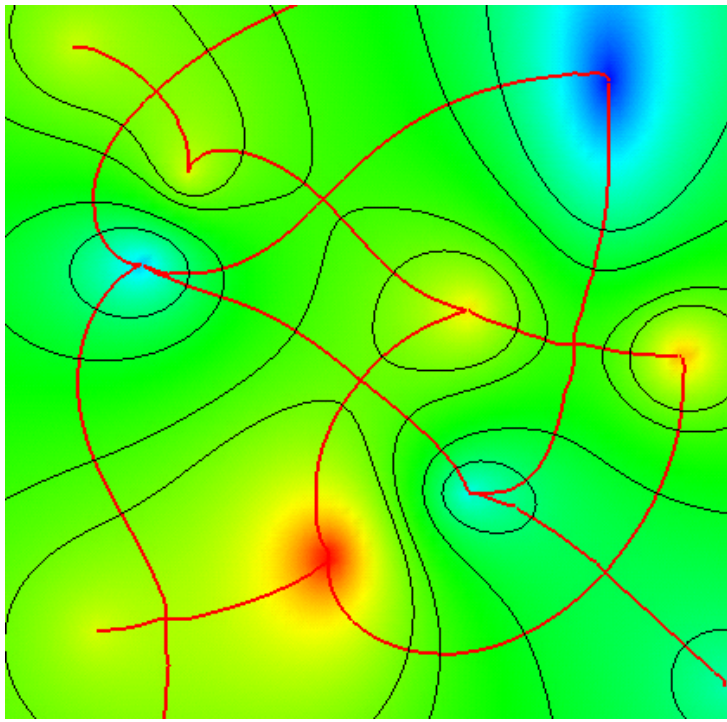
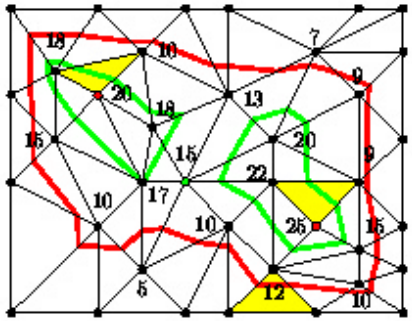
Algorithm/data-structure paradigms

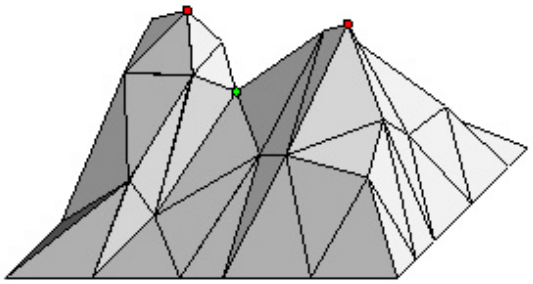
- Multi-resolution Representation
- Progressive algorithms
- Efficient encoding
- Static data analysis and partitioning

The Isocontour Computation Problem

- **Input:**
  - **Scalar Field *F* defined on a mesh**
  - **Multiple Isovalues *w* in unpredictable order**
- **Output (for each isovalue *w*):**
  Contour *C(w)* = {*x* | F(*x*) = *w*}







Related Work

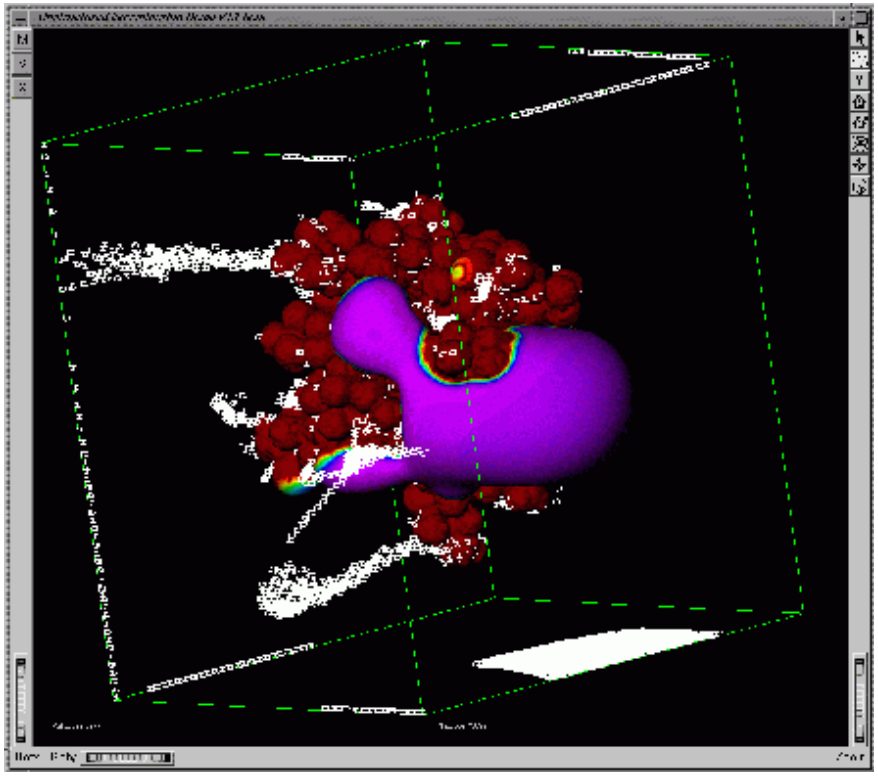
		Search Space	
		Geometric	**Value**
Contouring Strategy	**Cell by Cell**	Lorenson/Cline (Marching Cubes) Wilhelms/Van Gelder (octree)	Giles/Haimes (min-sorted ranges) Shen/Johnson (hierachical min-max ranges) Gallagher(span decomposed into backets) Livnat/Shen/Johnson (kd-tree) Shen/Livnat/Johnson/Hansen (LxL lattice) Cignoni/Montani/Puppo/Scopigno
	Mesh Propagation	Howie/Blake(propagation) Itoh/Koyamada (extrema graph) Itoh/Yamaguchi/Koyamada (volume thinnig)	van Kreveld Bajaj/Pascucci/Schikore van Kreveld /van Oostrum/Bajaj/ Pascucci/Schikore

Related Work

- Temporal Coherence
  Shen
- View Dependent
  Livnat/Hansen
- Adaptive
  Zhou/Chen/Kaufman
- Parallel (SIMD)
  Hansen/Hinker
- Parallel(cluster)
  Ellsiepen
- Out-of-core
  Chiang/Silva/Schroeder
- Parallel ray tracing
  Parker/Shirley/Livnat/
  Hansen/Sloan
- Parallel & Out-of-core
  Bajaj/Pascucci/
  Thompson/Zhang
- Temporal-coherence
  Sutton/Hansen

