Scientific Visualization at University of Chicago

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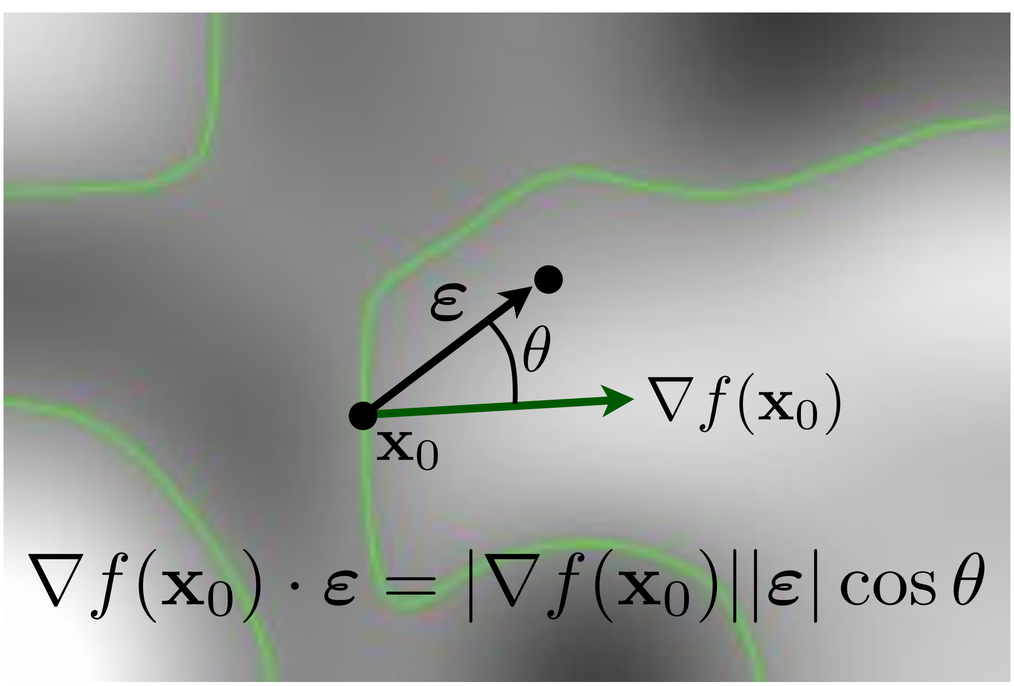
THE UNIVERSITY OF CHICAGO COMPUTER SCIENCE

Computation Institute

Let's recap some Calculus

Taylor expansion of scalar field

$$f(\mathbf{x}_0 + \boldsymbol{\varepsilon}) = f(\mathbf{x}_0) + \nabla f(\mathbf{x}_0) \cdot \boldsymbol{\varepsilon} + o(|\boldsymbol{\varepsilon}|)$$



Just kidding ...

Actually, not really kidding

I teach a Scientific Visualization class

Scientific Visualization depends on math

Math is just one principle for Sci Vis

Perception, Signal processing, Systems

I work to make the principles **intuitive**

This is the central challenge of teaching Sci Vis

CMSC 23710/33710, Scientific Visualization

Mechanics: UChicago on quarters

- 10 weeks of classes = not a lot of time

No standing curriculum for programming

- No engineering, not much applied math + CS

Both undergrad & grad students

- Many from outside CS

Plan: develop different Info Vis class

- Joint with Booth business school?

What are the principles?

