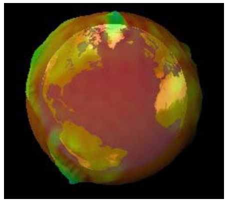
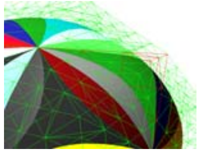
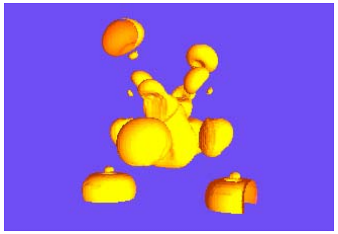


Computational Visualization

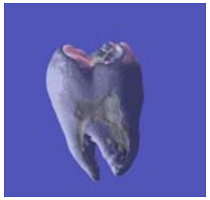
1. Sources, characteristics, representation

2. Mesh Processing

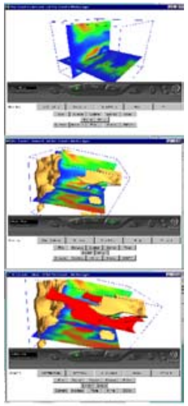




3. Contouring



4. Volume Rendering



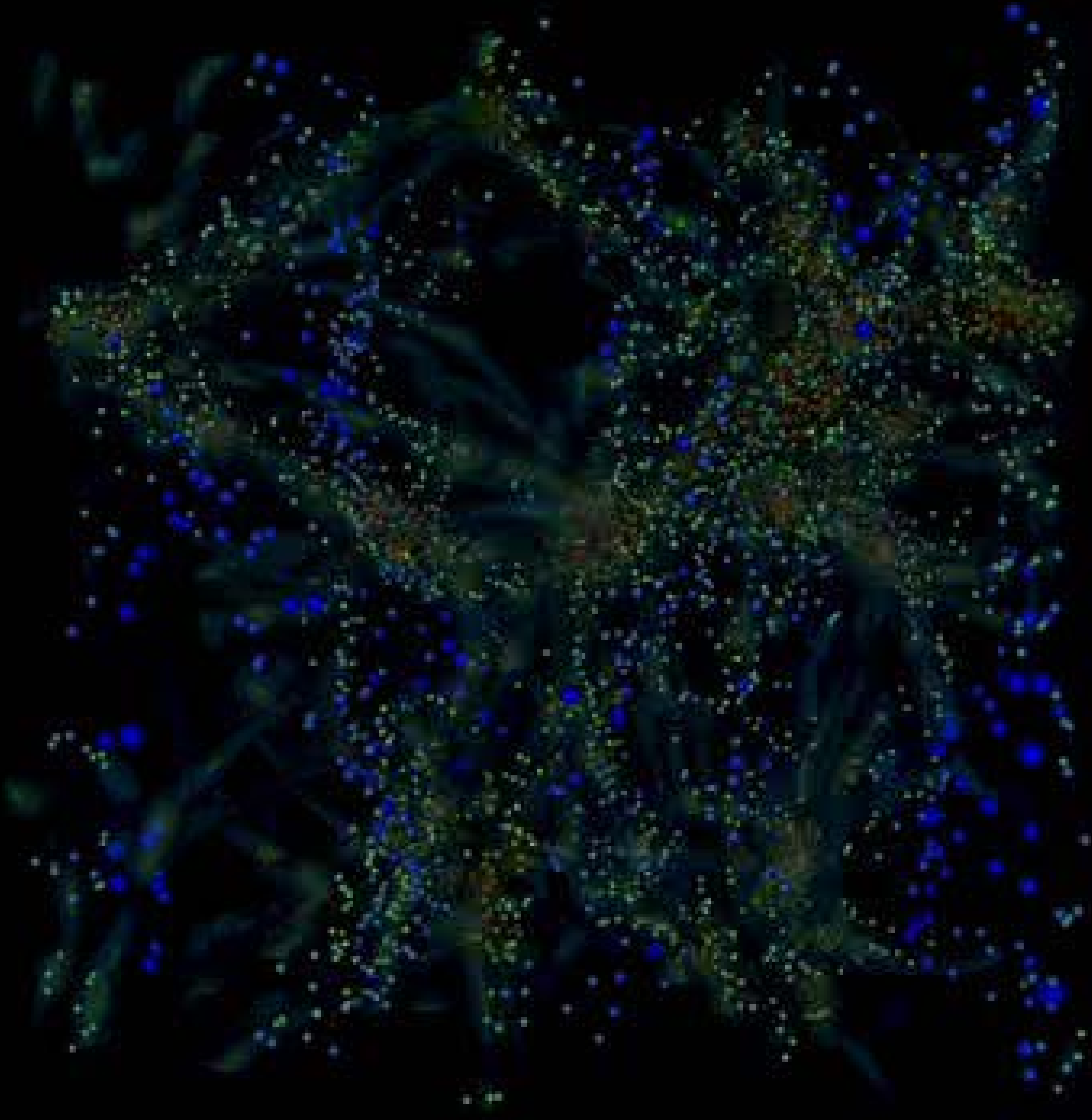
5. Flow, Vector, Tensor Field Visualization
6. Application Case Studies

Computational Visualization:
Contouring

Lecture 3

Outline

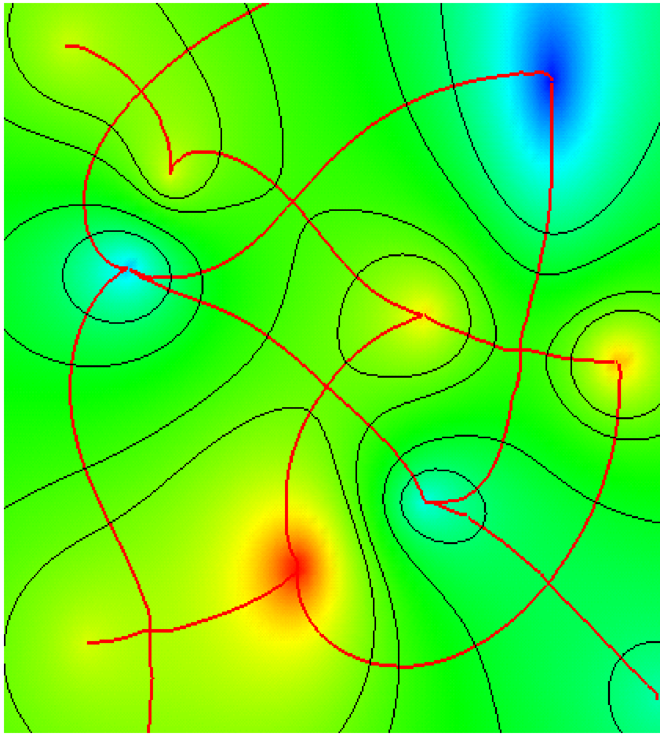
- Primal vs Dual
- Topology Look Up Table
- Seed Sets
- Spectrum for Isovalue Selection
- Progressive
- Time Varying

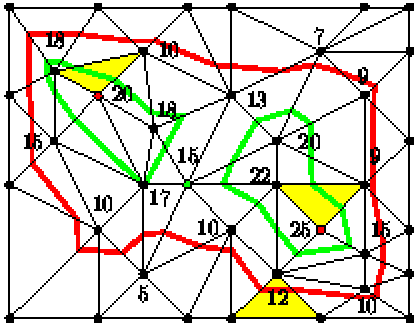


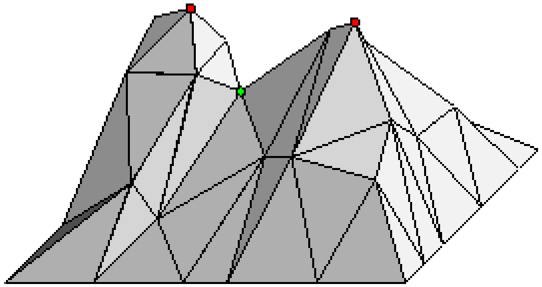
The Isocontour Computation Problem

– Input:
  - Scalar Field F defined on a mesh
  - Multiple Isovalues w in unpredictable order

– Output (for each isovalue w):
  Contour $C(w) = \{x \mid \mathbf{F}(x) = w\}$







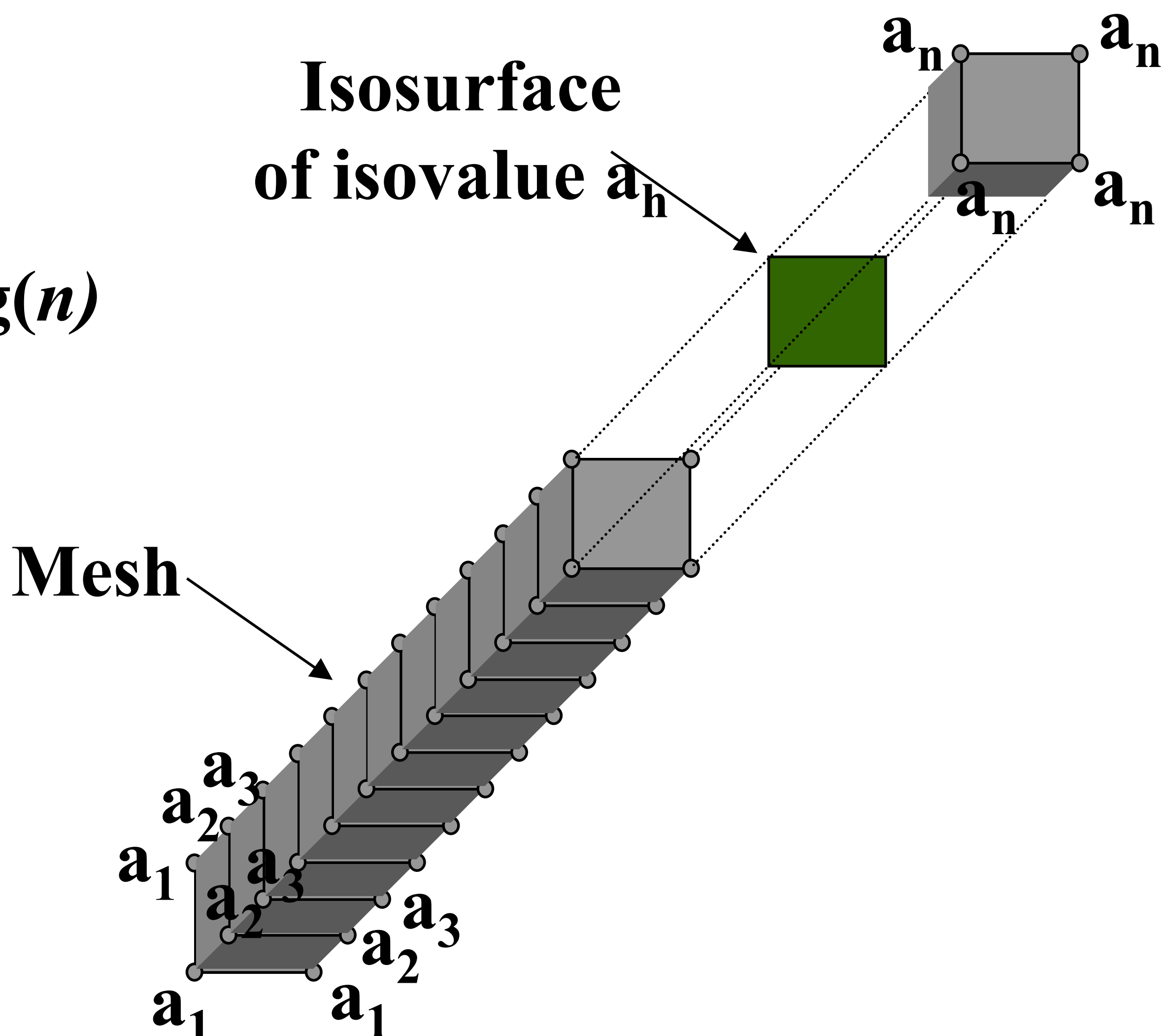
The Isocontour Computation Problem

Lower Bound

$$\left.\begin{array}{l}\text{Input size } n \\ \\ \text{Output size } m\end{array}\right\} m+\log(n)$$

The search for a_h takes at least $\log(n)$

$a_1, a_2, a_3, a_4, \ldots, a_n$



Related Work

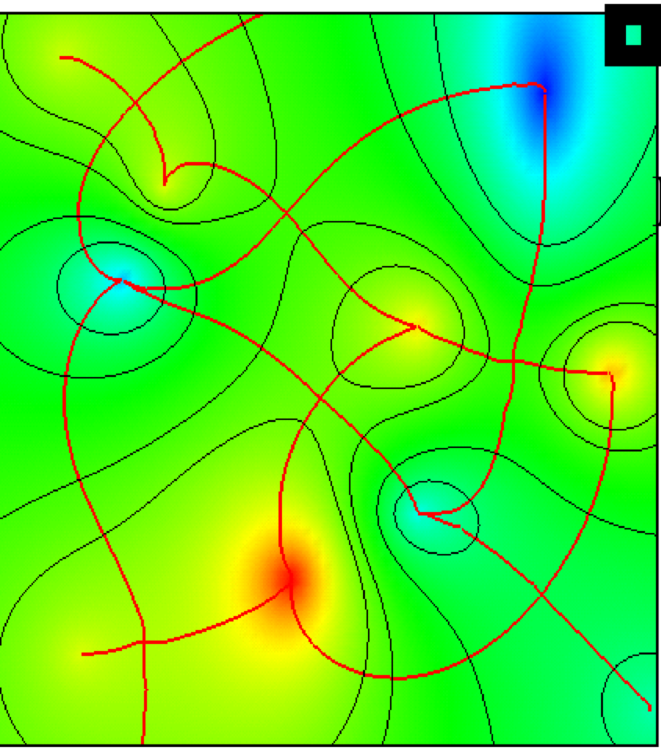
		Search Space	
		Geometric	Value
Contouring Strategy	Cell by Cell	Lorenson/Cline (Marching Cubes) Wilhelms/Van Gelder (octree)	Giles/Haimes (min-sorted ranges) Shen/Livnat/Johnson/Hansen (LxL lattice) Gallagher(span decomposed into backets) Shen/Johnson (hierachical min-max ranges) Cignoni/Montani/Puppo/Scopigno Livnat/Shen/Johnson (kd-tree)
	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
  -Zhang/Bajaj
  -Zhang/Bajaj/Ramachandran
- **Temporal-coherence**
  Sutton/Hansen

Optimal Single-Resolution Isocontouring

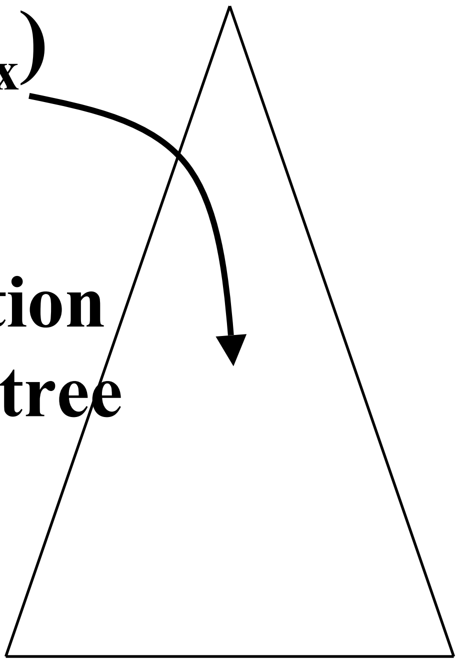
<u>The basic scheme</u>



Preprocessing: (f_{min}, f_{max})

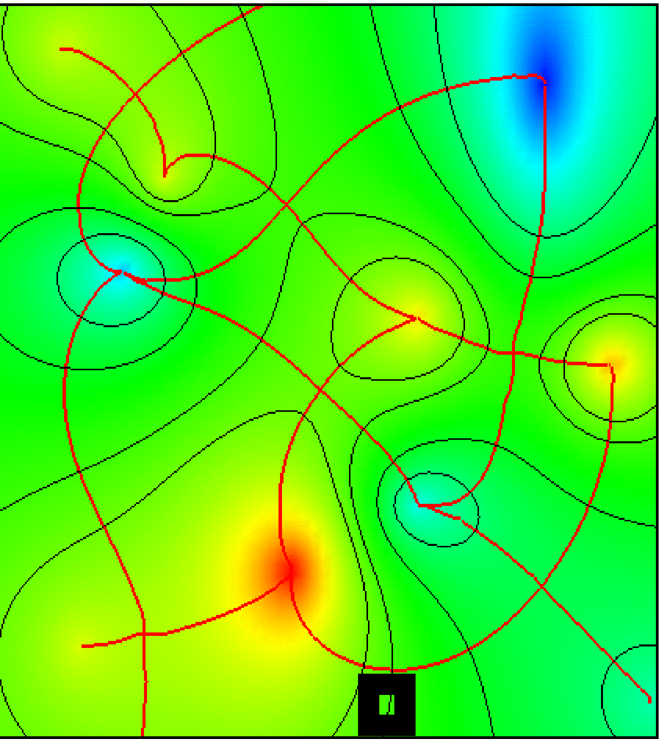
For each cell c in *M*

Enter its range of function values into an interval-tree



Optimal Single-Resolution Isocontouring

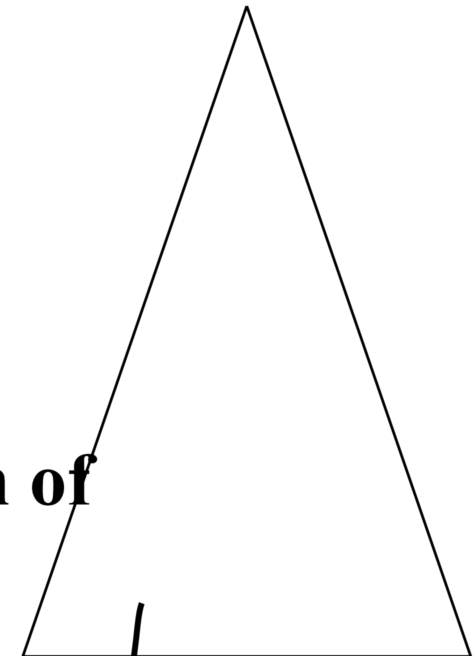
The basic scheme



Isocontour query *W*

For each interval containing *W*

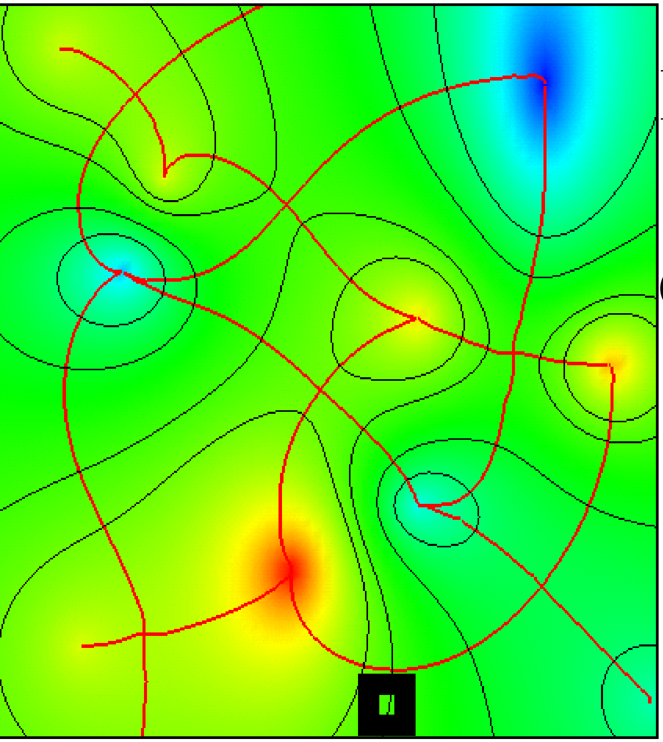
Compute the portion of isocontour in the the corresponding cell



(f_{min}, f_{max})

Optimal Single-Resolution Isocontouring

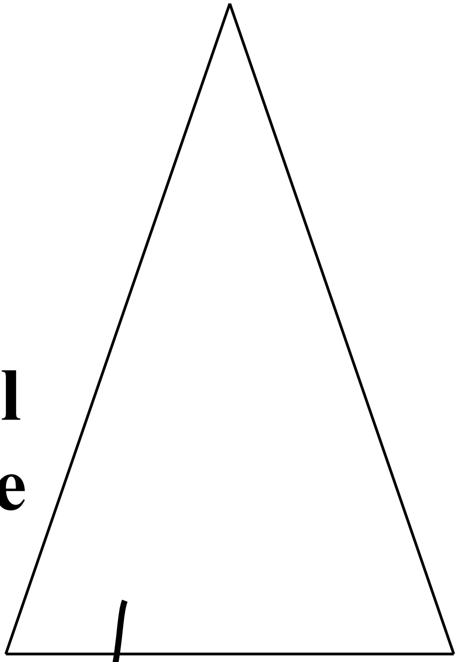
The basic scheme



Isocontour query *W*

Complexity: $m + \log(n)$

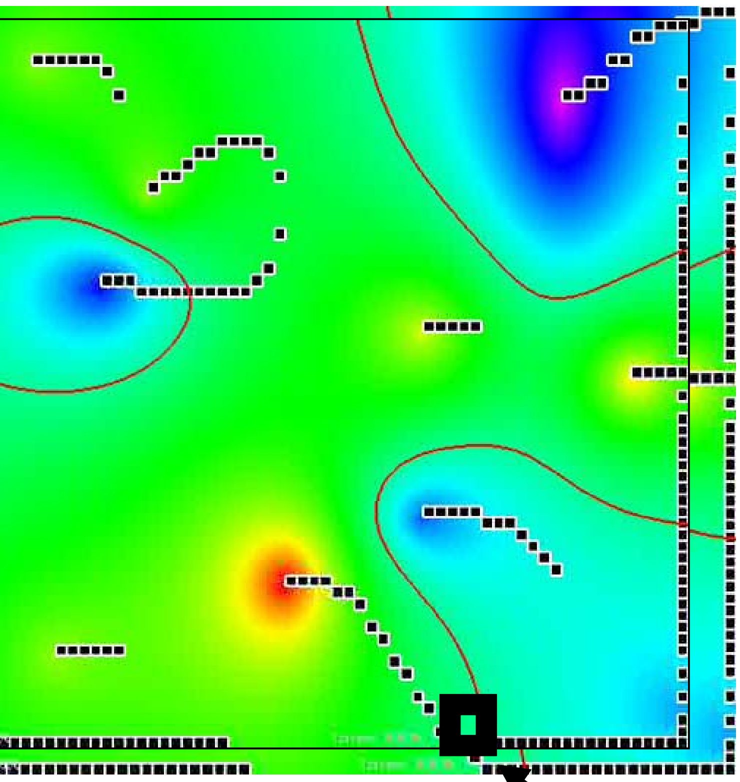
Optimal but impractical because of the size of the interval-tree



(f_{min}, f_{max})

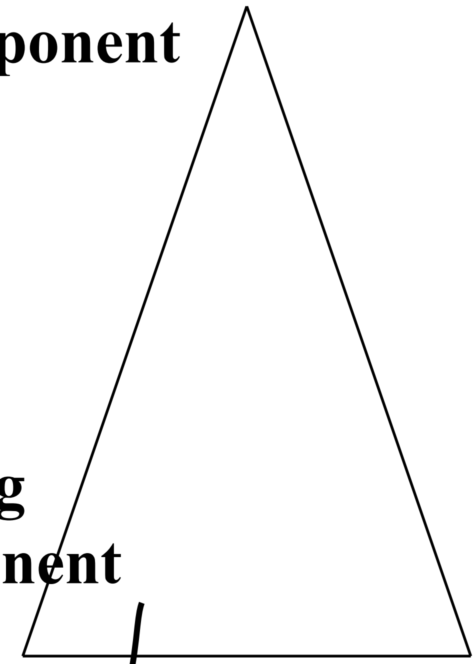
Optimal Single-Resolution Isocontouring

Seed Set Optimization



For each connected component we need only one cell (and then propagate by adjacency in the mesh)

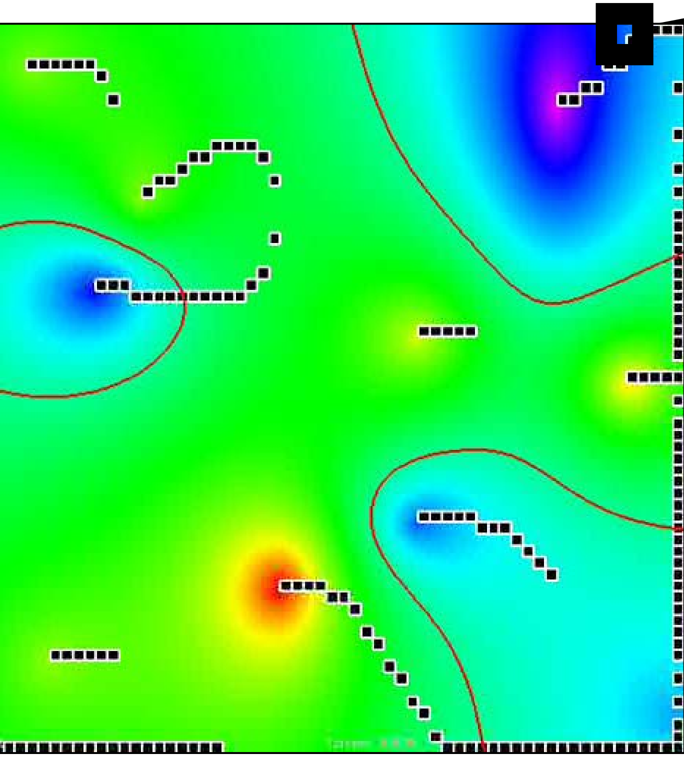
Seed Set:
a set of cells intersecting every connected component of every isocontour



(f_{min}, f_{max})

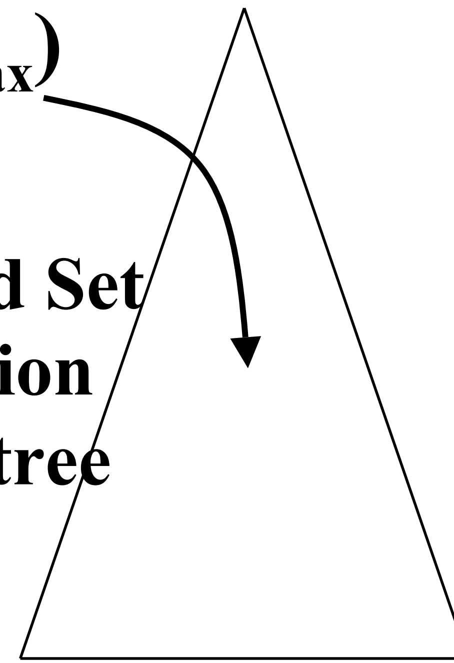
Optimal Single-Resolution Isocontouring

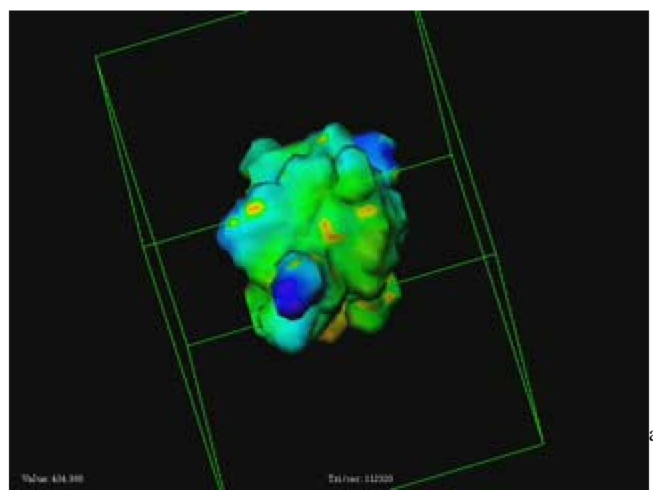
The basic scheme



Preprocessing (f_{min},f_{max}) (revised):

