King Abdullah University of Science and Technology KAUST

CS 247 – Scientific Visualization
Lecture 5: Data Representation, Pt. 3; Scalar Fields, Pt. 1

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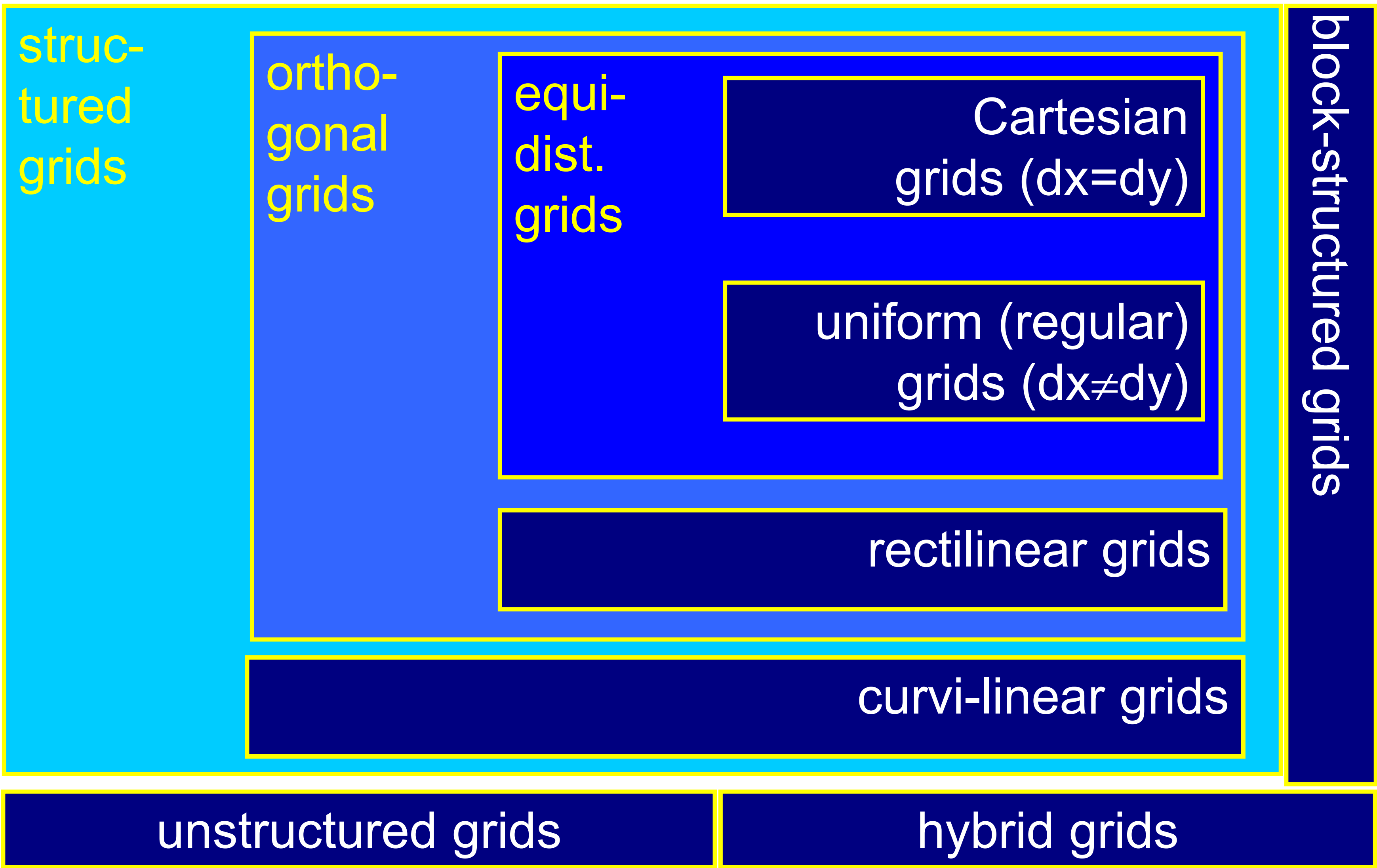
Reading Assignment #3 (until Feb 14)

Read (required):

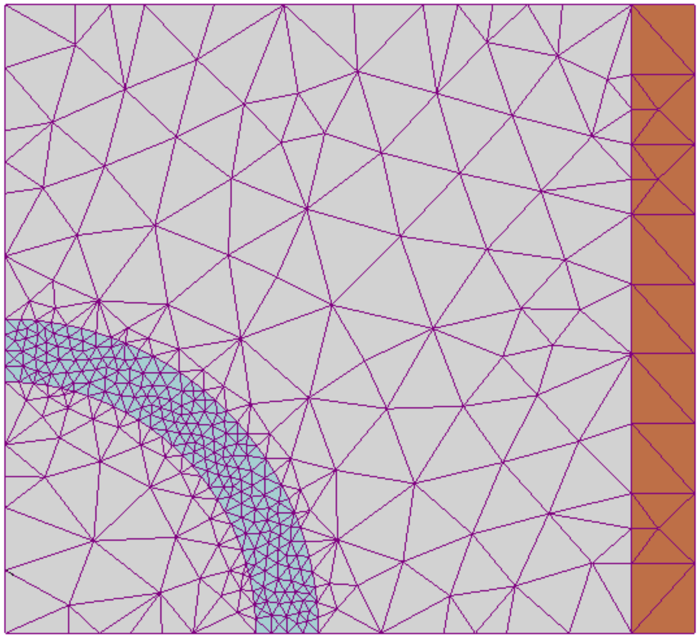
- Data Visualization book, finish Chapter 3 (read starting with 3.6)
- Data Visualization book, Chapter 5 until 5.3 (inclusive)