Optimal Single-Resolution Isocontouring

Seed set of a 3D scalar field



Progressive Isocontouring

We have an optimal isocontouring algorithm with minimal storage requirements

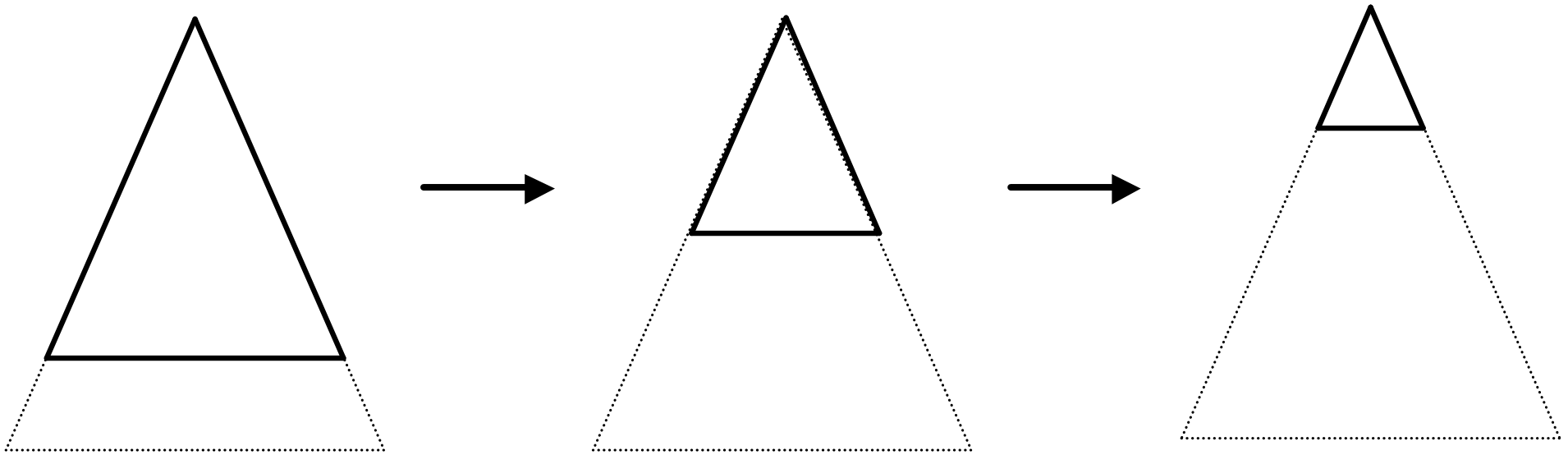
What more?

A Progressive Algorithm

N.B. not just a progressive data-structure but a progressive algorithm

Progressive Isocontouring

cascaded multi-resolution on-line algorithms

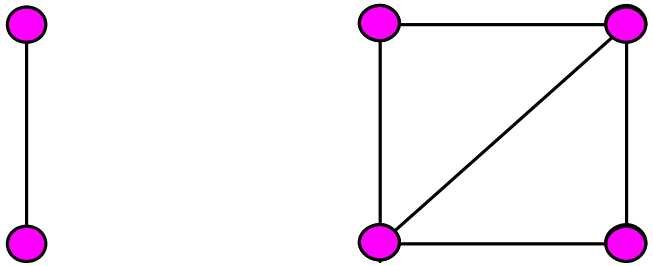


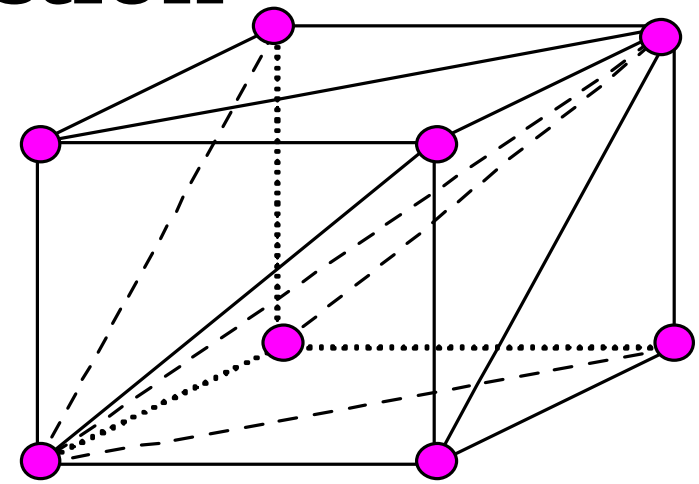
Progressive Isocontouring

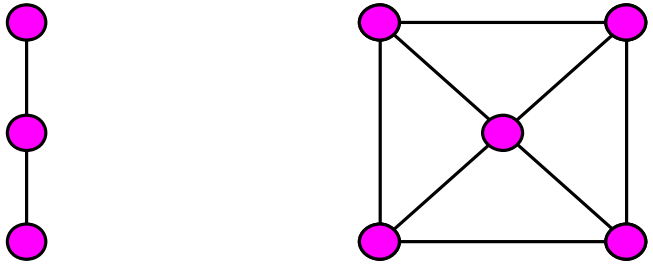
- Input:
  - hierarchical mesh (e.g. generated by edge bisection)
  - an isovalue
- Output:
  - a hierarchical representation of the required isosurface
  - the input mesh must be traversed from the coarse level to the fine level
  - as the input mesh is partially traversed the output contour hierarchy must be generated