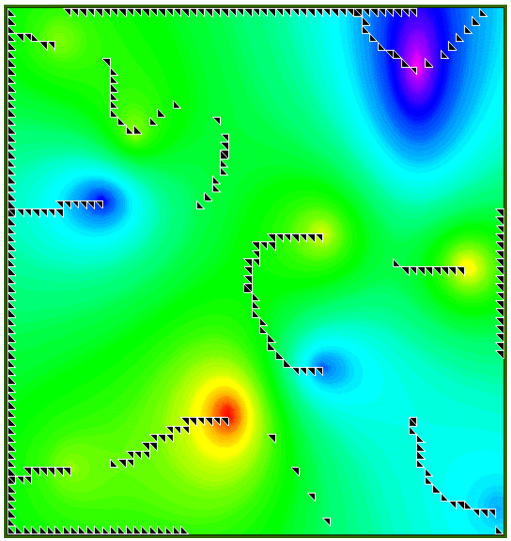
For each cell c in a Seed Set Enter its range of function values into an interval-tree

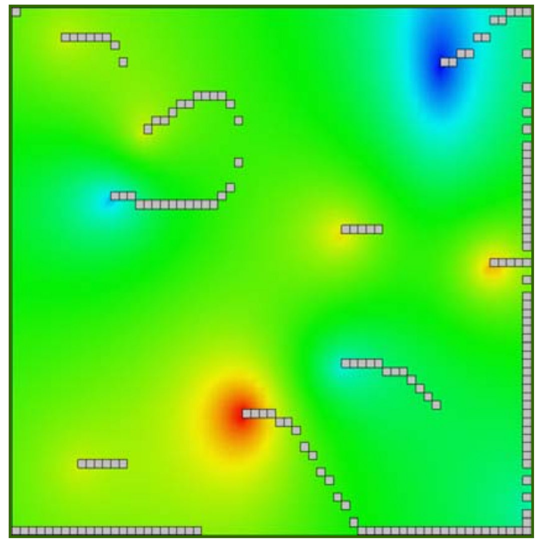


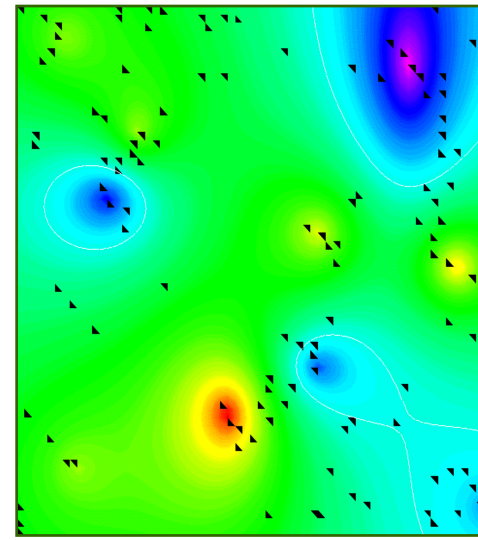


Optimal Single-Resolution Isocontouring

Seed Set Generation (k seeds from n cells)



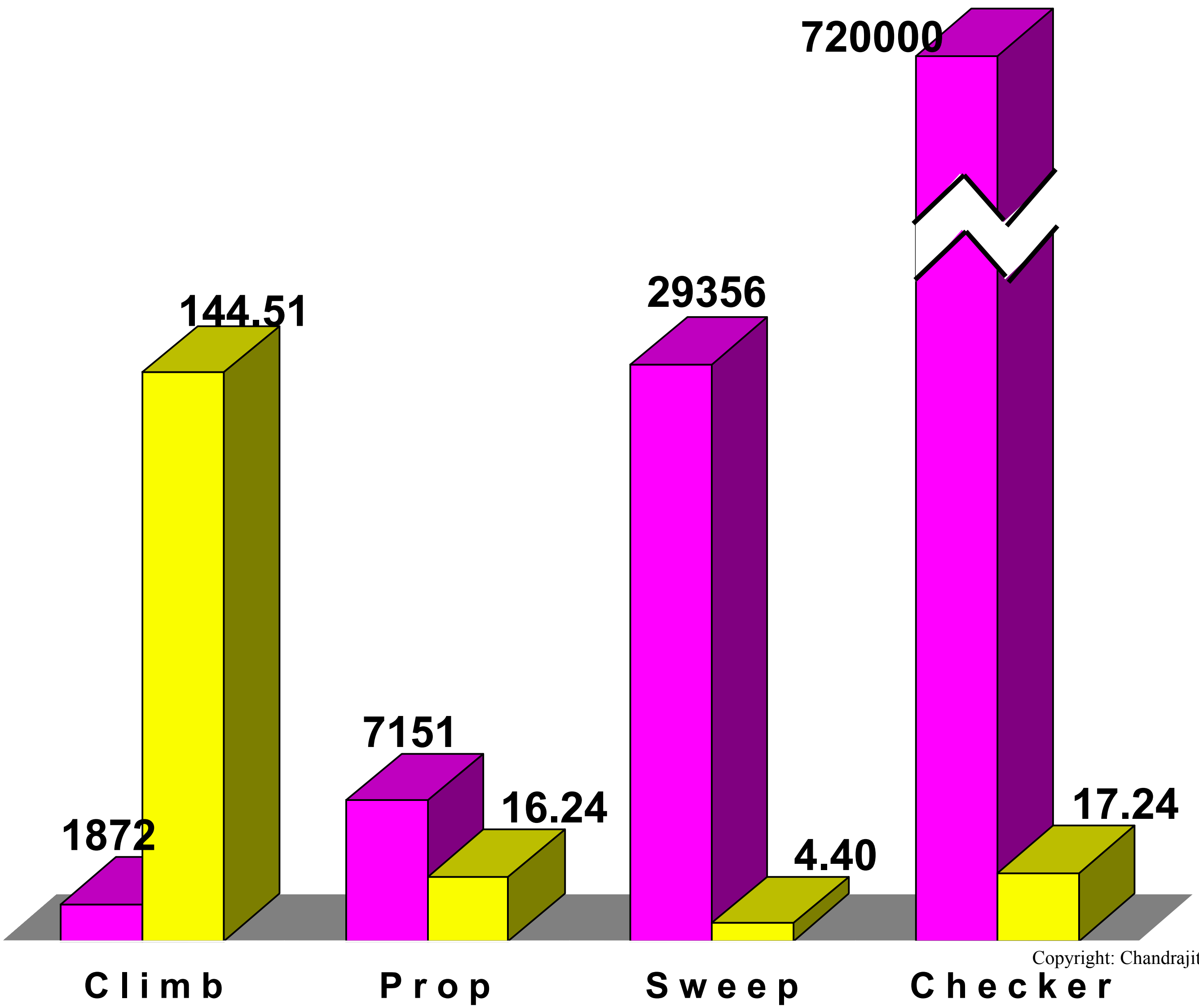




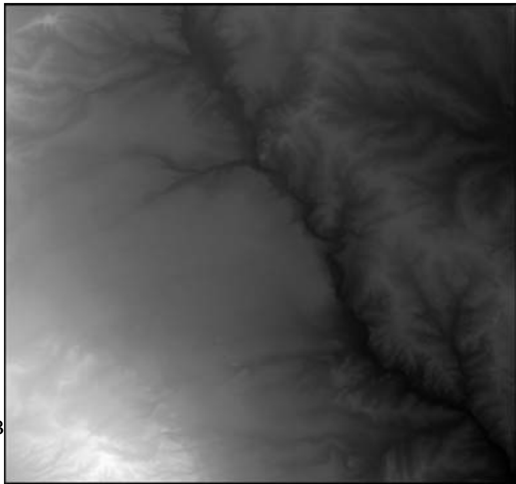
	Domain Sweep	Responsibility Propagation	Range Sweep
Time	**O(*n*)**	**O(*n*)**	**O(*n* log *n*)**
Space	**O(*k*)**	**O(*k*)**	**O(*n*)**
***k* =**	**?**	**?**	**$2\ k_{min}$**
Test	• 238 seed cells • 0.01 seconds	177 seed cells 0.05 seconds	59 seed cells 1.02 seconds

Optimal Single-Resolution Isocontouring

Seed Set Generation

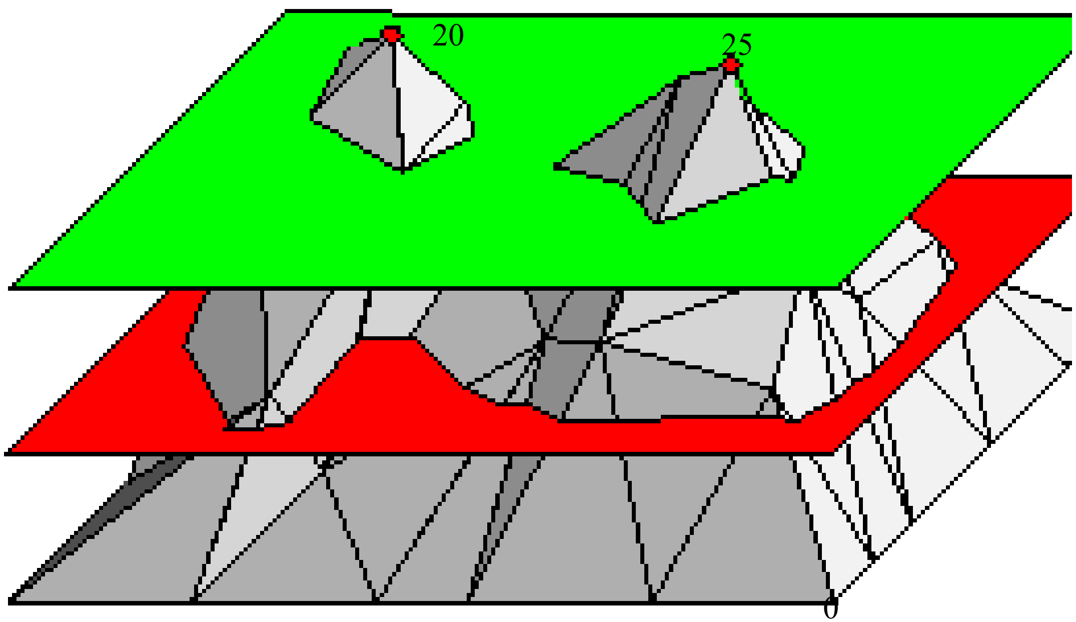


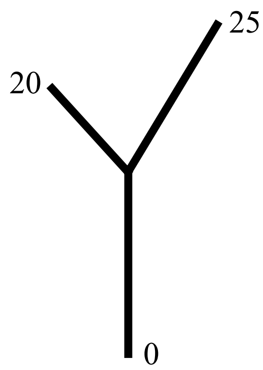
Eagle Pass Terrain
1.4 M total cells

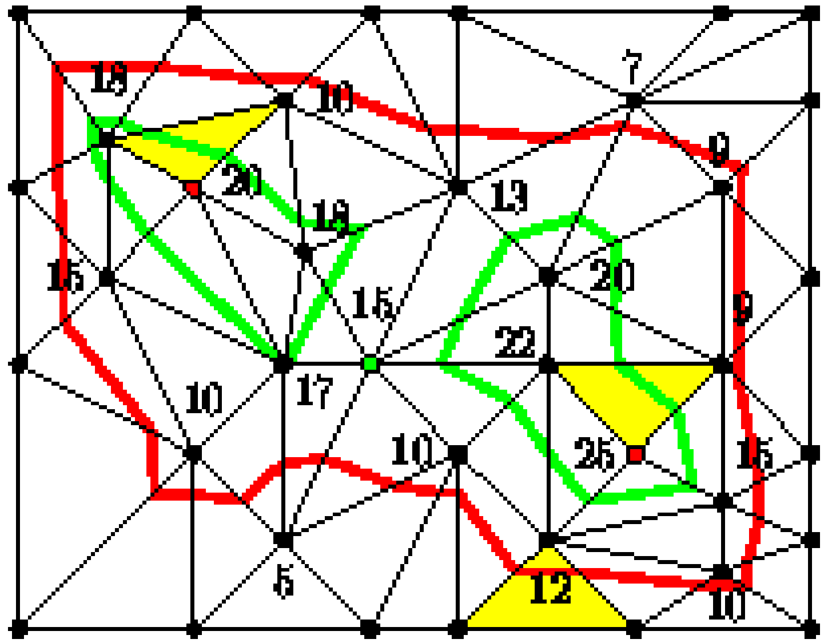


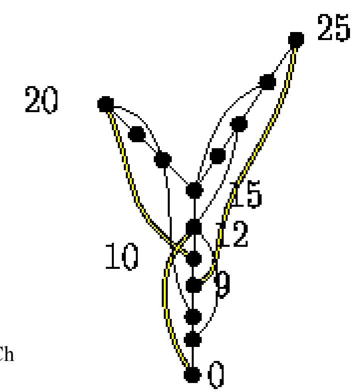
Optimal Single-Resolution Isocontouring

Contour tree

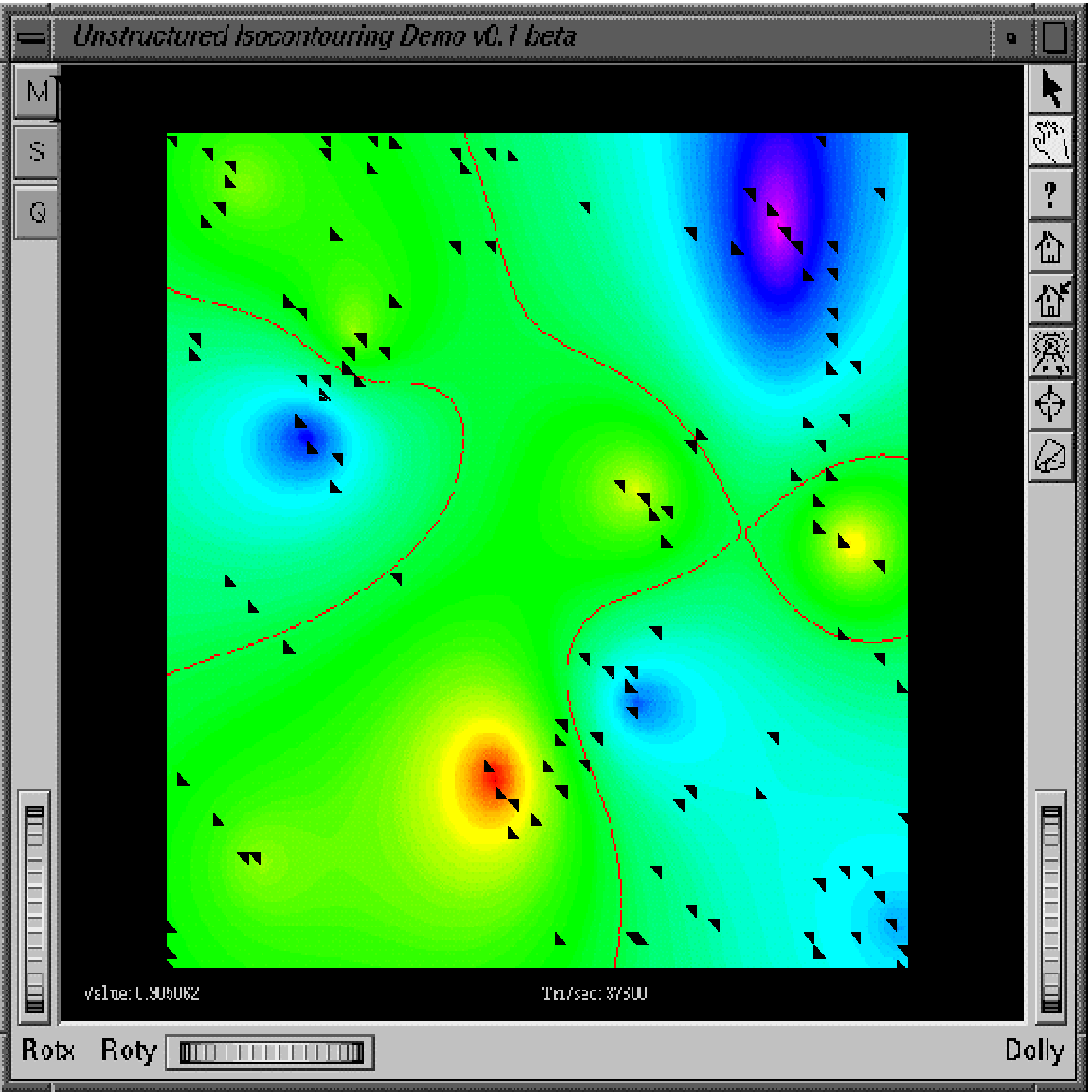




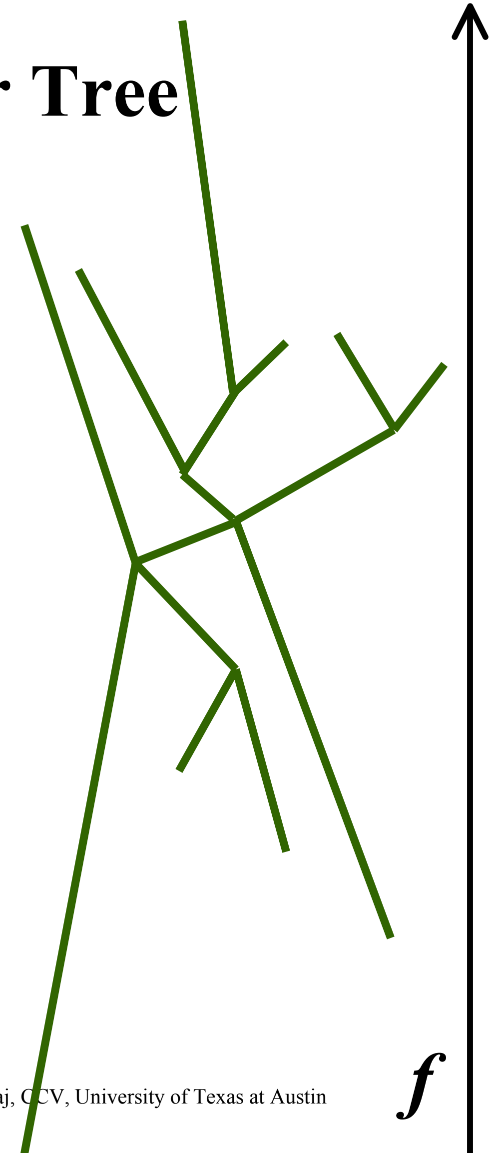




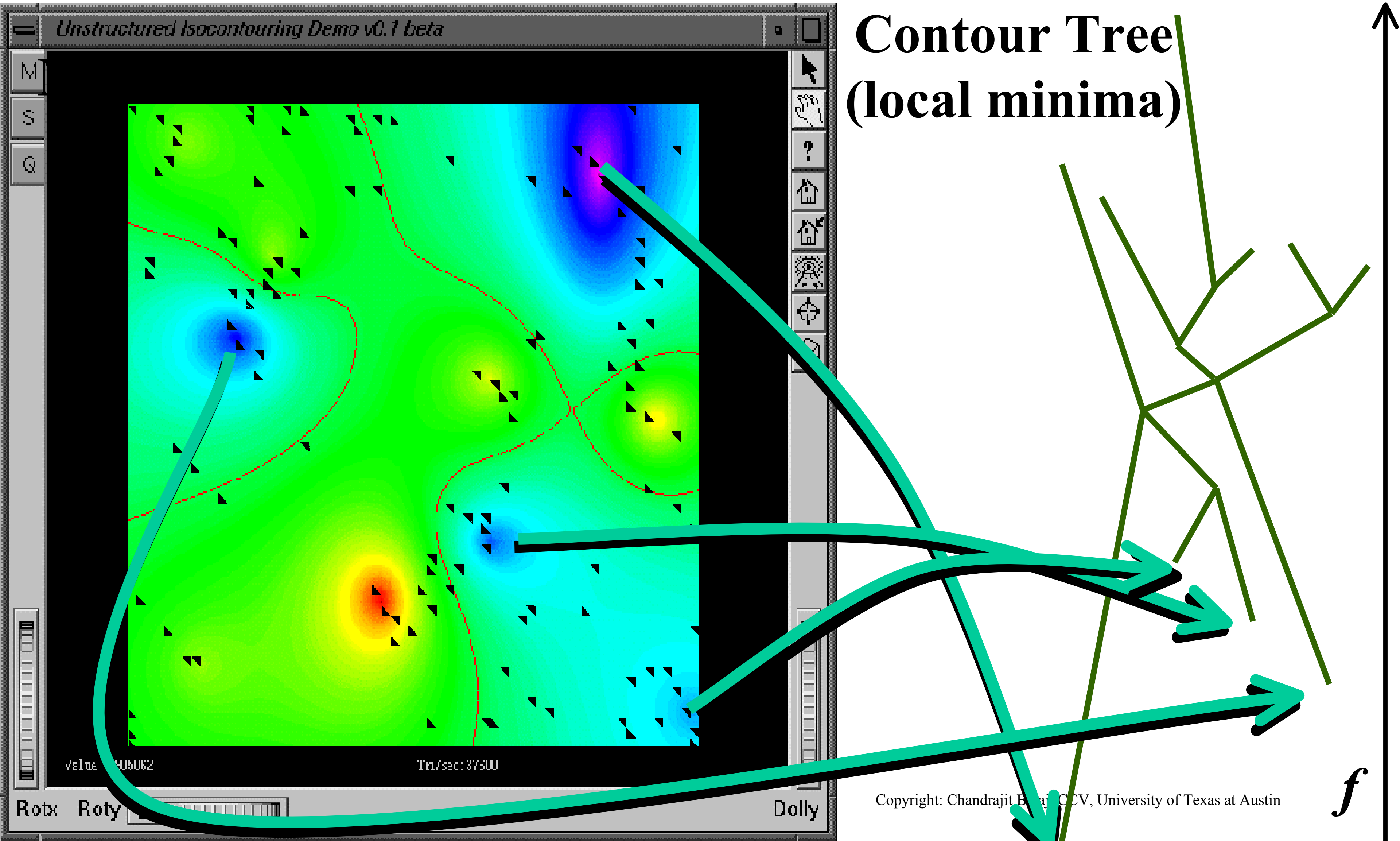
Optimal Single-Resolution Isocontouring



Contour Tree

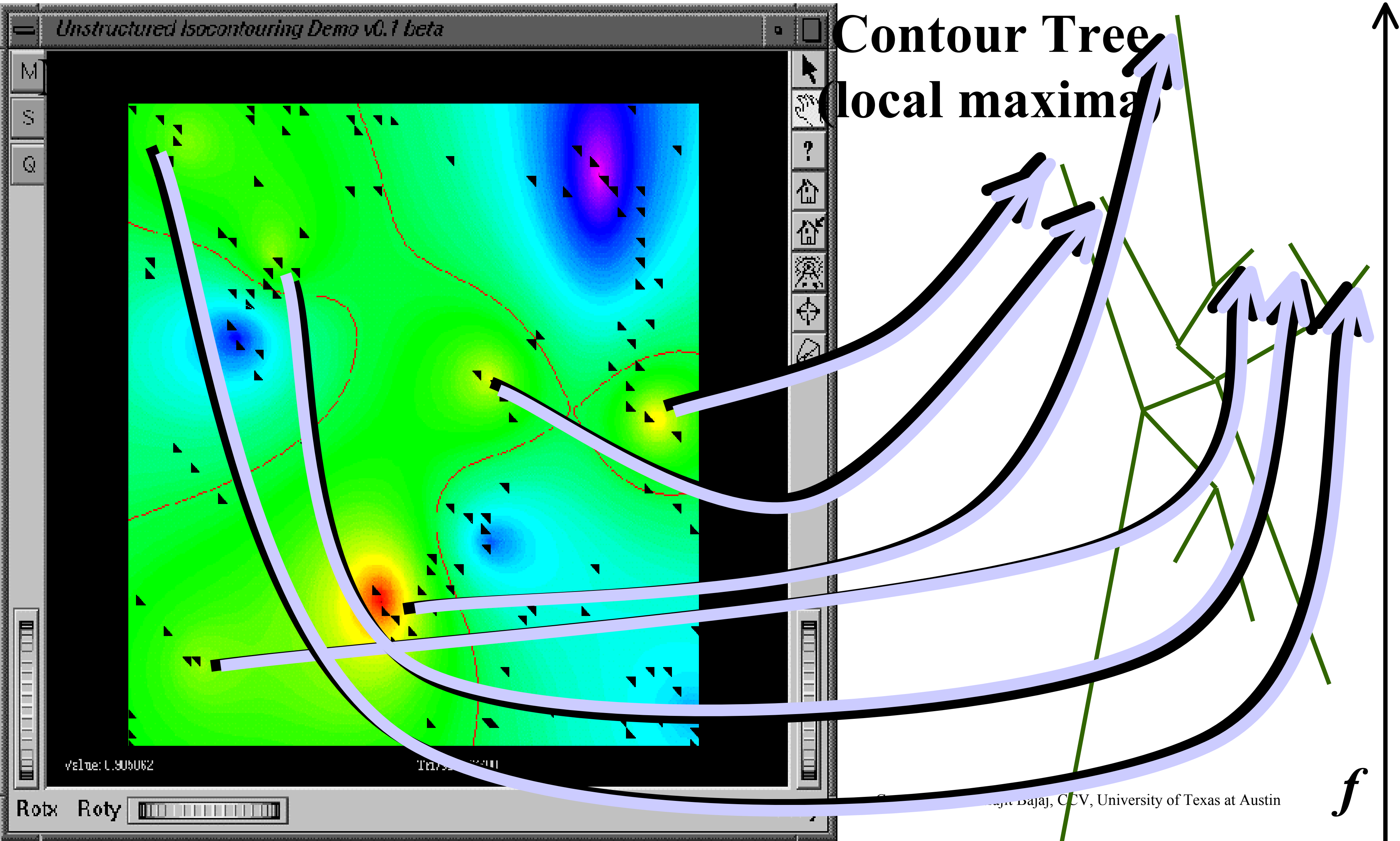


Optimal Single-Resolution Isocontouring

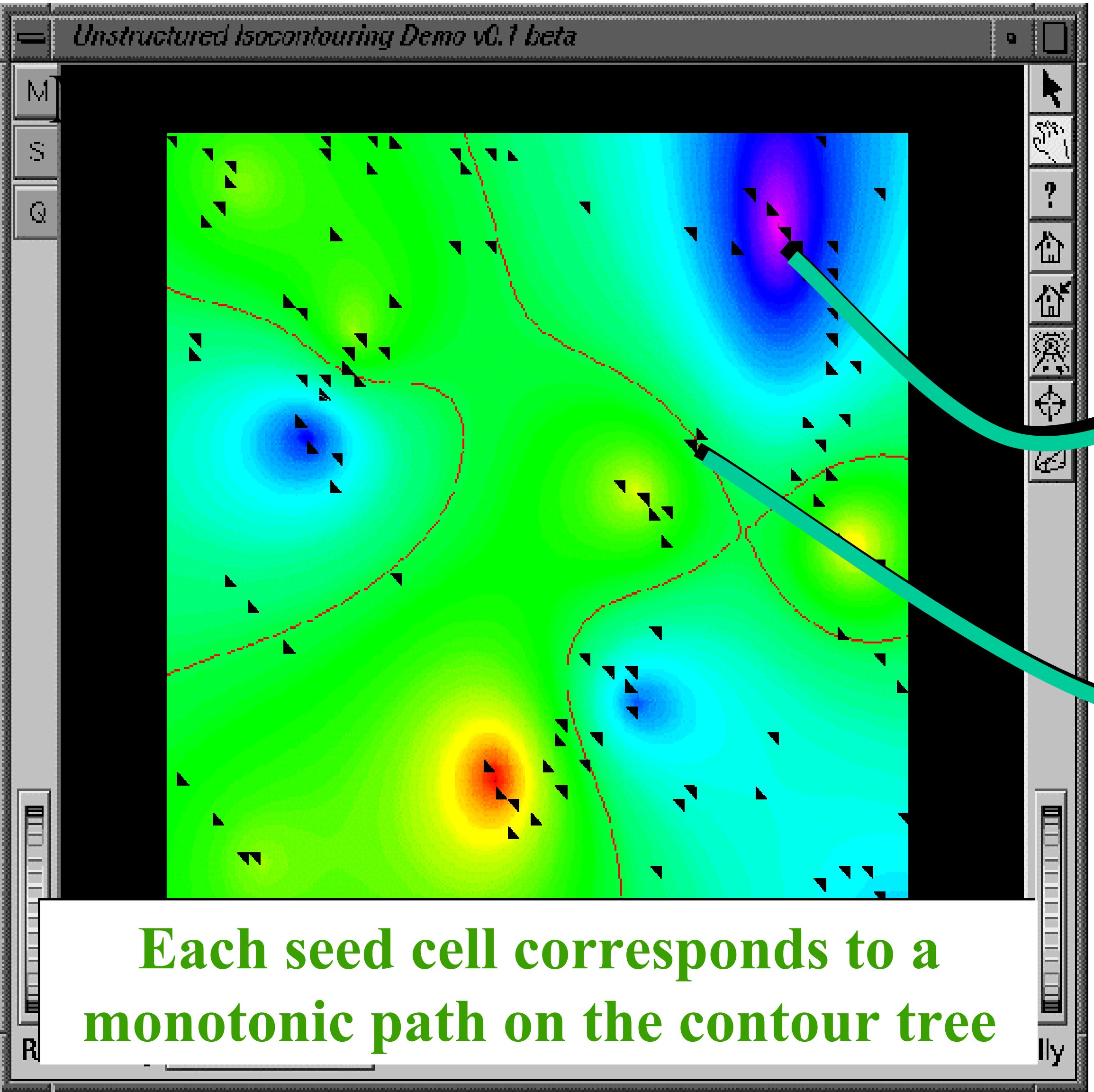


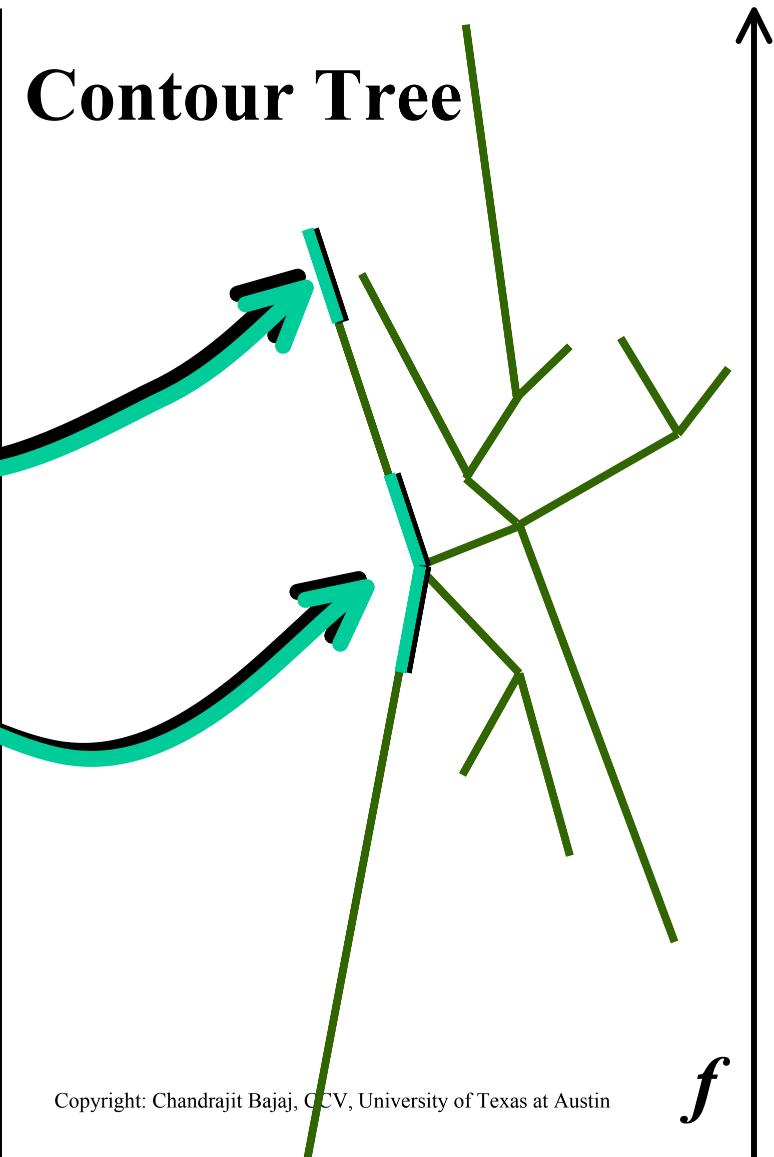
Center for Computational Visualization (CCV)