Grid Types - Overview

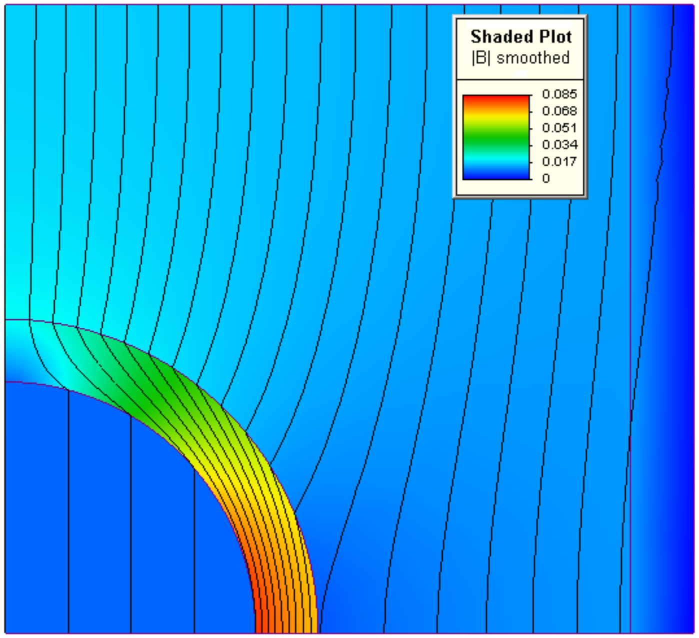


Grids vs. Data on Grids

grid



scalar field on grid



wikipedia

Data Structures

Unstructured 2D Grid: Direct Storage

Store list of vertices; vertices shared by triangles are replicated

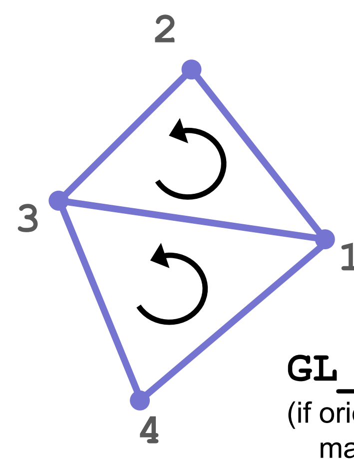
Render, e.g., with OpenGL immediate mode, …

coords for vertex 1 →

```
x1,y1,z1  ┐
x2,y2,z2  │ face 1
x3,y3,z3  ┘
x1,y1,z1  ┐
x3,y3,z3  │ face 2
x4,y4,z4  ┘

...
```

```
struct face
  float verts[3][3]
  DataType val;
```



GL_CCW
(if orientable manifold)

Redundant, large storage size, cannot modify shared vertices easily

Store data values per face, or separately

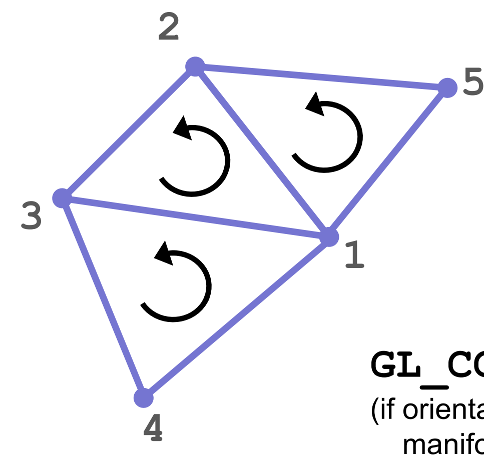
Unstructured 2D Grid: Indirect Storage

Indexed face set: store list of vertices; store triangles as indexes

Render using separate vertex and index arrays / buffers

coords for vertex 1 →

vertex list	face list
`x1,y1,(z1)`	`1,2,3`
`x2,y2,(z2)`	`1,3,4`
`x3,y3,(z3)`	`2,1,5`
`x4,y4,(z4)`	`...`
`...`	



`GL_CCW`
(if orientable manifold)

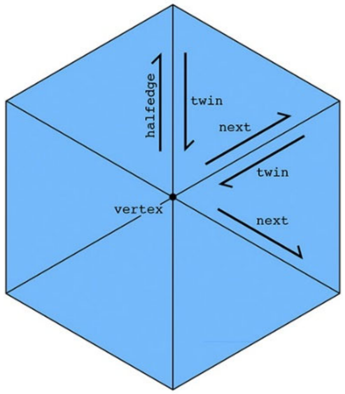
Less redundancy, more efficient in terms of memory

Easy to change vertex positions; still have to do (global) search for shared edges (local information)

Unstructured 2D Grids: Connectivity/Incidence

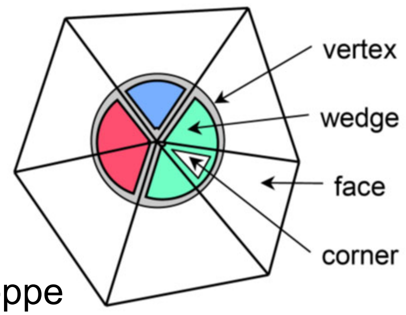
Half-edge (doubly-connected edge list) data structure

- Pointer to half-edge (twin) in neighboring face (mesh needs to be orientable 2-manifold)
- Pointer to next half-edge in same face
- Half-edge associated with one vertex, edge, face



Modifications: attributes, mesh simplification, …

- Vertices, corners, wedges, faces
- Express attribute continuity vs. discontinuity



Hugues Hoppe

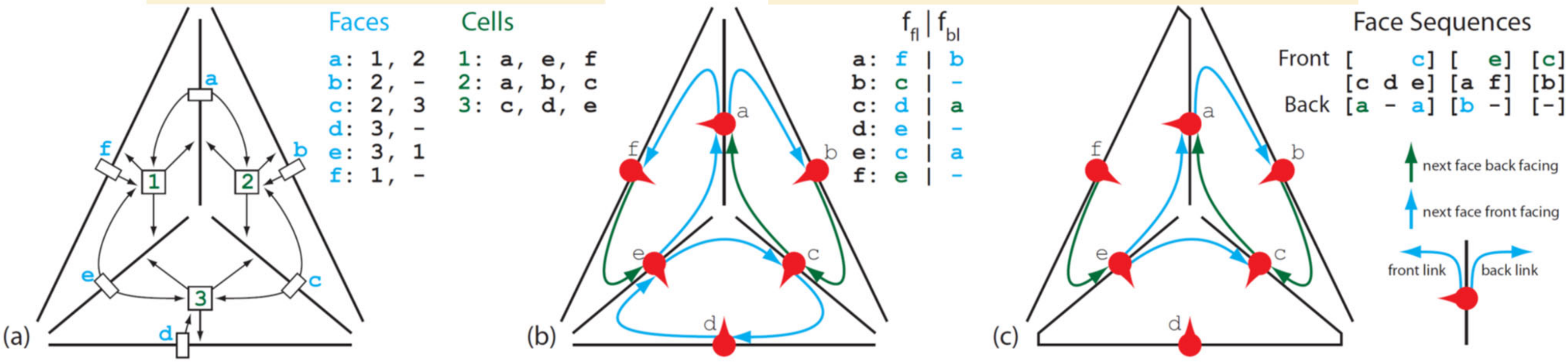
Visualization often needs volumetric version of these ideas
(tet meshes, polyhedral meshes, …)