Types of Data = Symmetries of Data

Perception (e.g. Color): natural axes

Convolution & Differentiation

Structure of Raster Data and meta-data

S. S. Stevens '46

SCIENCE

Vol. 103, No. 2684 Friday, June 7, 1946

On the Theory of Scales of Measurement

S. S. Stevens

Director, Psycho-Acoustic Laboratory, Harvard University

FOR SEVEN YEARS A COMMITTEE of the British Association for the Advancement of Science debated the problem of measurement. Appointed in 1932 to represent Section A (Mathematical and Physical Sciences) and Section J (Psychology), the committee was instructed to consider and report upon the possibility of "quantitative estimates of sensory events"—meaning simply: Is it possible to measure human sensation? Deliberation led only to disagreement, mainly about what is meant by the term measurement. An interim report in 1938 found one member complaining that his colleagues

by the formal (mathematical) properties of the scales. Furthermore—and this is of great concern to several of the sciences—the statistical manipulations that can legitimately be applied to empirical data depend upon the type of scale against which the data are ordered.

A CLASSIFICATION OF SCALES OF MEASUREMENT

Paraphrasing N. R. Campbell (Final Report, p. 340), we may say that measurement, in the broadest sense, is defined as the assignment of numerals to objects or events according to rules. The fact that

Stevens' 4 scales of measurements

Scale	Basic Empirical Operations	Mathematical Group Structure	Permissible Statistics (invariantive)
Nominal Categorical Qualitative	Determination of equality	*Permutation group* $x' = f(x)$ $f(x)$ means any one-to-one substitution	Number of cases Mode Contingency correlation
Ordinal	Determination of greater or less	*Isotonic group* $x' = f(x)$ $f(x)$ means any monotonic increasing function	Median Percentiles
Interval	Determination of equality of intervals or differences	*General linear group* $x' = ax + b$	Mean Standard deviation Rank-order correlation Product-moment correlation
Ratio	Determination of equality of ratios	*Similarity group* $x' = ax$	Coefficient of variation

- Let's ponder examples of these ...

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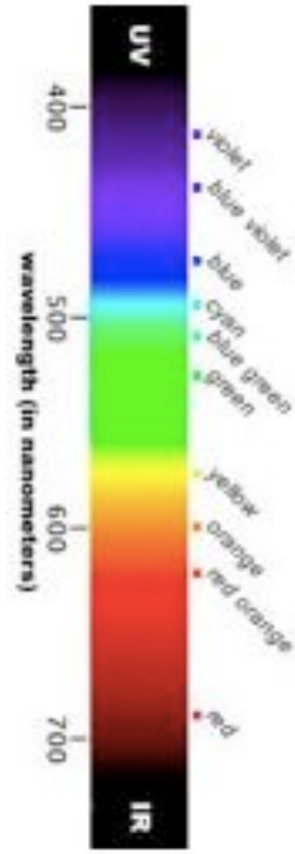
Simple perceptual psychology

What is this thing structuring our interpretation of images?

⇒ **Luminance**

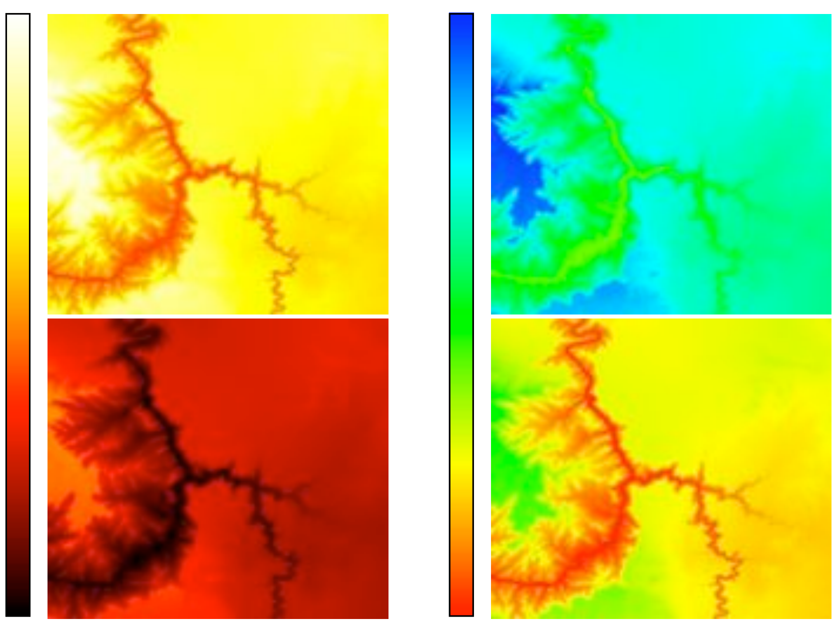
How is color best organized?