Optimal Single-Resolution Isocontouring



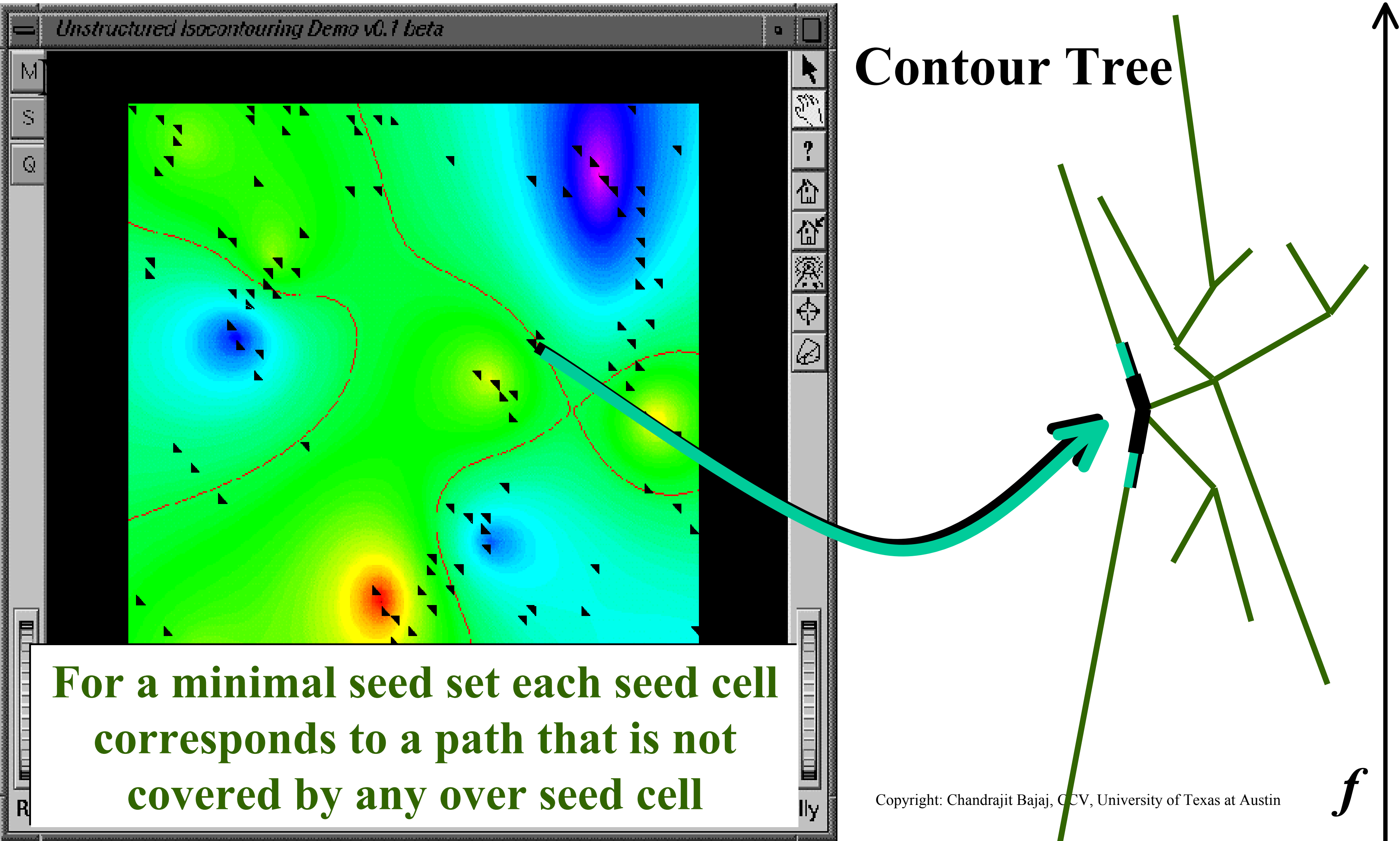
Optimal Single-Resolution Isocontouring





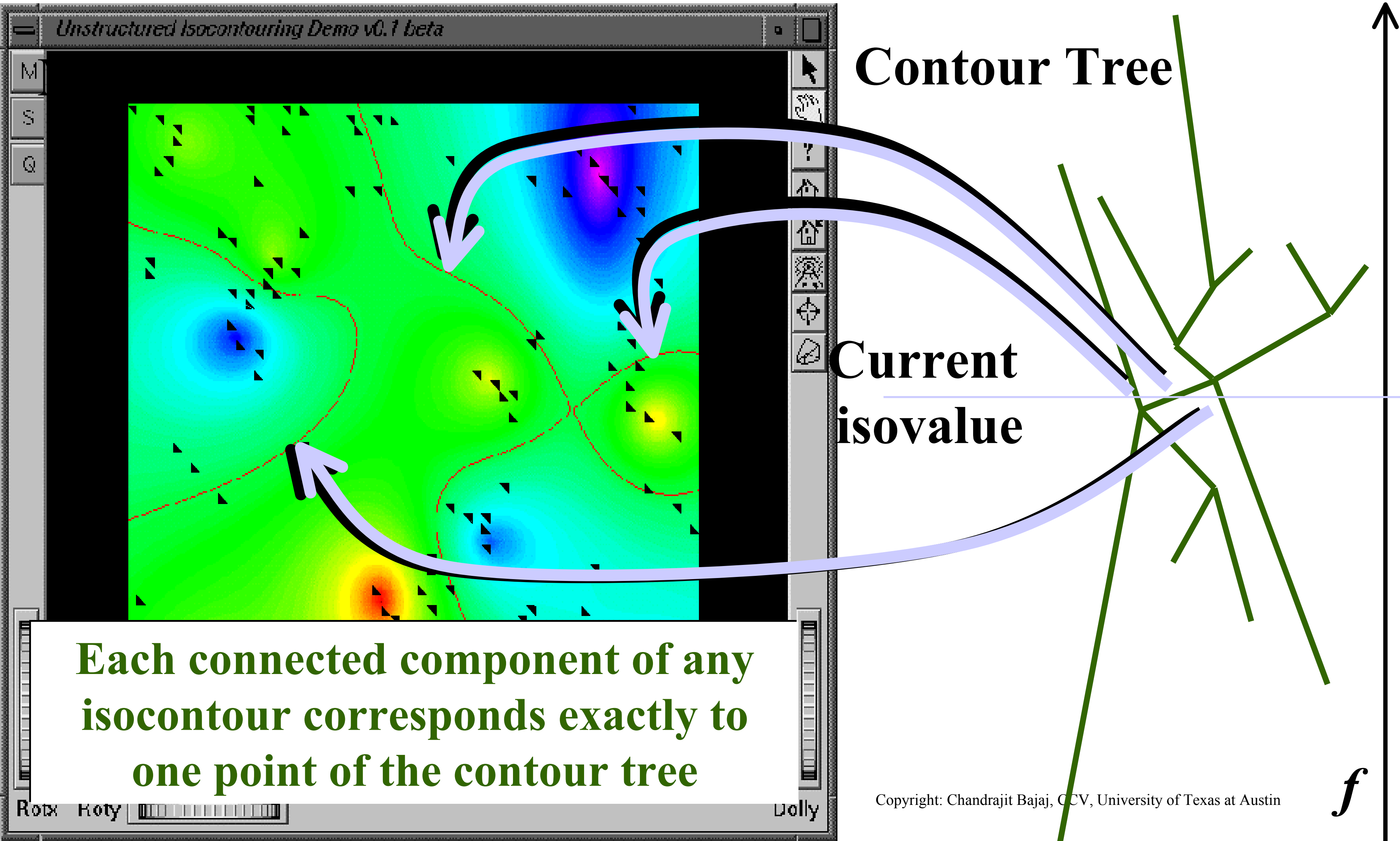
Each seed cell corresponds to a monotonic path on the contour tree

Optimal Single-Resolution Isocontouring



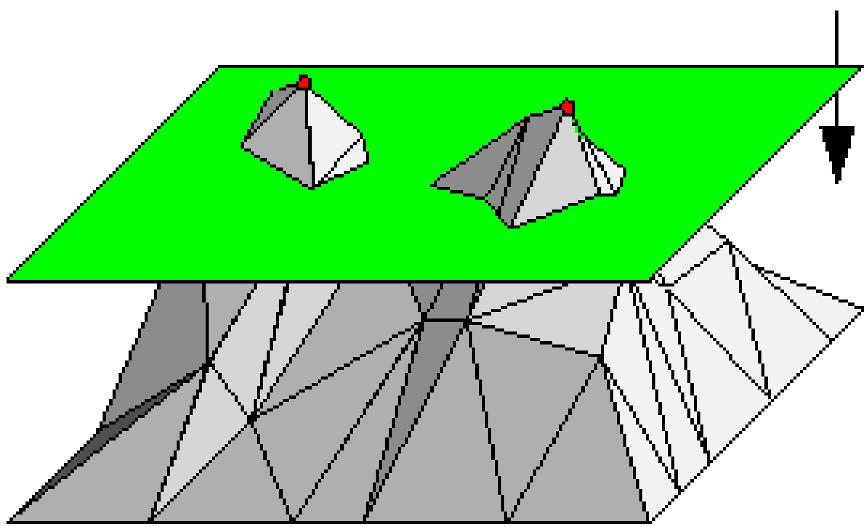
For a minimal seed set each seed cell corresponds to a path that is not covered by any over seed cell

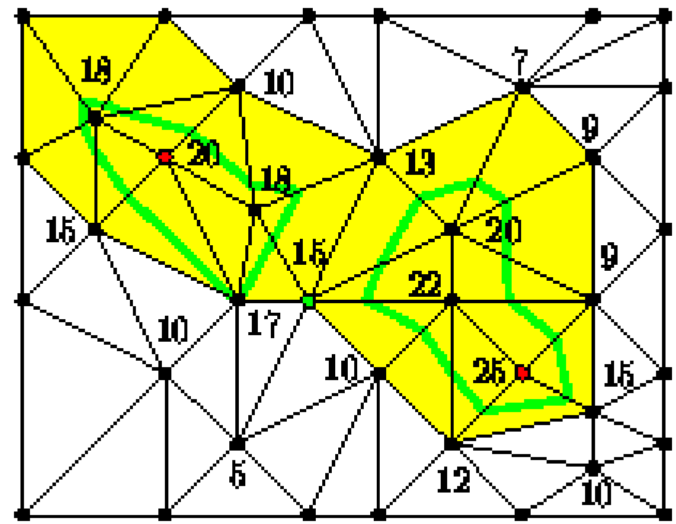
Optimal Single-Resolution Isocontouring

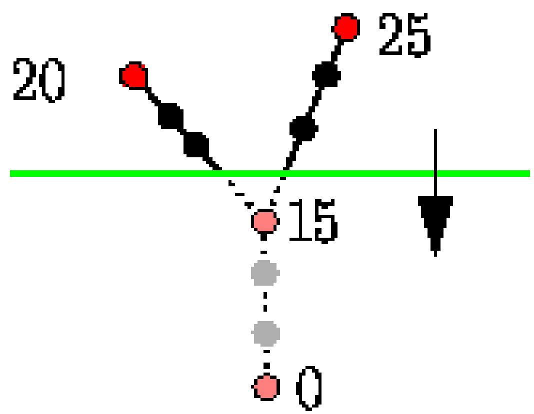


Each connected component of any isocontour corresponds exactly to one point of the contour tree

Optimal Single-Resolution Isocontouring

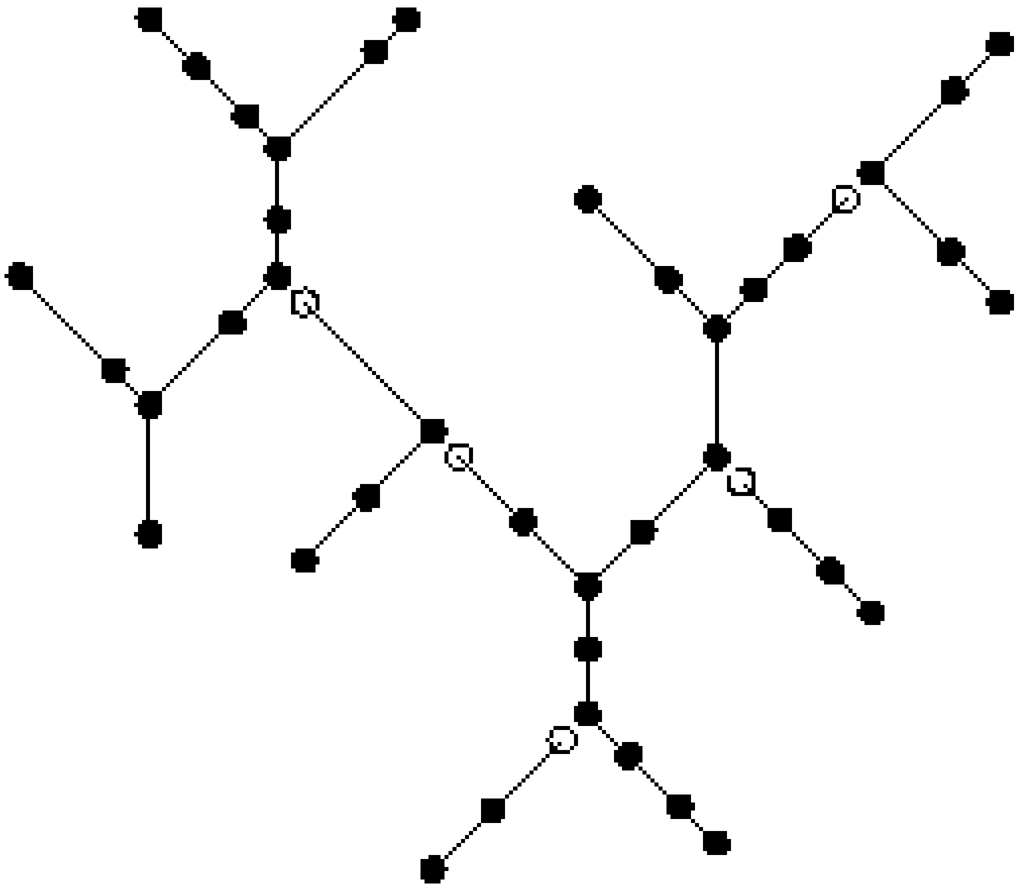






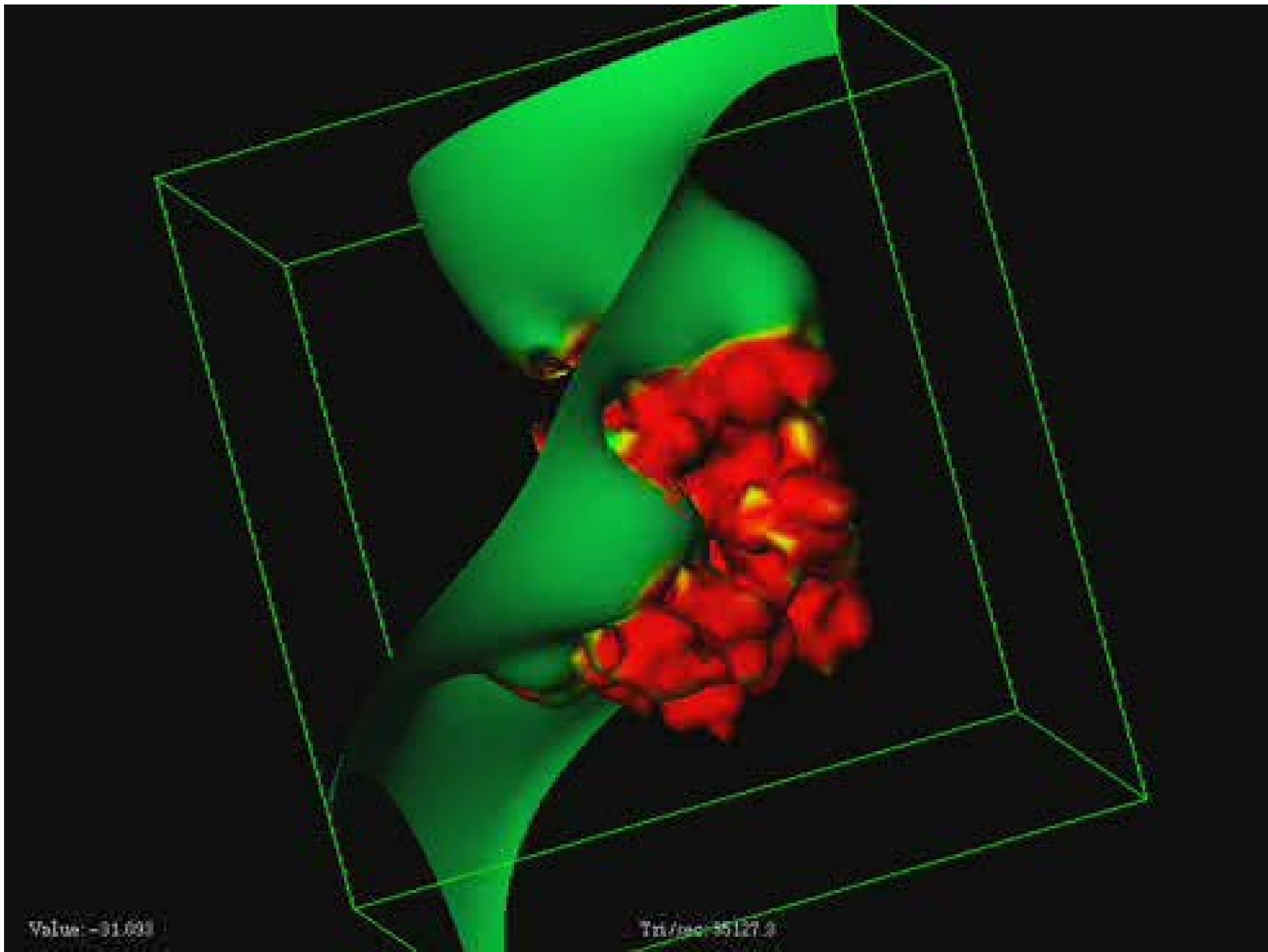
Optimal Single-Resolution Isocontouring

- The number of seeds selected is the minimum plus the number of local minima.



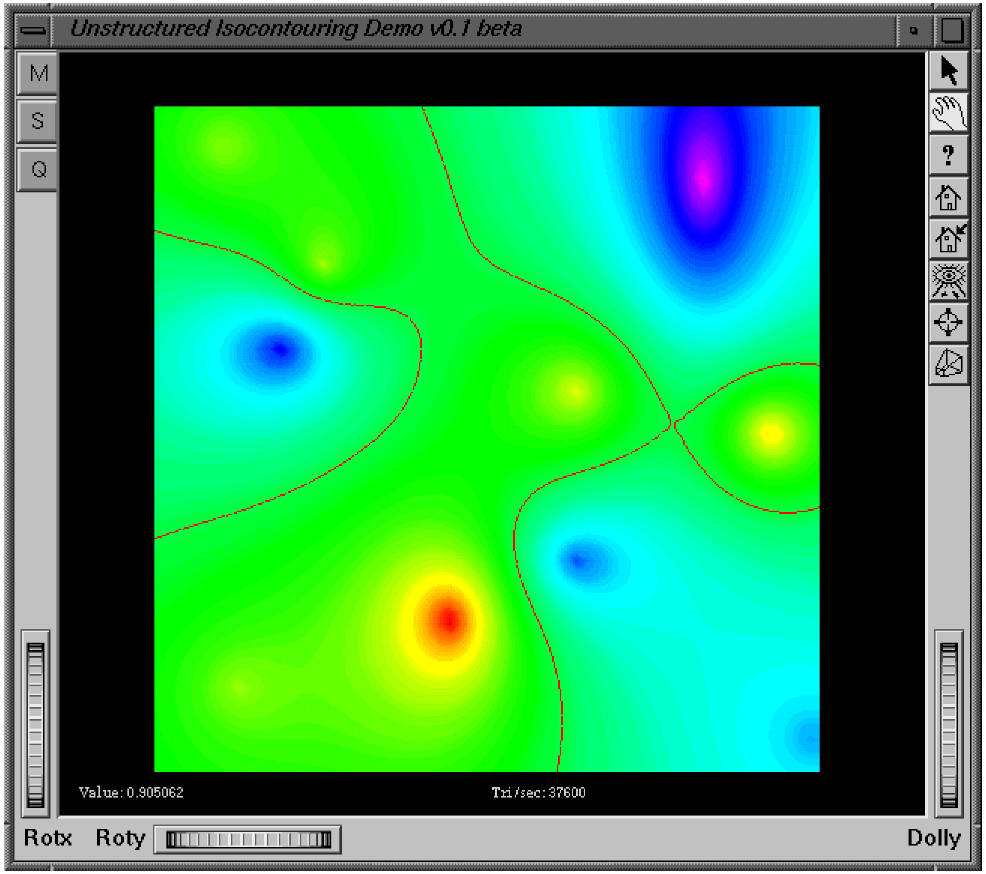
Optimal Single-Resolution Isocontouring

Seed set of a 3D scalar field



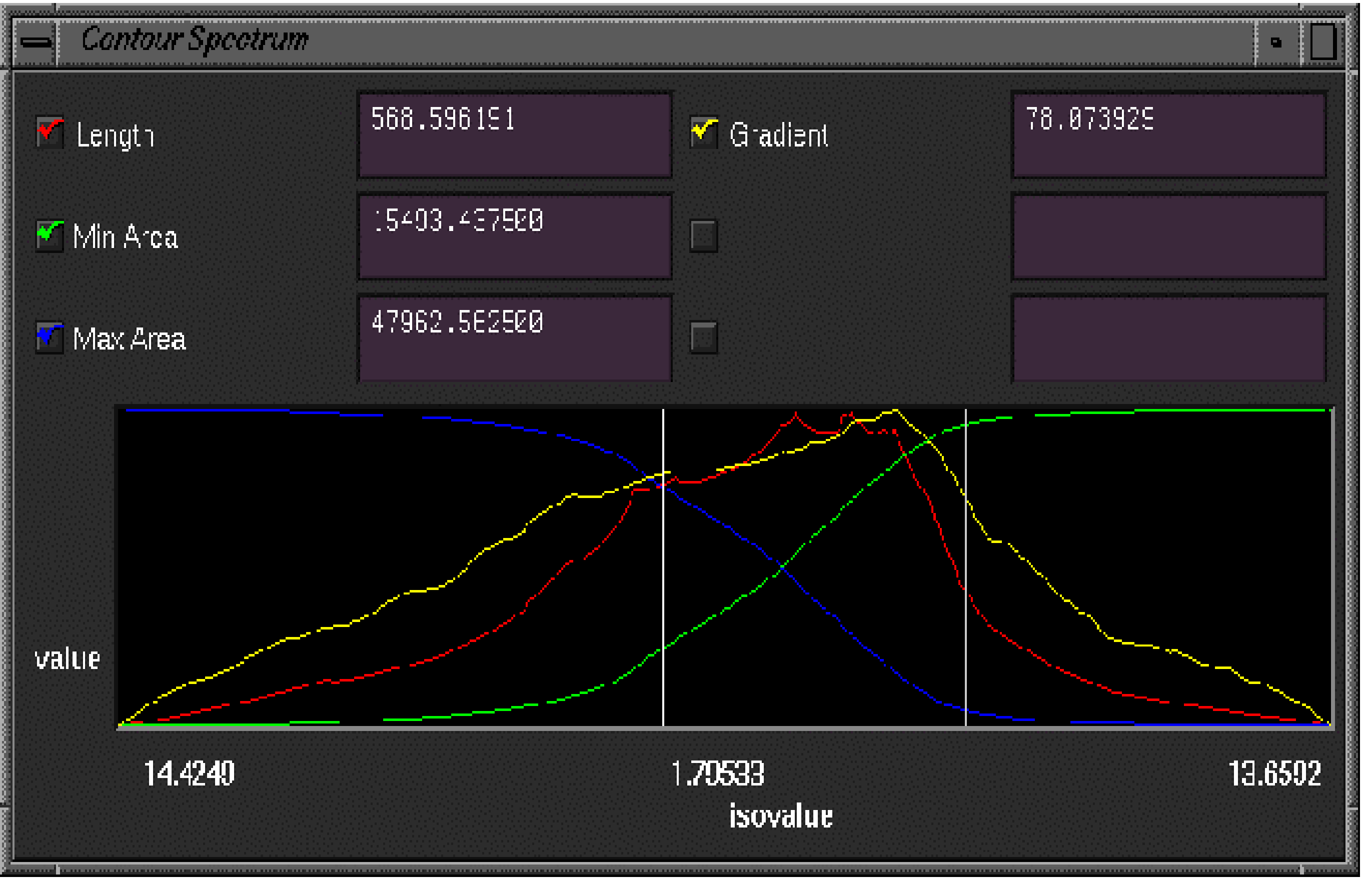
Spectral Analysis

- Consider a terrain of which you want to compute the length of each isocontour and the area contained inside each isocontour.