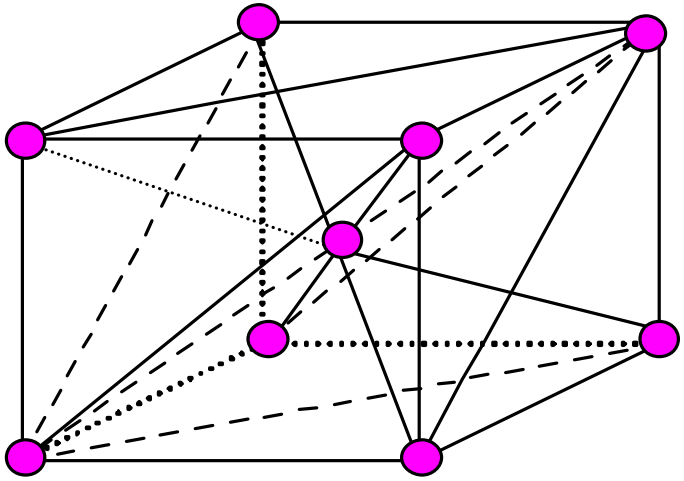
Progressive Isocontouring

Edge Bisection



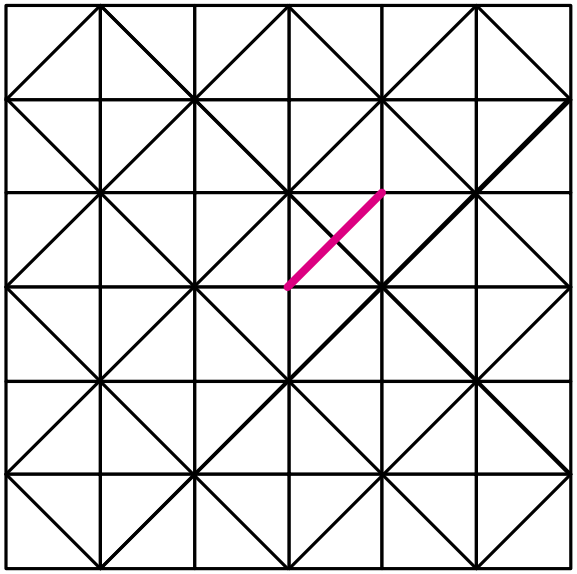


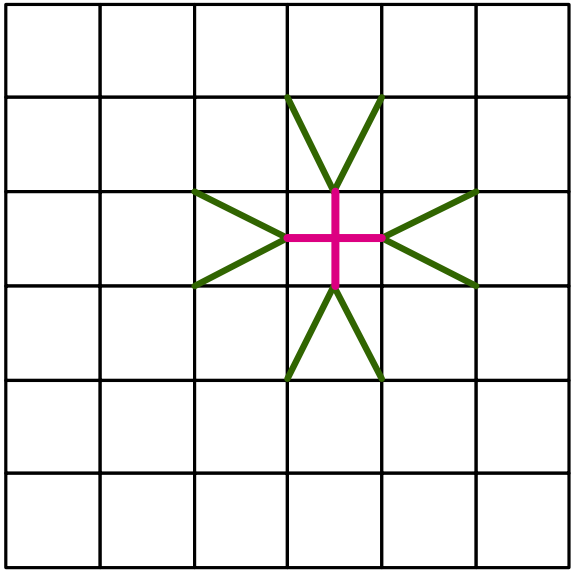




Progressive Isocontouring

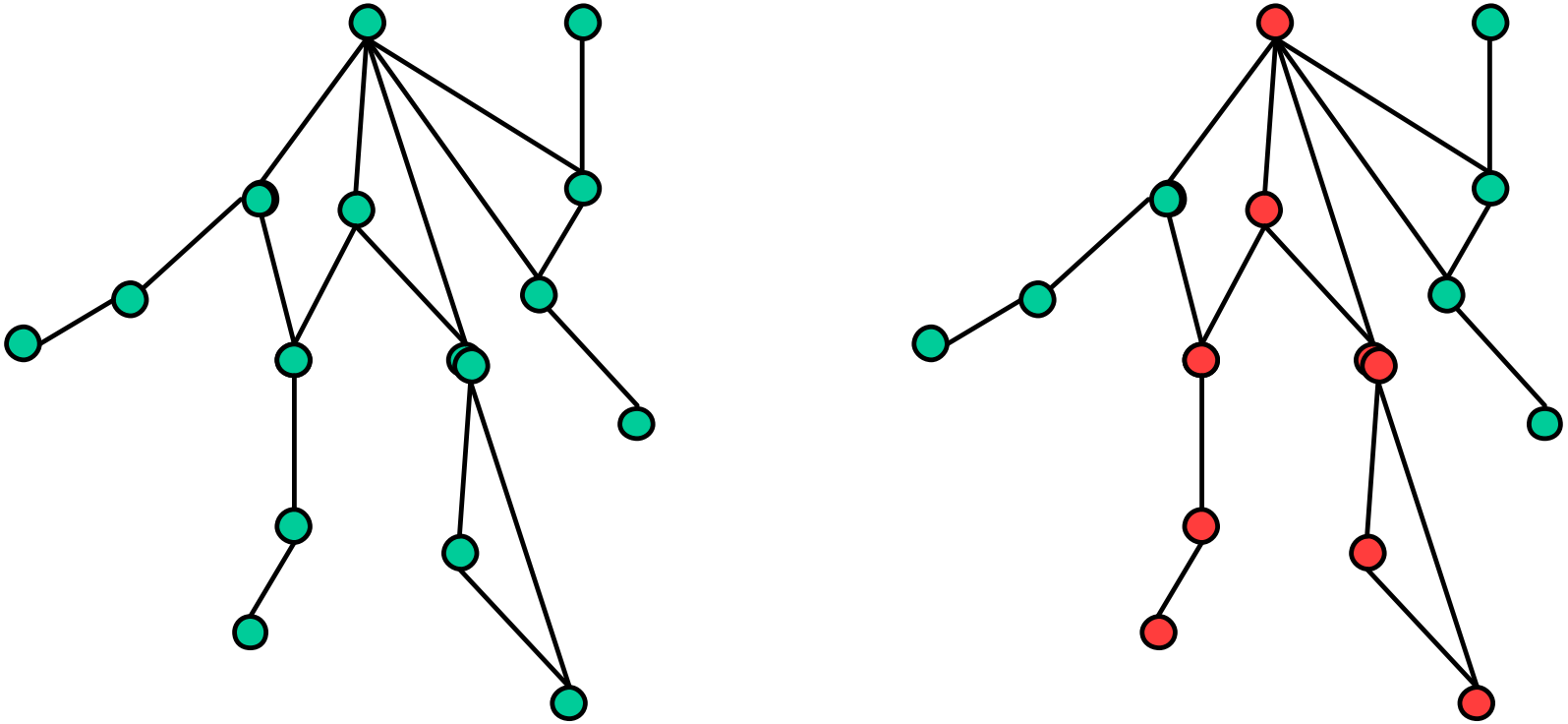
- **Local refinement:**
  only the cells incident to the split edge are refined.
- **Adaptivity without “temporary” subdivision.**





Progressive Isocontouring

The output hierarchy is a subgraph of the input hierarchy



Progressive Isocontouring

Correctness

Any adaptive resolution isocontour has consistent embedding in 3D space (no self intersections)

Progressive Isocontouring

Efficiency

(input size *n* balanced,output size *k*)

Very Large Output

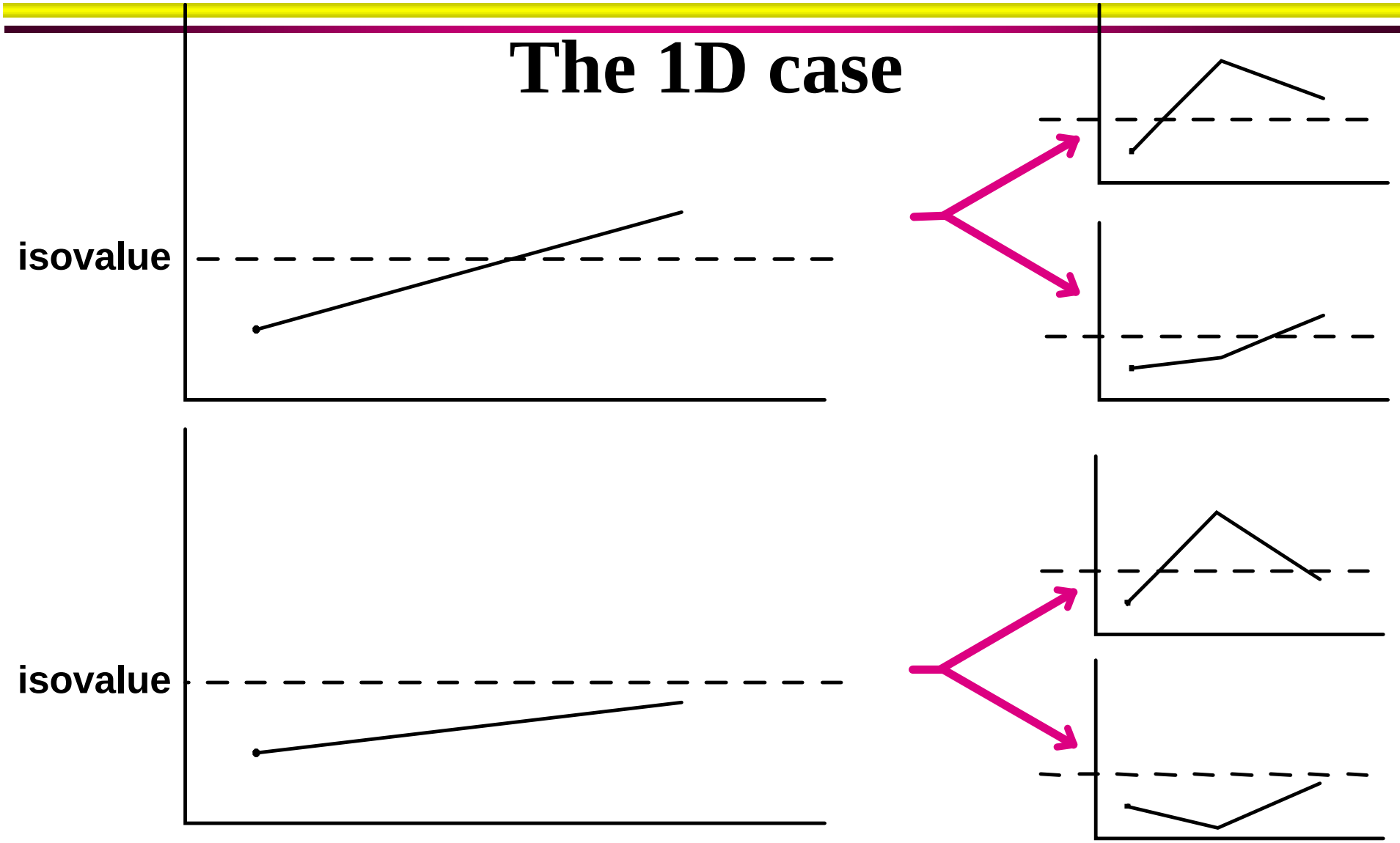
If the isocontour has size $k = Q(n)$ its hierarchy size and computation time are $O(k)$

Large Output

If the isocontour has size $k = O(n^h)$, with $h<1$, its hierarchy size and computation time are $O(k \log k)$