Artists
vs
Physicists



⇒ **Opponent Colors**

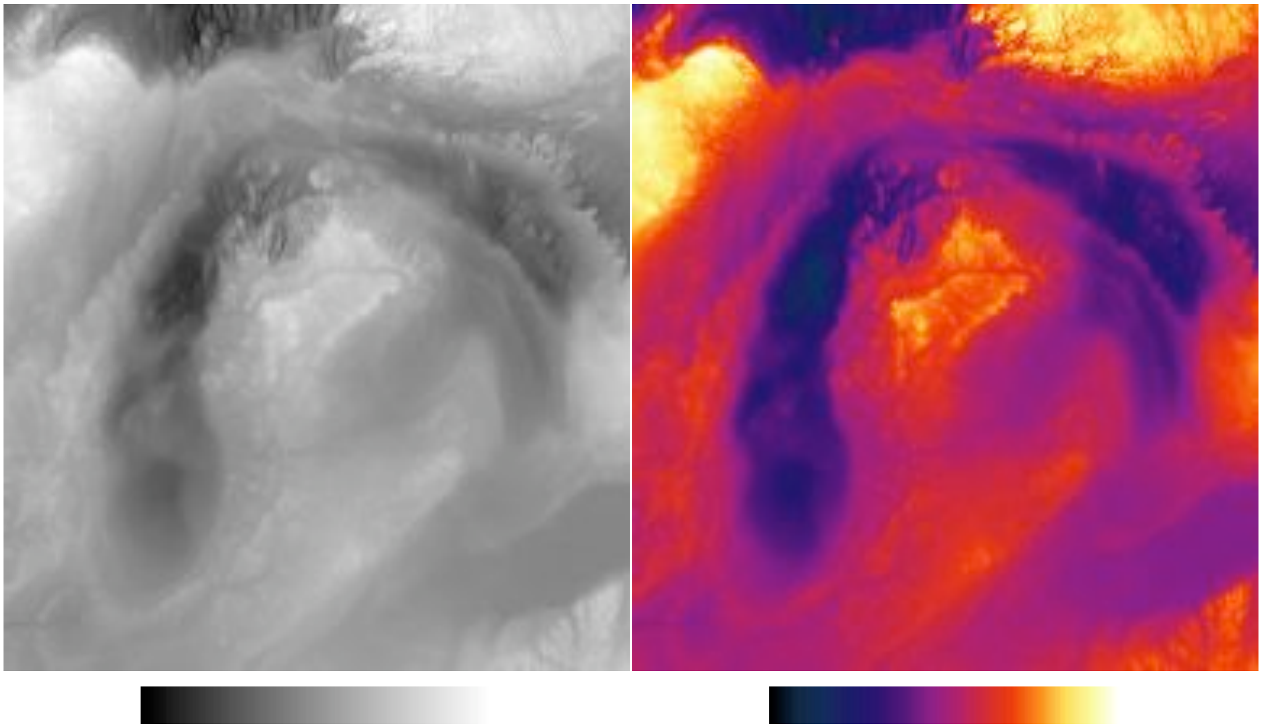
Colormap for **interval** data



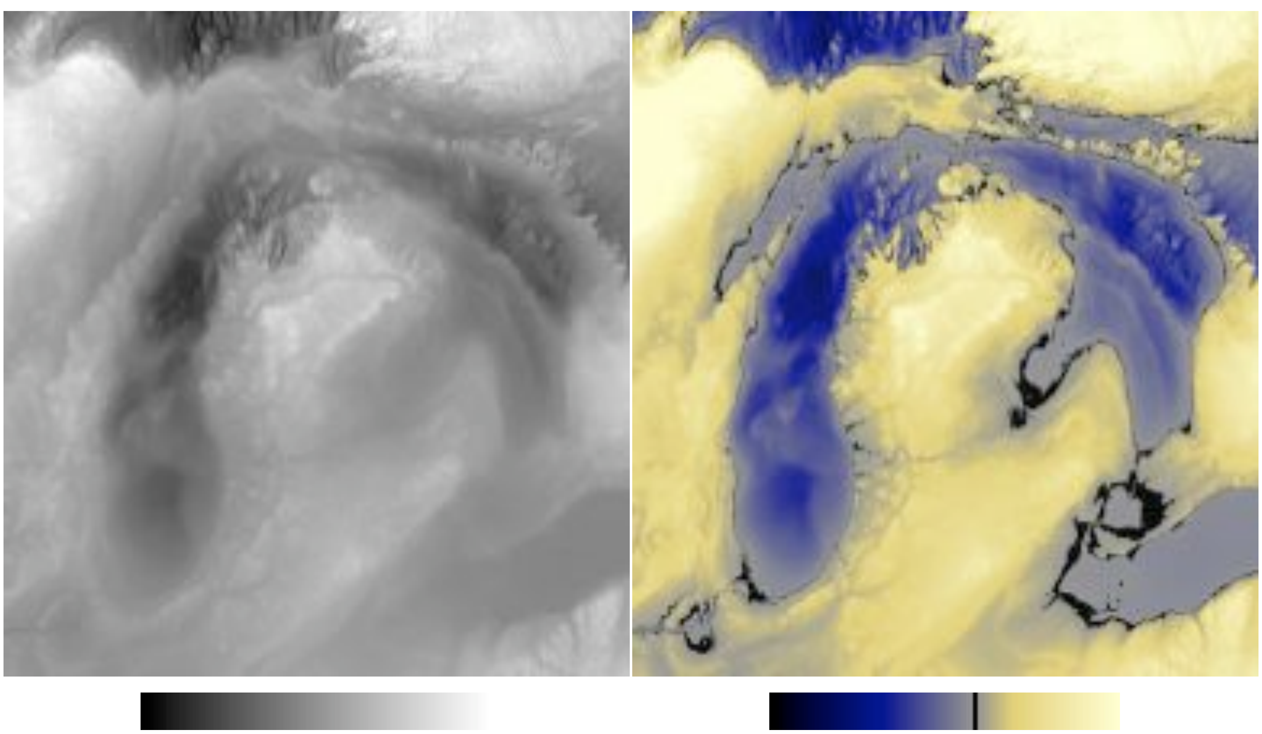
$V(D+c) \approx V(D)$ $V(D+c) \neq V(D)$

Coloring of **interval** values should be symmetric