Introduction to Computer Graphics with WebGL

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Polygonal Shading

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Polygonal Shading

- In per vertex shading, shading calculations are done for each vertex
  - Vertex colors become vertex shades and can be sent to the vertex shader as a vertex attribute
  - Alternately, we can send the parameters to the vertex shader and have it compute the shade
- By default, vertex shades are interpolated across an object if passed to the fragment shader as a varying variable (smooth shading)
- We can also use uniform variables to shade with a single shade (flat shading)

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Polygon Normals

- Triangles have a single normal
  - Shades at the vertices as computed by the modified Phong model can be almost same
  - Identical for a distant viewer (default) or if there is no specular component
- Consider model of sphere
- Want different normals at each vertex even though this concept is not quite correct mathematically

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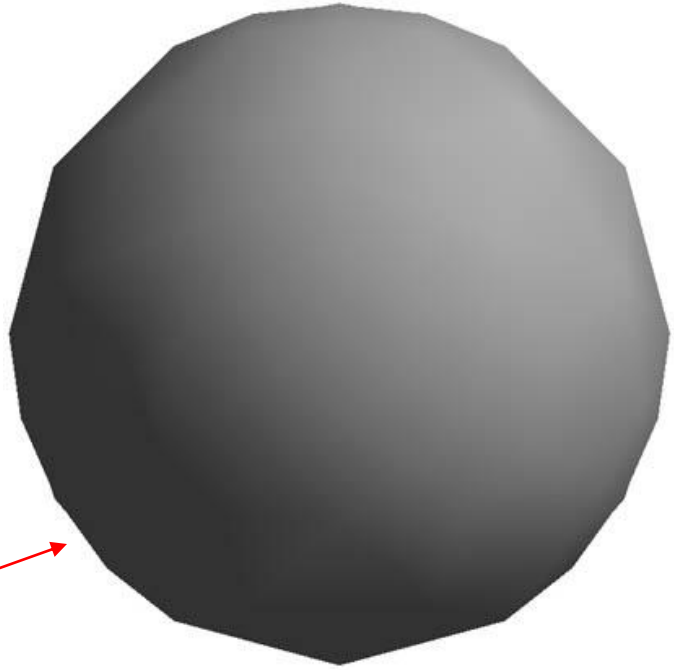
Smooth Shading

- We can set a new normal at each vertex
- Easy for sphere model
  - If centered at origin $\mathbf{n} = \mathbf{p}$
- Now smooth shading works
- Note *silhouette edge*



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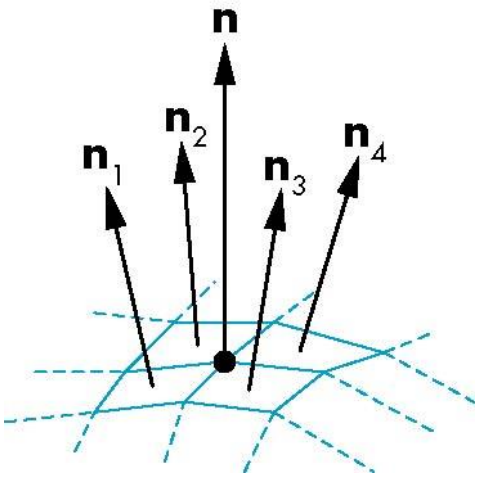
Mesh Shading

- The previous example is not general because we knew the normal at each vertex analytically
- For polygonal models, Gouraud proposed we use the average of the normals around a mesh vertex

$$\mathbf{n} = (\mathbf{n}_1+\mathbf{n}_2+\mathbf{n}_3+\mathbf{n}_4)/\,|\mathbf{n}_1+\mathbf{n}_2+\mathbf{n}_3+\mathbf{n}_4|$$



Gouraud and Phong Shading

- Gouraud Shading
  - Find average normal at each vertex (vertex normals)
  - Apply modified Phong model at each vertex
  - Interpolate vertex shades across each polygon
- Phong shading
  - Find vertex normals
  - Interpolate vertex normals across edges
  - Interpolate edge normals across polygon
  - Apply modified Phong model at each fragment