Spectral Analysis

Graphical User Interface for Static Data



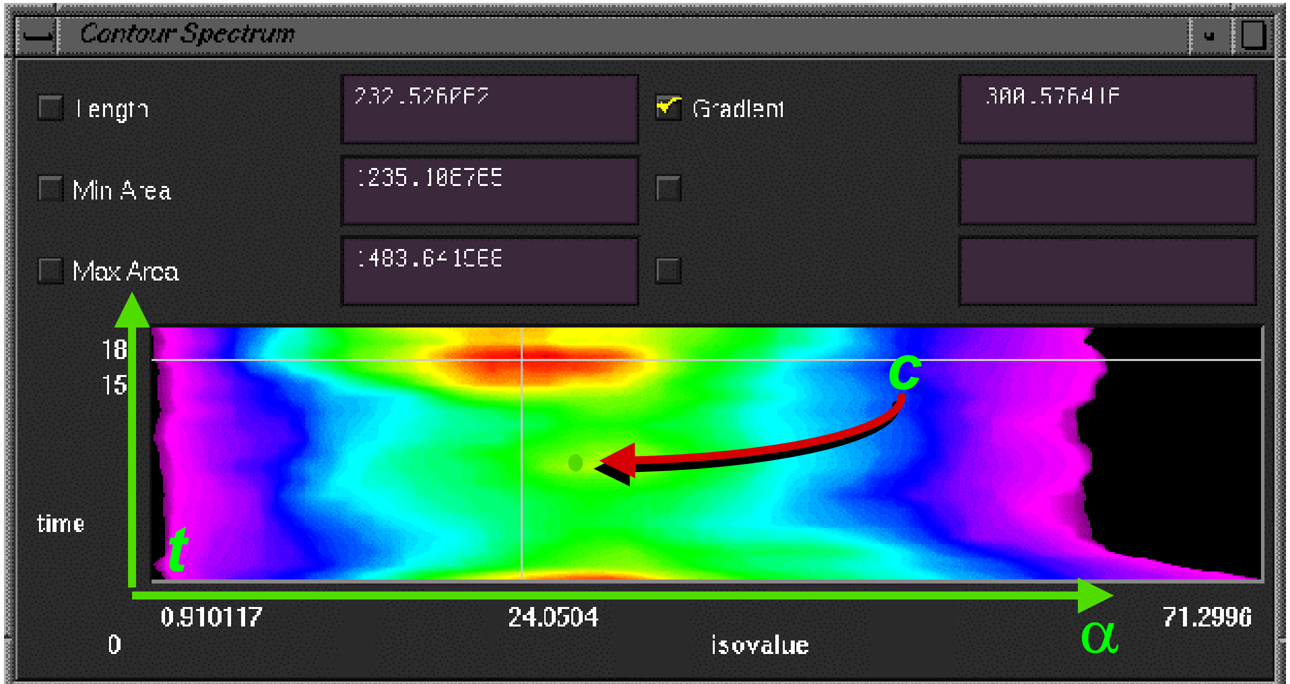
– The horizontal axis spans the scalar values α.

– Plot of a set of signatures (length, area, gradient ...) as functions of the scalar value α.

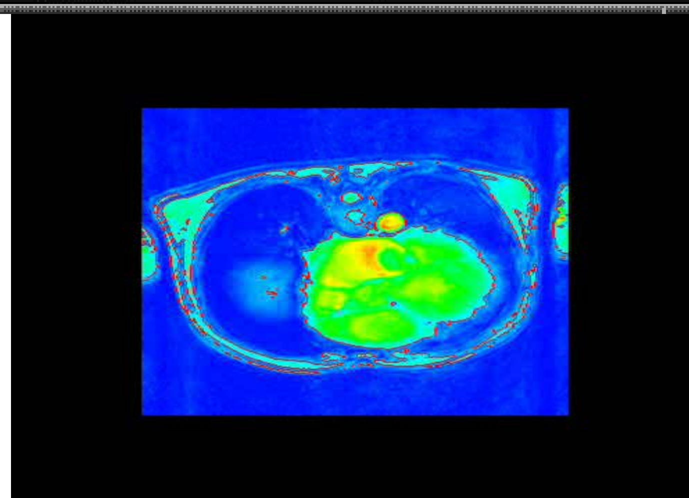
- Vertical axis spans normalized ranges of each signature.

Spectral Analysis

Graphical User Interface for time varying data



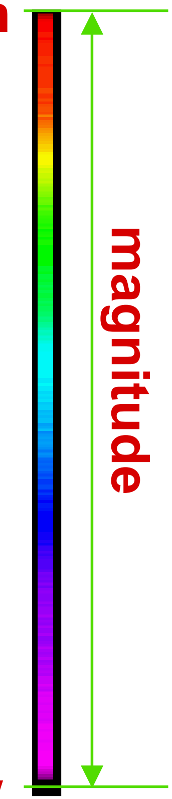
The horizontal axis spans the scalar value dimension α The vertical axis spans the time dimension t



(α, t) --> c

The color c is mapped to the magnitude of a signature function of time t and isovalue α

high

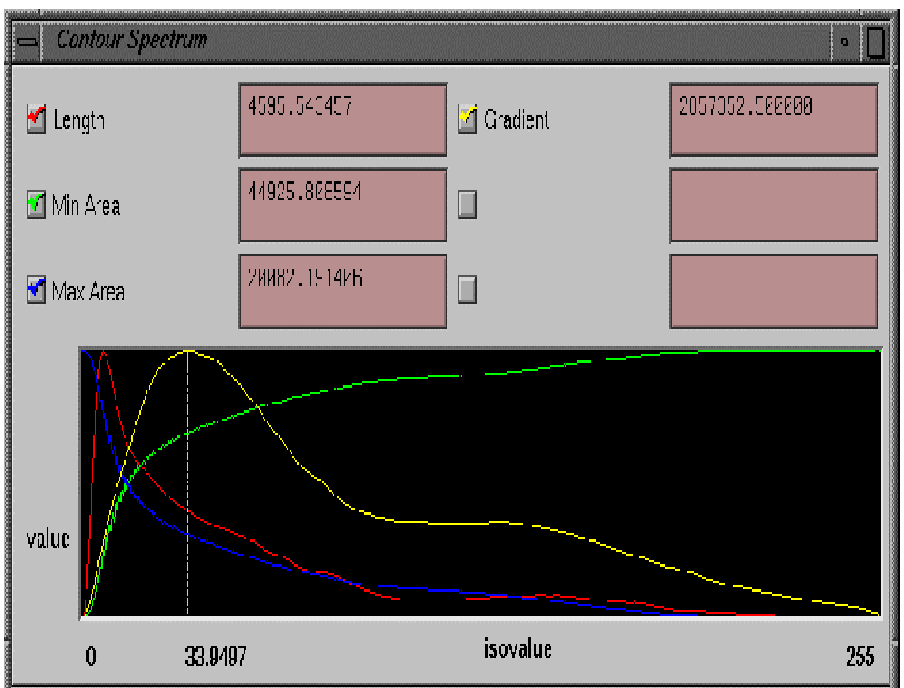


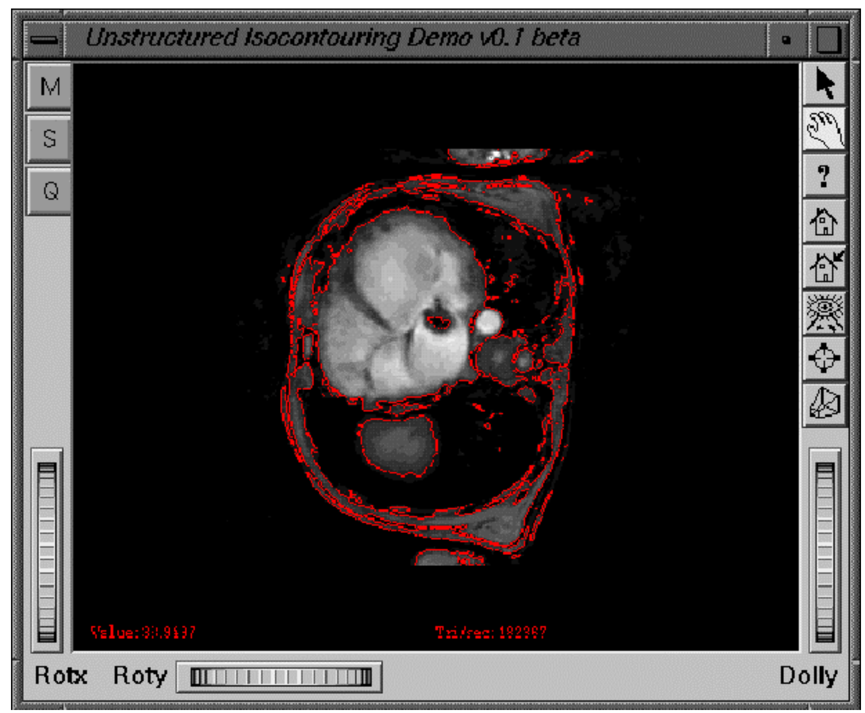
low

Spectral Analysis

(MRI human torso)

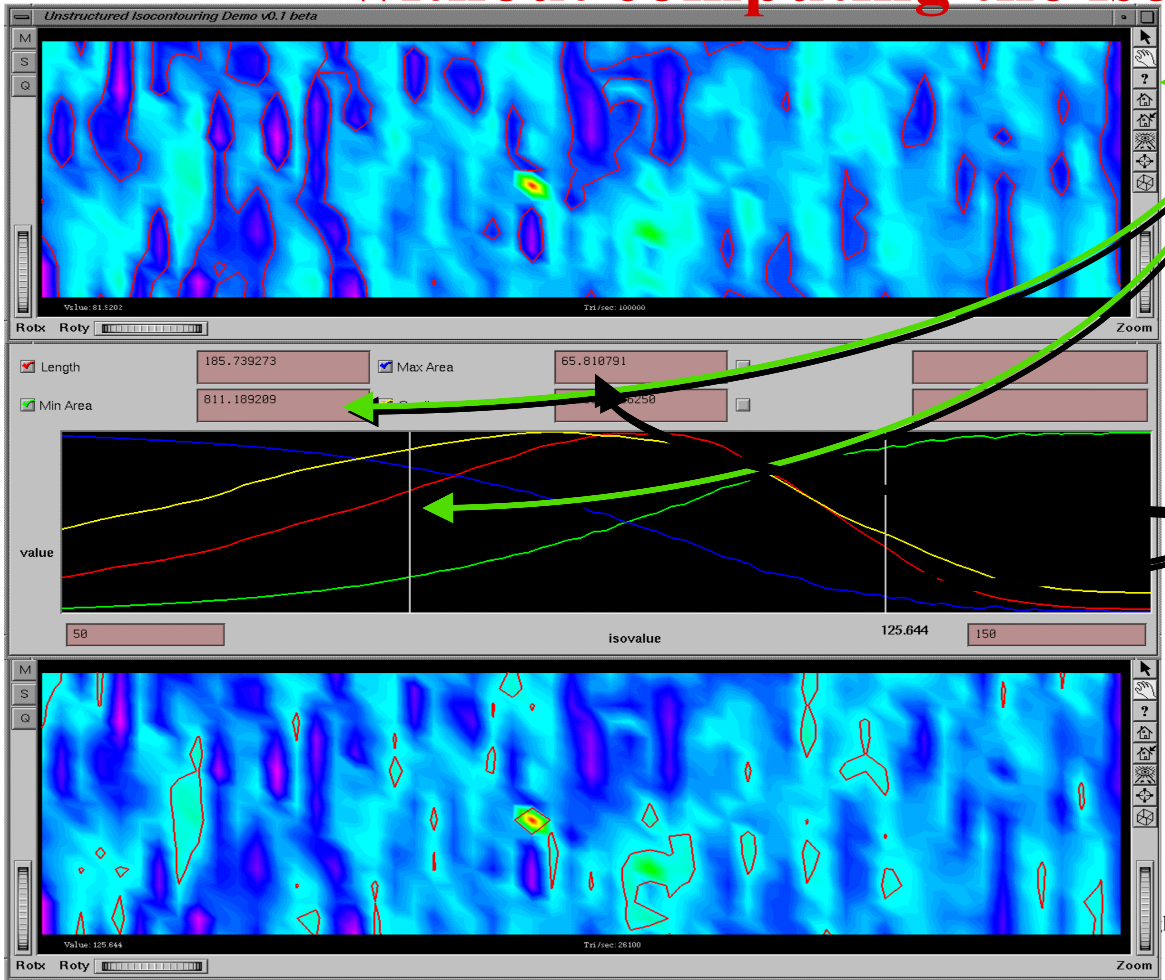
- The isocontour that bounds the region of *interest* is obtained by selecting the maximum of the gradient signature.
- In real time the exact value of each signature is displayed.





Real Time Quantitative Queries (agricultural yield data)

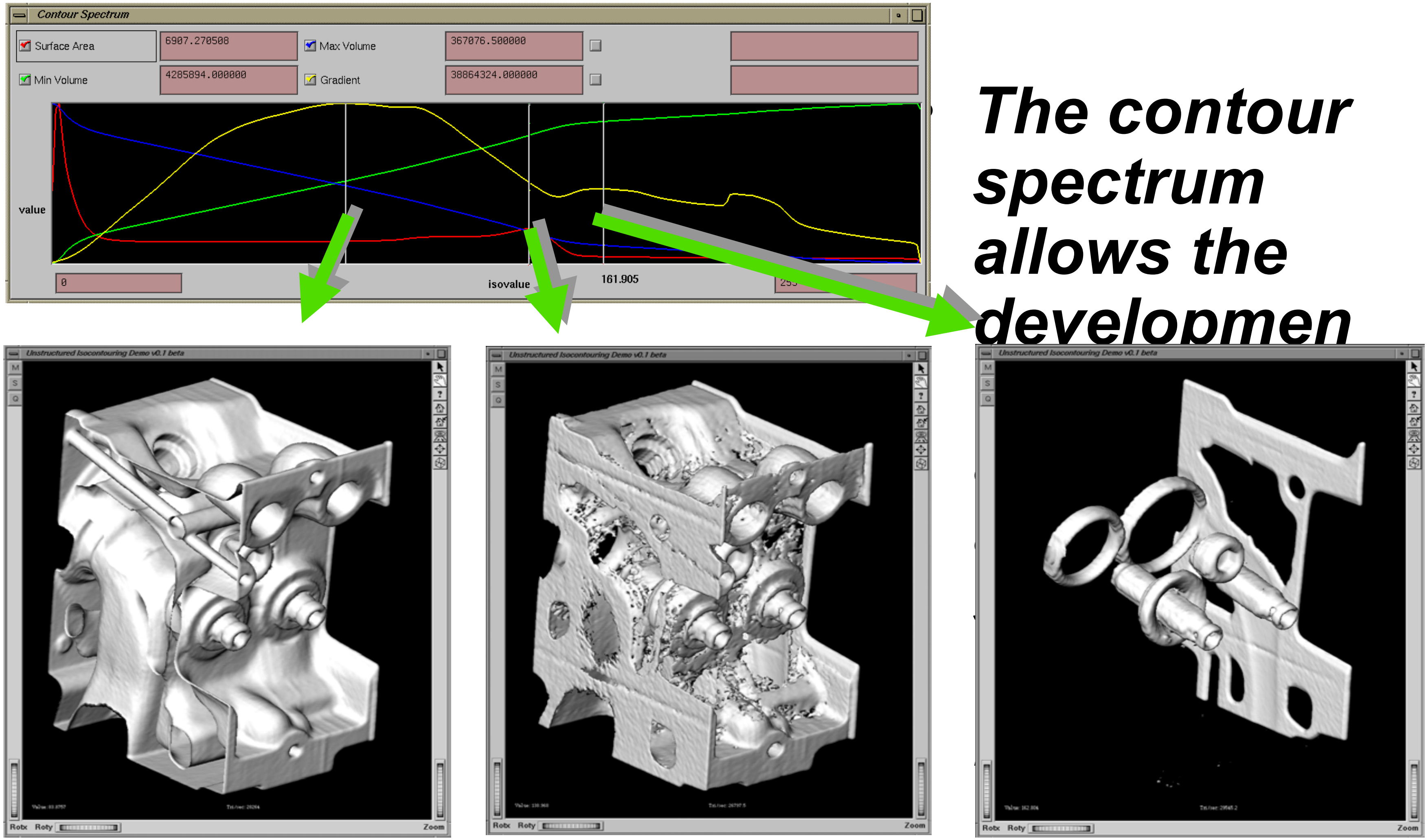
You can compute the area of an isosurface without computing the isosurface



– **size and position of the region with unsatisfactory production**

size and position of the region where incorrect data acquisition occurred

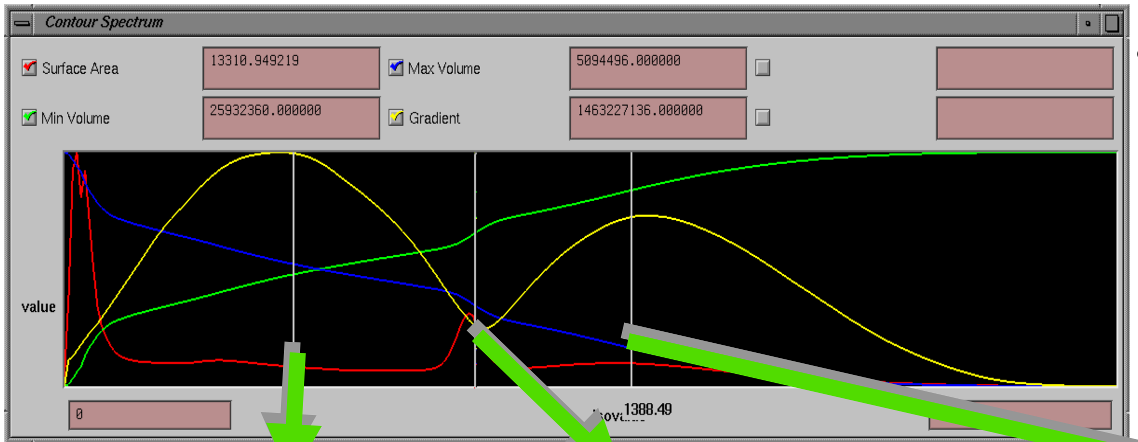
Rule-based Contouring (CT scan of an engine)



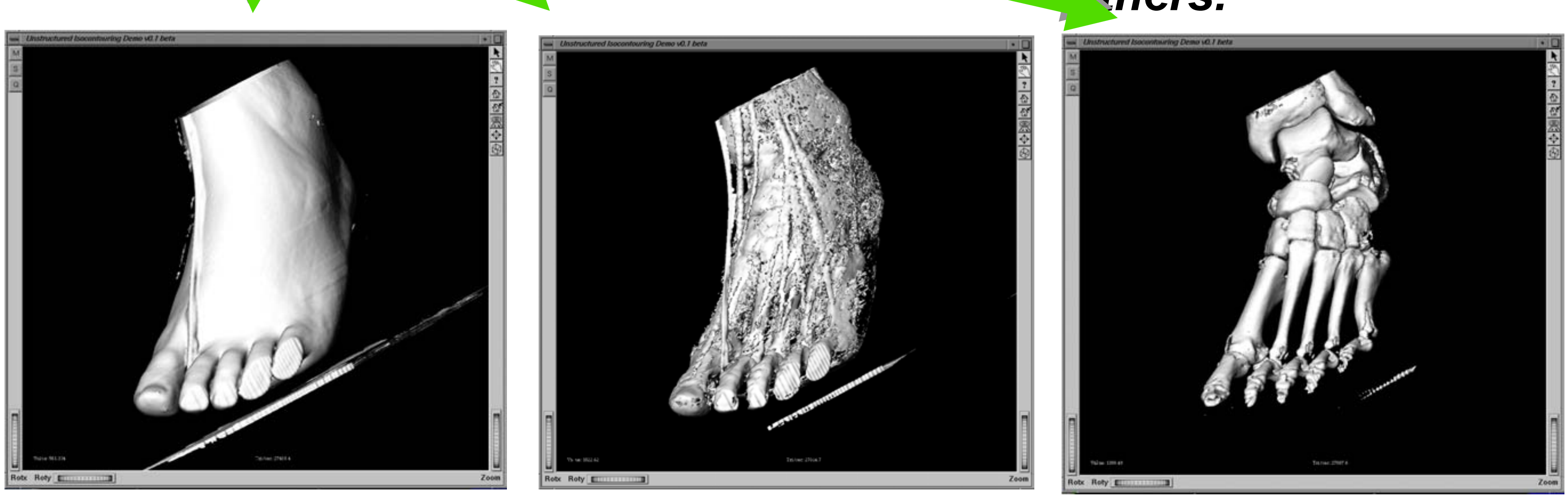
The contour spectrum allows the developmen

others

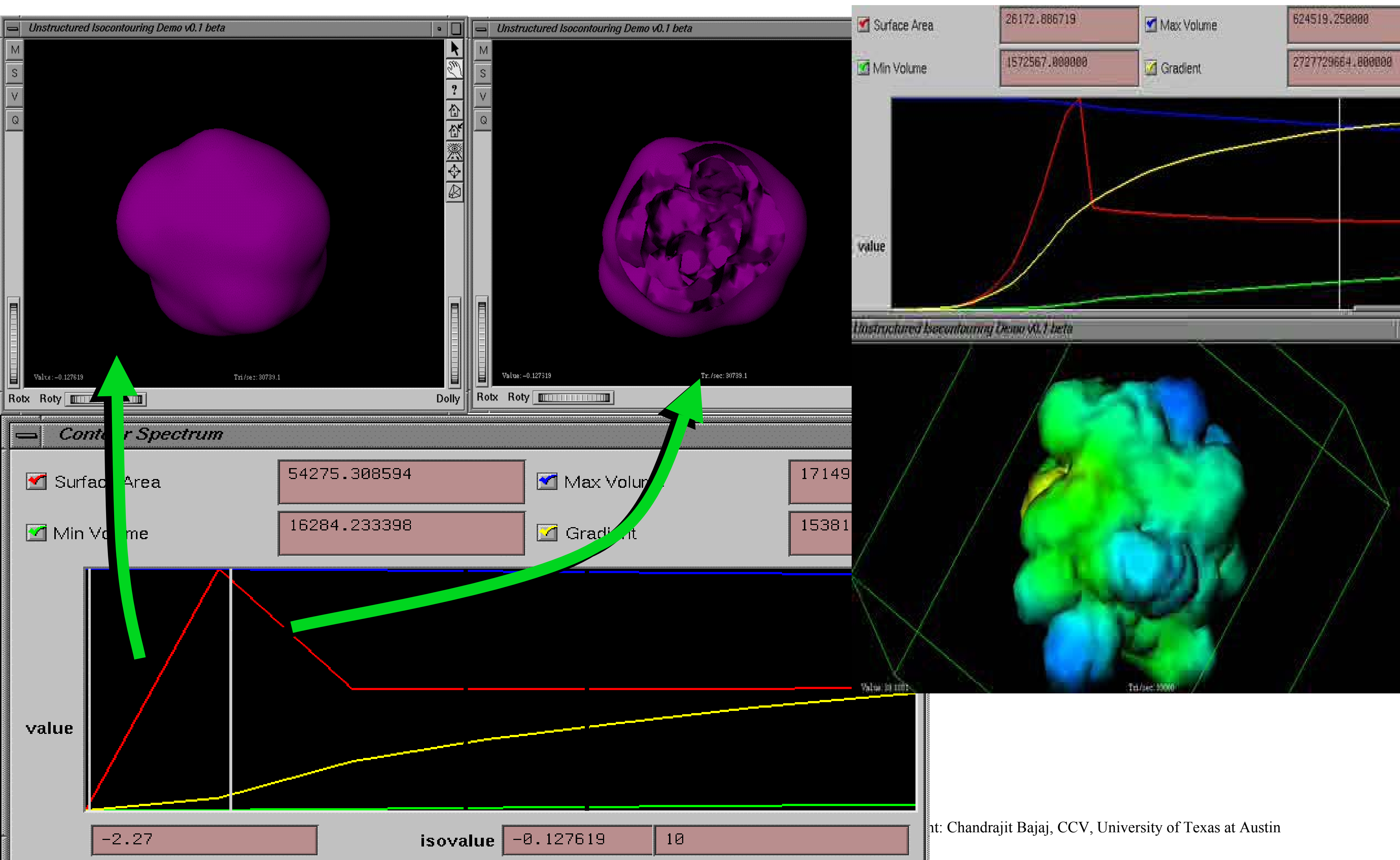
Rule-based Contouring (foot of the Visible Human)



- ***The contour spectrum allows the development of an adaptive ability to separate interesting isovalues from the others.***

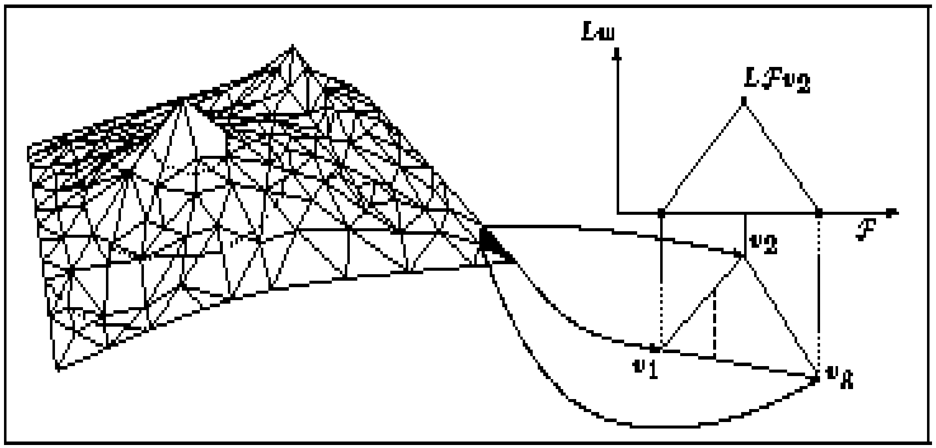


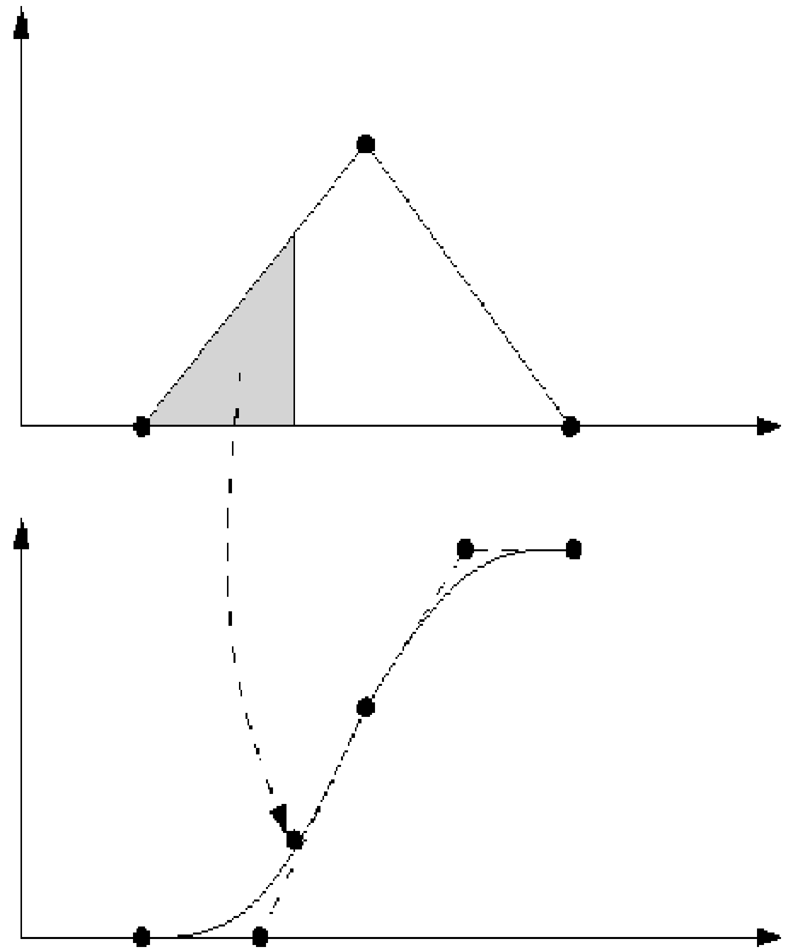
Spectral Analysis
(a view inside the data)



nt: Chandrajit Bajaj, CCV, University of Texas at Austin

Spectral Analysis (signature computation)