under addition of constant (should convey intrinsic **ordering**)

Is elevation “interval” data?



Or is elevation “ratio” data?



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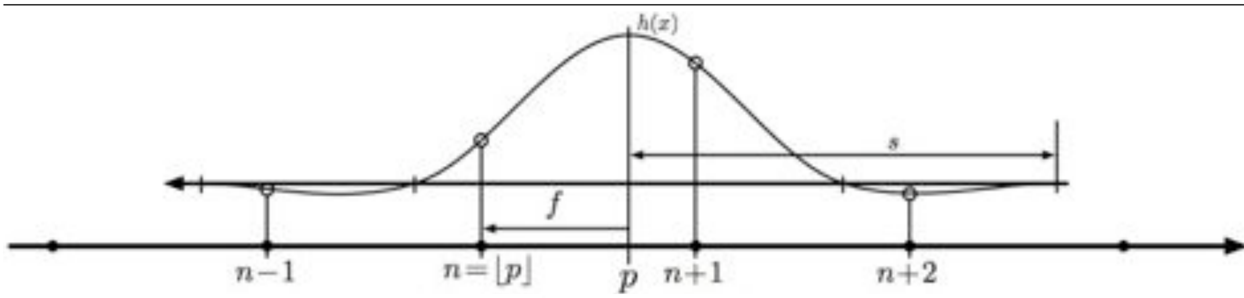
Convolution in 1D and 2D