Progressive Isocontouring

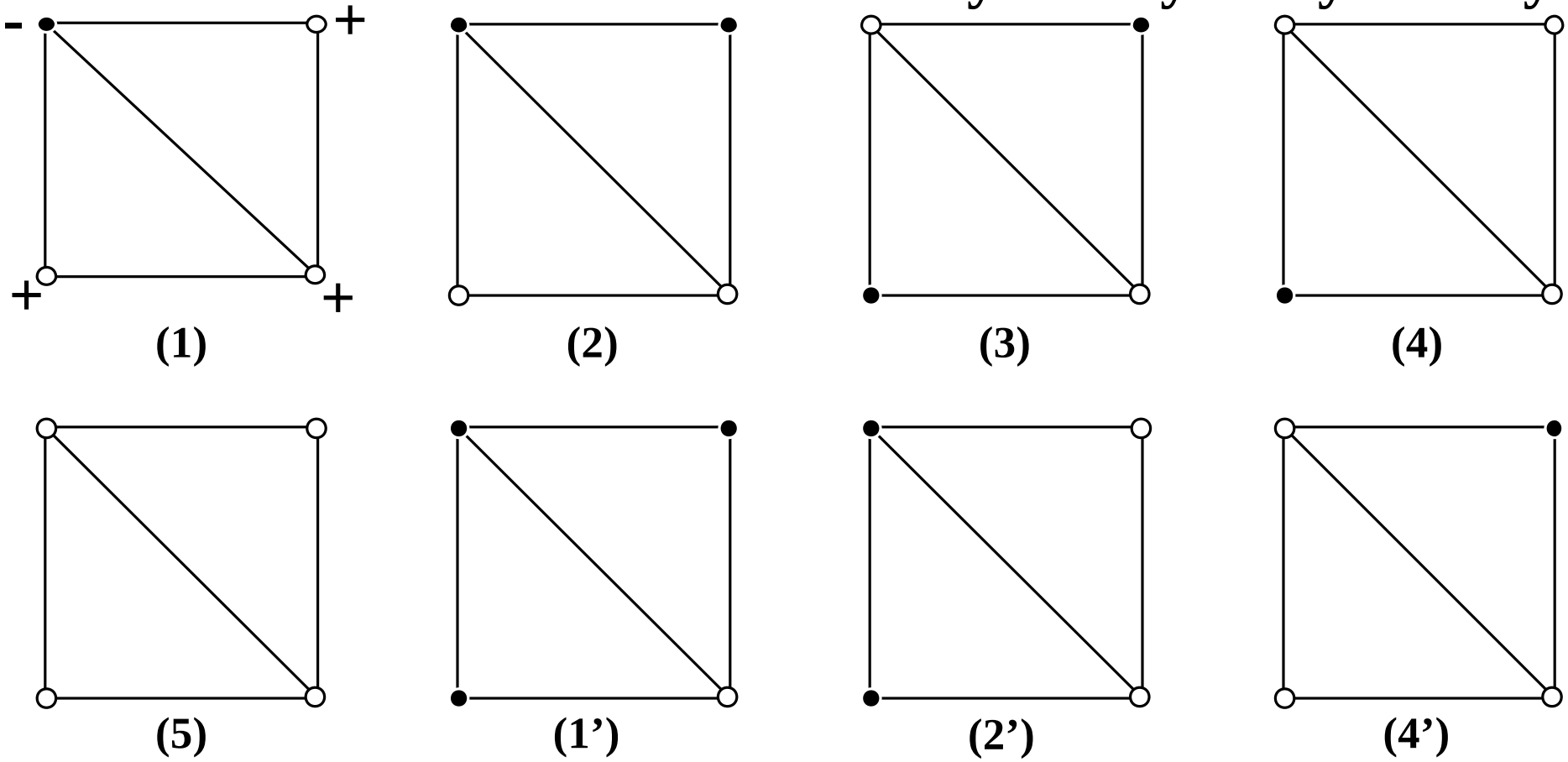
The 1D case



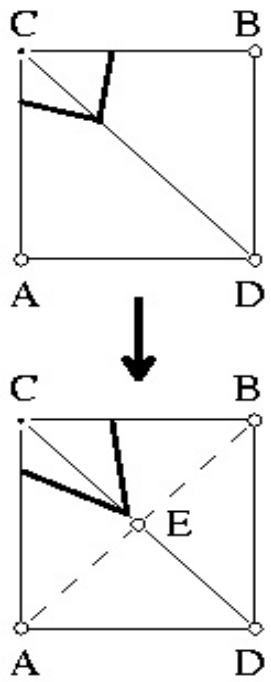
Progressive Isocontouring

2D case

16 cases can be reduced immediately to 8 by +/- symmetry

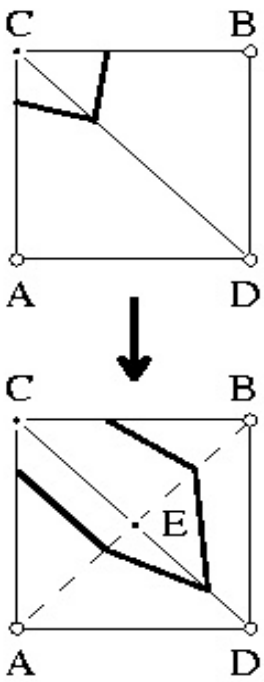


Progressive Isocontouring



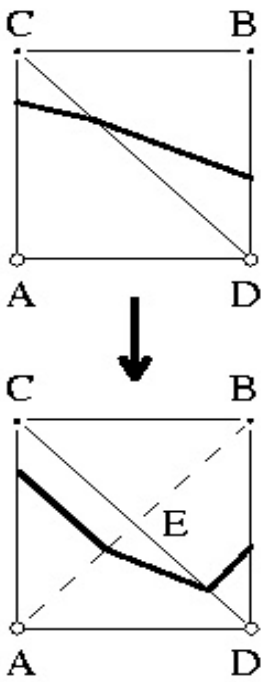
- Vertex Move

(1)



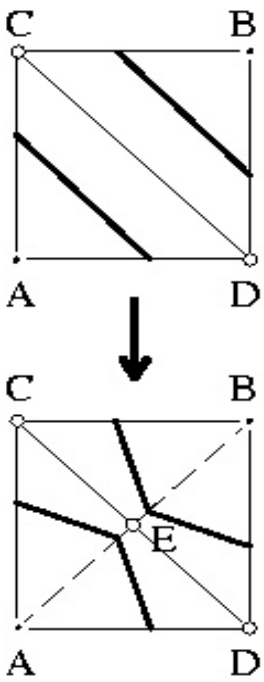
- Vertex Move
- Vertex Split
- Vertex Split

(1)



- Vertex Move
- Vertex Split

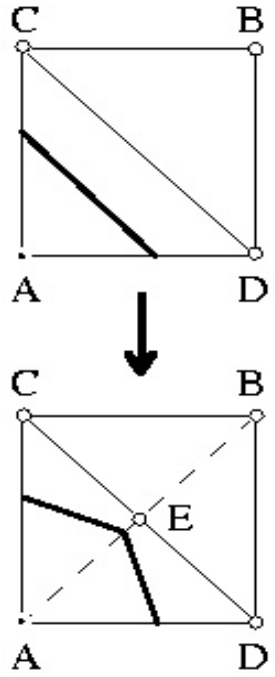
(2)



- Vertex Split
- Vertex Split

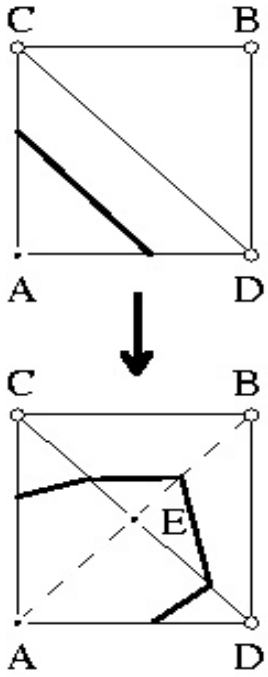
(3)

Progressive Isocontouring



- Vertex Split

(4)



