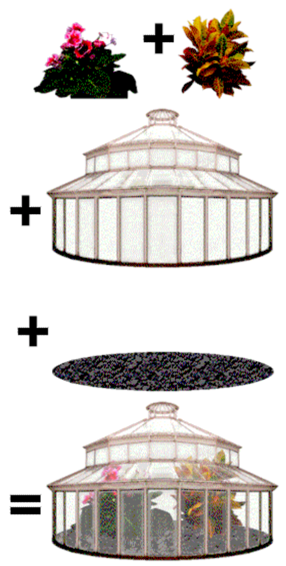
Topics in Imaging

A wee bit of recursion

Alpha Compositing
Filling Algorithms
Dithering
DCTs

Alpha Blending



Alpha blending simulates the *opacity* of *celluloid* layers

General rules:

- Adds one channel to each pixel [α, r, g, b]
- Usually process layers back-to-front (using the *over* operator)
- 255 or 1.0 indicates an opaque pixel
- 0 indicates a transparent pixel
- Result is a function of foregrond and background pixel colors
- Can simulate partial-pixel coverage for anti-aliasing

See Microsoft's Image Composer for more info on these images

Alpha Compositing Details

Definition of the *Over* compositing operation:

$$\alpha_{result}c_{result} = \alpha_{fg}\, c_{fg} + (1 - \alpha_{fg})\, \alpha_{bg}c_{bg}$$

$$\alpha_{result} = \alpha_{fg} + (1 - \alpha_{fg})\, \alpha_{bg}$$

Issues with alpha:

Premultiplied (integral) alphas:

- pixel contains (α, αr, αg, αb)
- saves computation
  $\alpha_{result}c_{result} = \alpha_{fg}\, c_{fg} + \alpha_{bg}c_{bg} - \alpha_{fg}\alpha_{bg}c_{bg}$
- alpha value constrains color magnitude
- alpha modulates image shape
- conceptually clean - multiple composites are well defined

Non-premultiplied (independent) alphas:

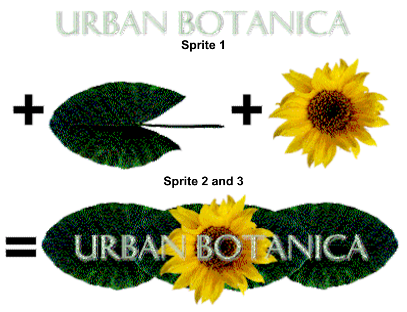
- pixel contains (α, r, g, b)
- what Photoshop does
- color values are independent of alpha
- transparent pixels have a color
- divison required to get color component back

(An excellent reference on the subject)

Compositing Example

Alpha-blending features:

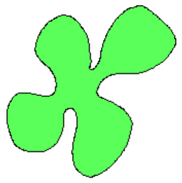
- Allows image to encode the shape of an object (Sprite)
- Can be used to represent partial pixel coverage for anti-aliasing (independent of the final background color)
- Can be used for transparency effects
- Should be adopted by everyone!
  (what were you planning to do with that extra byte anyway)



Finished Composition

Area Fill Algorithms?

- Used to fill regions *after* their boundary or contour has been determined.
- Handles Irregular boundaries
- Supports freehand drawings
- Deferred fills for speed (only fill visible parts)
- Allows us to recolor primitives
- Can be adapted for other uses (selecting regions)
- Unaware of any other primitives previously drawn.
- Later we'll discuss filling areas during rasterization



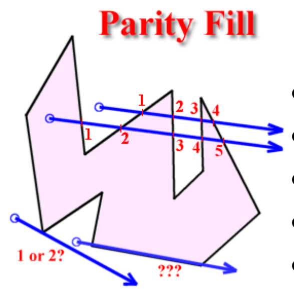
Parity Fill

Problem:

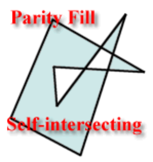
For each pixel determine if it is inside or outside of a given polygon.

Approach:

- from the point being tested cast a ray in an arbitary direction
- if the number of crossings is odd then the point is inside
- if the number of crossings is even then the point is outside

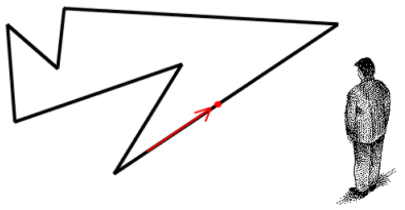


- Very fragile algorithm
- What if ray crosses a vertex?
- What if ray falls on an edge?
- Commonly used in ECAD
- Suitable for H/W



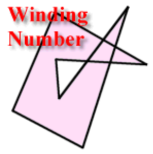
Winding Number

Imagine yourself watching a point traverse the boundary of the polygon in a counter-clockwise direction and pivoting so that you are always facing at it.