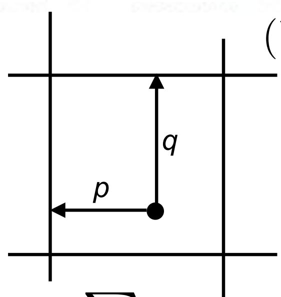
$V[n\text{-}1]h(f\text{+}1)$ + $V[n]h(f)$ + $V[n\text{+}1]h(f\text{-}1)$ + $V[n\text{+}2]h(f\text{-}2)$

$$(V \circledast h)(p) = \sum_i V[i]h(p-i)$$
$$= \sum_{1-s}^{s} V[n+i]h(f-i)$$

$n = \text{floor}(p); f = p - n$

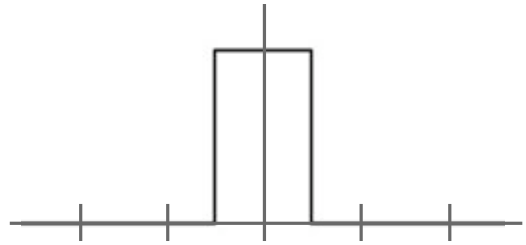
$s = \text{support}(h)$

In 2D:

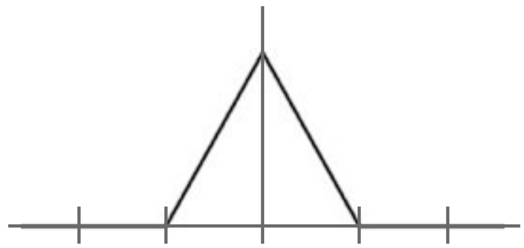


$$(V \circledast h)(p,q) = \sum_{i,j} V[i,j]h_2(p-i, q-j)$$
$$= \sum_{i,j} V[i,j]h_1(p-i)h_1(q-j)$$

2D Convolution examples 1

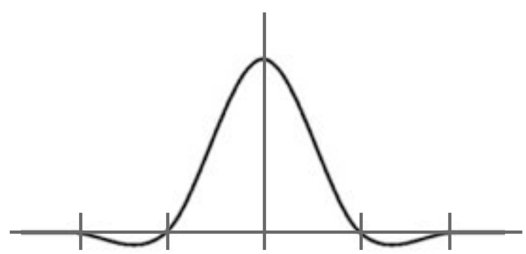


box, nearest neighbor

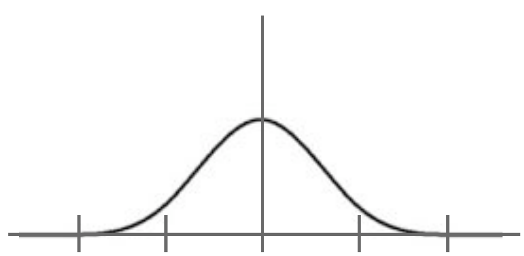


tent, linear

2D Convolution examples 2

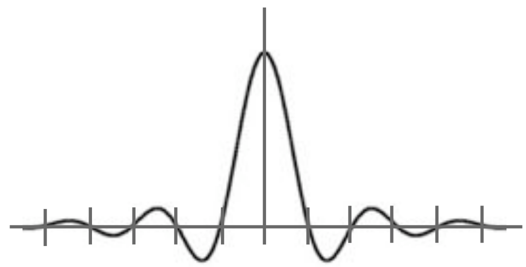


Interpolating cubic spline
“Catmull-Rom”