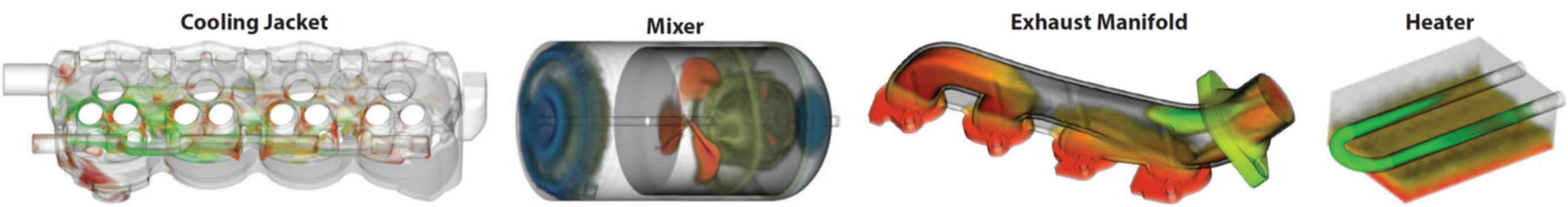
3D Grids: Two-Sided Face Sequence Lists

General polyhedral grids (arbitrary polyhedral cells); example: TSFSL (Muigg et al., 2011)

standard face/cell incidence

two-sided face (sequence) lists

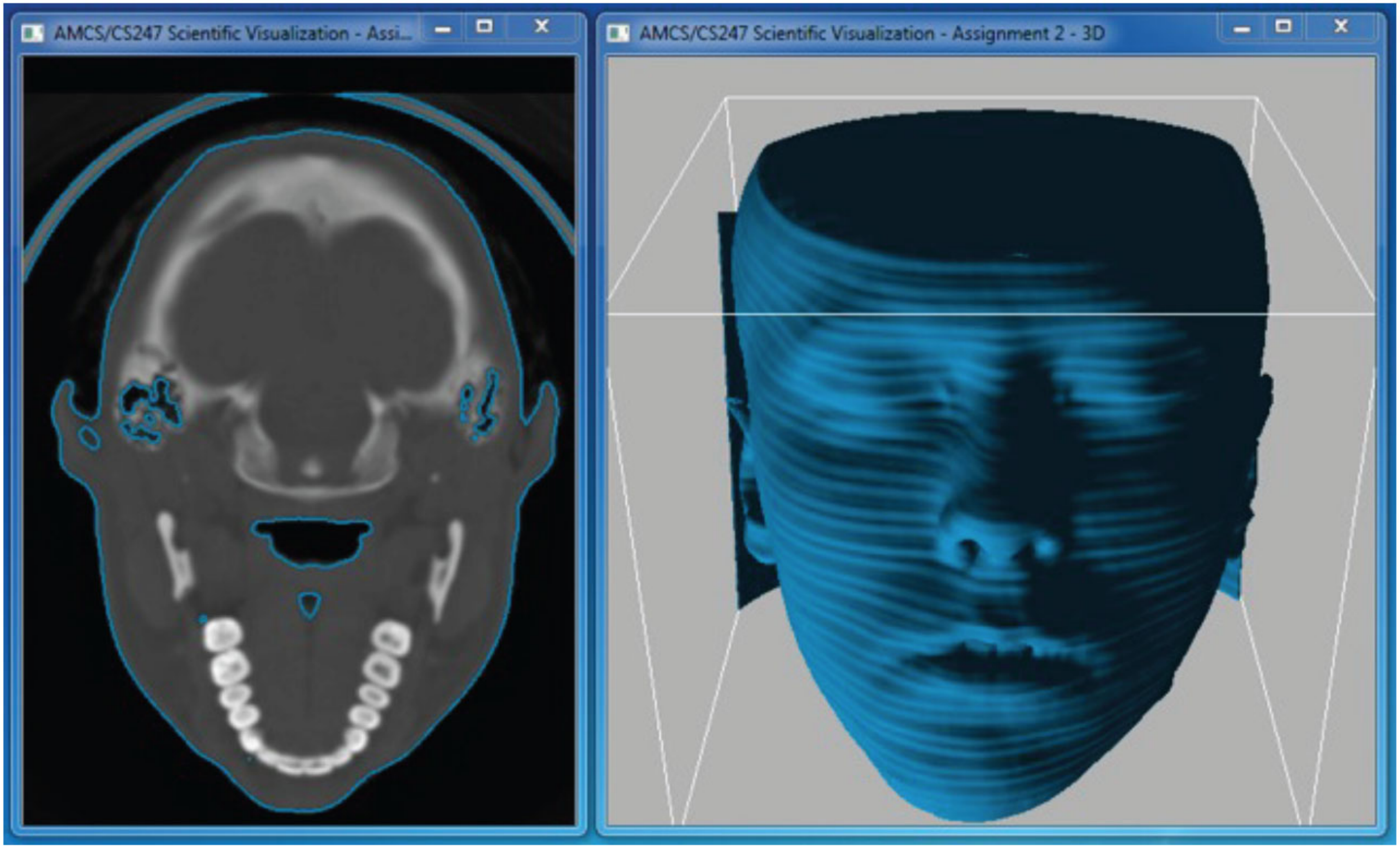




	Cooling Jacket	Mixer	Exhaust Manifold	Heater
Cells/Vertices/Faces:	1,538K / 1,631K / 4,707K	1,362K / 7,432K / 8,869K	82K / 324K / 441K	17K / 68K / 91K
Tetrahedra:	17,044K (~8.5 byte/tet)	89,417K (~7.5 byte/tet)	4,095K (~7.0 byte/tet)	851K (~7.0 byte/tet)
Celltypes:	tets/pyramids/wedges/hexas	general (non-convex) polyhedra	general (non-convex) polyhedra	general (non-conv.) polyh.
Bricks/Cell Overhead:	4/1.7%	10/8.6%	1/0%	1/0%
TSFSL Creation Time:	4.0s	9.0s	1.7s	1.0s