Your *winding number* is the number of full revolutions that you complete.

If you winding number is 0 then you are outside of the polygon, otherwise you are inside.

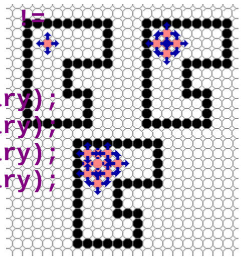


Boundary Fills

Boundary fills start from a point known to be inside of a region and fill the region until a boundry is found.

A simple recursive algorithm can be used:

```
    public void boundaryFill(int x, int y, int
fill, int boundary) {
        if ((x < 0) || (x >= width)) return;
        if ((y < 0) || (y >= height)) return;
        int current = raster.getPixel(x, y);
        if ((current != boundary) && (current !=
fill)) {
            raster.setPixel(fill, x, y);
            boundaryFill(x+1, y, fill, boundary);
            boundaryFill(x, y+1, fill, boundary);
            boundaryFill(x-1, y, fill, boundary);
            boundaryFill(x, y-1, fill, boundary);
        }
    }
```



Let's Watch it in Action

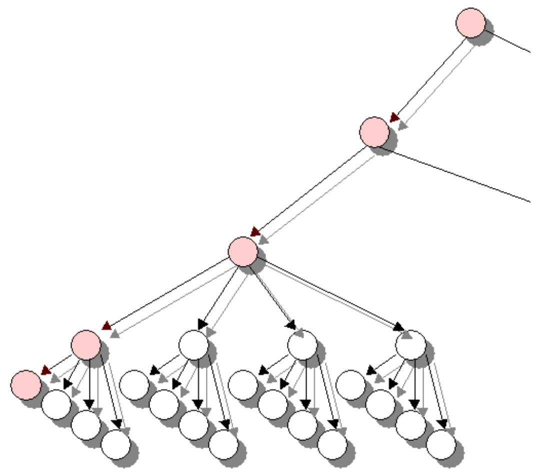
First, you should guess how you expect the algorithm to behave. Then select a point on the figure's interior. Did the algorithm act as you expected?

Serial Recursion is Depth-First

So the fill algorithm will continue in one direction until a boundary is reached.

It will then change directions momentarily and attempt to continue back in the original direction.

Will parallel execution of the algorithm behave the same way?



At Full Speed

To the right is the same algorithm operating at full speed.

Left-button click inside one of the regions to start the fill process. Click the right button to reset the image to its original state

A Flood-Fill

Sometimes we'd like a area fill algorithm that replaces all *connected* pixels of a selected color with a fill color. The *flood-fill algorithm* does exactly that.

```
            public void floodFill(int x, int y,
int fill, int old) {
                if ((x < 0) || (x >= width))
return;
                if ((y < 0) || (y >= height))
return;
                if (raster.getPixel(x, y) == old)
{
                    raster.setPixel(fill, x, y);
                    floodFill(x+1, y, fill, old);
                    floodFill(x, y+1, fill, old);
                    floodFill(x-1, y, fill, old);
                    floodFill(x, y-1, fill, old);
                }
            }
```

Flood fill is a small variant on a boundary fill. It replaces *old* pixels with the *fill* color.

Flood-Fill in Action

It's a little awkward to kick off a flood fill algorithm, because it requires that the *old* color must be read before it is invoked. It is usually, established by the initial pixel *(x, y)* where a mouse is clicked.

Self-Starting Fast Flood-Fill Algorithm

The follow implementation self-starts, and is also somewhat faster.

```
            public void fillFast(int x, int y, int
fill)
            {
                if ((x < 0) || (x >=
raster.width)) return;
                if ((y < 0) || (y >=
raster.height)) return;
                int old = raster.getPixel(x, y);
                if (old == fill) return;
                raster.setPixel(fill, x, y);
                fillEast(x+1, y, fill, old);
                fillSouth(x, y+1, fill, old);
                fillWest(x-1, y, fill, old);
                fillNorth(x, y-1, fill, old);
            }
```

Fill East

```
    private void fillEast(int x, int y, int fill,
int old) {
        if (x >= raster.width) return;
        if (raster.getPixel(x, y) == old) {
            raster.setPixel(fill, x, y);
            fillEast(x+1, y, fill, old);
            fillSouth(x, y+1, fill, old);
            fillNorth(x, y-1, fill, old);
        }
    }
```

Note:

There is only one clipping test, and only three subsequent calls.
Why?
How much faster do you expect this algorithm to be?