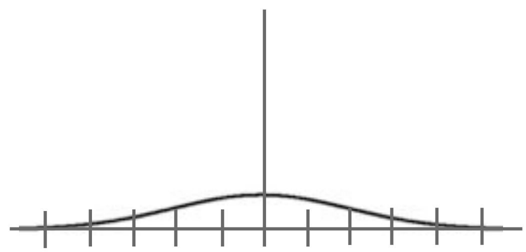


(non-interpolating)
Cubic B-spline

2D Convolution examples 3



Hann-windowed sinc
sinc(x) = sin(πx)/(πx)



Gaussian (stdv=2,
cutoff = 4 stdv)

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Arecibo Message

- Radio telecope in Puerto Rico
- built in 1964, renovated in 1974
- To celebrate: sent message to M13 in Hercules (25,000 light years away)

The Message

1679 bits were encoded as 2380MHz plus and minus 10Hz

```
00000010101010000000000001010000010100000001001000100010001001011001010
10101010101010010010000000000000000000000000000000000000011000000000000
00000011010000000000000000000001101000000000000000000000101010000000000000
0001111100000000000000000000000000000000001100001110001100001100010000000
0000001100100001101000110001100001101011111101111110111111011111100000000
0000000000000000100000000000000000100000000000000000000000000000100000000
0000000000111111000000000000000111100000000000000000000000000110000110000011
1000110001000000010000000000100001101000011000111001101011111101111111011111
1011111000000000000000000000000001000000011000000000001000000000000110000000
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0000010000000000100000000001000001000000110000000010000000110000110000001000
0000000110001000001100000000000000000001100110000000000000000011000100001100000
00011000011000000010000000010000000100000000010000010000000011000000000100010
0000000110000000000100010000000000010000000010000010000000010000000010000000010
0000000000001100000000001100000000001100000000000010001110101100000000000000010000
000100000000000000000010000011111000000000000000010000101110100101101100000000100
111001001111111101110000111000001101110000000000010100000111011001000000010
1000000111111001000000001010000001100000010000001101100000000000000000000000
00000000000011100000010000000000000000011101010001010101010100111000000000001
010101000000000000000000101000000000000000000111110000000000000000000011111111100
000000000001110000000001110000000000001100000000000001100000000011010000000000001011
0000011001100000000110011000010001010000001010001000010001001000100100010
0000000100010100010000000000000000100001000010000000000000001000000000000100000000
00000001001010000000000000001111001111101001111000
```

A **1-D** sequence of bits in time

How will an alien understand this list of bits?

(will have different symbols than "0" "1")

No meta-information!

Understanding the message

- Perhaps some “visual” representation of bits

  - But why not green and red, or foo and bar?
- Aliens notice 1679 = 23 x 73 ...
- Perhaps its not a linear sequence: 2-D array ...
- Two ways of sequencing values in 2D array ...
- Various ways of laying them out in 2D space ...
- Then decipher it

73 x 23

23 x 73: what was different?

5 basic pieces of image metadata

- Interpretation of individual values
  - units, scalars, vectors, tensors, measurement frame
- Dimension of array
  - dimension of domain sampled
  - # axes, or # indices for getting a single sample
- Choice of axis ordering (fast-to-slow, or slow-to-fast)
  - Culturally specific
- # samples along each axis
  - "640-by-480 image" or "N-by-M matrix"
- Image location & Orientation of each Axis
  - Summarized by affine transform

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What else? Are these the right ones?