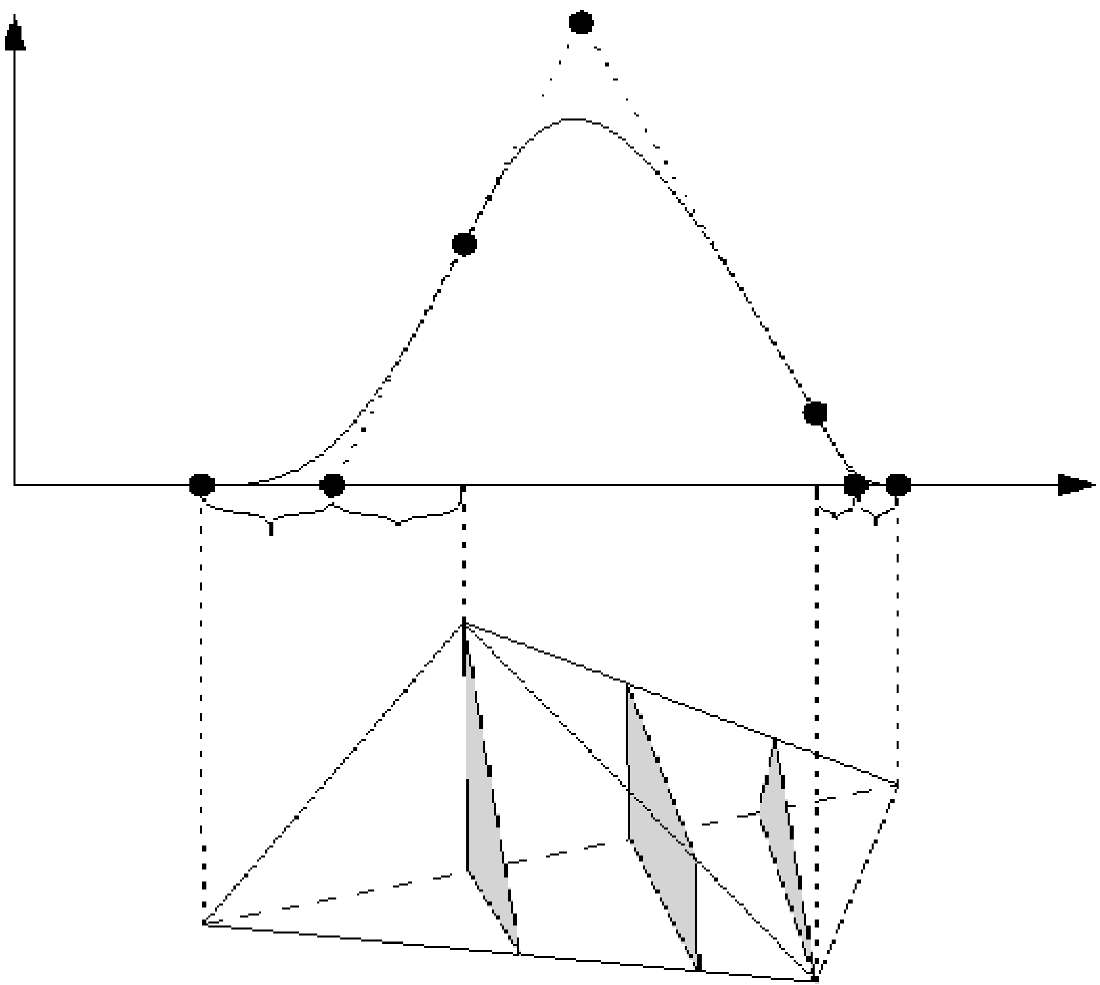


– **The length of each contour is a C^0 spline function.**

The area inside/outside each isocontour is a C^1 spline function.

Spectral Analysis (signature computation)

- *In general the size of each isocontour of a scalar field of dimension* d *is a spline function of* d-2 *continuity.*
- *The size of the region inside/outside is given by a spline function of* d-1 *continuity*



Progressive Isocontouring

We have an optimal isocontouring algorithm with minimal storage requirements

What more?

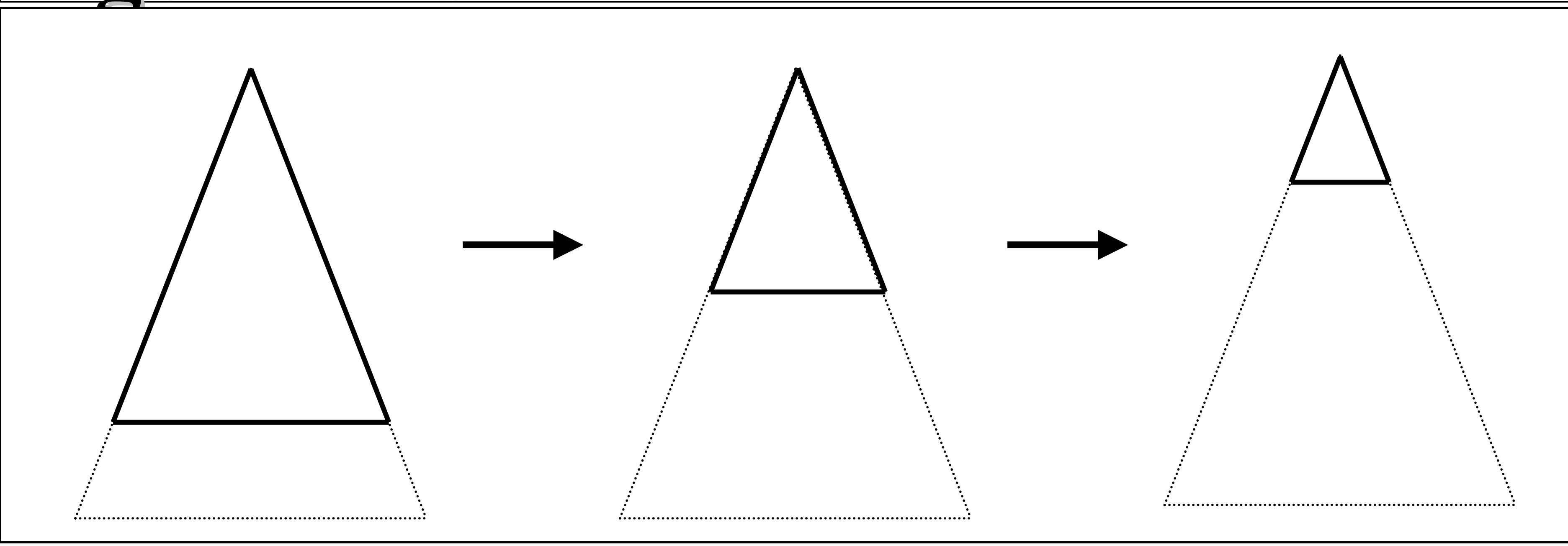
A <u>Progressive</u> Algorithm

N.B. not just a progressive data-structure but a progressive <u>algorithm</u>

Bring on the coffee! Or Mineral Wasser !!

Progressive Isocontouring

cascaded <u>multi-resolution</u> <u>on-line</u> algorithms



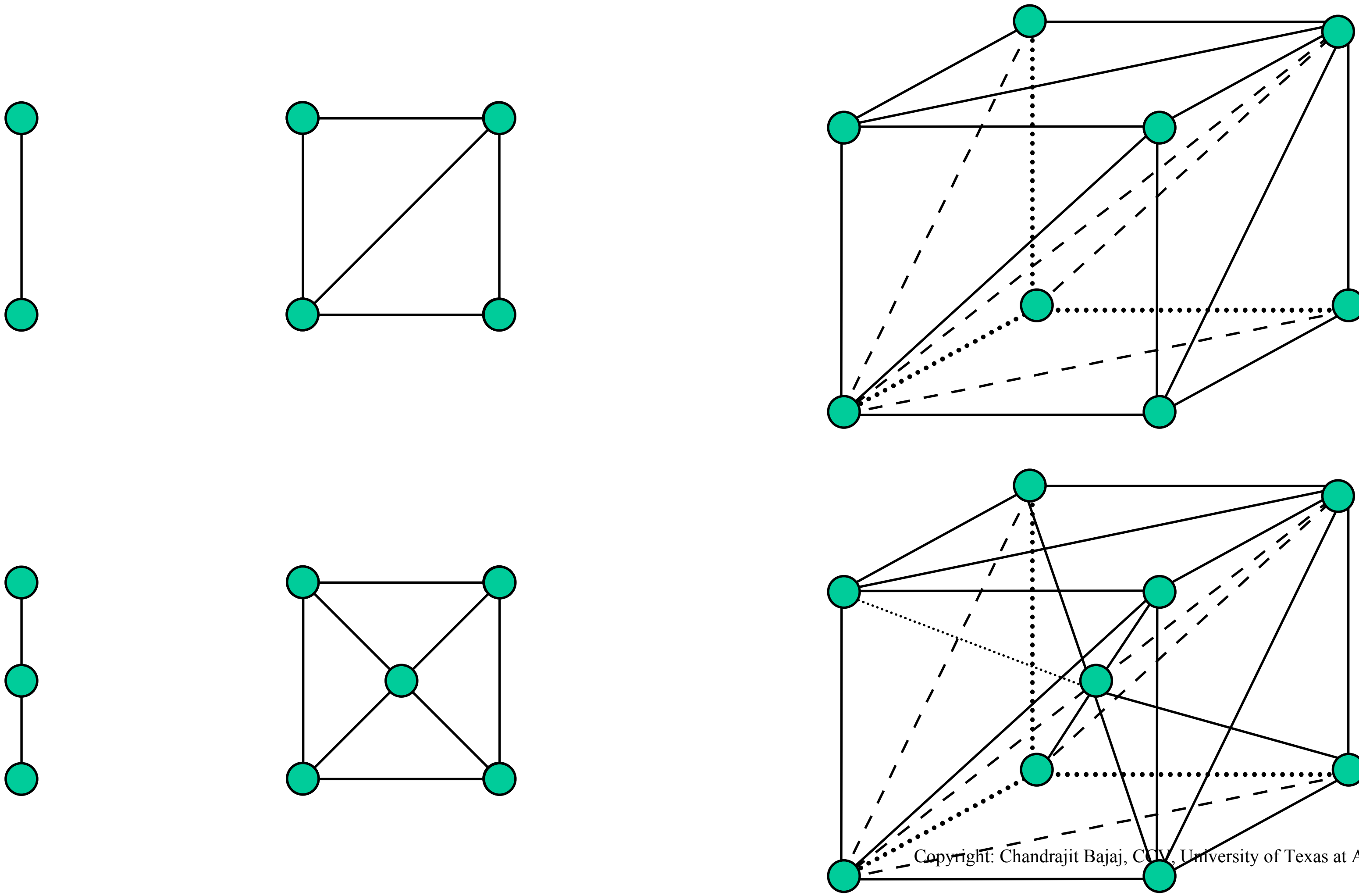
Mesh Refinement → Isocontourin
g → Display

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

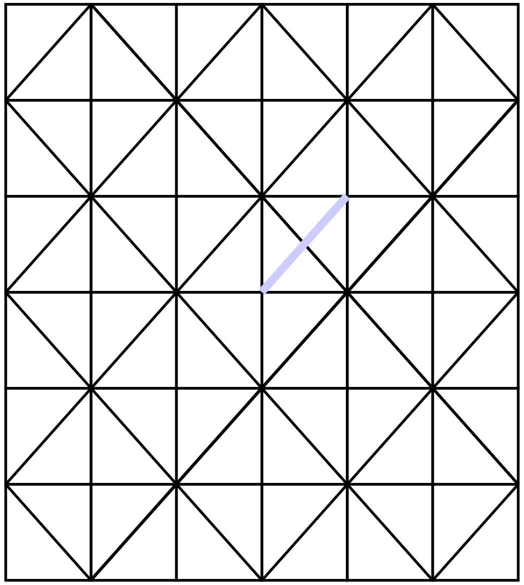
Progressive Isocontouring

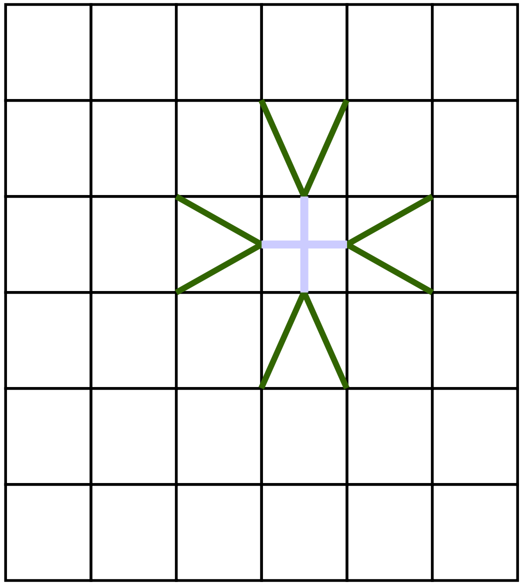
Edge Bisection



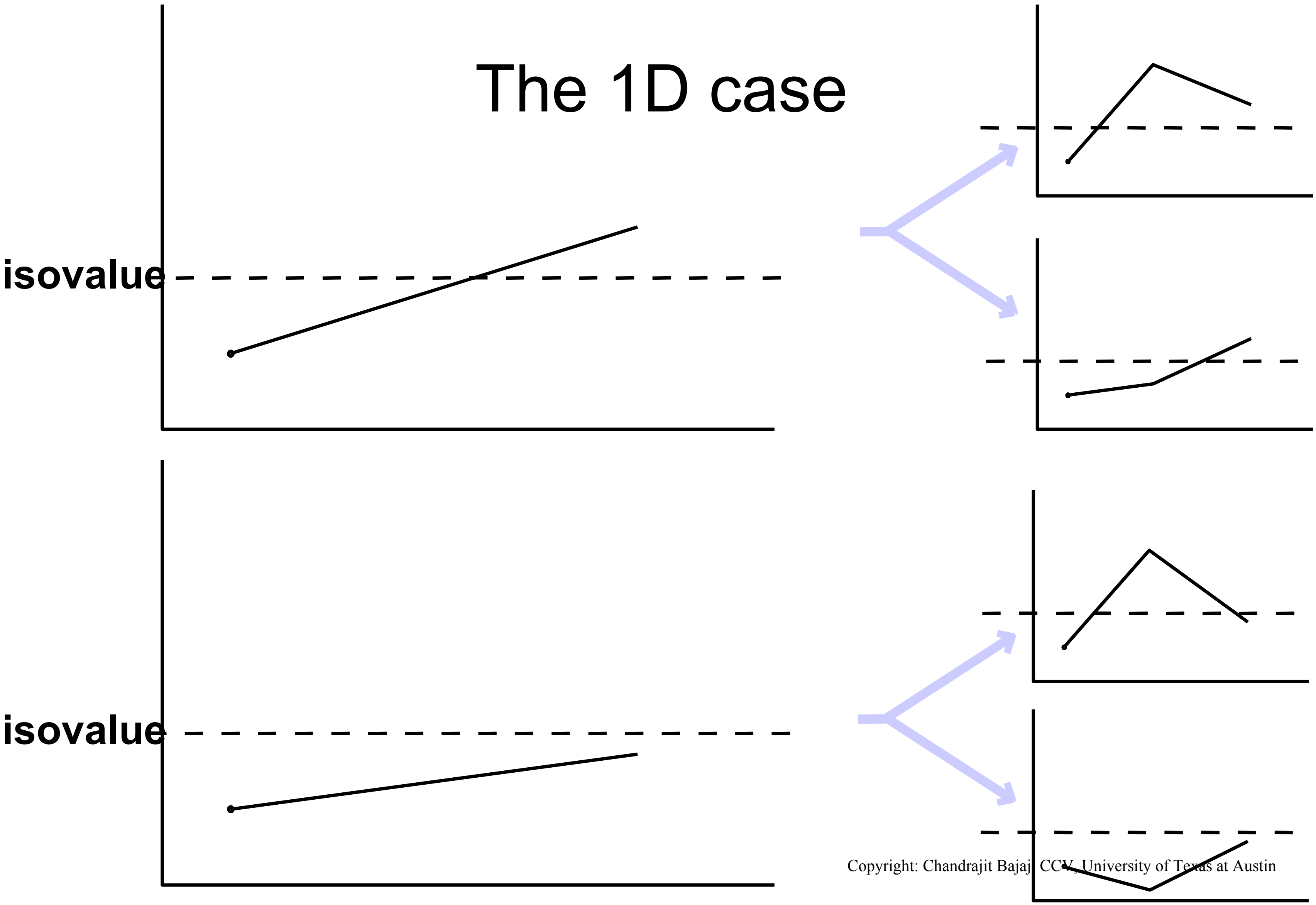
Progressive Isocontouring

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





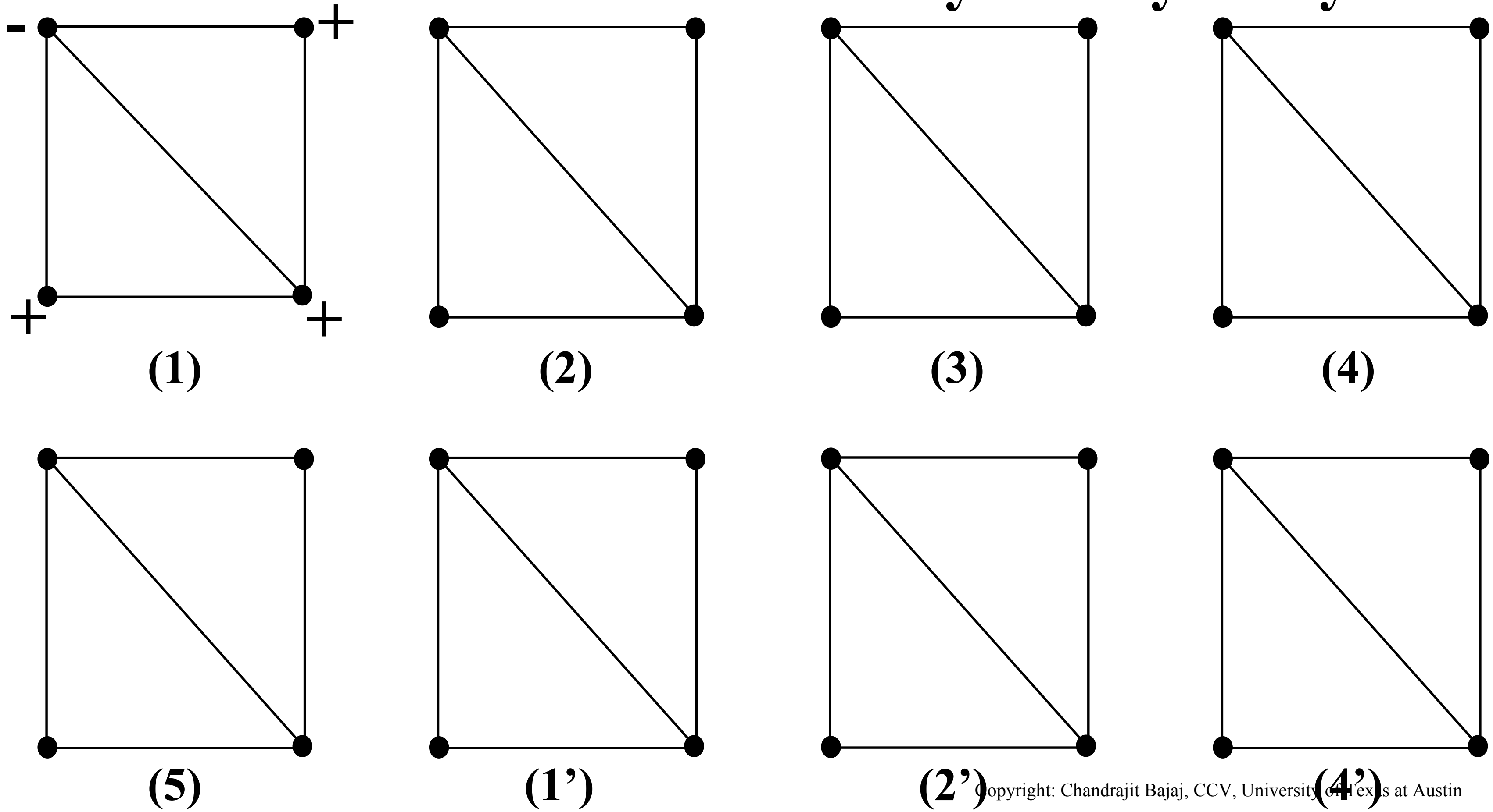
Progressive Isocontouring



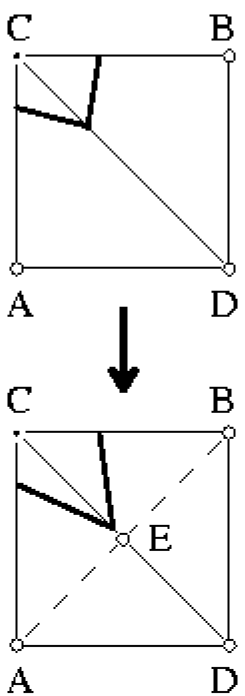
Progressive Isocontouring

2D case

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

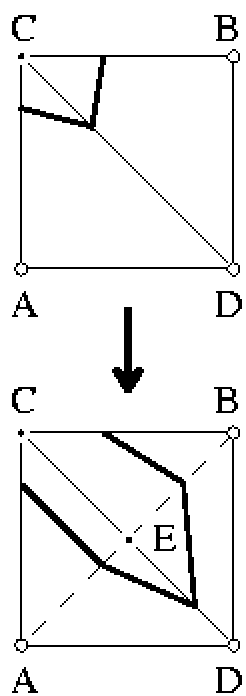


Progressive Isocontouring



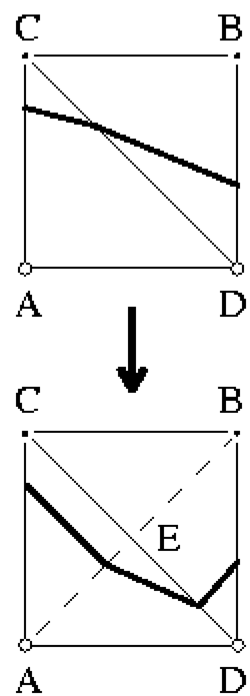
- **Vertex Move**

(1)



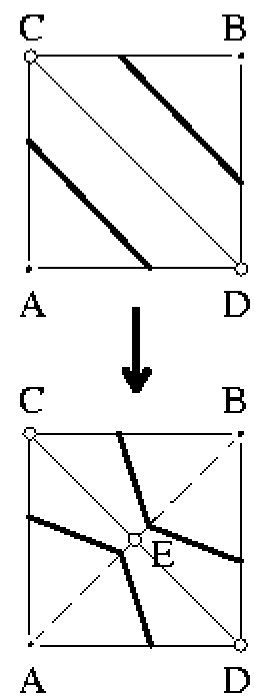
Vertex Move
Vertex Split
Vertex Split

(1)



Vertex Move
Vertex Split

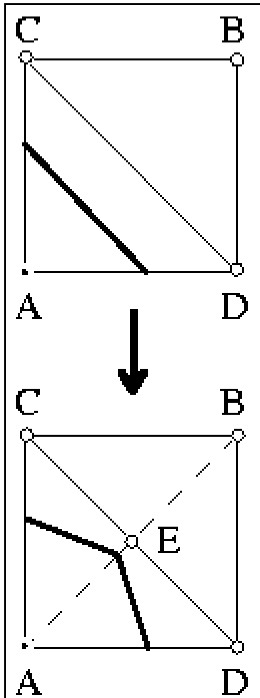
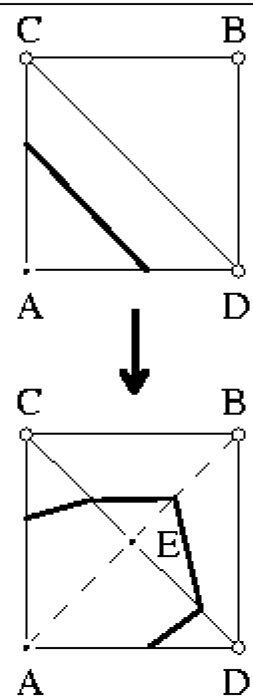
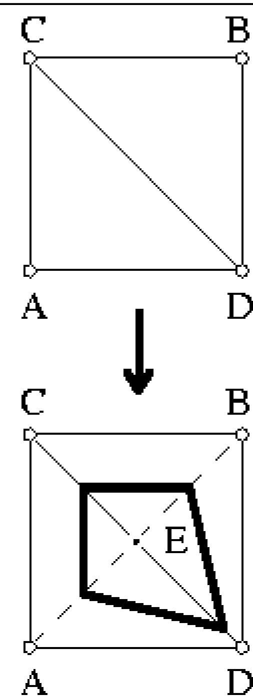
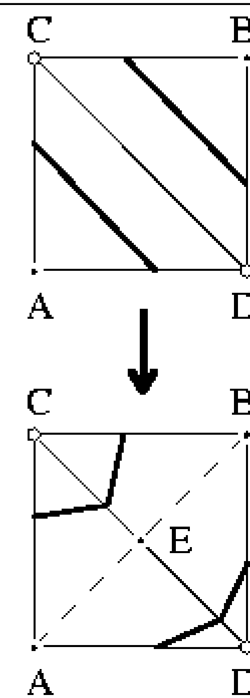
(2)



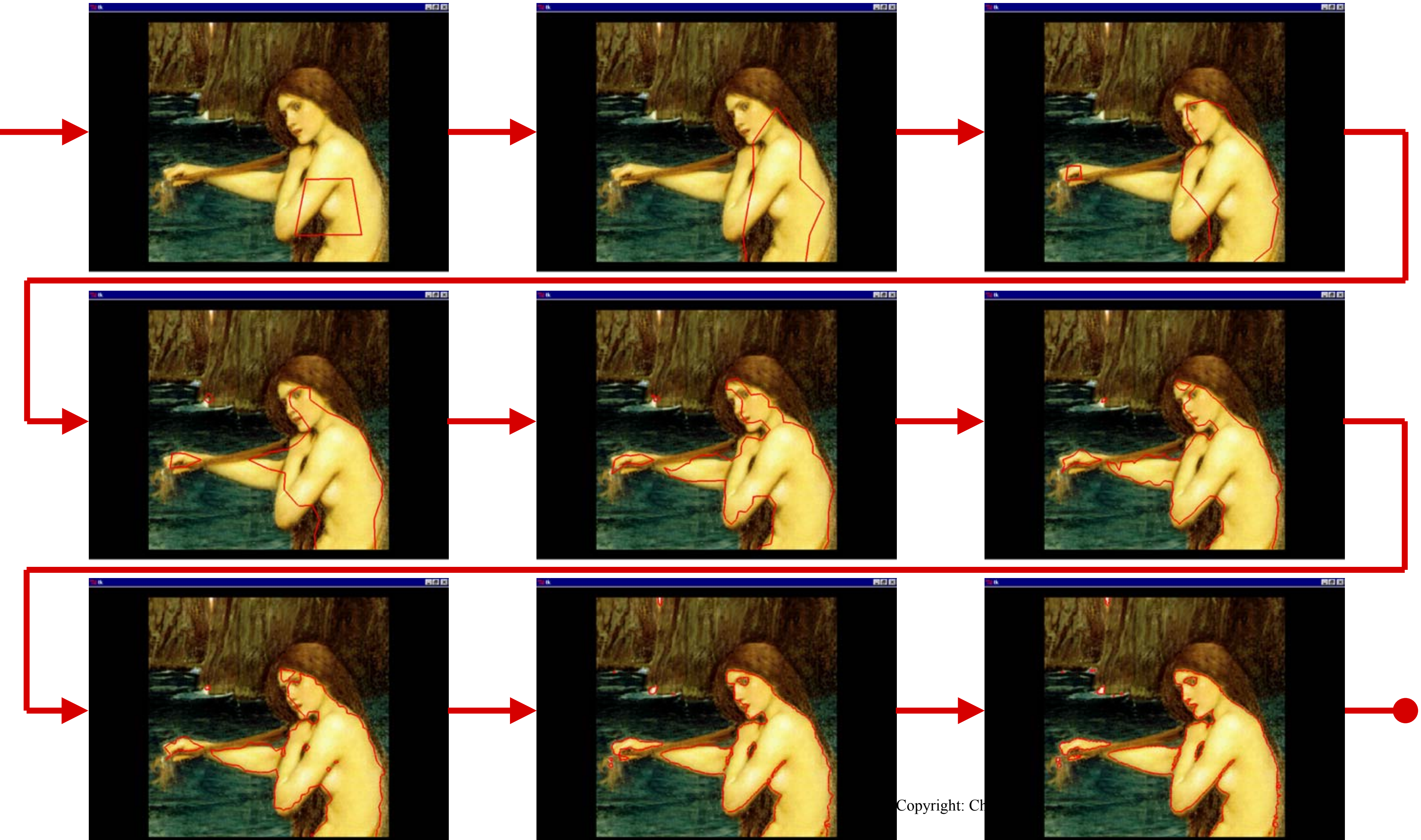
Vertex Split
Vertex Split

(3)