Comparison

- If the polygon mesh approximates surfaces with a high curvatures, Phong shading may look smooth while Gouraud shading may show edges
- Phong shading requires much more work than Gouraud shading
  - Until recently not available in real time systems
  - Now can be done using fragment shaders
- Both need data structures to represent meshes so we can obtain vertex normals

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Per Vertex and Per Fragment Shaders

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Vertex Lighting Shaders I

```
// vertex shader

attribute vec4 vPosition;
attribute vec4 vNormal;
varying vec4 fColor;
uniform vec4 ambientProduct, diffuseProduct, specularProduct;
uniform mat4 modelViewMatrix;
uniform mat4 projectionMatrix;
uniform vec4 lightPosition;
uniform float shininess;

void main()
{
```

Vertex Lighting Shaders II

```
vec3 pos = -(modelViewMatrix * vPosition).xyz;
 vec3 light = lightPosition.xyz;
 vec3 L = normalize( light - pos );
 vec3 E = normalize( -pos );
 vec3 H = normalize( L + E );

 // Transform vertex normal into eye coordinates

        vec3 N = normalize( (modelViewMatrix*vNormal).xyz);

 // Compute terms in the illumination equation
```

Vertex Lighting Shaders III

```
// Compute terms in the illumination equation
    vec4 ambient = AmbientProduct;

    float Kd = max( dot(L, N), 0.0 );
    vec4  diffuse = Kd*DiffuseProduct;
    float Ks = pow( max(dot(N, H), 0.0), Shininess );
    vec4  specular = Ks * SpecularProduct;
    if( dot(L, N) < 0.0 )  specular = vec4(0.0, 0.0, 0.0, 1.0);
    gl_Position = Projection * ModelView * vPosition;

    fColor = ambient + diffuse + specular;
    fColor.a = 1.0;
}
```

Vertex Lighting Shaders IV

```
// fragment shader

precision mediump float;

varying vec4 fColor;

voidmain()
{
    gl_FragColor = fColor;
}
```

Fragment Lighting Shaders I

```
// vertex shader

attribute vec4 vPosition;
attribute vec4 vNormal;
varying vec3 N, L, E;
uniform mat4 modelViewMatrix;
uniform mat4 projectionMatrix;
uniform vec4 lightPosition;
```

Fragment Lighting Shaders II

```
void main()
{
   vec3 pos = -(modelViewMatrix * vPosition).xyz;
   vec3 light = lightPosition.xyz;
   L = normalize( light - pos );
   E =  -pos;
   N = normalize( (modelViewMatrix*vNormal).xyz);
   gl_Position = projectionMatrix * modelViewMatrix * vPosition;
   };
```

Fragment Lighting Shaders III

```
// fragment shader

precision mediump float;

uniform vec4 ambientProduct;
uniform vec4 diffuseProduct;
uniform vec4 specularProduct;
uniform float shininess;
varying vec3 N, L, E;

void main()
{
```

Fragment Lighting Shaders IV

```
    vec4 fColor;
    vec3 H = normalize( L + E );
    vec4 ambient = ambientProduct;
    float Kd = max( dot(L, N), 0.0 );
    vec4  diffuse = Kd*diffuseProduct;
    float Ks = pow( max(dot(N, H), 0.0), shininess );
    vec4  specular = Ks * specularProduct;
        if( dot(L, N) < 0.0 ) specular = vec4(0.0, 0.0, 0.0, 1.0);
    fColor = ambient + diffuse +specular;
    fColor.a = 1.0;
    gl_FragColor = fColor;
}
```