- Vertex Split
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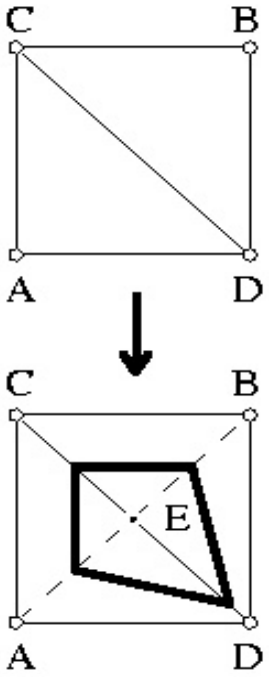
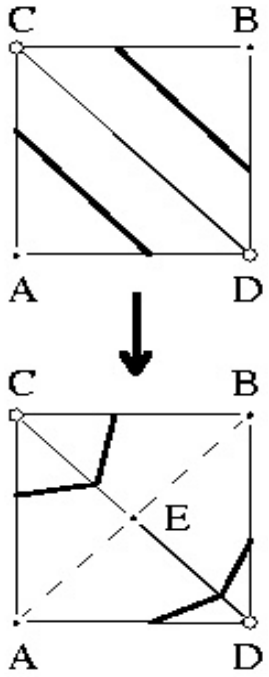
- Vertex Split

(4)



- **New Loop**

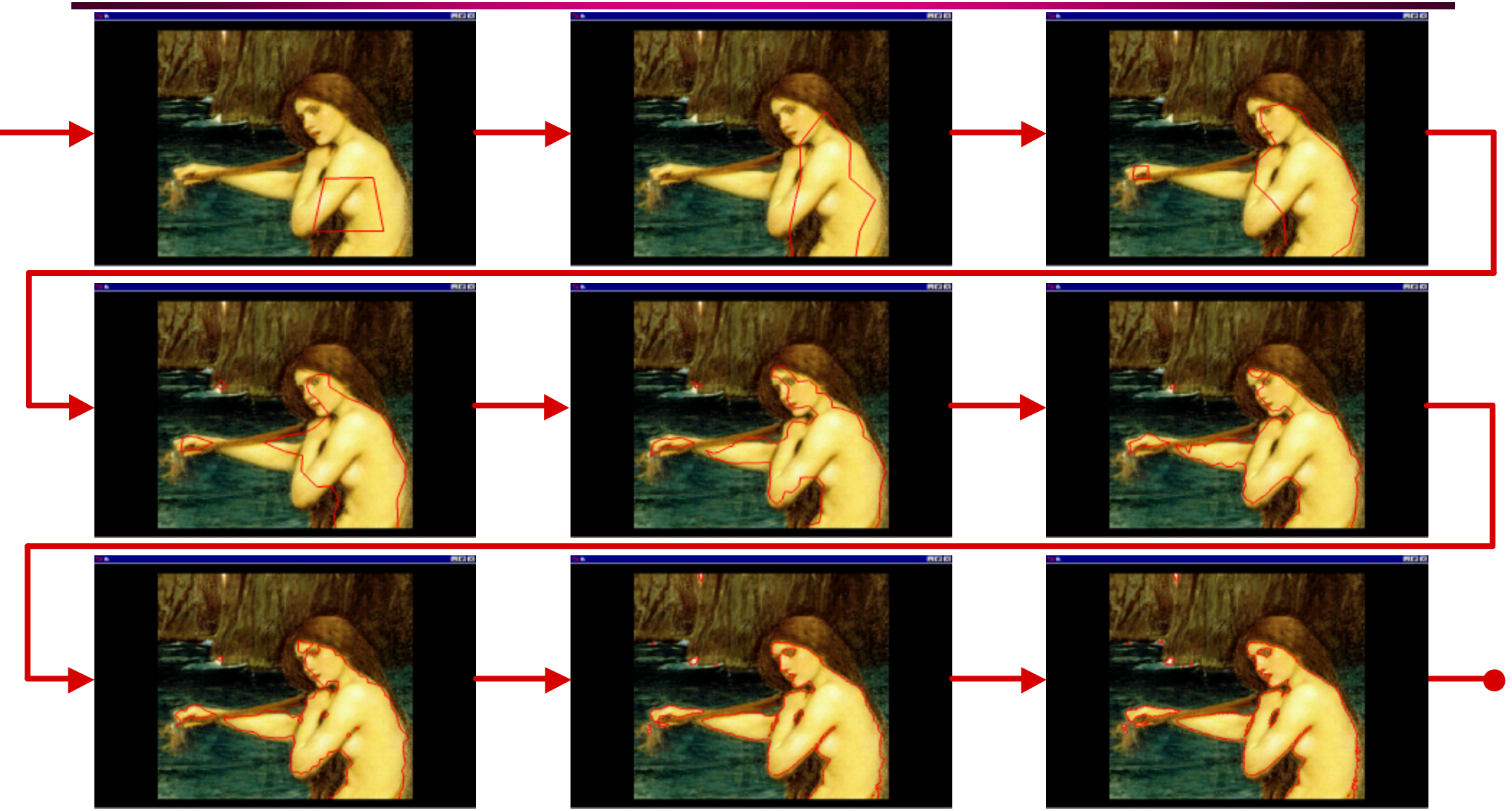
(5)



- **Edge Flip**
- Vertex Split
- Vertex Split

(3)

Progressive Isocontouring



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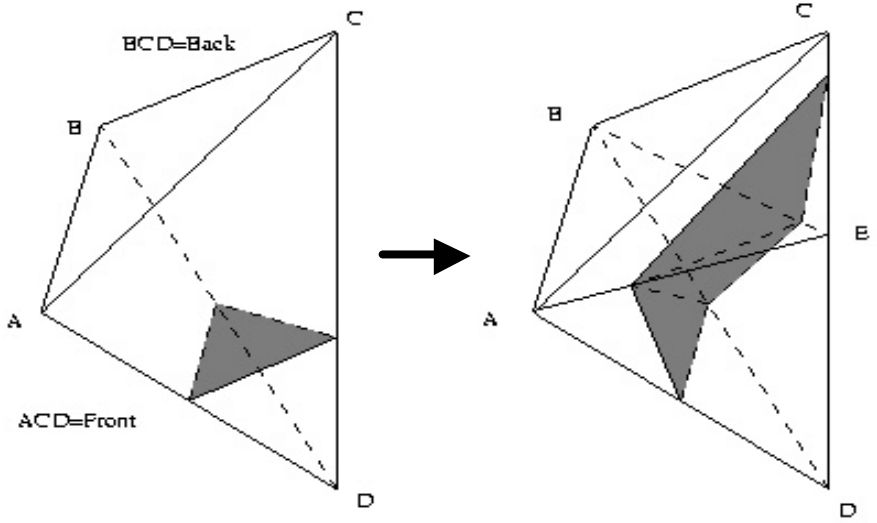
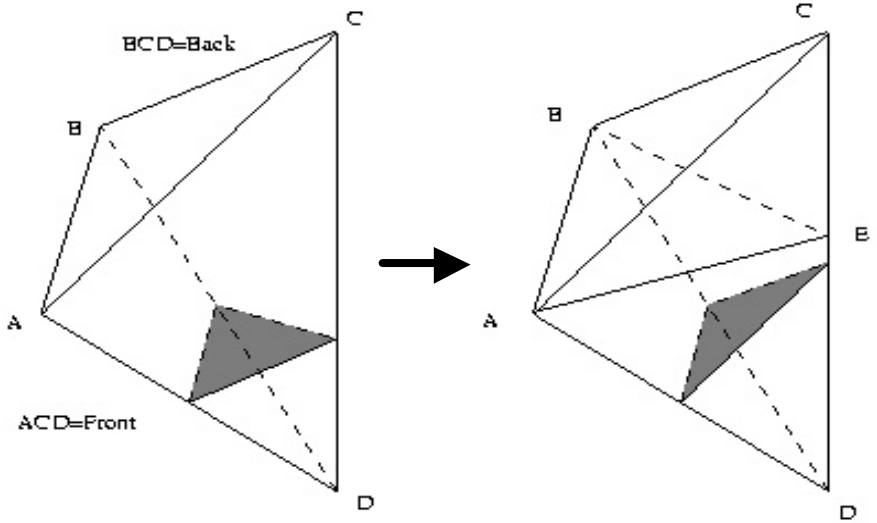
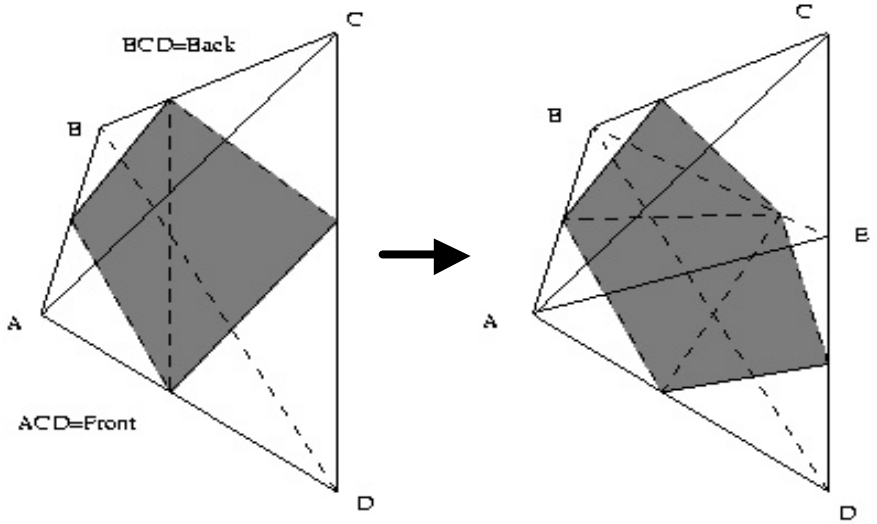