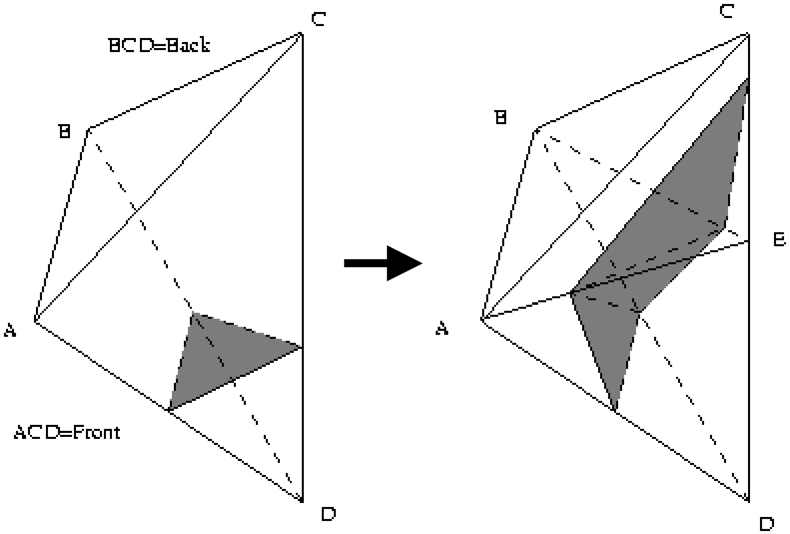
Progressive Isocontouring

			
• **Vertex Split** **(4)**	**Vertex Split** **Vertex Split** **Vertex Split** **(4)**	New Loop **(5)**	Edge Flip **Vertex Split** **Vertex Split** **(3)**

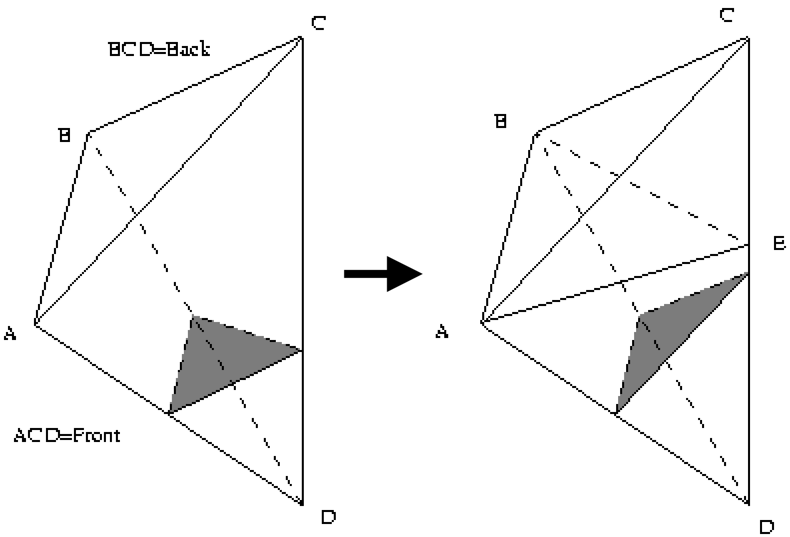
Progressive Isocontouring



Progressive Isocontouring

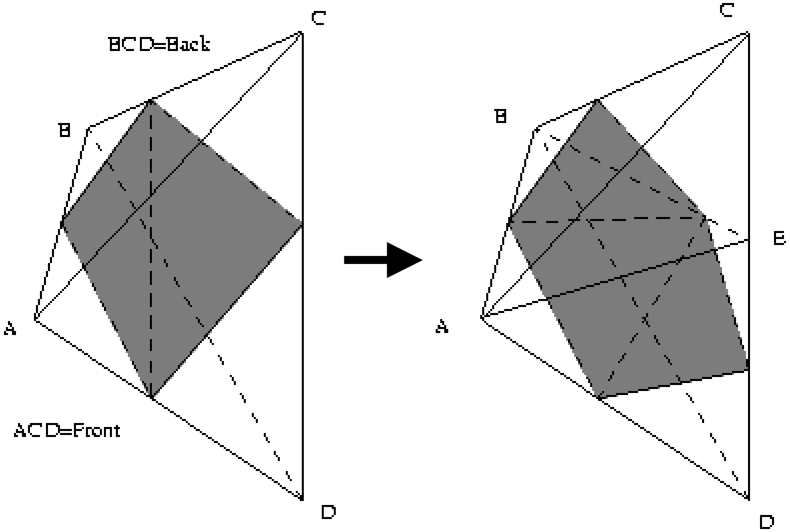


Vertex Move
Vertex Split
Vertex Split

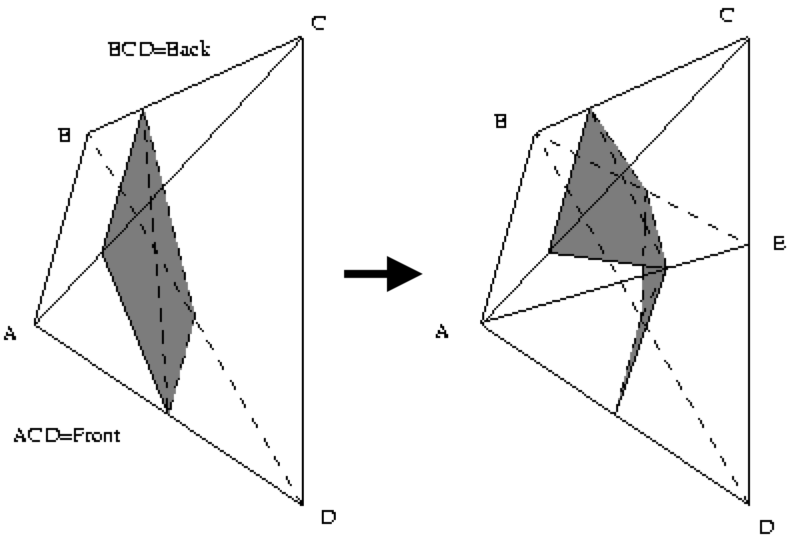


Vertex Move

Progressive Isocontouring

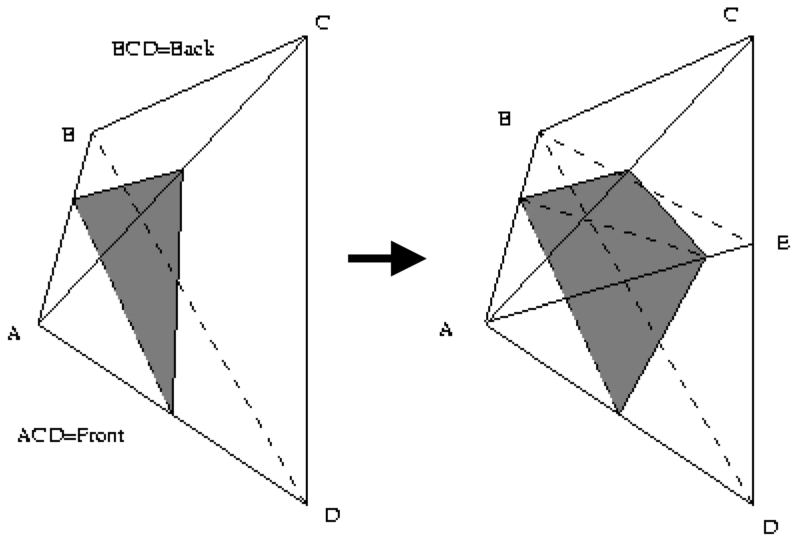


Vertex Move
Vertex Split

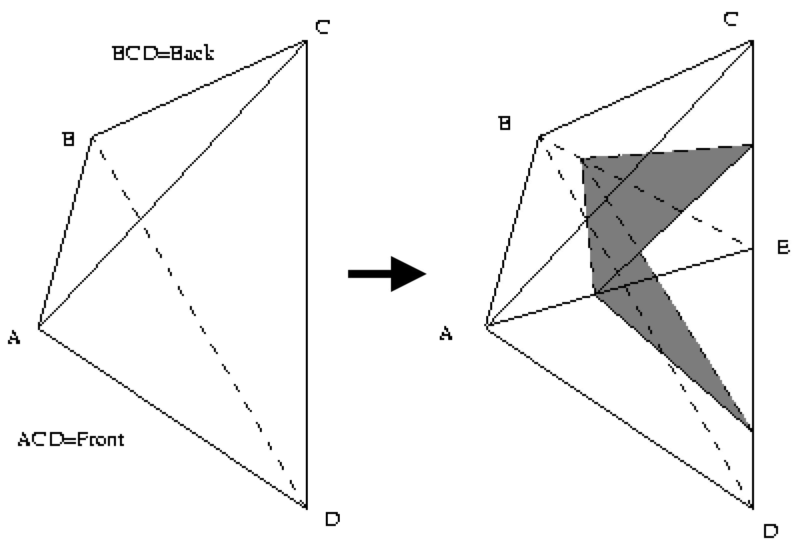


Vertex Split
Vertex Split

Progressive Isocontouring

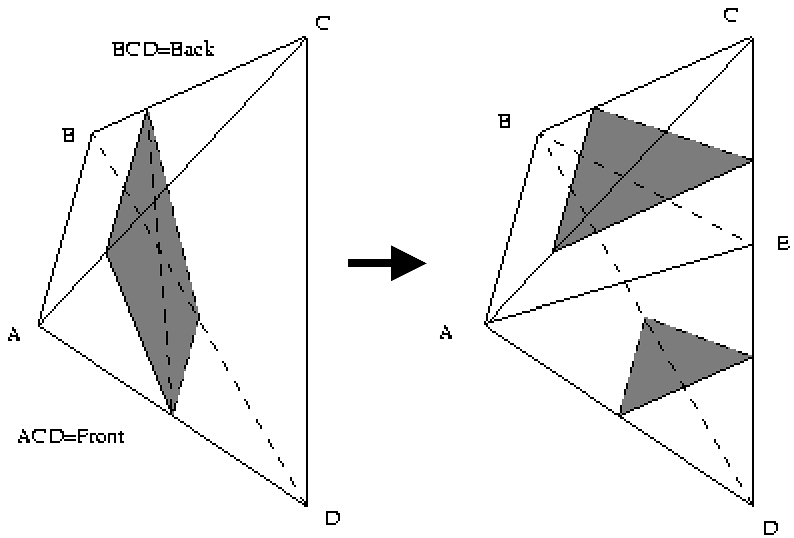


Vertex Split

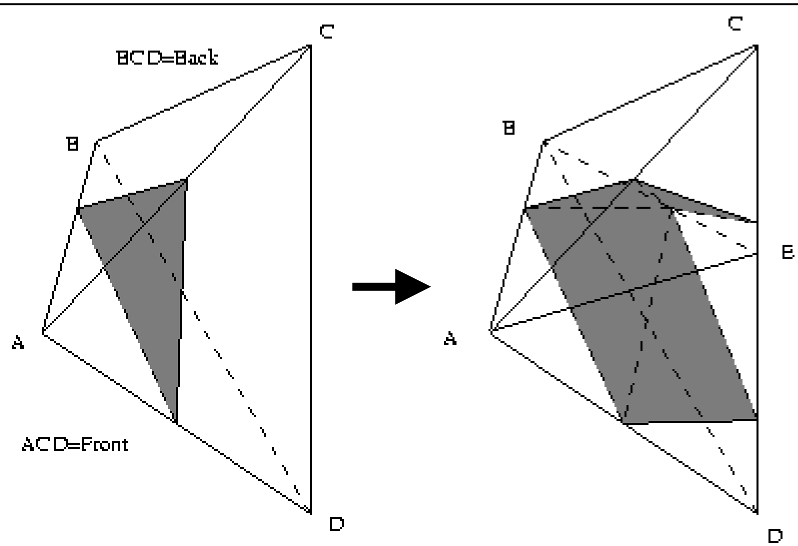


New Loop
Vertex Split

Progressive Isocontouring

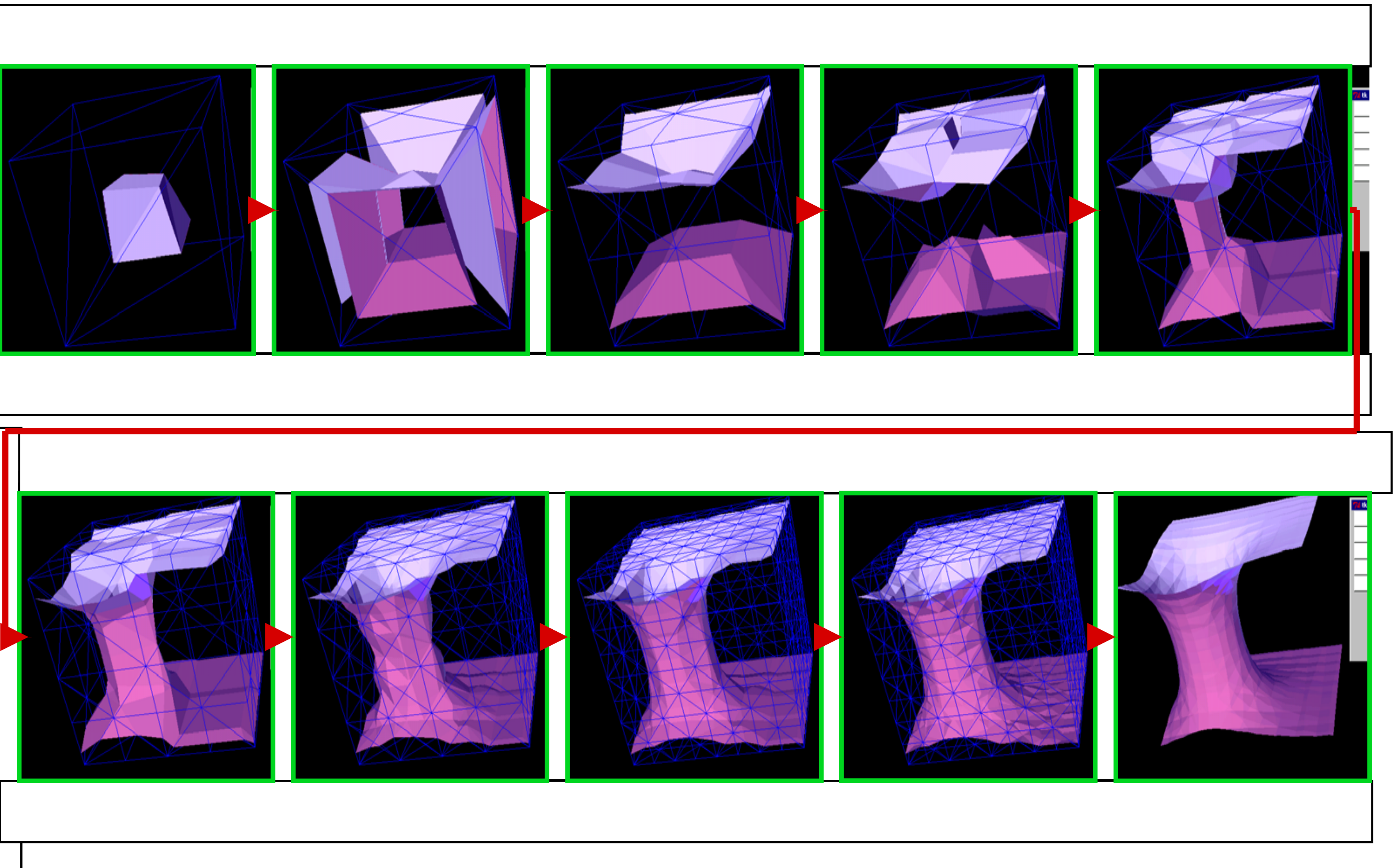


Vertex Flip
Vertex Flip

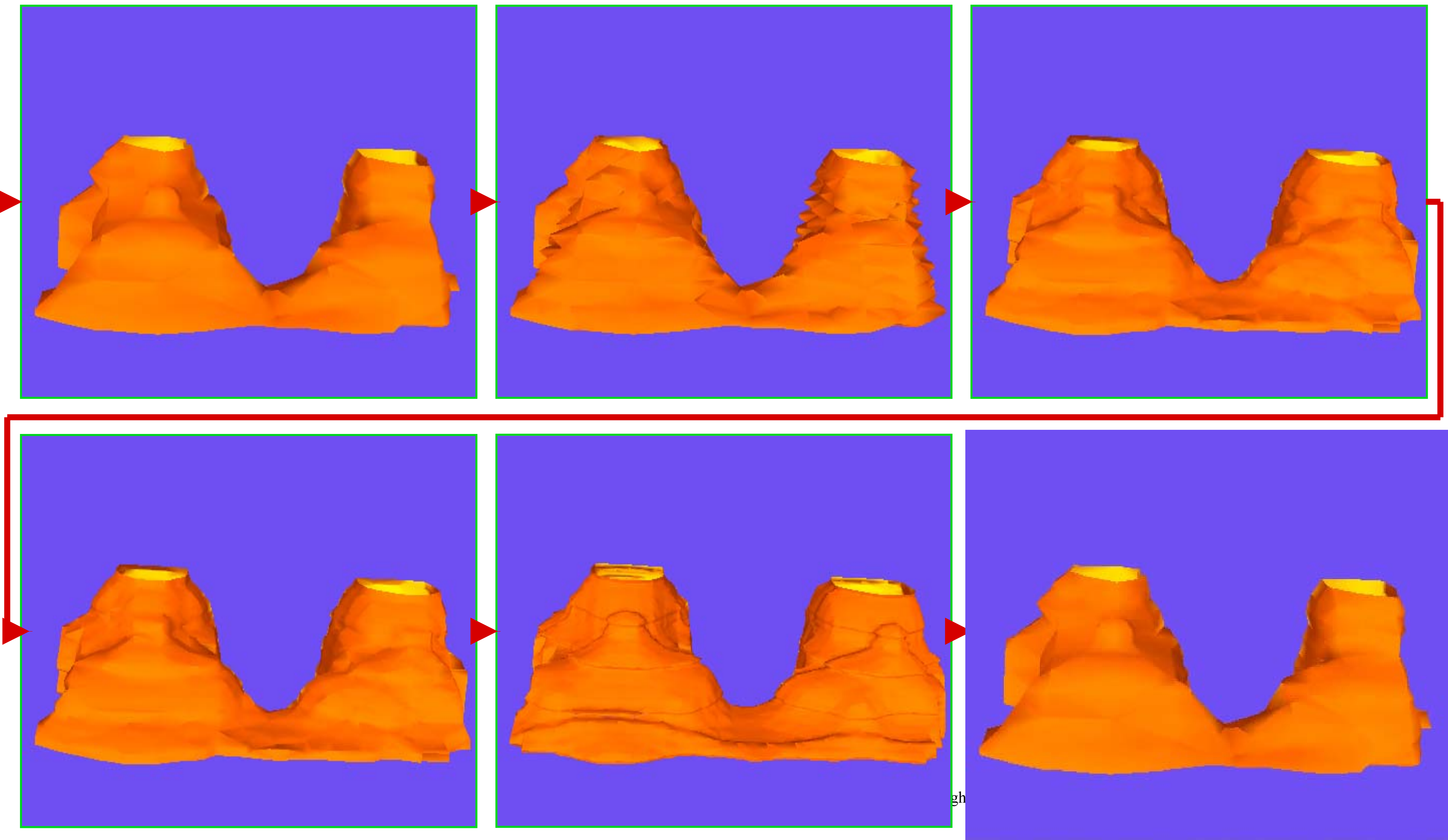


Vertex Split
Vertex Split
Vertex Split

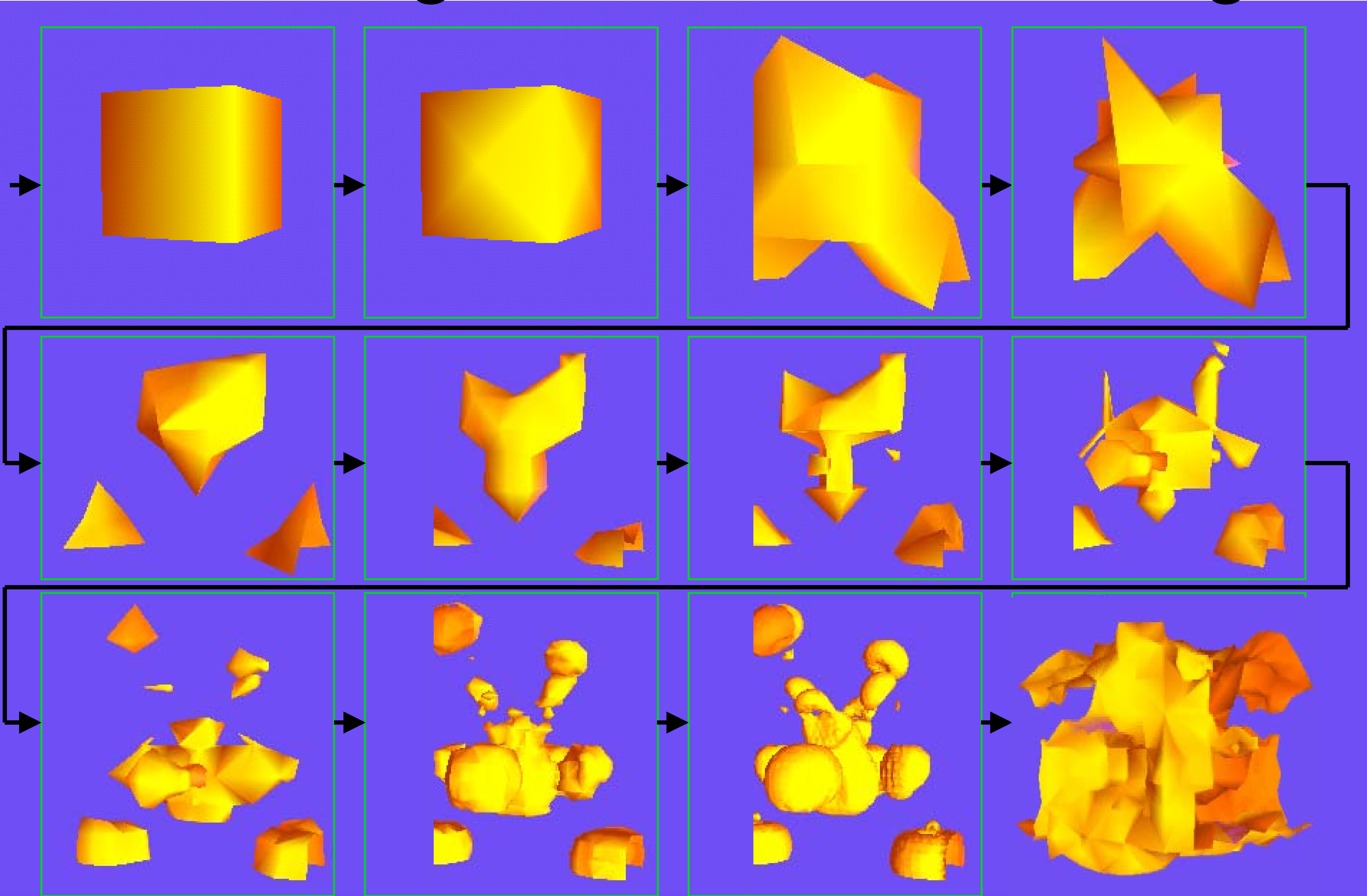
Progressive Isocontouring



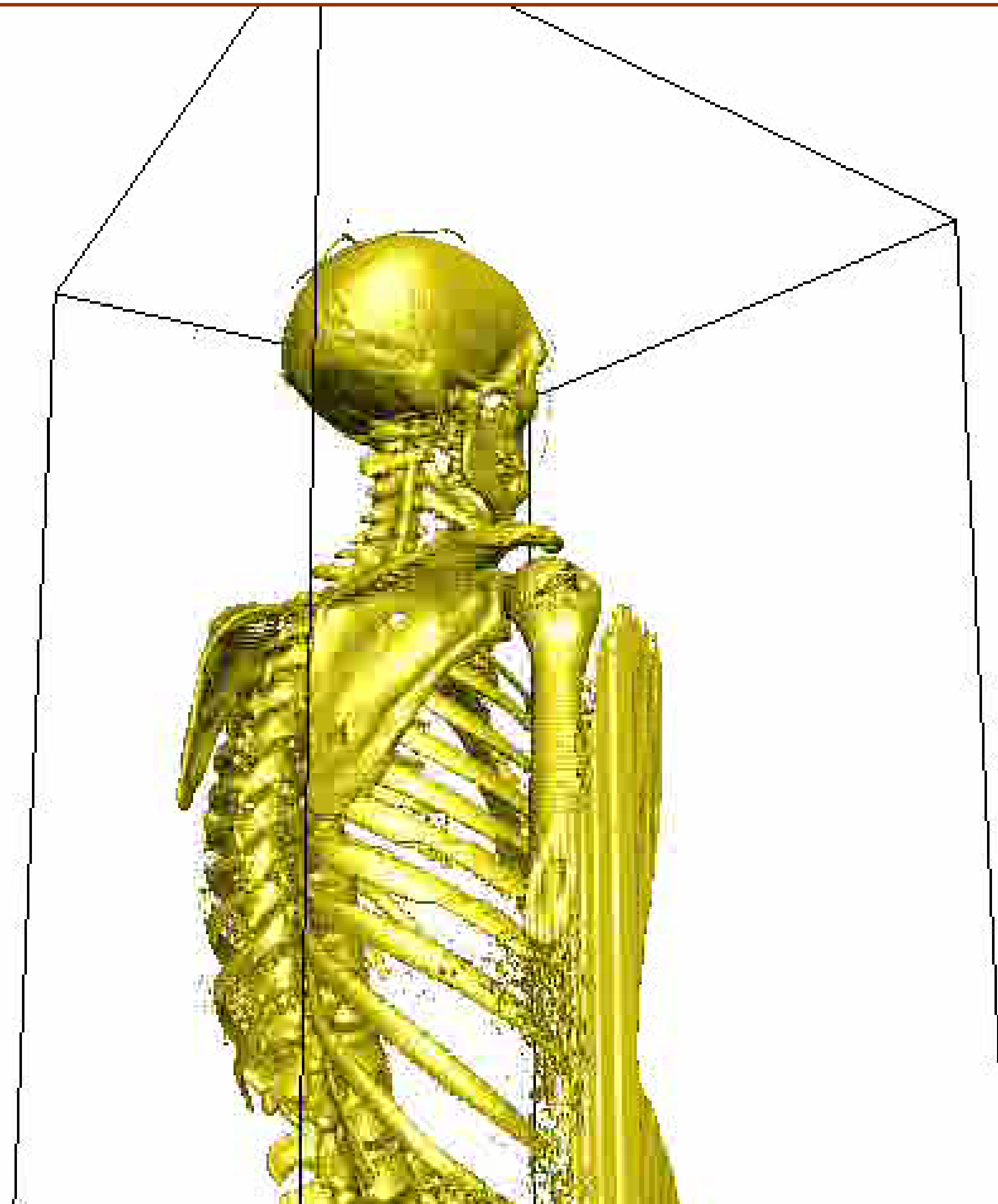
Progressive Isocontouring



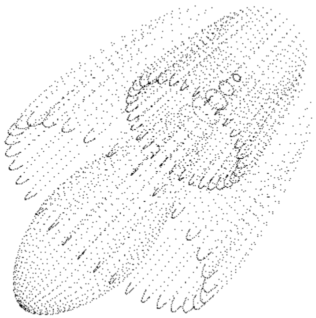
Progressive Isocontouring

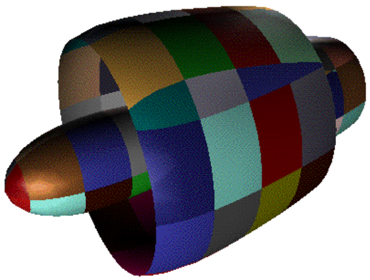


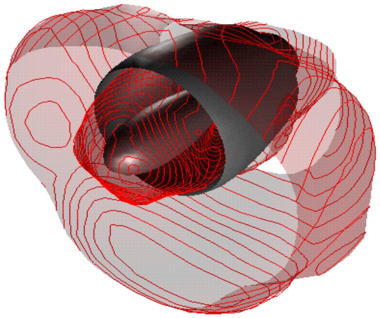
What more Contouring ?