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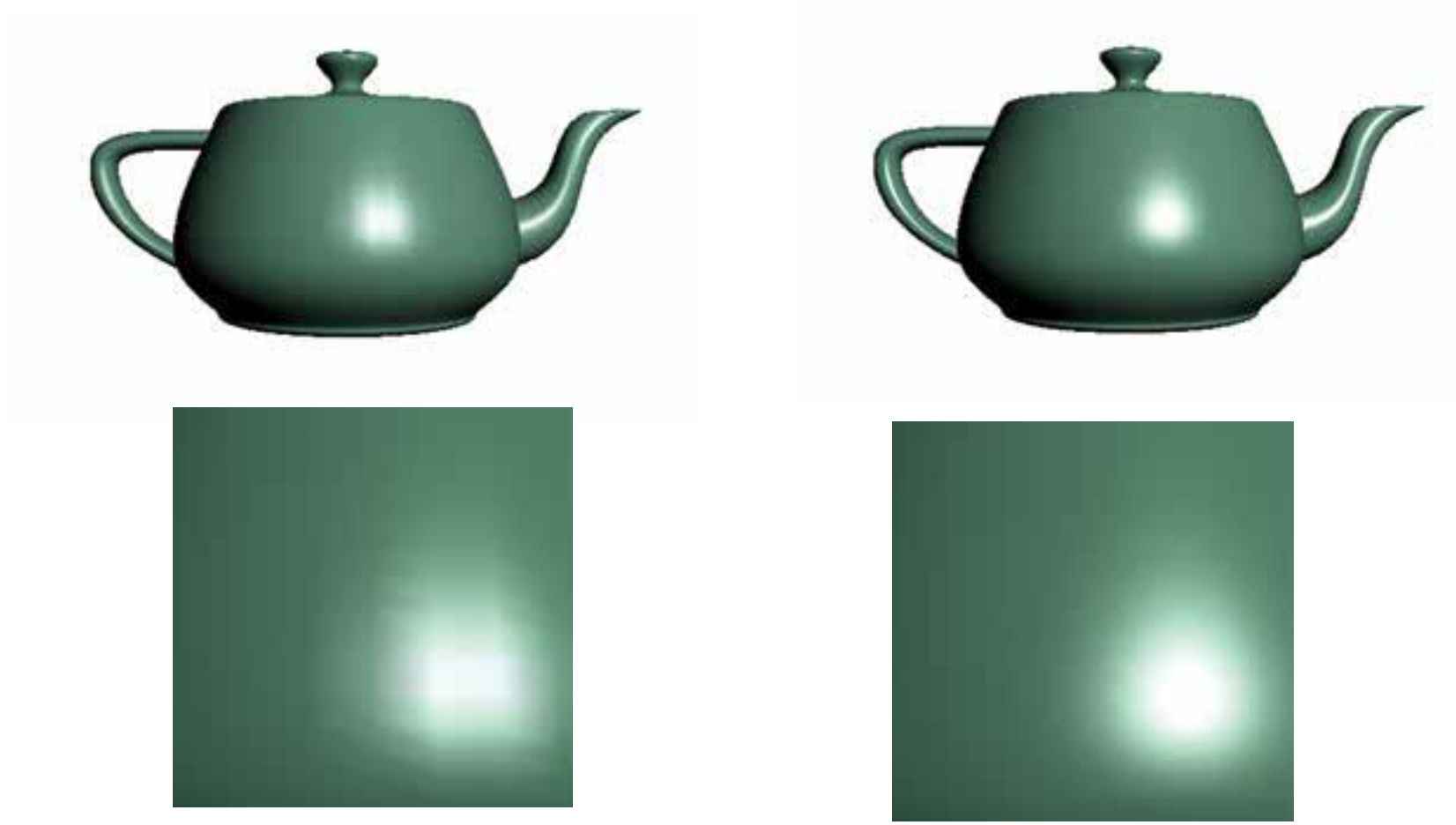
Teapot Examples



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Marching Squares

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Objectives

- Nontrivial two-dimensional application
- Important method for
  - Contour plots
  - Implicit function visualization
- Extends to important method for volume visualization
- This lecture is optional but should be interesting to most of you

Displaying Implicit Functions

- Consider the implicit function

$$g(x,y)=0$$

- Given an x, we cannot in general find a corresponding y
- Given an x and a y, we can test if they are on the curve