Scalar Fields

Programming Assignment 2 + 3



Scalar Fields are Functions

- 1D scalar field: $\Omega \subseteq R \rightarrow R$
- 2D scalar field: $\Omega \subseteq R^2 \rightarrow R$
- 3D scalar field: $\Omega \subseteq R^3 \rightarrow R$

  $\rightarrow$ **volume visualization!**

more generally: $\Omega \subseteq$ n-manifold

Basic Visualization Strategies

Mapping to geometry

- Function plots
- Height fields
- Isocontours/isolines, isosurfaces

Color mapping

Specific techniques for 3D data

- Indirect volume visualization
- Direct volume visualization
- Slicing

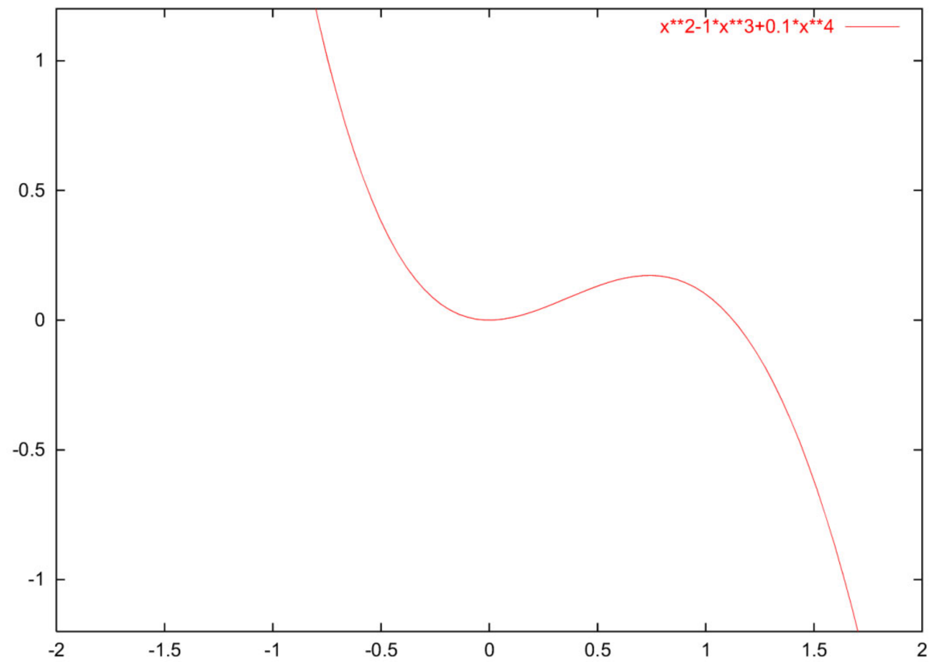
Visualization methods depend heavily on dimensionality of domain

Function Plots and Height Fields (1)

Function plot for a 1D scalar field

$$\{(x, f(x)) | x \in \mathbb{R}\}$$

- Points
- 1D manifold: line

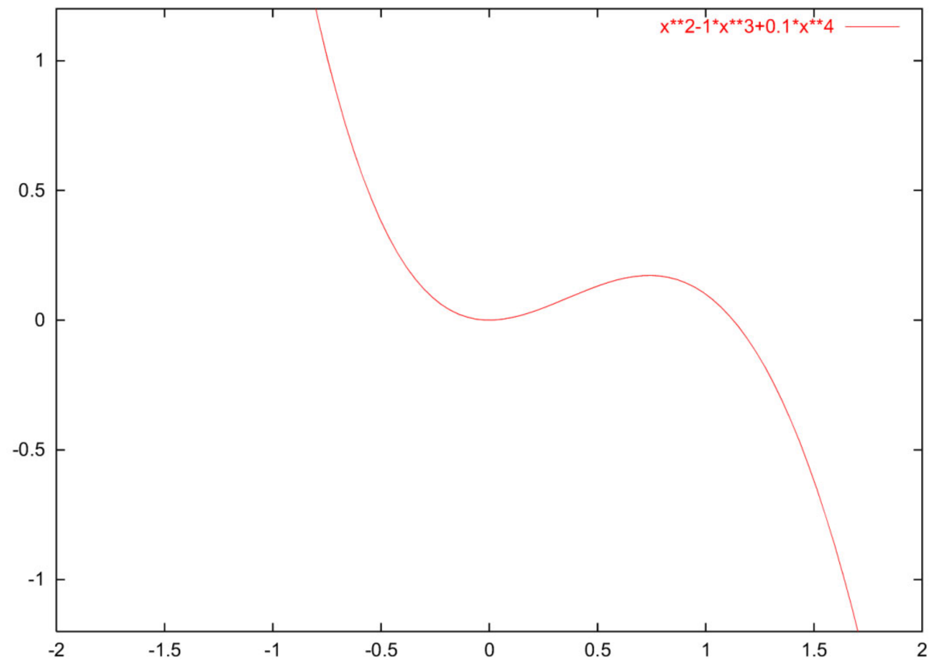


Function Plots and Height Fields (1)

Function plot for a 1D scalar field

$$\{(s, f(s)) \,|\, s \in \mathbb{R}\}$$

- Points
- 1D manifold: line



Function Plots and Height Fields (2)