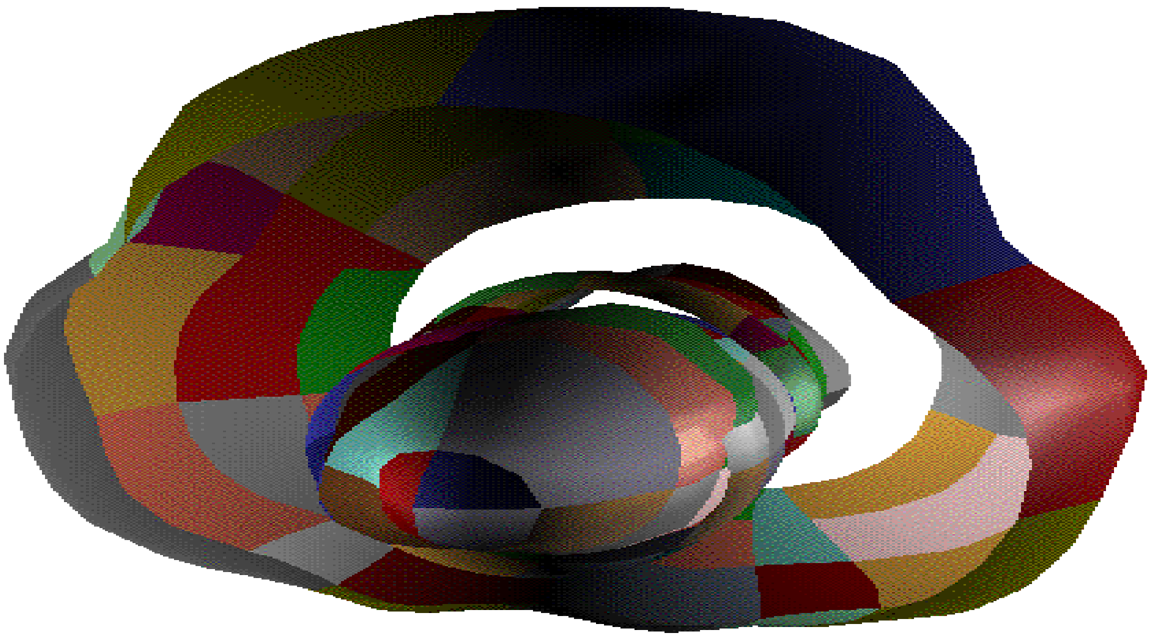


Higher Order Contouring with A-patches





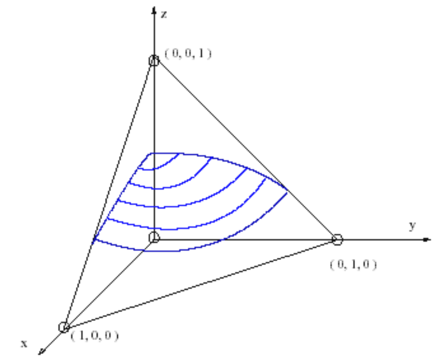




A-patches in BB-form

- Given tetrahedron vertices $p_i=(x_i,y_i,z_i)$, $i=1,2,3,4$,
  α is barycentric coordinates of $p=(x,y,z)$:

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ y_1 & y_2 & y_3 & y_4 \\ z_1 & z_2 & z_3 & z_4 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix}$$



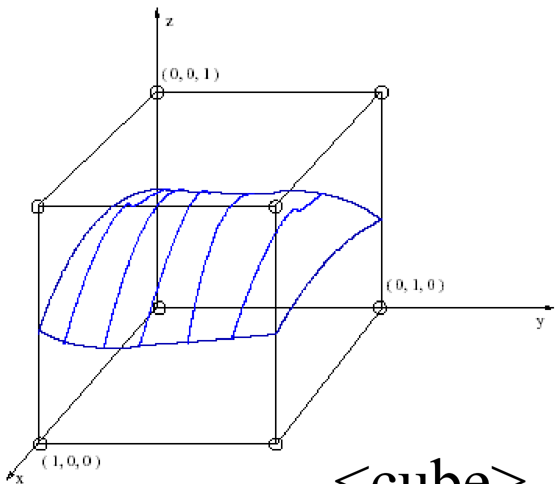
- function $f(p)$ of degree n can be expressed in Bernstein-Bezier form :

$$f(p) = \sum_{|\lambda|=n} b_\lambda \, B_\lambda^n(\alpha), \;\; \lambda \in \mathcal{Z}_+^4 \qquad B_\lambda^n(\alpha) = \frac{n!}{\lambda_1!\lambda_2!\lambda_3!\lambda_4!} \, \alpha_1^{\lambda_1} \alpha_2^{\lambda_2} \alpha_3^{\lambda_3} \alpha_4^{\lambda_4}$$

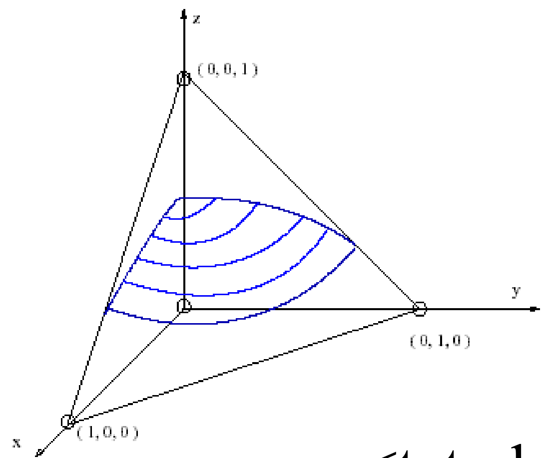
- Algebraic surface patch(A-patch) within the tet is defined as $f(p)=0$.

High Order Contouring using A-patches

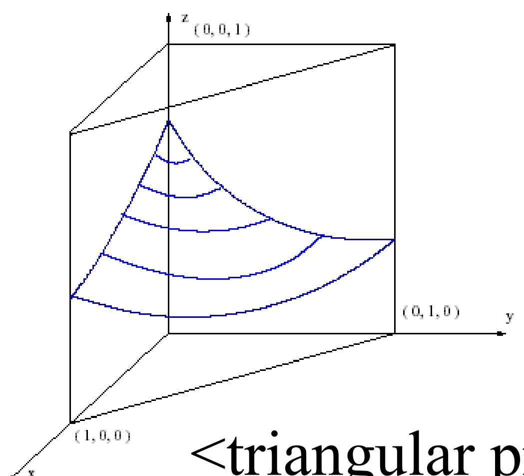
- Implicit form of Isocontour : $f(x,y,z) = w$



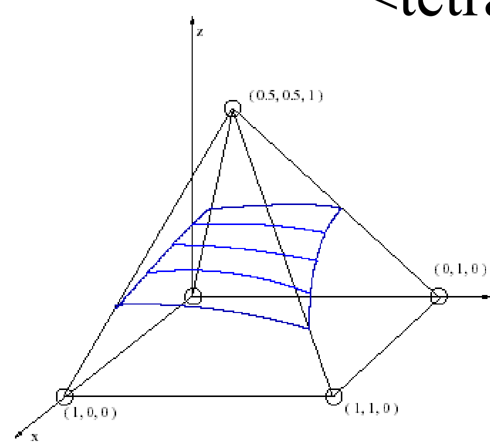
<cube>



<tetrahedron>



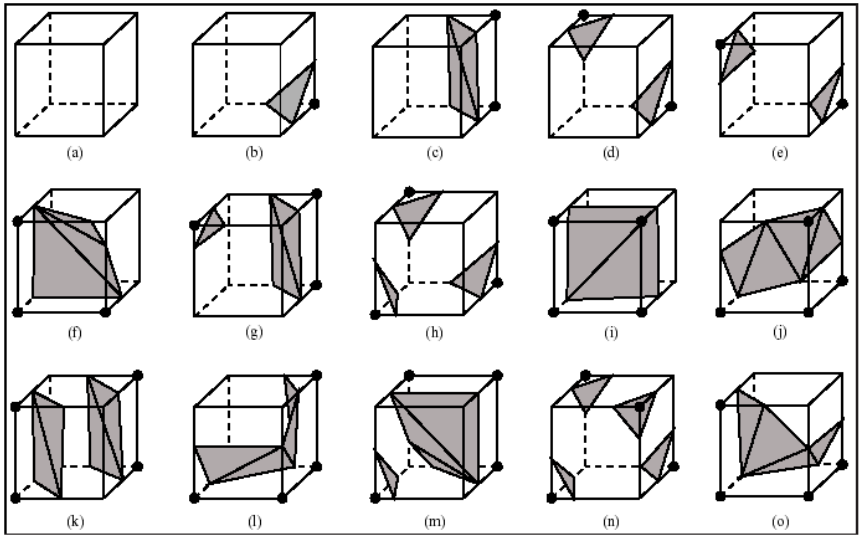
<triangular prism>

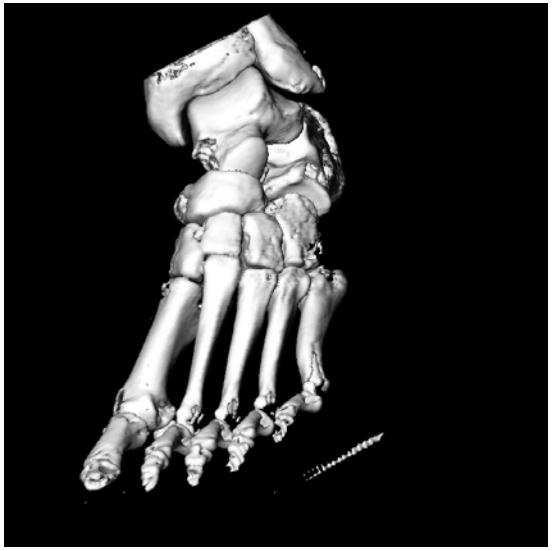


<square pyramid>

Marching Cubes

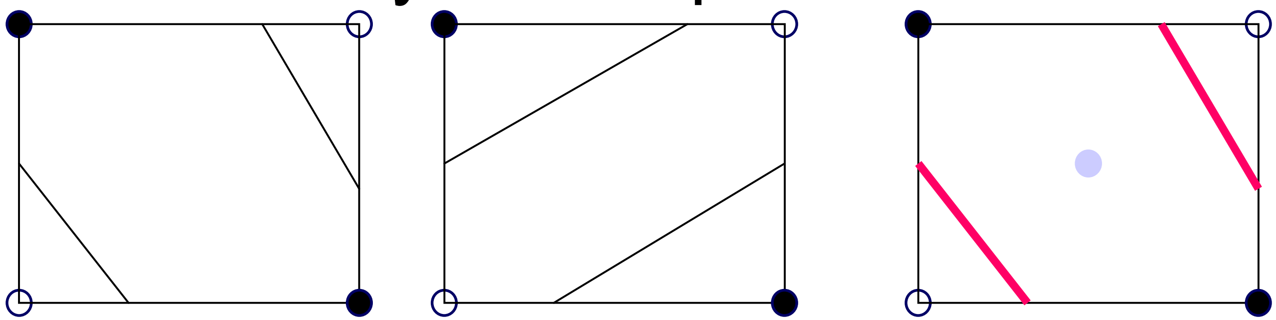
- Piecewise linear approximation of an isosurface
- Visit and Triangulate Each Cells based on a Table
- Triangulation Table (256 → 15 cases)

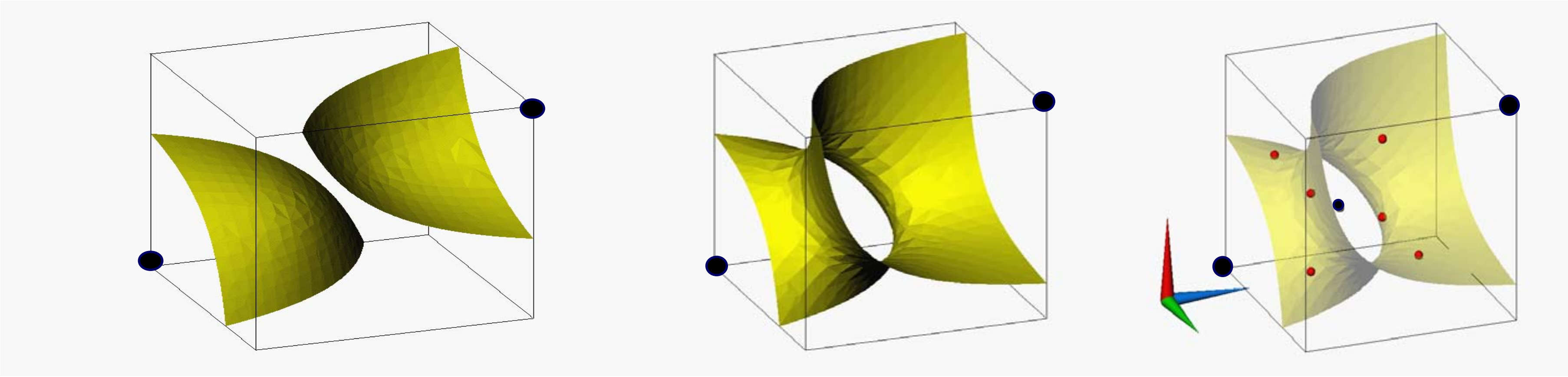




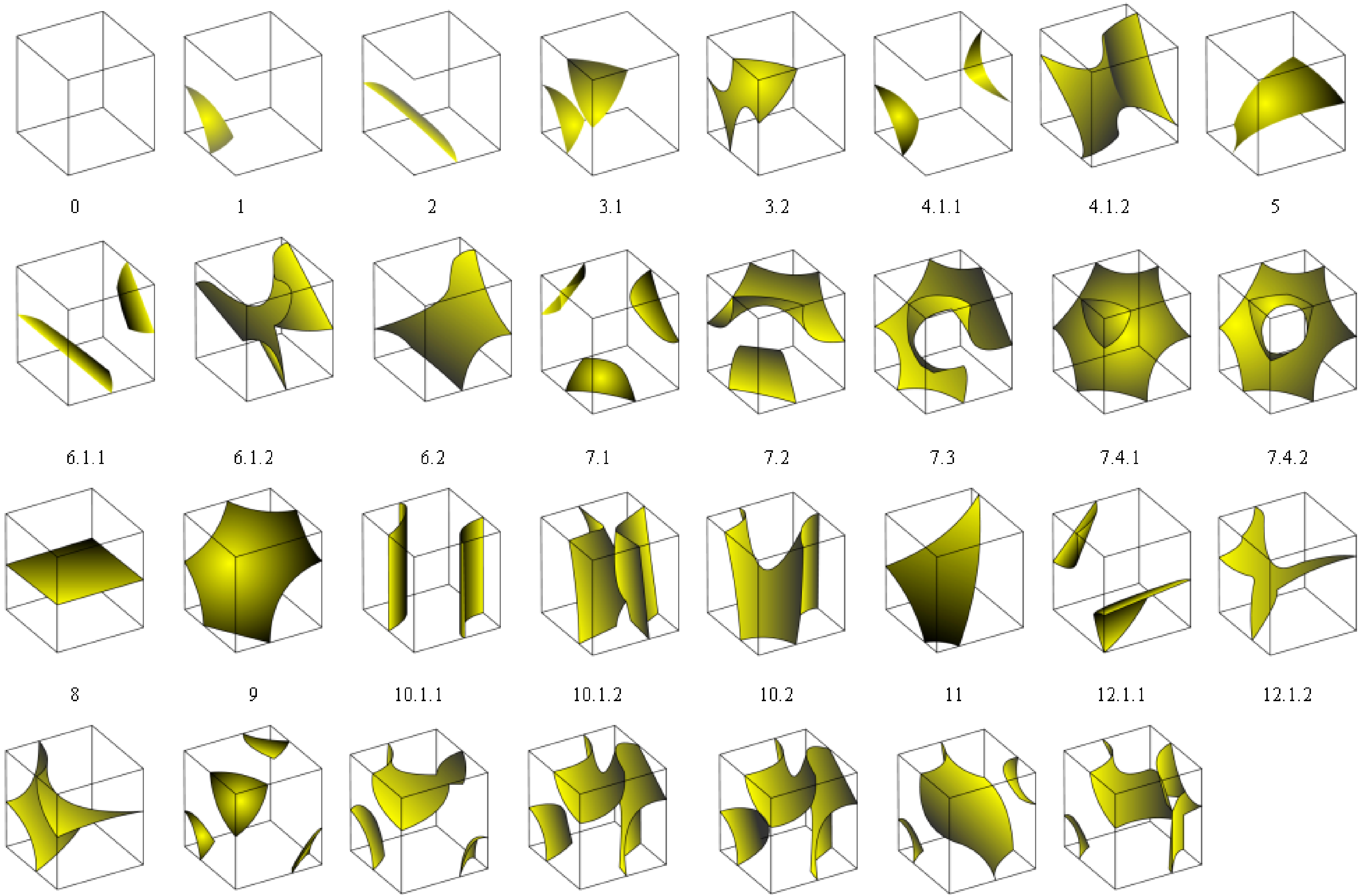
Good Approximation

- Topological accuracy
  - Decided by saddle point values



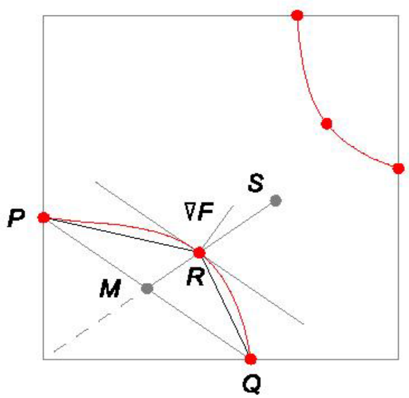


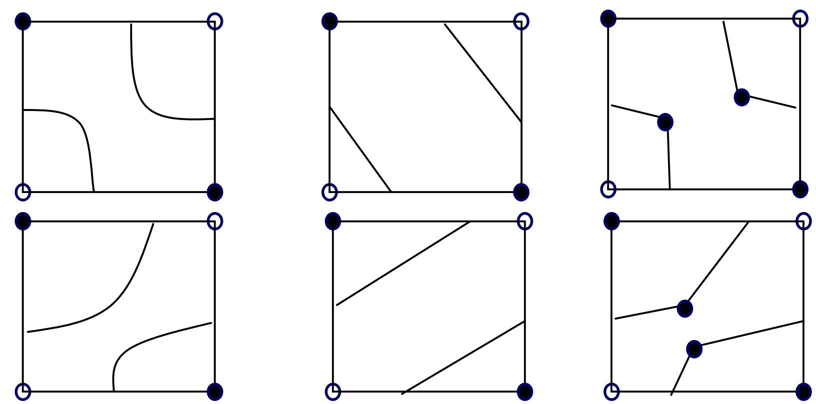
31 Cases

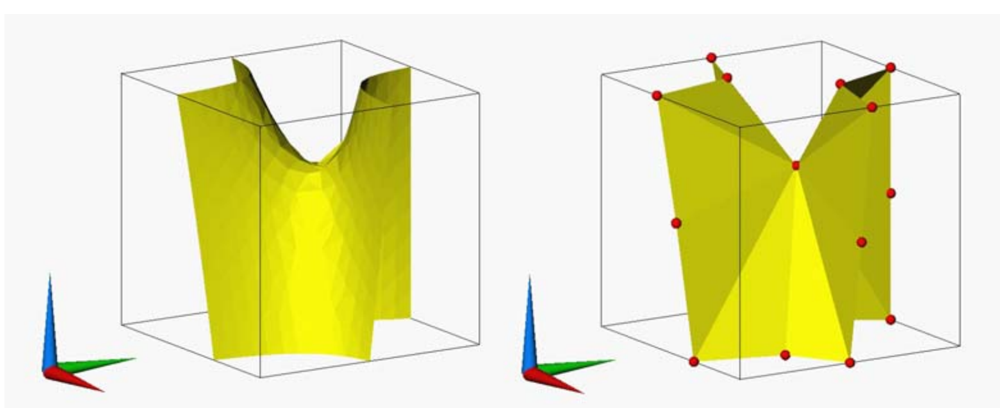

0
1
2
3.1
3.2
4.1.1
4.1.2
5
6.1.1
6.1.2
6.2
7.1
7.2
7.3
7.4.1
7.4.2
8
9
10.1.1
10.1.2
10.2
11
12.1.1
12.1.2
12.2
13.1
13.2
13.3
13.4
13.5.1
13.5.2

Good Approximation

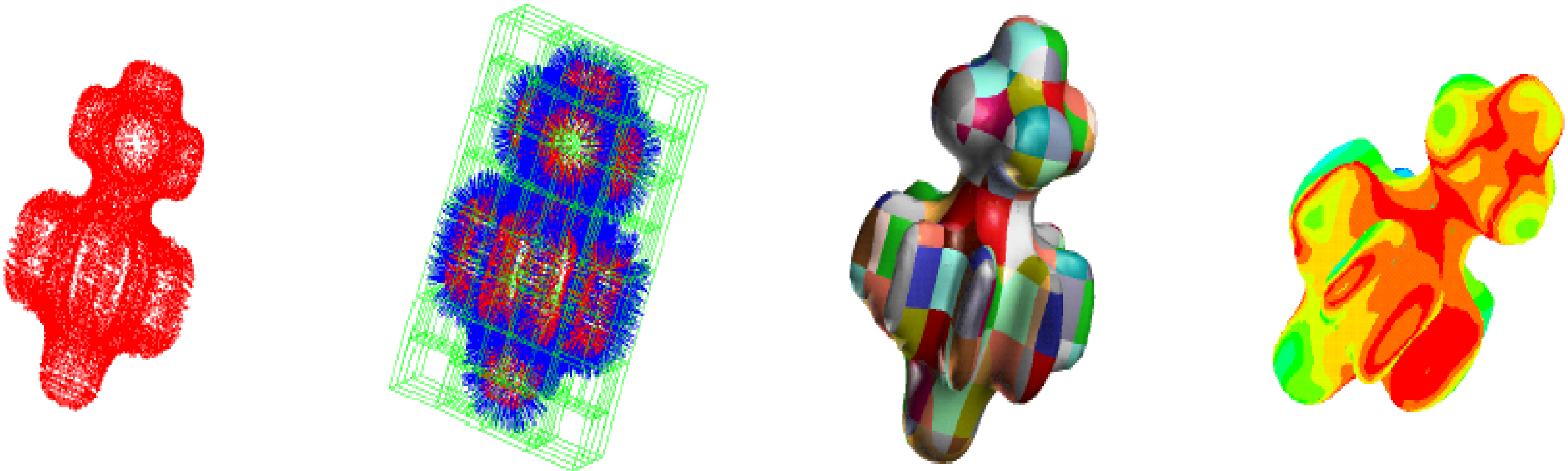
- Better appoximation of trilinear interpolant
  - Adding a shoulder and inflection points







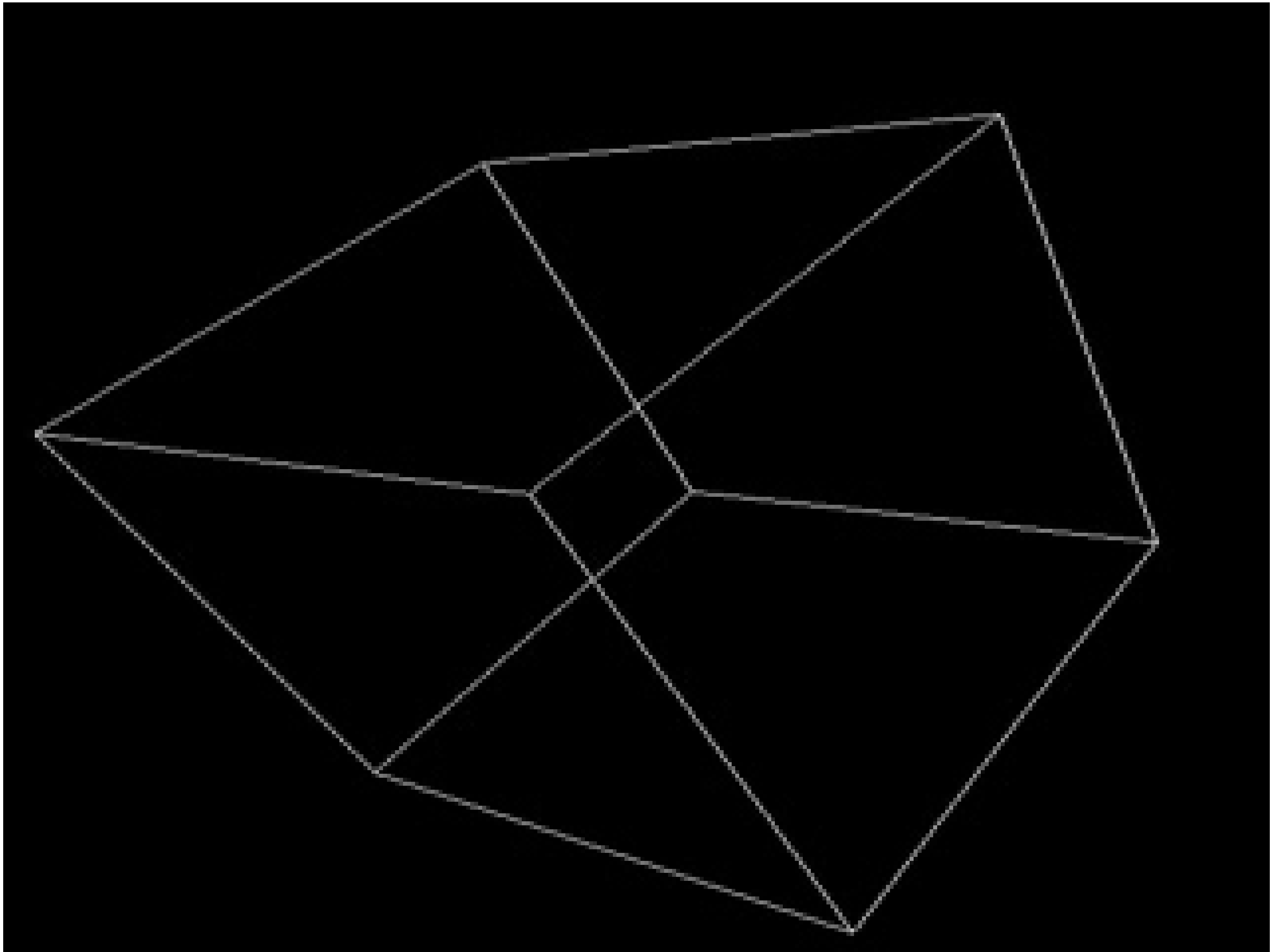
High Order Contouring with A-patches



(a) (b) (c) (d)

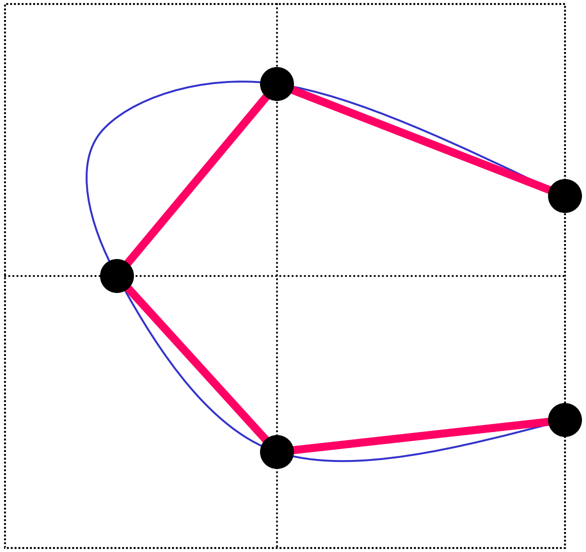
(a) Scattered points
(b) Octree subdivision → function interpolation
(c) Piecewise polynomial approximation
(d) Reconstructed scalar fields

No more Contouring !