- Vertex Move
- Vertex Split
- Vertex Split



- Vertex Move

Progressive Isocontouring



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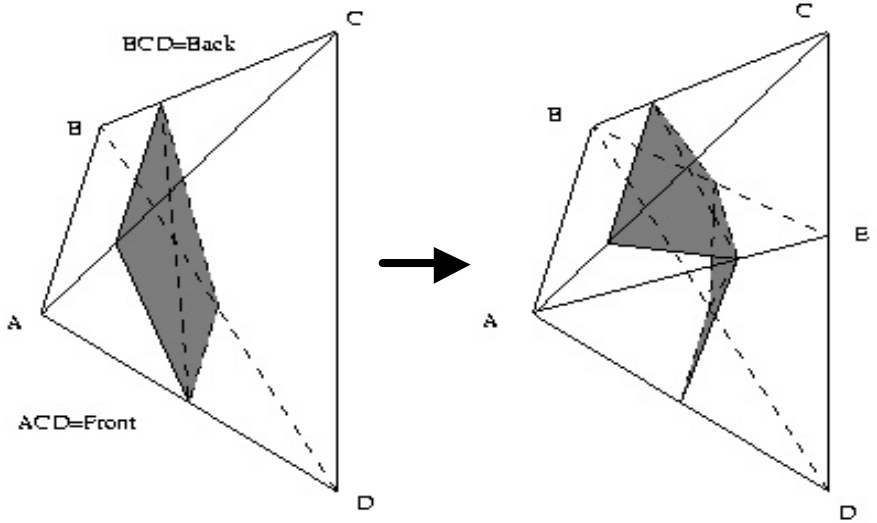

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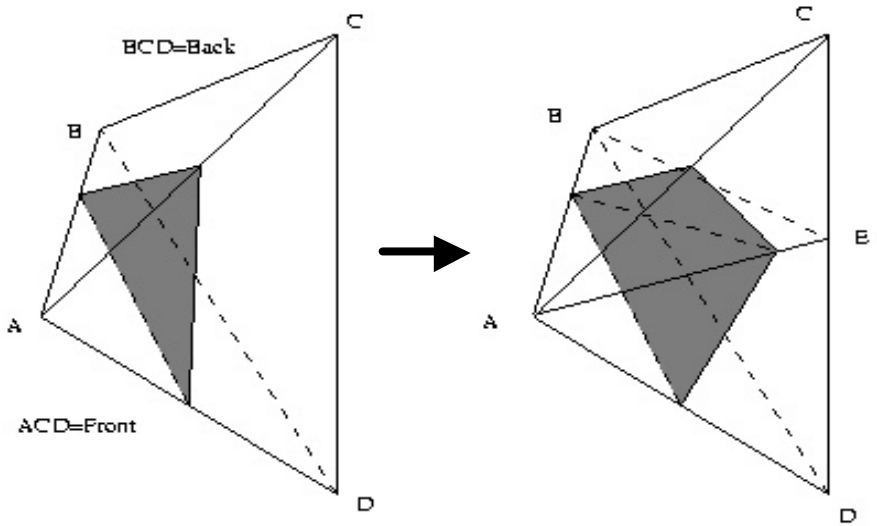
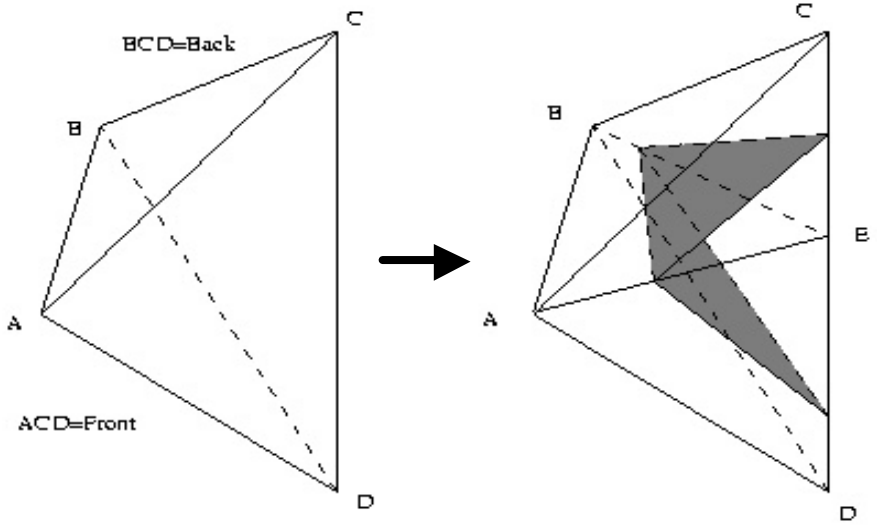
Progressive Isocontouring