Teaching strategy

<u>Illustrate & Engage</u> underlying principles

- Have to connect with intuition/experience

Principles should hold regardless of discipline

Grading based on projects (only)

- Write-up plus code
- Be able to communicate in prose (but not a publication)
- Implement methods themselves (no black boxes)
- Readings geared towards projects
- "... must reflect understanding of readings"

Programming environment balance

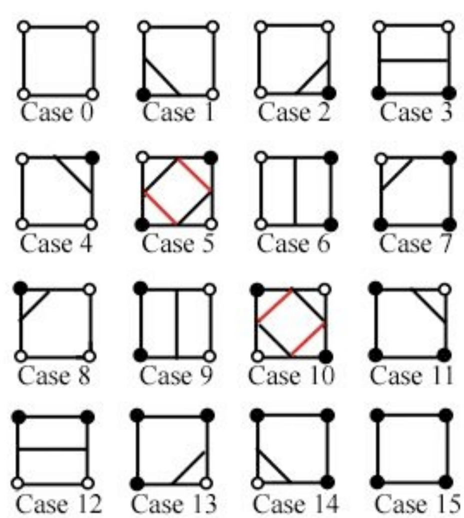
- Easy to use: Python
- Powerful: Python wrappers around Teem

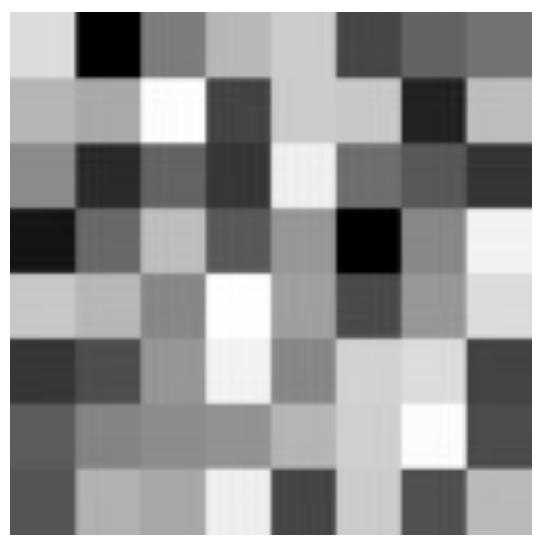
http://teem.sf.net

Teaching strategy, cont.

Teach discipline of testing visualization code on custom-made synthetic data

Marching Squares cases ...





Teaching strategy, cont.

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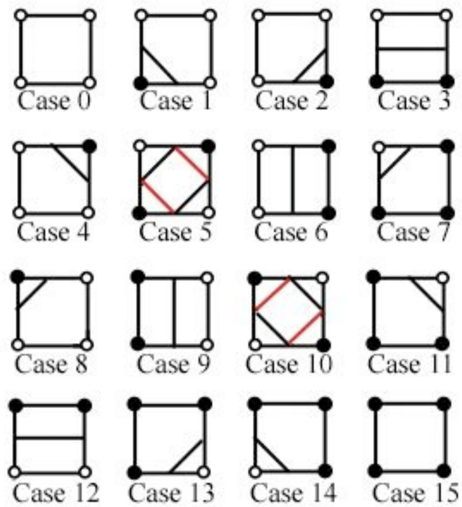
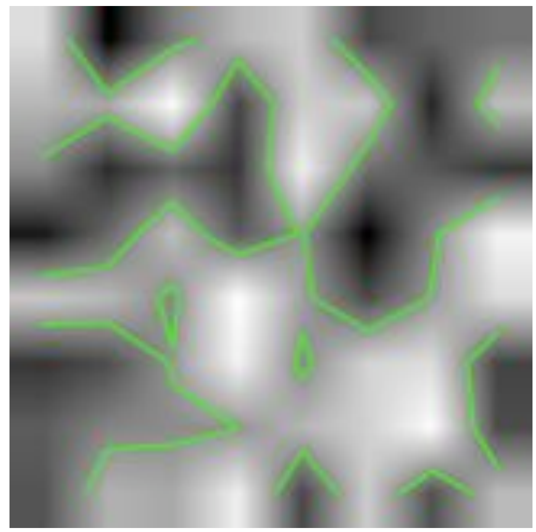
Marching Squares cases ...