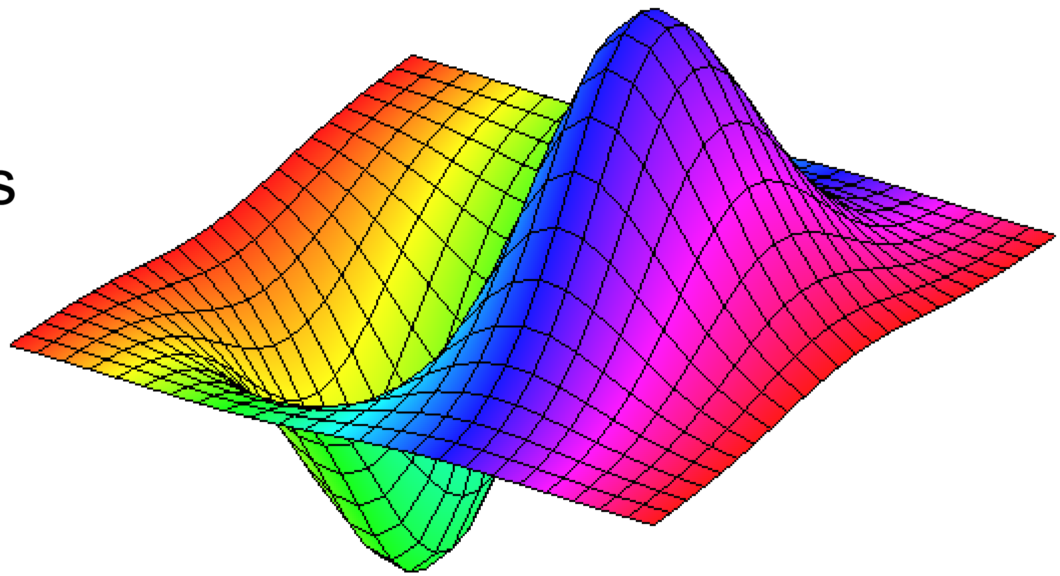
Function plot for a 2D scalar field

$$\{(x, f(x)) | x \in \mathbb{R}^2\}$$

- Points
- 2D manifold: surface

Surface representations

- Wireframe
- Hidden lines
- Shaded surface



Function Plots and Height Fields (2)

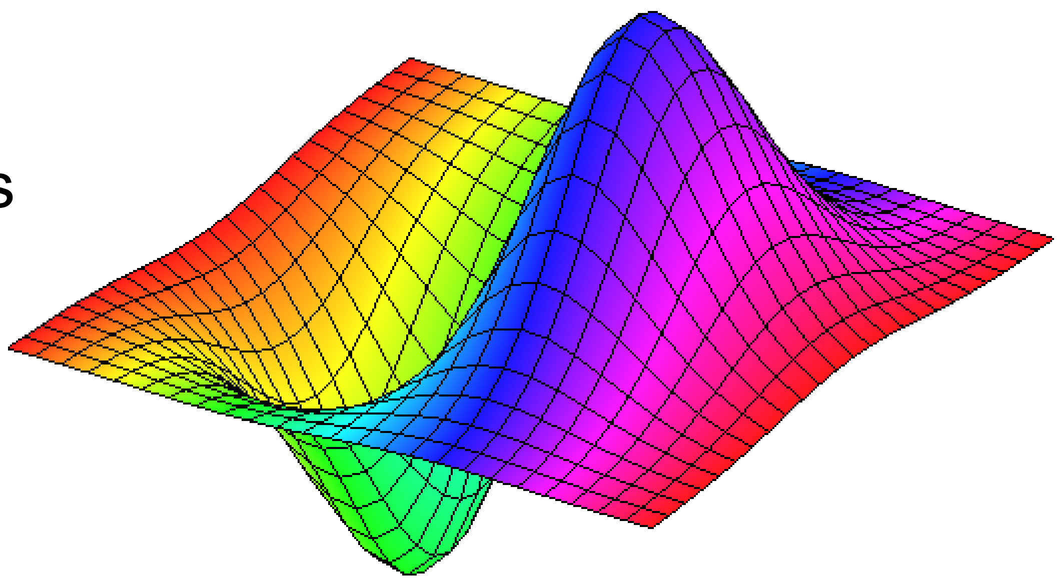
Function plot for a 2D scalar field

$$\{(s,t,f(s,t))\,|\,(s,t)\in\mathbb{R}^2\}$$

- Points
- 2D manifold: surface

Surface representations

- Wireframe
- Hidden lines
- Shaded surface

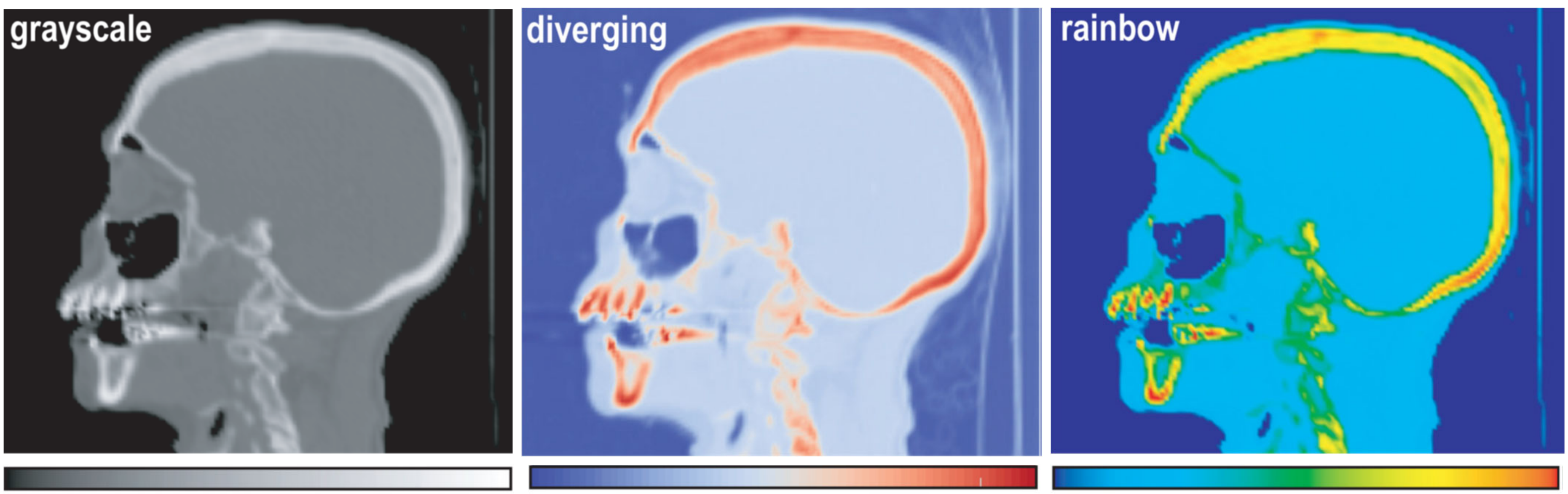


Color Mapping / Color Coding

Map scalar value to color

- Color table (e.g., array with RGB entries)
- Procedural computation; manual specification

With opacity (alpha value “A”): 1D *transfer function* (RGBA table, …)



not recommended!