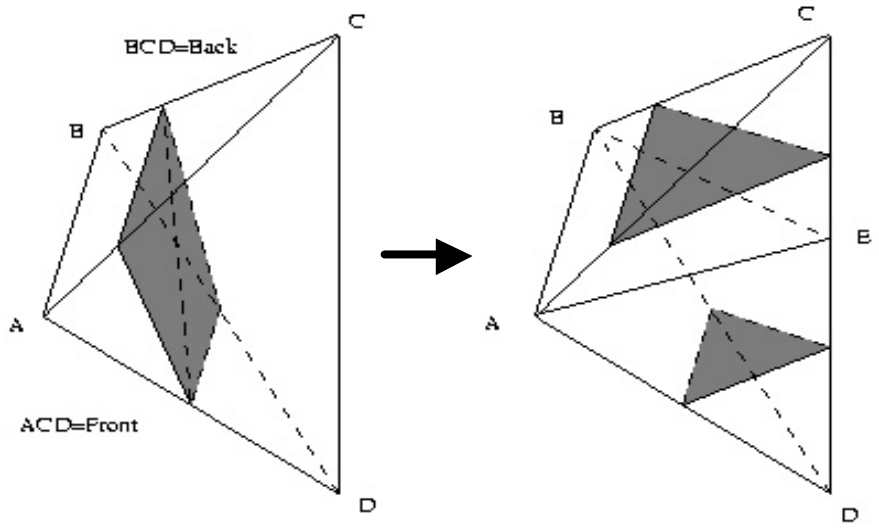


- Vertex Split

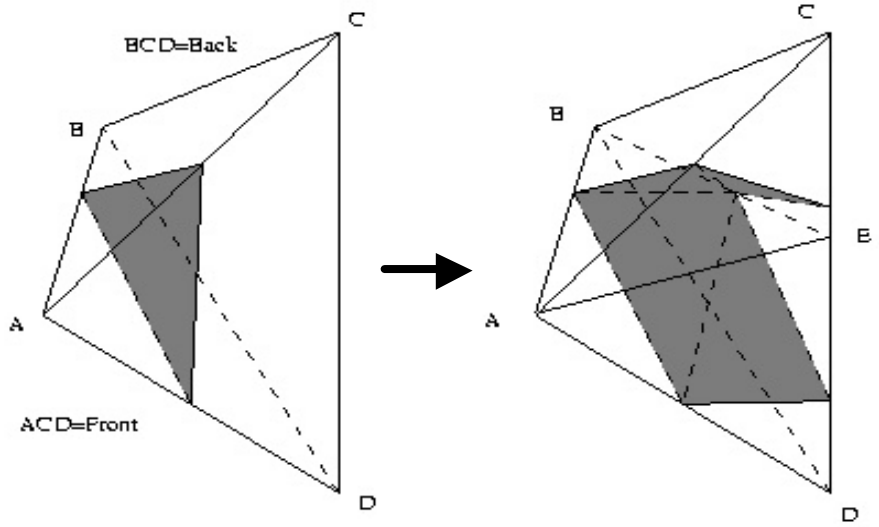


- New Loop
- Vertex Split

Progressive Isocontouring

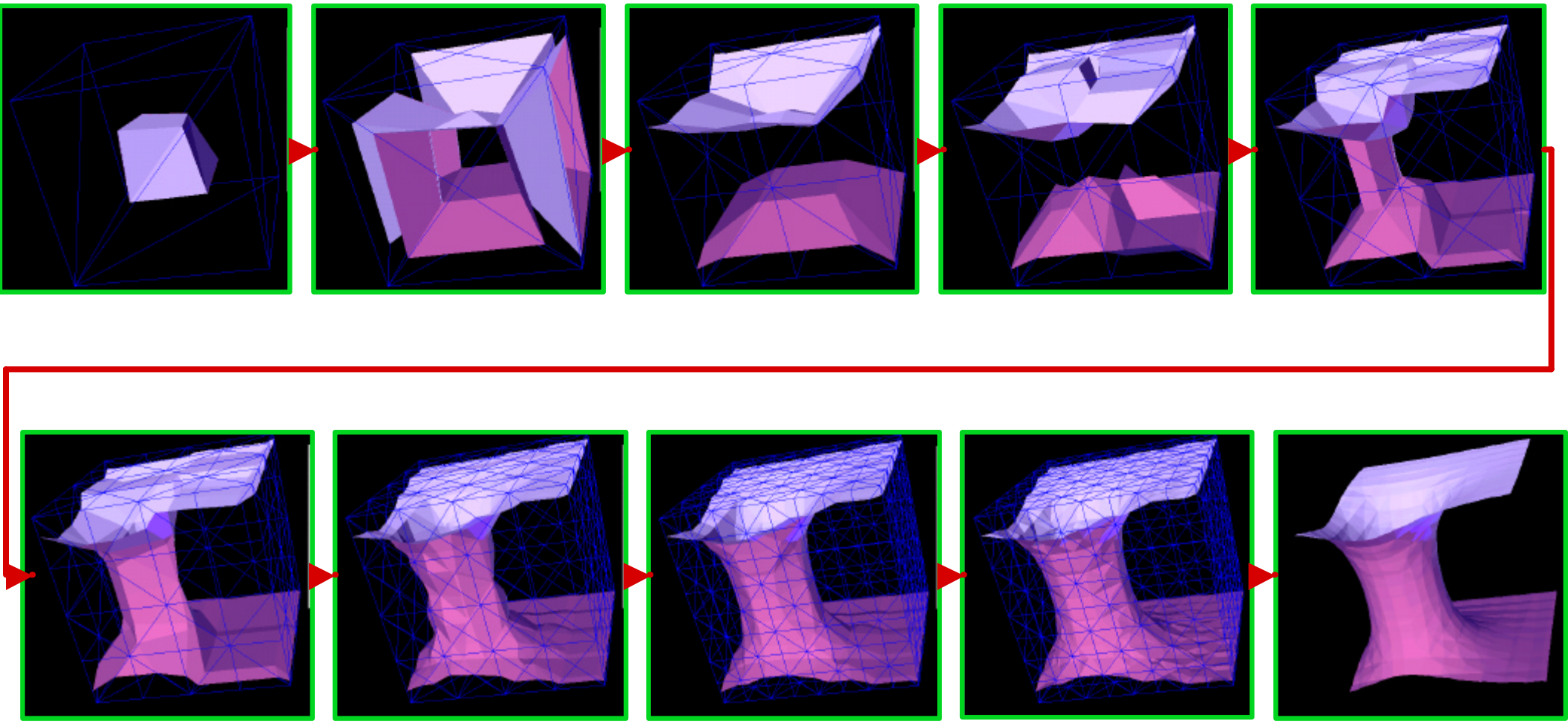


- Vertex Flip
- Vertex Flip

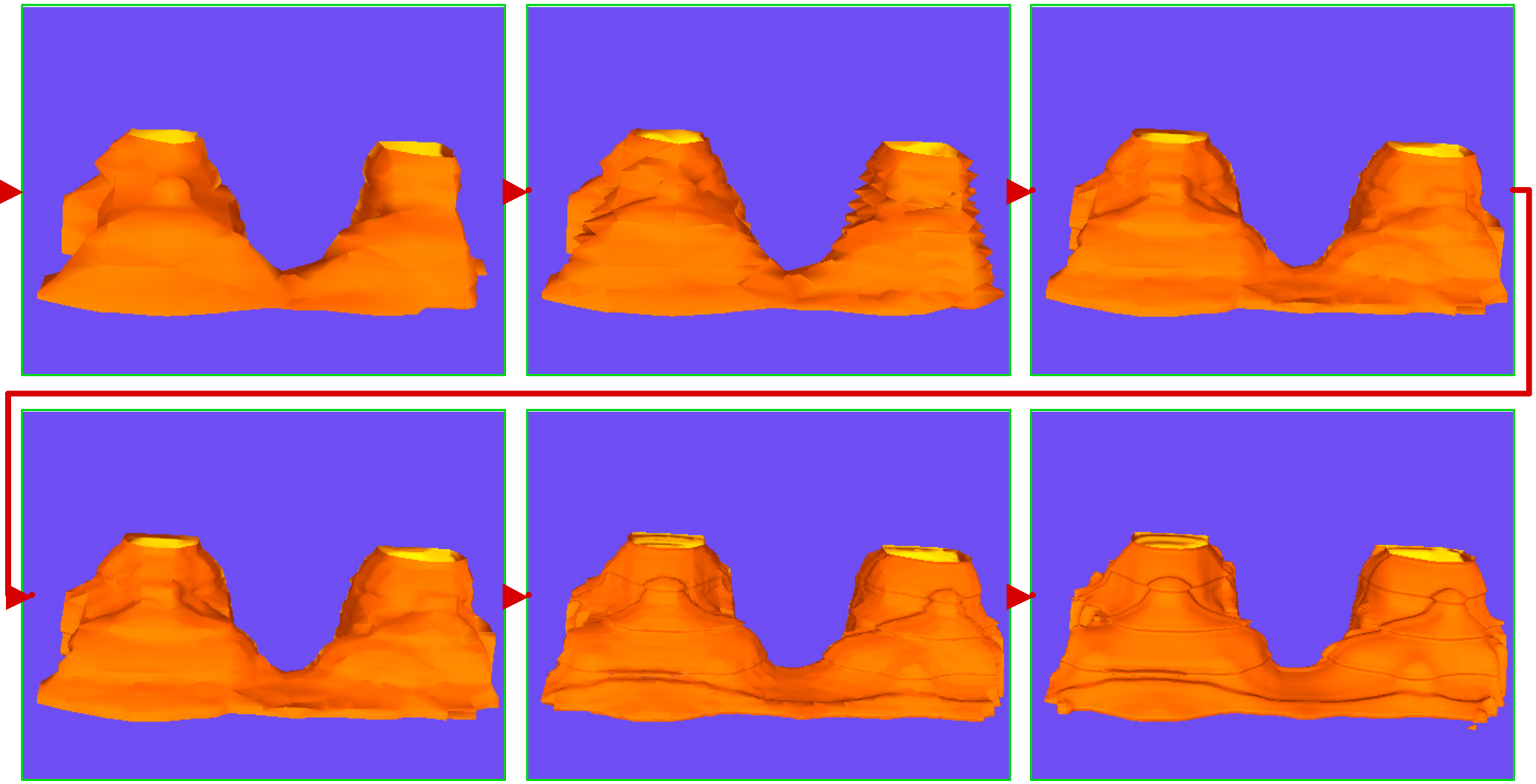


- Vertex Split
- Vertex Split
- Vertex Split

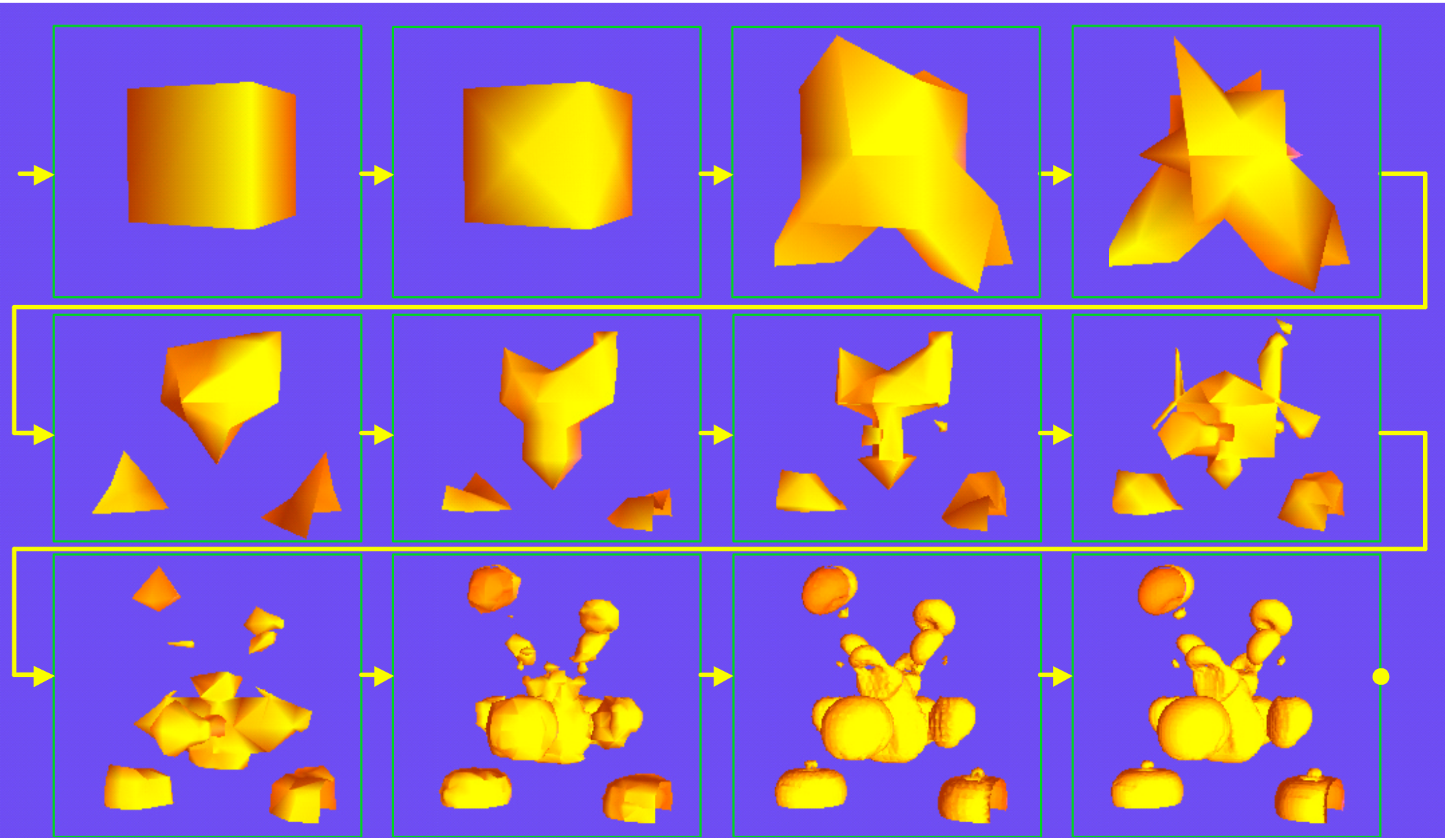
Progressive Isocontouring



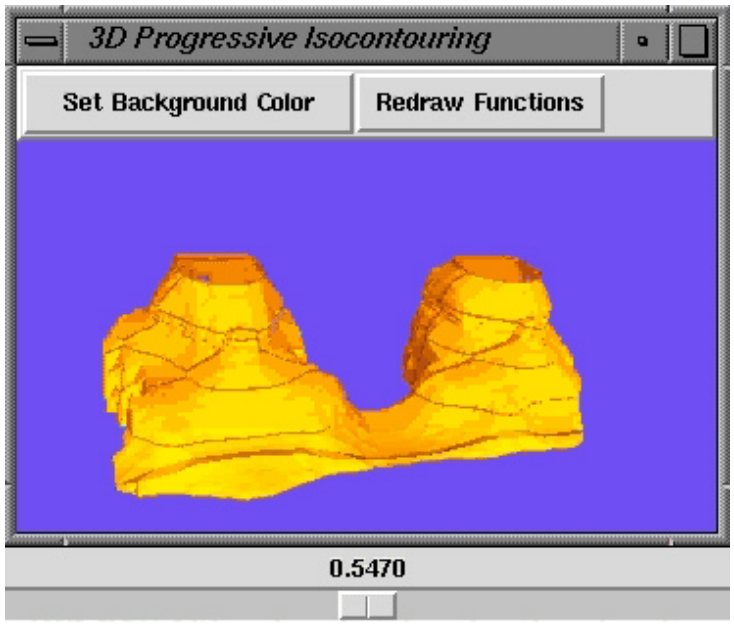