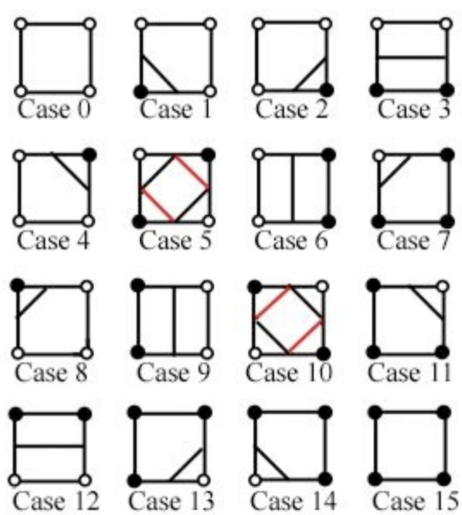


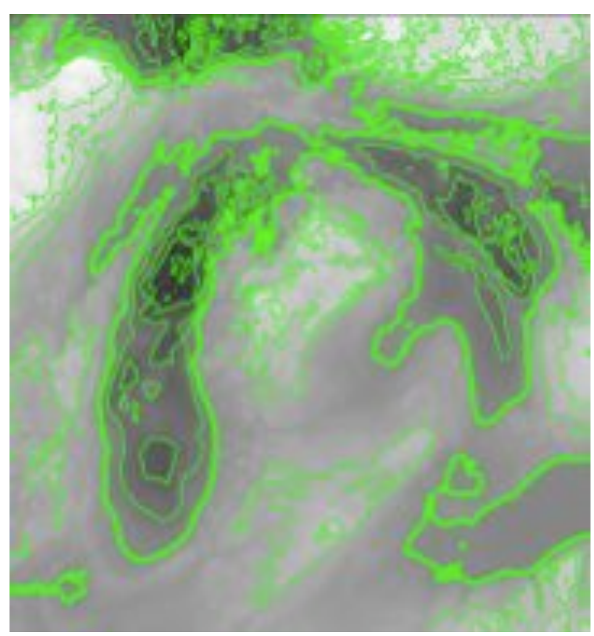
Every case used at least once

Teaching strategy, cont.

Teach discipline of testing visualization code on custom-made synthetic data

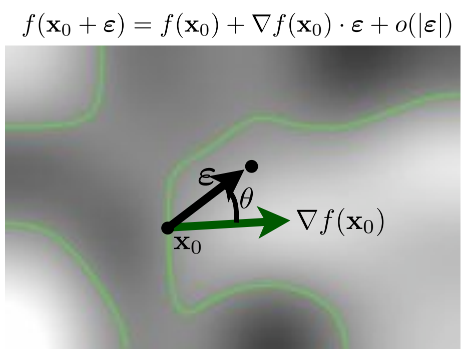
Marching Squares cases ...

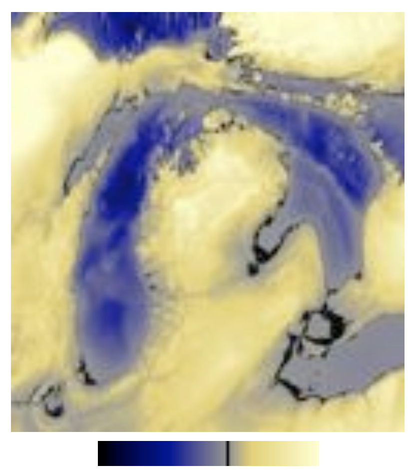




Future Goals for teaching Sci Vis

- Better ways communicating the math
  - We need a Mechanical Universe for Scientific Visualization (see youtube)
- Better languages/tools for easily implementing heavy-weight computing
  - Volume rendering, streamlines: rewarding but slow
  - May have to invent a new language
- Need to determine principles to use
- Need a good first-principles textbook
  - (open to suggestions)





Thank you
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