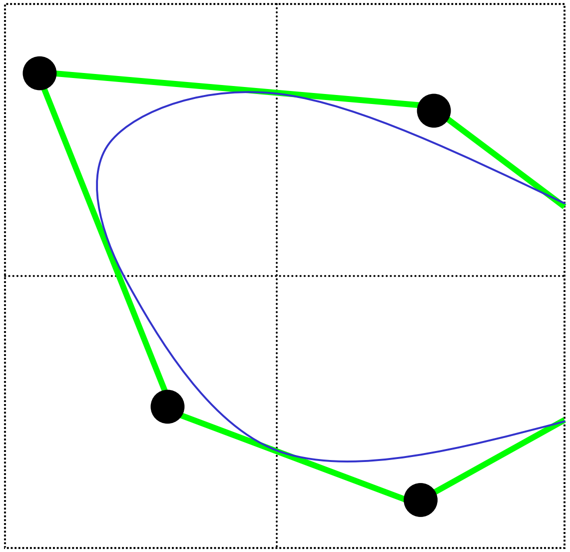


Dual Contouring

- Primal Contouring vs Dual Contouring



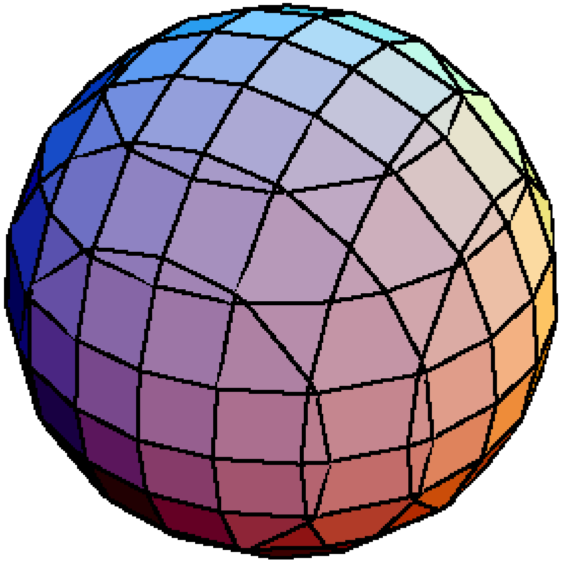
Primal contour

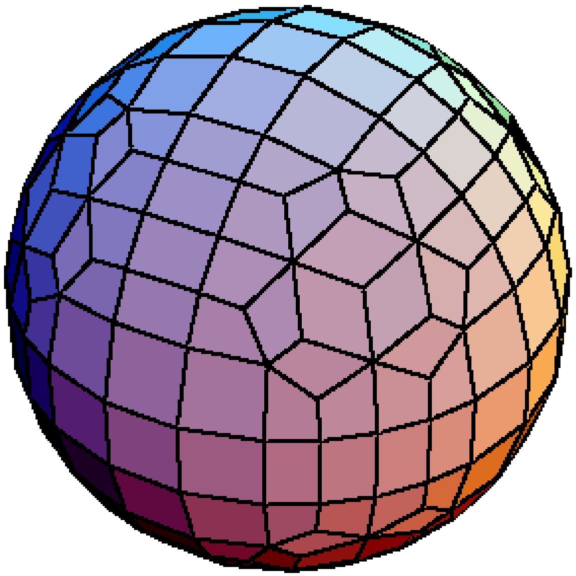


Dual Contour

Dual Contouring

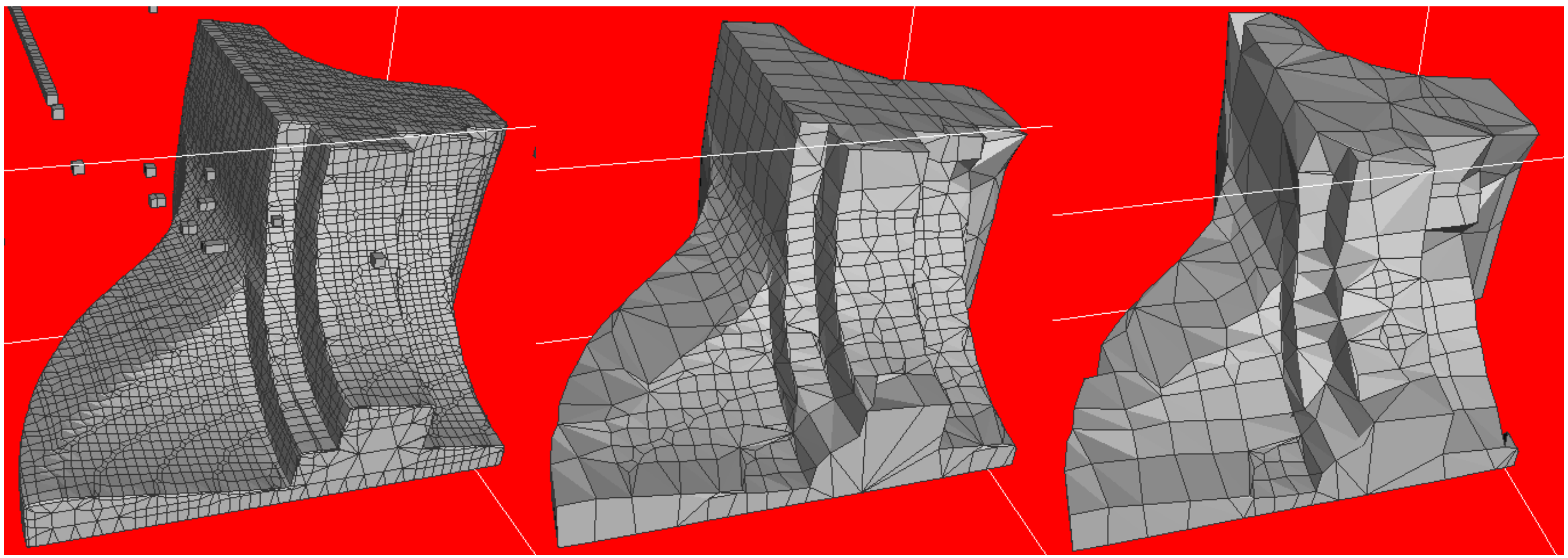
- Polygons with better aspect ratio

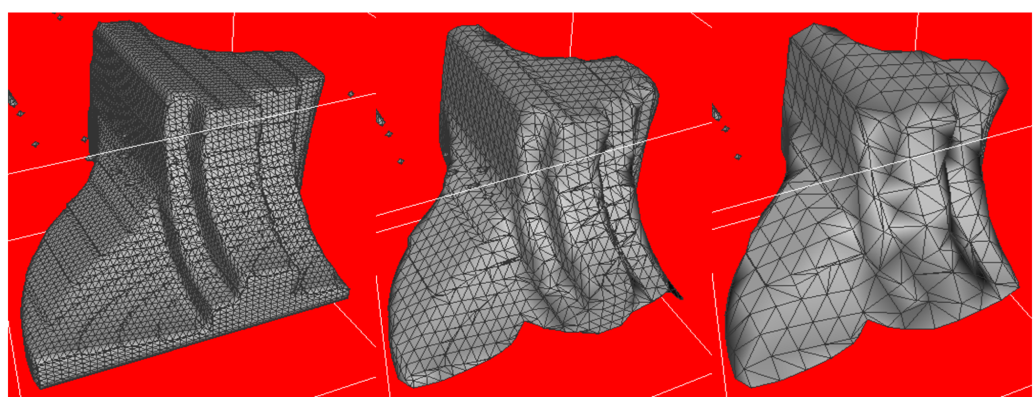




Adaptive Dual Contouring

- Feature preservation

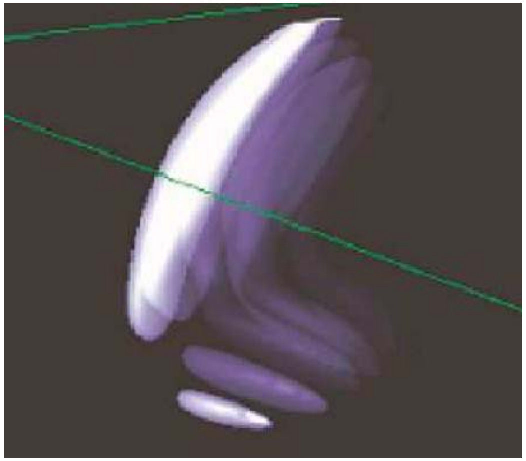




Normal
adaptive isocontouring

Isosurface Tracking

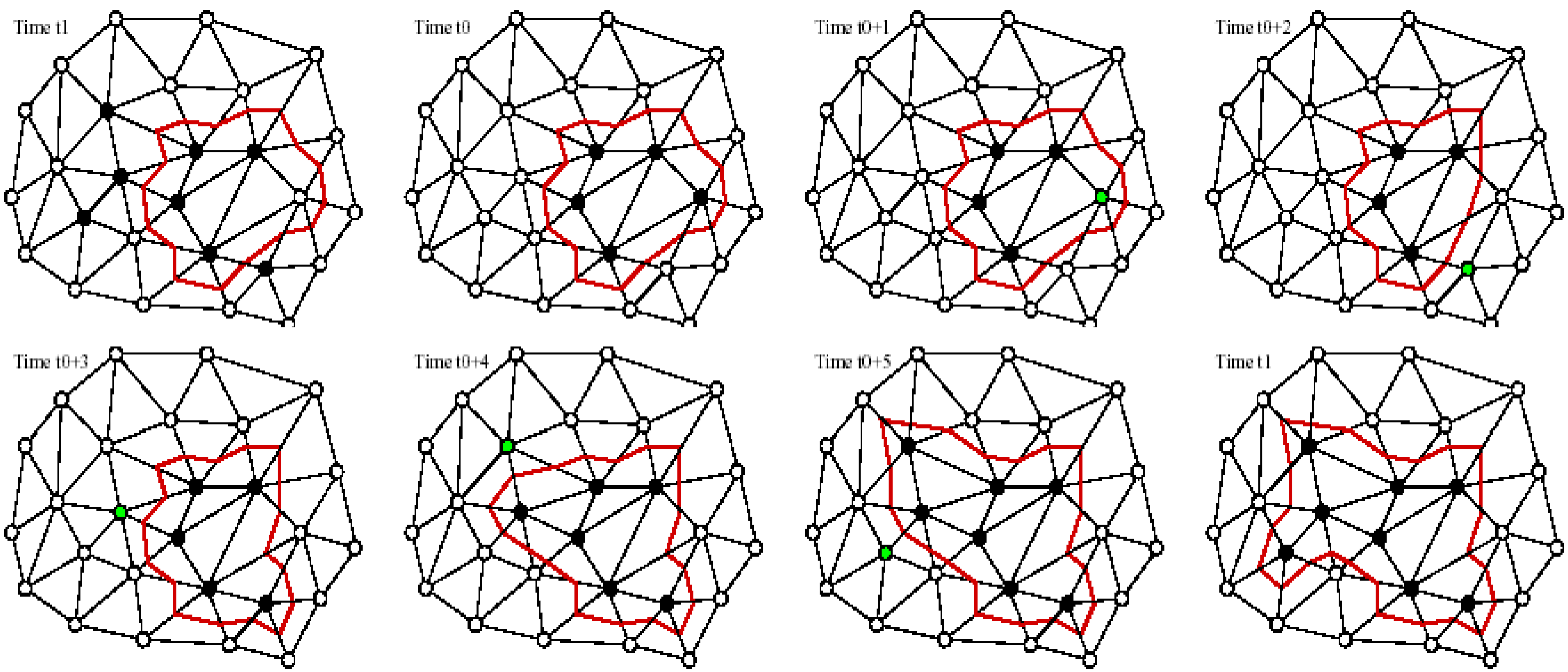
- Isosurface component tracking
  - traces and updates the movement and topology changes of an
    isosurface component in time-varying fields.



- **Tracking smooth evolution of an isosurface**
- **Tracking isosurface topology changes over time**
- **Efficiency : I/O optimization , delta seedset.**

Isosurface Tracking

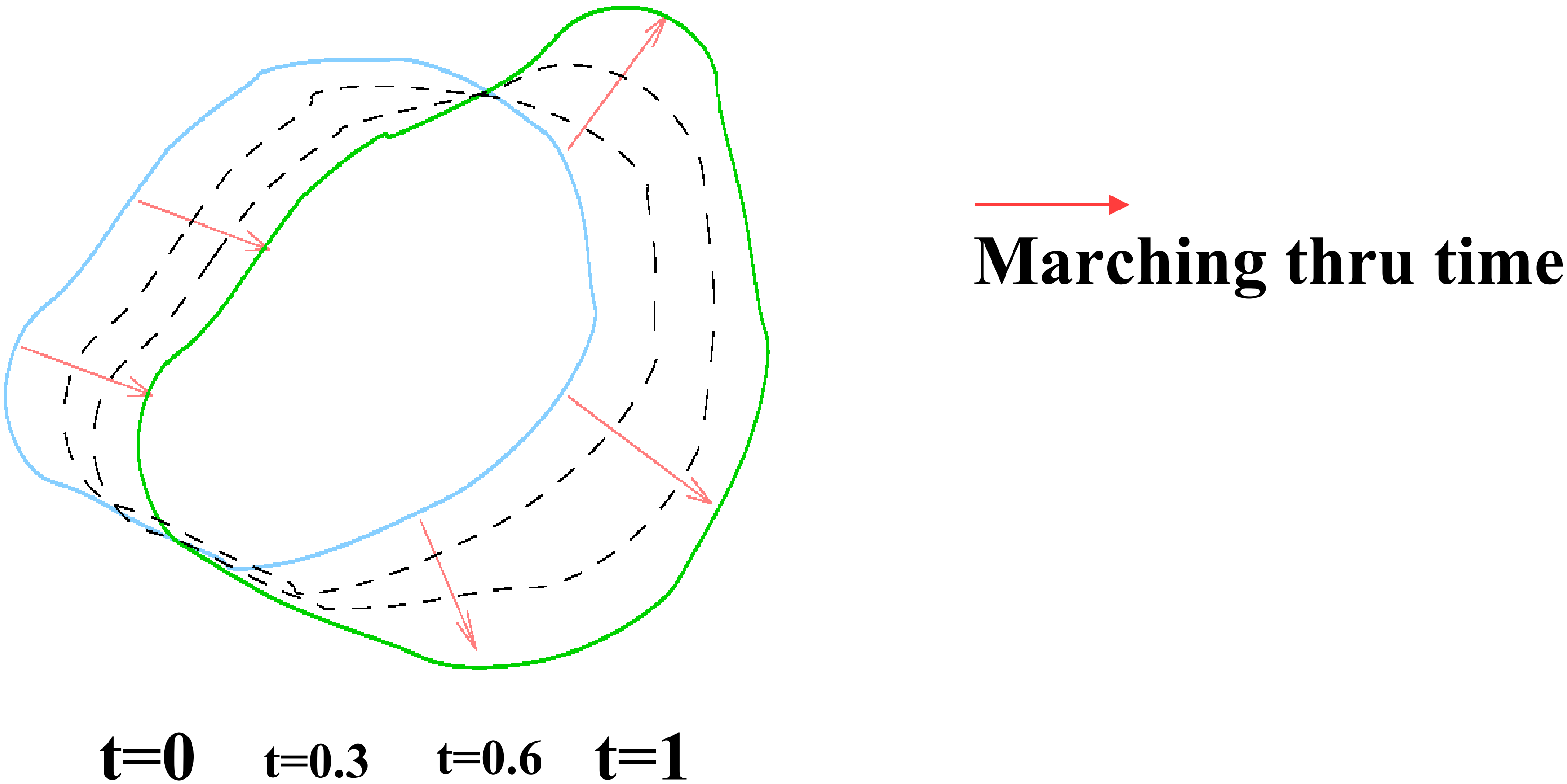
- Temporal Propagation
  - **Given an isosurface component Ct at time t,**
  - **Track the movement of Ct**
  - **Construct the isosurface component Ct' at time t'=t+Δt**



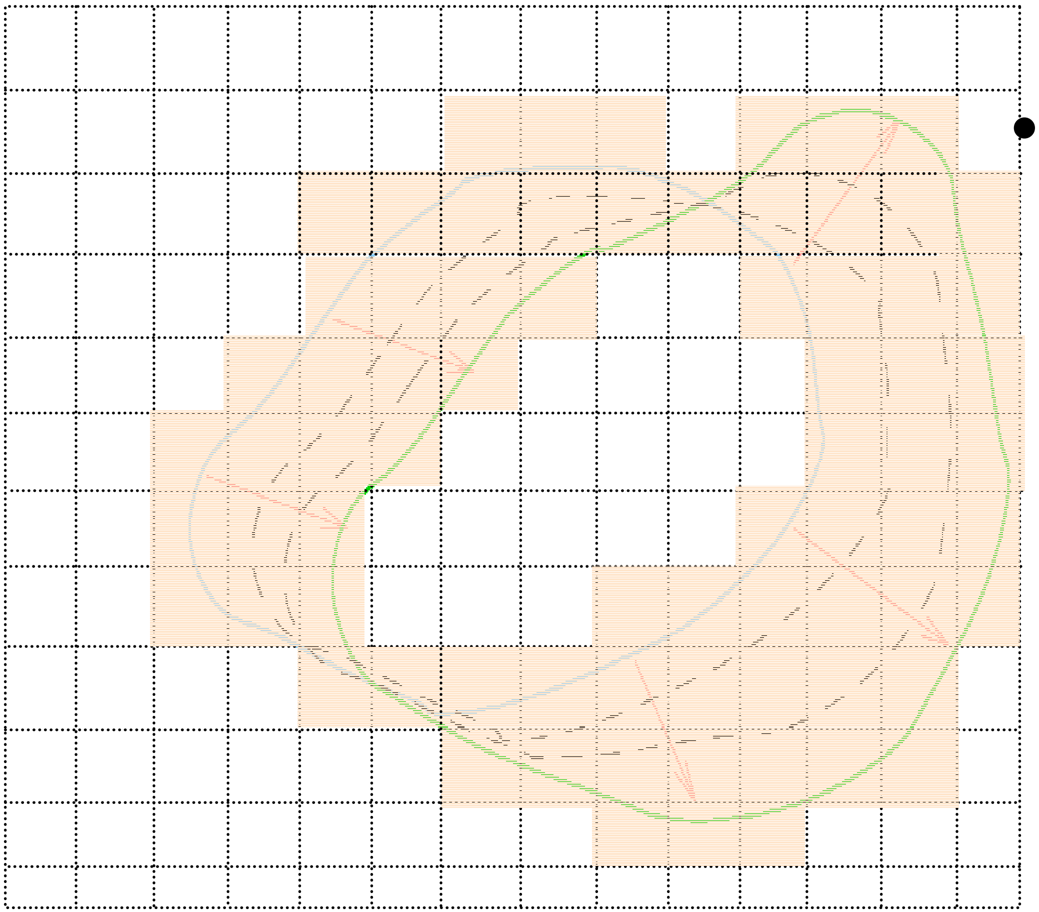
● **above isovalue** ○ **below isovalue**

Isosurface Tracking

- Smooth animation of time dependent isosurfaces



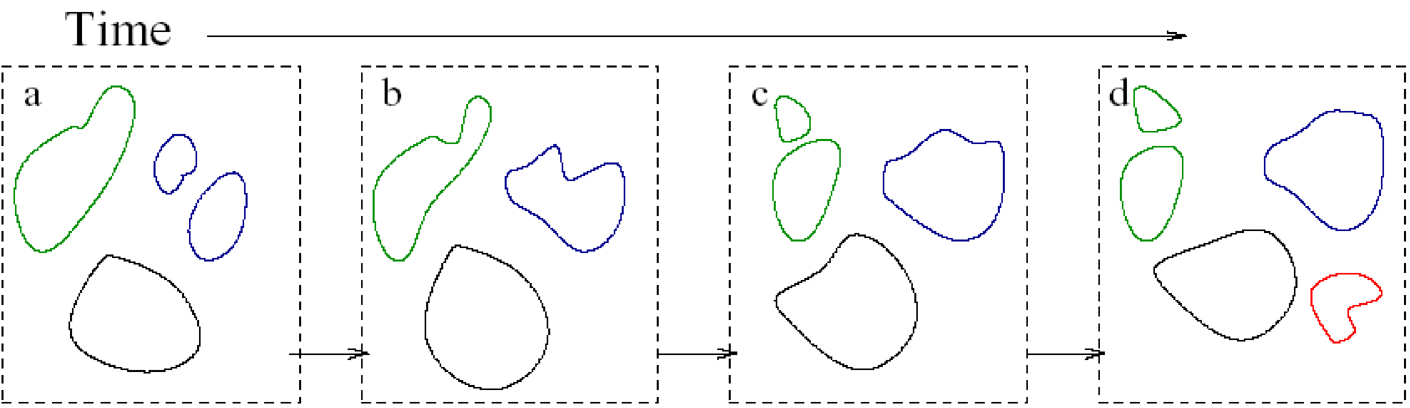
Isosurface Tracking



- I/O optimization
  – load and process only necessary data blocks

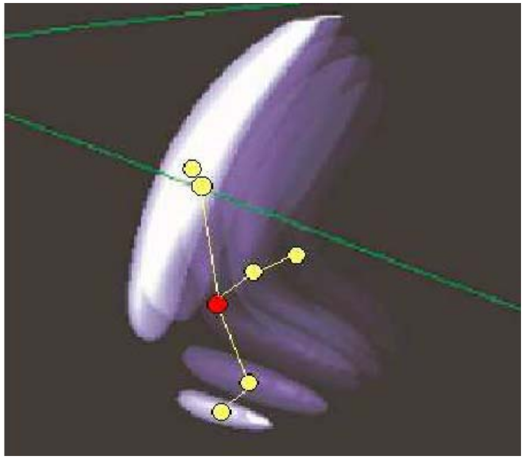
Isosurface Tracking

- Isocontour Topology Tracking



Topology Change

- **create**
- **disappear**
- **merge**
- **split**

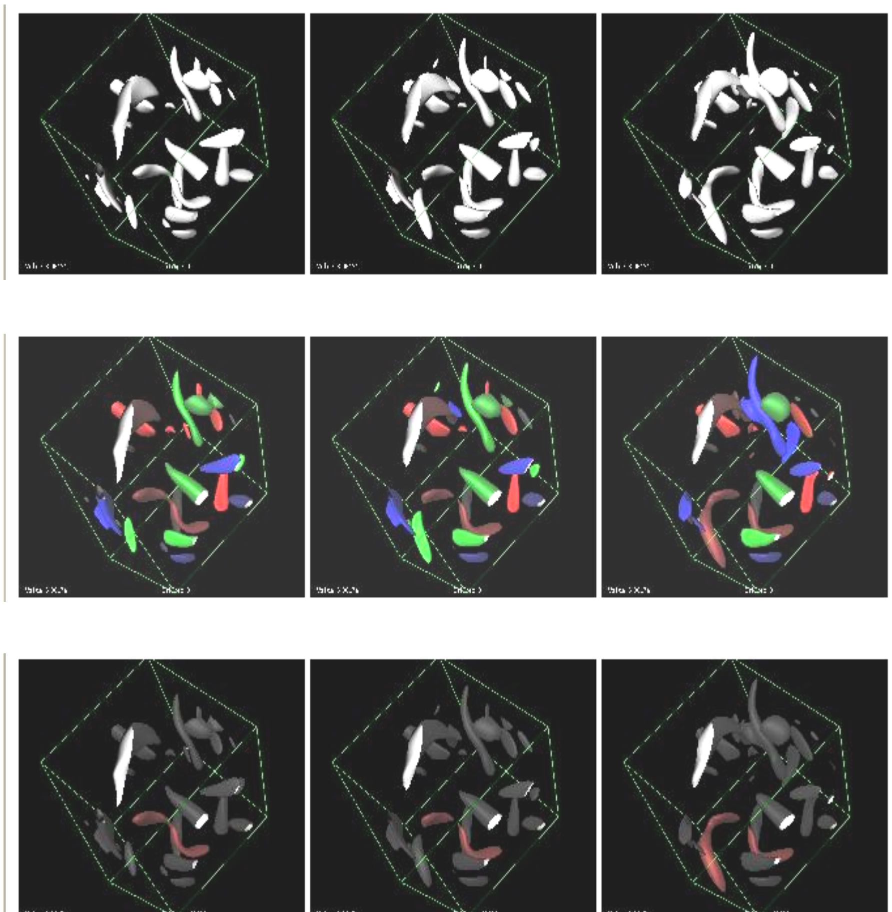


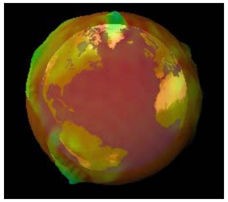
Visualization of time-dependent isosurfaces structur

- **Connecting the centroid of each component**
- **topology change and the movement direction of the surface.**

Isosurface Tracking

- Isocontour Topology Tracking

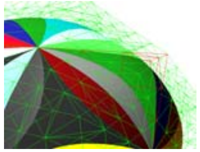




Computational Visualization

1. Sources, characteristics, representation

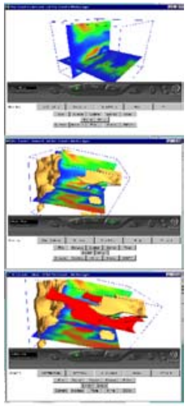
2. Mesh Processing



3. Contouring

4. Volume Rendering

5. Flow, Vector, Tensor Field Visualization



6. Application Case Studies

Further Reading

- **Fast Isocontouring for Improved Interactivity**
  Proceedings: *ACM Siggraph/IEEE Symposium on Volume Visualization*, ACM Press, (1996), San Francisco, CA
- A. Lopes, K. Brodlie, “Improving the Robustness and Accuracy of the Marching Cubes Algorithm for Isosurfacing”, TVCG
- Tao Ju, Frank Losasso, Scott Schaefer, Joe Warren , “Dual Contouring of Hermite Data”, SIGGRAPH 2002
- Leif P. Kobbelt, Mario Botsch, Ulrich Schwanecke, Hans-Peter Seidel, “Feature Sensitive Surface Extraction from Volume Data”, SIGGRAPH 2001
- Z. Wood, M. Desbrun, P. Schröder and D.E. Breen, “Semi-Regular Mesh Extraction from Volumes”, IEEE Visualization 2000

Further Reading (contd)

- **The Contour Spectrum**
  Proceedings of the 1997 IEEE Visualization Conference,167-173, October 1997 Phoeniz, Arizona.
- **Contour Trees and Small Seed Sets for Isosurface Traversal**, *In Proceedings Thirtheen ACM Symposium on Computational Geometry (Theory Track)*, (Nice, France, June 4-6, (1997), ACM Press, pp. 212-219
- C. Bajaj, "Modeling Physical Fields for Interrogative Data Visualization", 7th IMA Conference on the Mathematics of Surfaces, *The Mathematics of Surfaces VII*, edited by T.N.T. Goodman and R. Martin, Oxford University Press, (1997).
- **Parallel and Out-of-core View-dependent Isocontour Visualization Using Random Data Distribution** *Joint Eurographics-IEEE TCVG Symposium on Visualization 2002, pages 9-18*