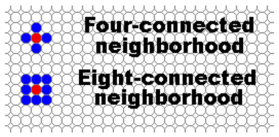
Working Algorithm

```
private void fillSouth(int x, int y, int fill, int
old) {
    if (y >= raster.height) return;
    if (raster.getPixel(x, y) == old) {
        raster.setPixel(fill, x, y);
        fillEast(x+1, y, fill, old);
        fillSouth(x, y+1, fill, old);
        fillWest(x-1, y, fill, old);
    }
}
```

You can figure out the other routines yourself.

4-Way and 8-Way Connectedness

A final consideration when writing a area-fill algorithm is the size and connectivity of the neighborhood, around a given pixel.



An eight-connected neighborhood is able to get into knooks and crannies that an algorithm based on a four-connected neighborhood cannot.

Code for an 8-Way Connected Flood Fill

As you expected...
the code is a simple modification of the 4-way connected flood fill.

```
  public void floodFill8(int x, int y, int fill,
int old) {
        if ((x < 0) || (x >= raster.width)) return;
        if ((y < 0) || (y >= raster.height)) return;
        if (raster.getPixel(x, y) == old) {
            raster.setPixel(fill, x, y);
            floodFill8(x+1, y, fill, old);
            floodFill8(x, y+1, fill, old);
            floodFill8(x-1, y, fill, old);
            floodFill8(x, y-1, fill, old);
            floodFill8(x+1, y+1, fill, old);
            floodFill8(x-1, y+1, fill, old);
            floodFill8(x-1, y-1, fill, old);
            floodFill8(x+1, y-1, fill, old);
        }
  }
```

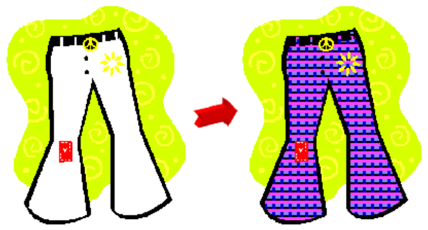
More 8-Way Connectedness

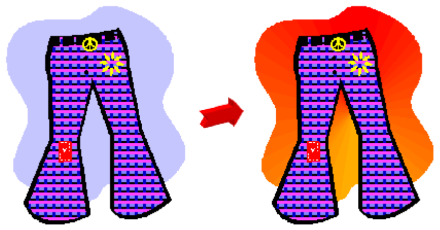
Sometimes 8-way connectedness can be too much.

Flood-Fill Embellishments

The flood-fill and boundary-fill algorithms can easily be modified for a wide variety of new uses:

1. Patterned fills
2. Approximate fills
3. Gradient fills
4. Region selects
5. Triangle Rendering!

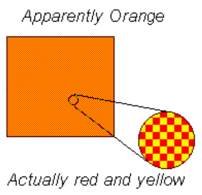




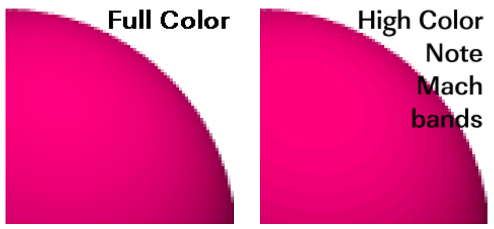
Monochrome and Color Dithering

Dithering techniques are used to render images and graphics with more apparent colors than are actually displayable. Dithering is sometimes called digital half-toning.

When our visual systems are confronted with large regions of high-frequency color changes they tend to blend the individual colors into uniform color field. Dithering attempts to uses this property of perception to represent colors that cannot be directly represented.



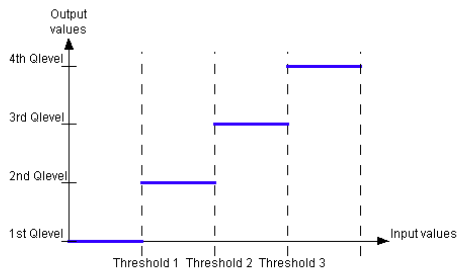
When do we need dithering?