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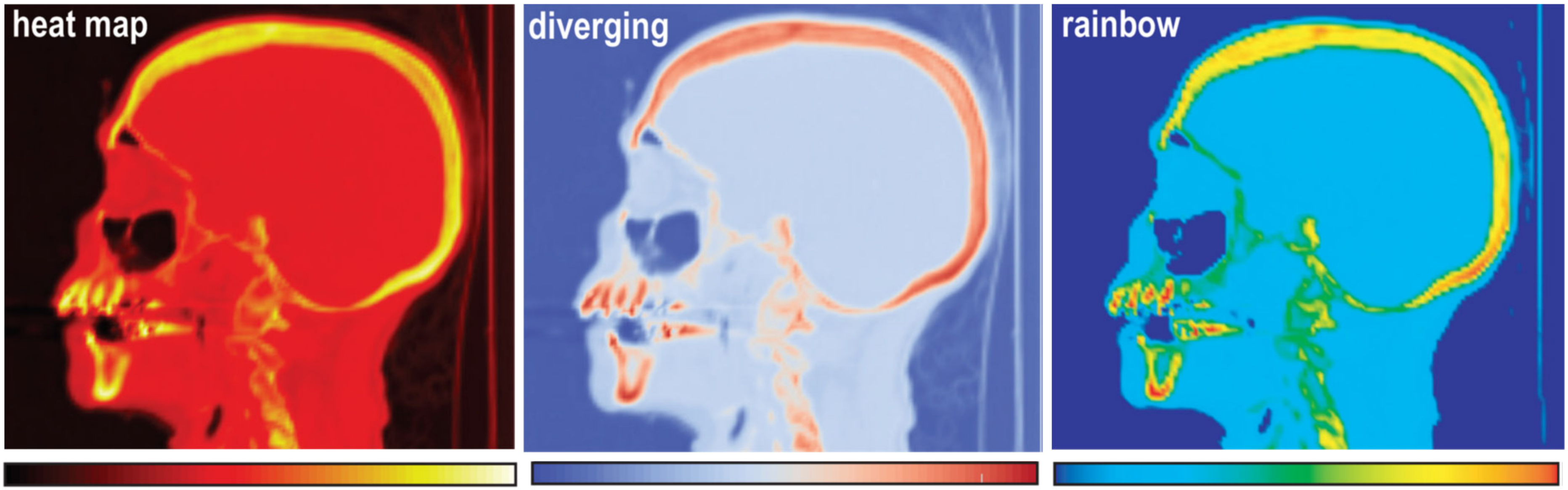


not recommended!

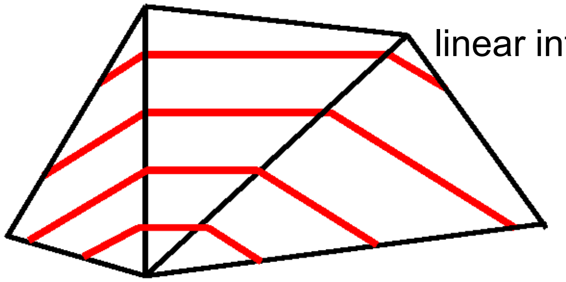
Contours

Set of points where the scalar field *s* has a given value *c*:

$$S(c) := f^{-1}(c) \qquad S(c) := \{x \in \mathbb{R}^n : f(x) = c\}$$

Common contouring algorithms

- 2D: marching squares, marching triangles
- 3D: marching cubes, marching tetrahedra



Implicit methods

- Point-on-contour test
- Isosurface ray-casting

Contours

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Common contouring algorithms

- 2D: marching squares, marching triangles
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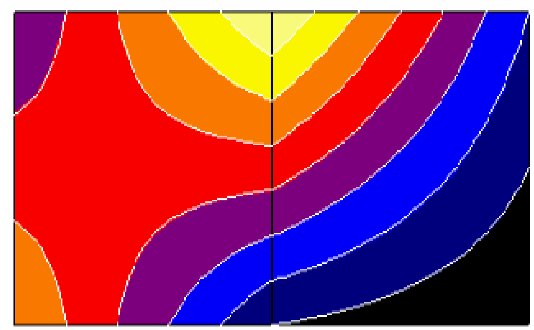
bilinear interpolation



Implicit methods

- Point-on-contour test
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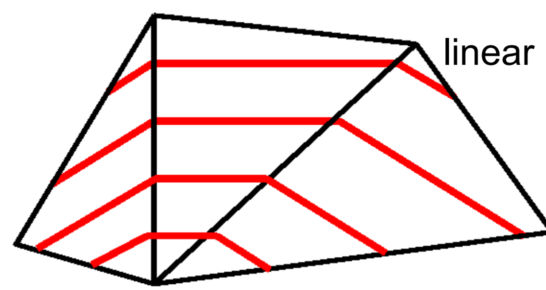

Contours

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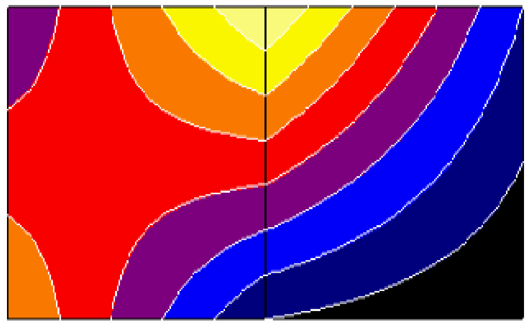

Common contouring algorithms

- 2D: marching squares, marching triangles
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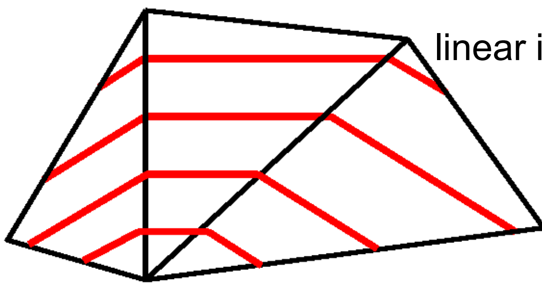


Implicit methods

- Point-on-contour test
- Isosurface ray-casting

What are contours?