Progressive Isocontouring

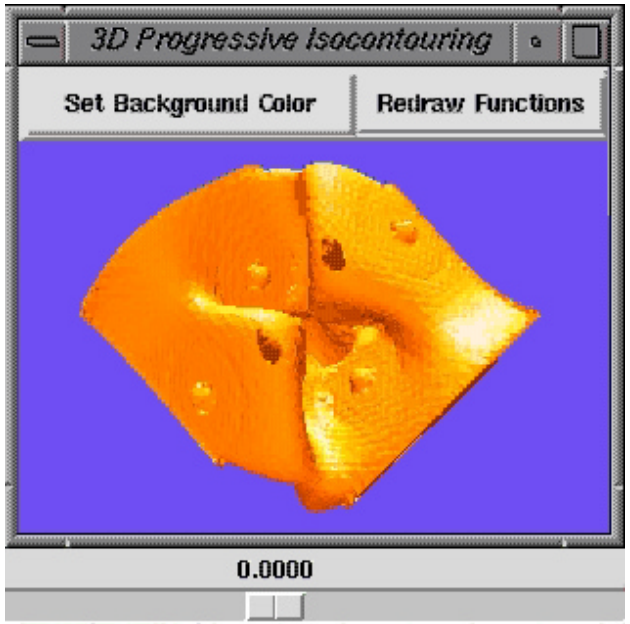


Progressive Isocontouring



Progressive Isocontouring





Conclusions

- First exercise done

To do

- View dependent progressive traversal
- Combination of progressive with parallel/out-of-core
- Build progressively a higher quality hierarchy
- Apply the same techniques to other class of algorithms (rendering, meshing, data analysis,…)