- We can discern approximately 100 brightness levels (depends on hue and ambient lighting)
- True-color displays are usually adequate under normal indoor lighting (when the nonlinearities of the display are properly compensated for).
- High-color displays provide only 32 shades of a each primary. Without dithering you will see contours.
- Made worse by Mach-banding
- Worse on indexed displays
- Largest use of dithering is in printed media (newsprint, laser printers)

Quantization and Thresholding

The process of representing a continuous function with discrete values is called *quantization*. It can best be visualized with a drawing:

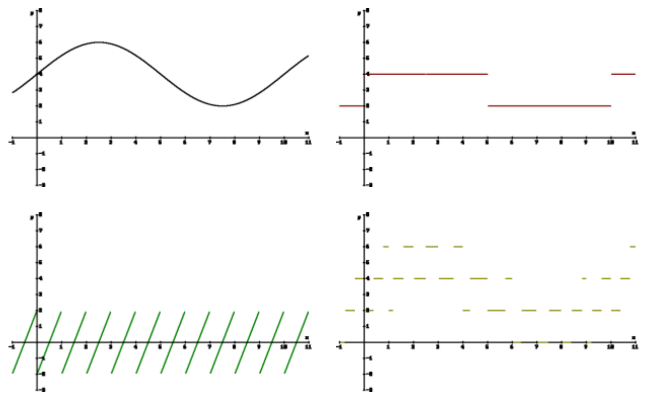


The input values that cause the quantization levels to change output values are called *thresholds*. The example above has 4 quantization levels and 3 thresholds. When the spacing between the thresholds and the quantization levels is constant the process is called *uniform quantization*.

The Secret... Noise

Dithering requires the addition of *spatial noise* to the original signal (color intensity). This noise can be regular (a repeated signal that is independent of either the input or output), correlated (a signal that is related to the input), random, or some combination.

Dithering can be neatly summarized as a quantization process where noise has has been introduced to the input. The character of the dither is determined entirely by the structure of the noise. Note: Dithering decreases the SNR yet improves the percieved quality of the output.



Dither Noise Patterns

Let's consider some dither noise patterns.

One simple type of noise is called *uniform* or *white noise*. White noise generates values within an interval such that all outcomes are equally likely. Here we add *zero-mean* white noise to our image. The term zero-mean indicates that the average value of the noise is zero. This will assure that our dithering does not change the apparent brightness of our image.

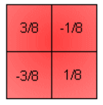
The only thing left to specify is the range of noise values, this is called the noise's *amplitude*. The amplitude that makes the most sense is the spacing between thresholds. This is not, however a requirement. It is rare to specify a larger amplitude (Why?), but frequently slightly smaller amplitudes are used. Let's look back at our example to see what random noise dithering looks like.

The result is not a good as expected. The noise pattern tends to clump in different regions of the image. The unsettling aspect of this clumping is that it is unrelated to the image. Thus the dithering process adds apparent detail to the image that are not really in the image.

Ordered Dither

The next noise function uses a regular spatial pattern. This technique is called *ordered dithering*. Ordered dithering adds a noise pattern with specific amplitudes.

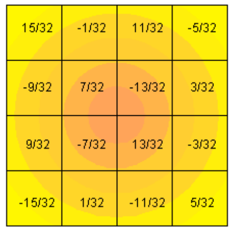
2 by 2 Ordered dither noise pattern



3/8	-1/8
-3/8	1/8

Units are the fraction of the difference between quantization levels.

4 by 4 Ordered dither noise pattern



15/32	-1/32	11/32	-5/32
-9/32	7/32	-13/32	3/32
9/32	-7/32	13/32	-3/32
-15/32	1/32	-11/32	5/32

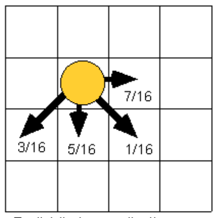
Ordered dither gives a very regular screen-like pattern remincent of newsprint.

Error Diffusion

Error diffusion is a *correlated* dithering technique, meaning that the noise value added to a given pixel is a function of the image.

Error diffusion attempts to transfer the residual error due to quantization to a region of surrounding pixels. Most common techniues are designed so that the pixels can be processed in an ordered single pass. For example the following pattern assumes that each scanline is processed from left to right as the image is scaned from top to bottom.