Set of points where the scalar field *s* has a given value *c*:

$$S(c) := \{x \in \mathbb{R}^n : f(x) = c\}$$

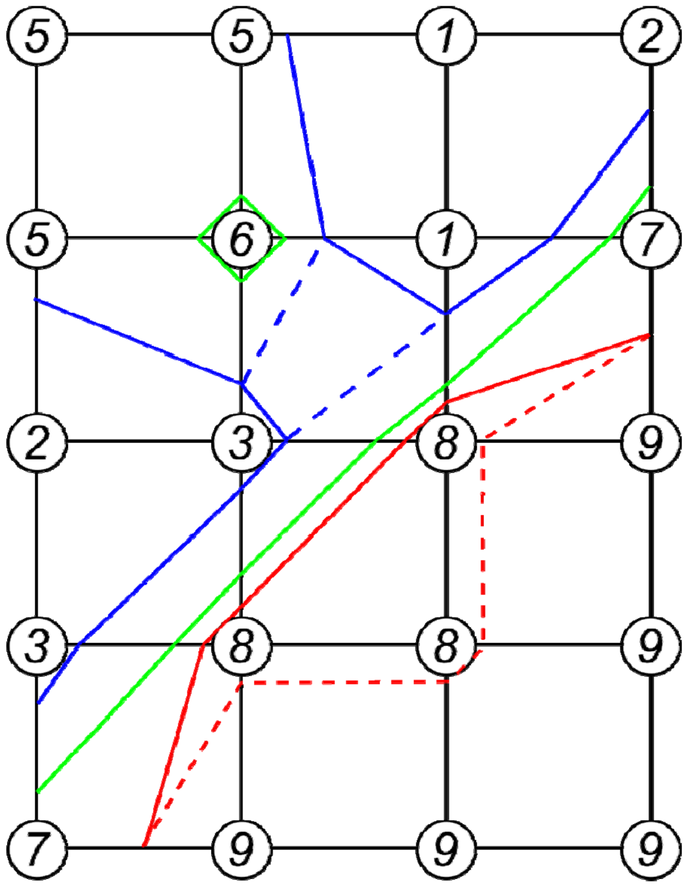
Examples in 2D:

- height contours on maps
- isobars on weather maps

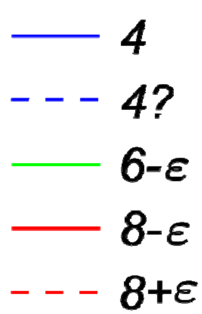
Contouring algorithm:

- find intersection with grid edges
- connect points in each cell

Example



contour levels



2 types of degeneracies:

- isolated points (c=6)
- flat regions (c=8)

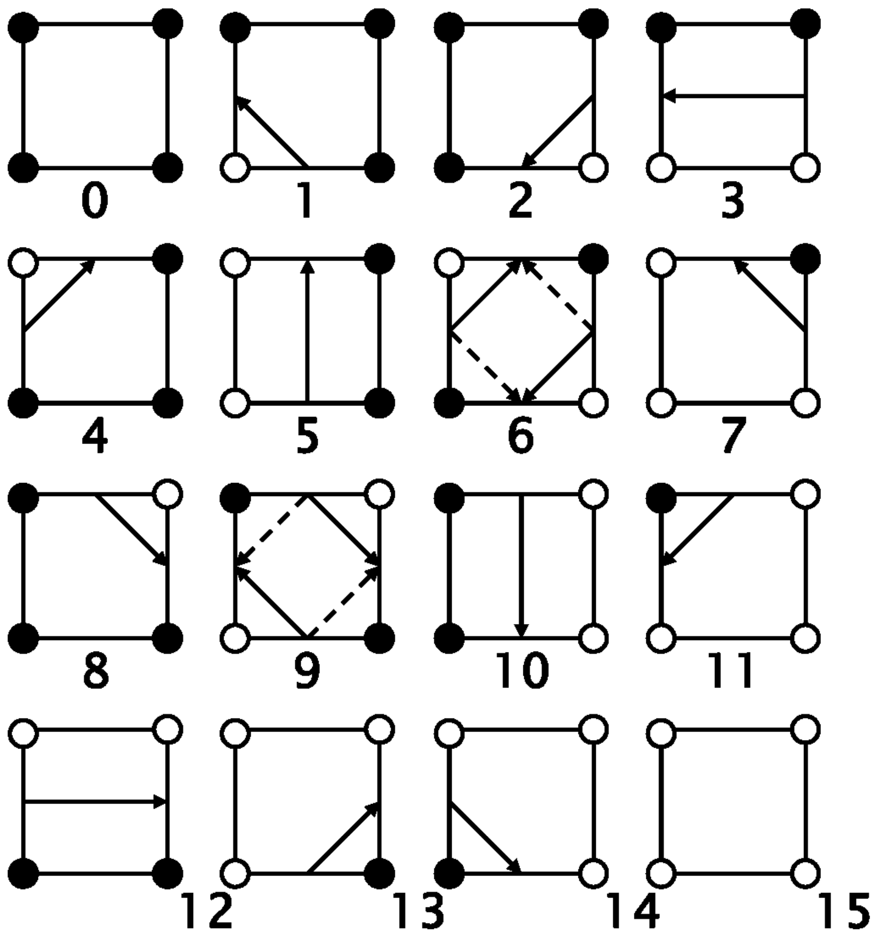
Basic contouring algorithms:

- cell-by-cell algorithms: simple structure, but generate disconnected segments, require post-processing
- contour propagation methods: more complicated, but generate connected contours

"Marching squares" algorithm (systematic cell-by-cell):

- process nodes in ccw order, denoted here as x_0, x_1, x_2, x_3
- compute at each node $\mathbf{x}_i$ the reduced field $\tilde{f}(x_i) = f(x_i) - (c - \varepsilon)$ (which is forced to be nonzero)
- take its sign as the i^{th} bit of a 4-bit integer
- use this as an index for lookup table containing the connectivity information:

Contours in a quadrangle cell



● $\tilde{f}(x_i) < 0$

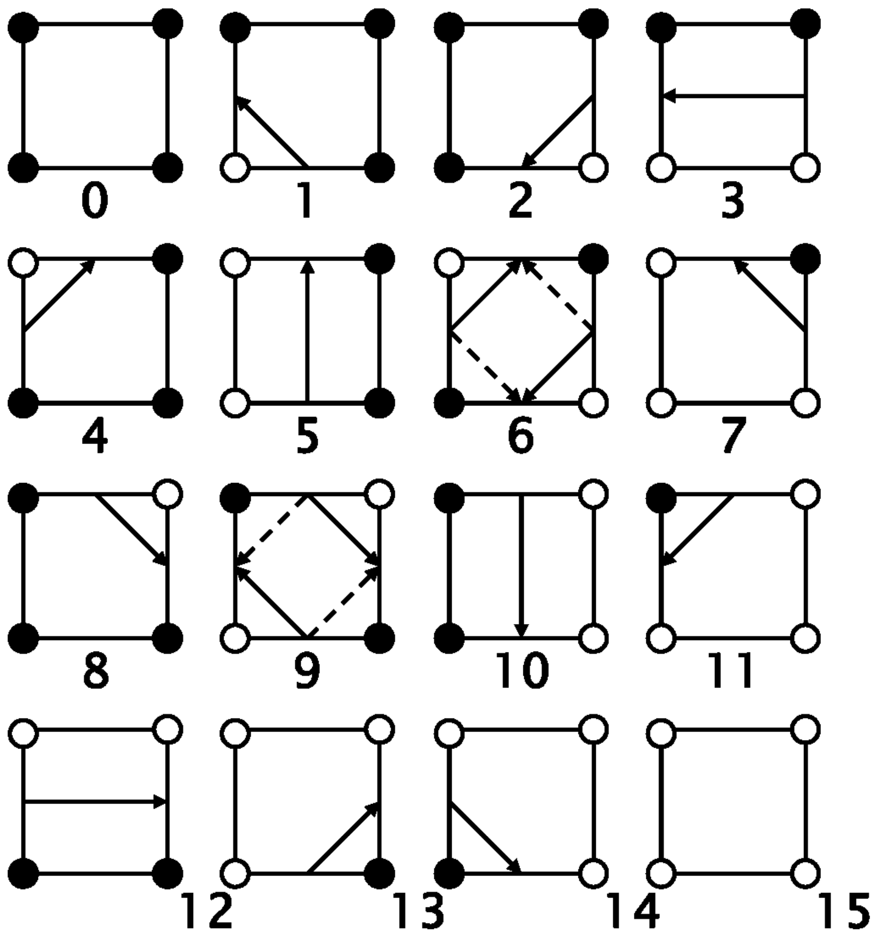
○ $\tilde{f}(x_i) > 0$

Alternating signs exist in cases 6 and 9.

Choose the solid or dashed line?

Both are possible for topological consistency.

This allows to have a fixed table of 16 cases.



- ● $f(x_i) < c$
- ○ $f(x_i) \geq c$

Alternating signs exist in cases 6 and 9.

Choose the solid or dashed line?

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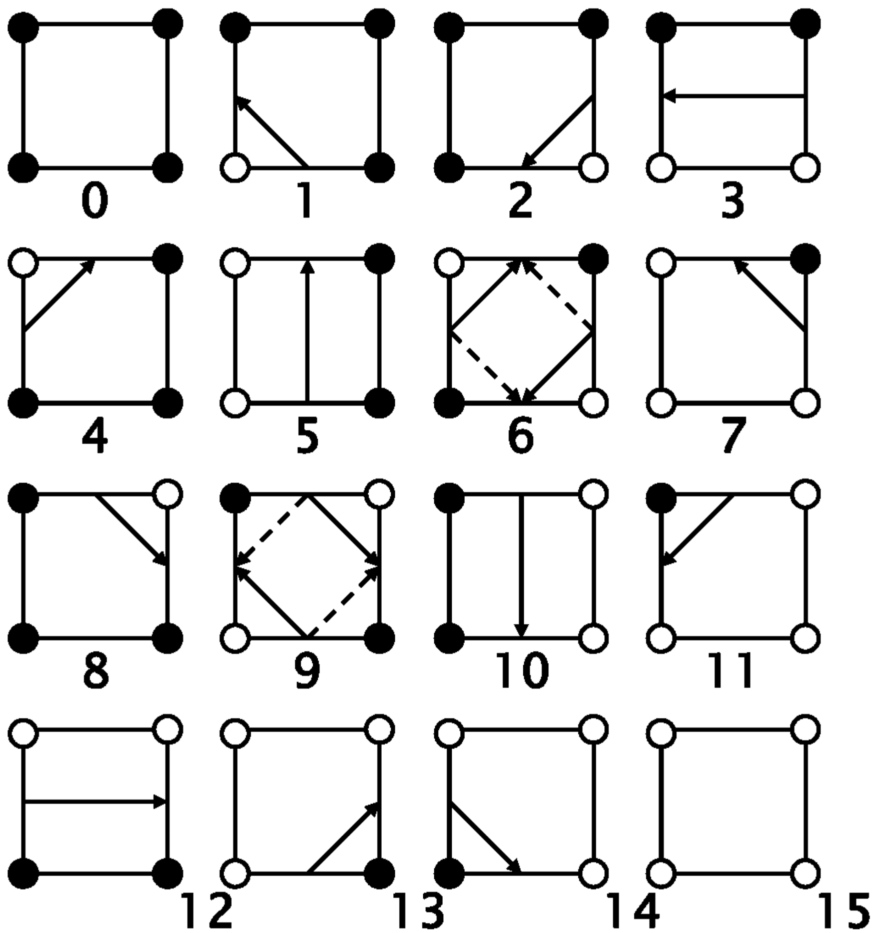
Contours in a quadrangle cell



● $f(x_i) \leq c$

○ $f(x_i) > c$

Alternating signs exist in cases 6 and 9.

Choose the solid or dashed line?

Both are possible for topological consistency.

This allows to have a fixed table of 16 cases.

Thank you.

Thanks for material

- Helwig Hauser
- Eduard Gröller
- Daniel Weiskopf
- Torsten Möller
- Ronny Peikert
- Philipp Muigg
- Christof Rezk-Salama