Error = actual - quantized



Redistribute quanitzation error to your neighbors

Error diffusion is generally, the preferred method for the display of images on a computer screen. The most common artifacts are vissible worm-like patterns, and the leakage of noise into uniform regions.

Lossy Image Compression

The topic of image compression is a very involved and decribes a wide range of methods. Our goal here is to provide a sufficient background for understanding the most common compression techniques used. In particular those used on the WWW.

There are generally two types of images that are widely used on the WWW, gifs and jpegs. As you are probably aware, each method has its own strengths and weaknesses. Both methods also use some form of image compression.

Some of the highlights of these compression methods are summarized in the table shown on the right.

	GIF	JPEG
Colors	256	2^{24}
Compression	Dictionary-based (LZW)	Transform Based
Processing Order	Quantize, Compress	Transform, Quantize
Primary Use	Graphics, Line Art	Photos
Special Features	Transparency, Interleaving	Progressive

LZW Compression

Input String ="*WED*WE*WEE*WEB*WET"

LZW compression is an acronym for Lemple-Ziv-Welch compression. This is a classical, lossless dictionary-based compression system.

Prior, to compression any GIF image must be reduced to 256 colors. This can be done using quantization followed by dithering as discussed earlier. This is the where the *loss* occurs in GIF compression.

After the image is quantized then LZW compression is applied to reduce the image size. LZW compression starts with a dictionary that contains all possible symbols (in our case numbers from 0 to 255). For the sake of illustration, I will use characters in this explaination.

Basically, builds up a dictionary of longer and longer strings based on the input stream. The encoder compares the incoming characters for the longest possible match and returns the index for that dictionary entry. It then then adds a new dictionary entry with the current character concatenated to the longest match.

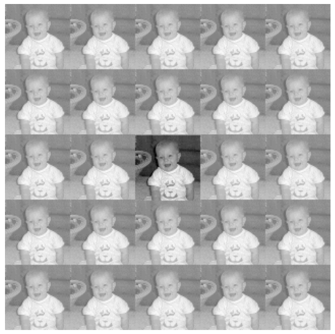
Input	Output	New Dictionary Entry
*W	*	256="*W"
E	W	257="WE"
D	E	258="ED"
*	D	259="D*"
WE	256	260="*WE"
*	E	261="E*"
WEE	260	262="*WEE"
*W	261	263="E*W"
EB	257	264="WEB"
*	B	265="B*"
WET	260	266="*WET"

Transform Coding

Transform coding removes the redundancies (correlation) in an images by changing coordinate systems.

We can think of a cluster of pixels, for instance those in an 8 by 8 block, as a vector in some high-dimensional space (64 dimension in this case). If we transform this matrix appropriately we can discover that a otherwise random collection of numbers is, in fact, highly correlated.

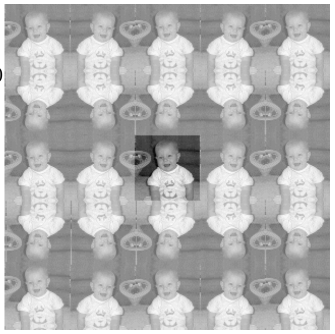
One common transform basis function that you have seen if the Fourier Basis (FFT). However the Fourier basis makes some assumptions that are not optimal for images.



First, it assumes that the image tiles an infinite plane. This leads to a transform that contains both even (cosine-like) and odd (sine-ike) components.

If we make copies of the images with various flips we can end up with a function that has only even (cosine-like) components.

The resulting FFT will only have real parts. This transform is called the *Cosine Transform*.



DCT example

By clicking on the image below you can transform it to and from it's Discrete Cosine Representation.

The DCT like the FFT is a *separable* transfrom. This means that a 2-D transfrom can be realized by first transfroming in the x direction, followed by a transforms in the y direction.

The blocksize shown here is 8 by 8 pixels.

Notice how the transformed image is a uniform gray color. This is indicative of a correlated image. In fact, most of the coefficients in a DCT transform are typically very close to zero (shown as gray here because these coefficients are signed values). Both JPEG and MPEG take advantage of this property by applying a quantization to these coefficents, which causes most values to be zero.

If we ignore floating point trucation errors, then the DCT transformation is an entirely lossless transform. The loss incurred in JPEG and MPEG types of compression is due to the quantization that is applied to each of the cofficients after the DCT transform.

Next Time

(Really and Truly this time)