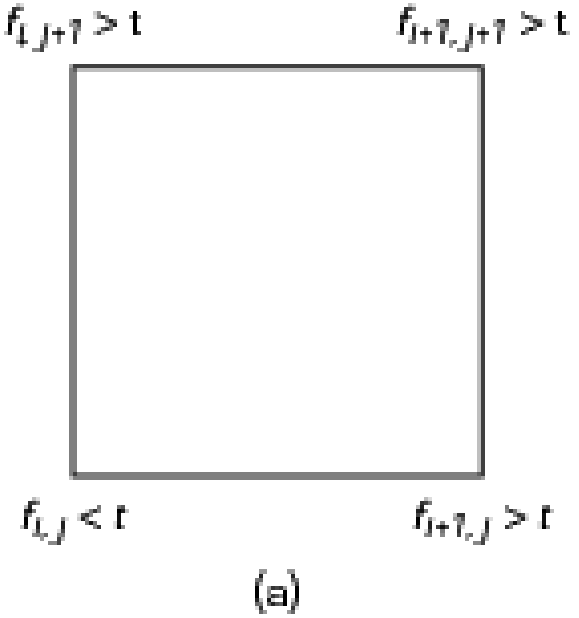
Height Fields and Contours

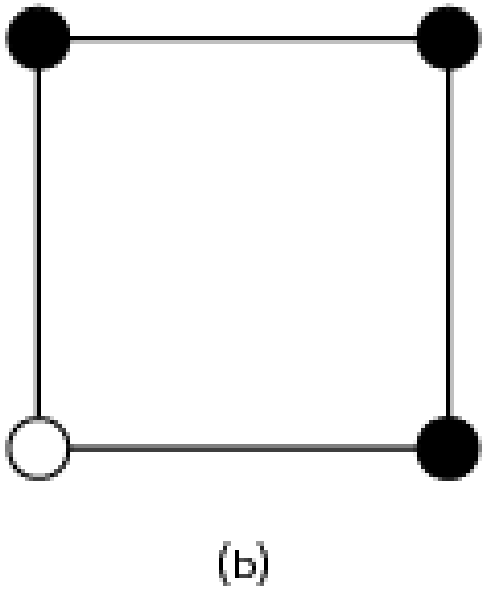
- In many applications, we have the heights given by a function of the form $z=f(x,y)$
- To find all the points that have a given height t, we have to solve the implicit equation $g(x,y)=f(x,y)-t=0$
- Such a function determines the **isocurves** or **contours** of f for the **isovalue** t

Marching Squares

- Displays isocurves or contours for functions $f(x,y) = t$
- Sample $f(x,y)$ on a regular grid yielding samples $\{f_{ij}(x,y)\}$
- These samples can be greater than, less than, or equal to t
- Consider four samples $f_{ij}(x,y)$, $f_{i+1,j}(x,y)$, $f_{i+1,j+1}(x,y)$, $f_{i,j+1}(x,y)$
- These samples correspond to the corners of a cell
- Color the corners by whether they exceed or are less than the contour value t

Cells and Coloring





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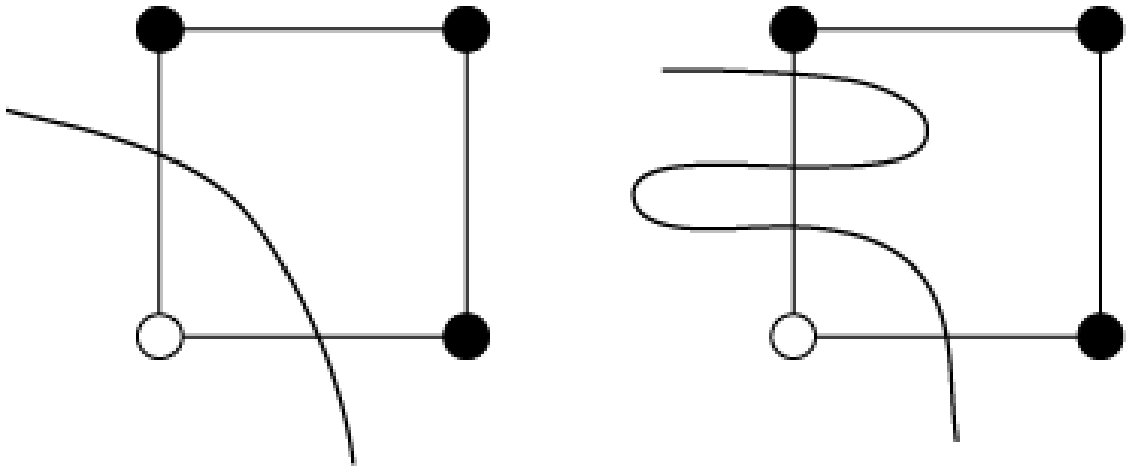
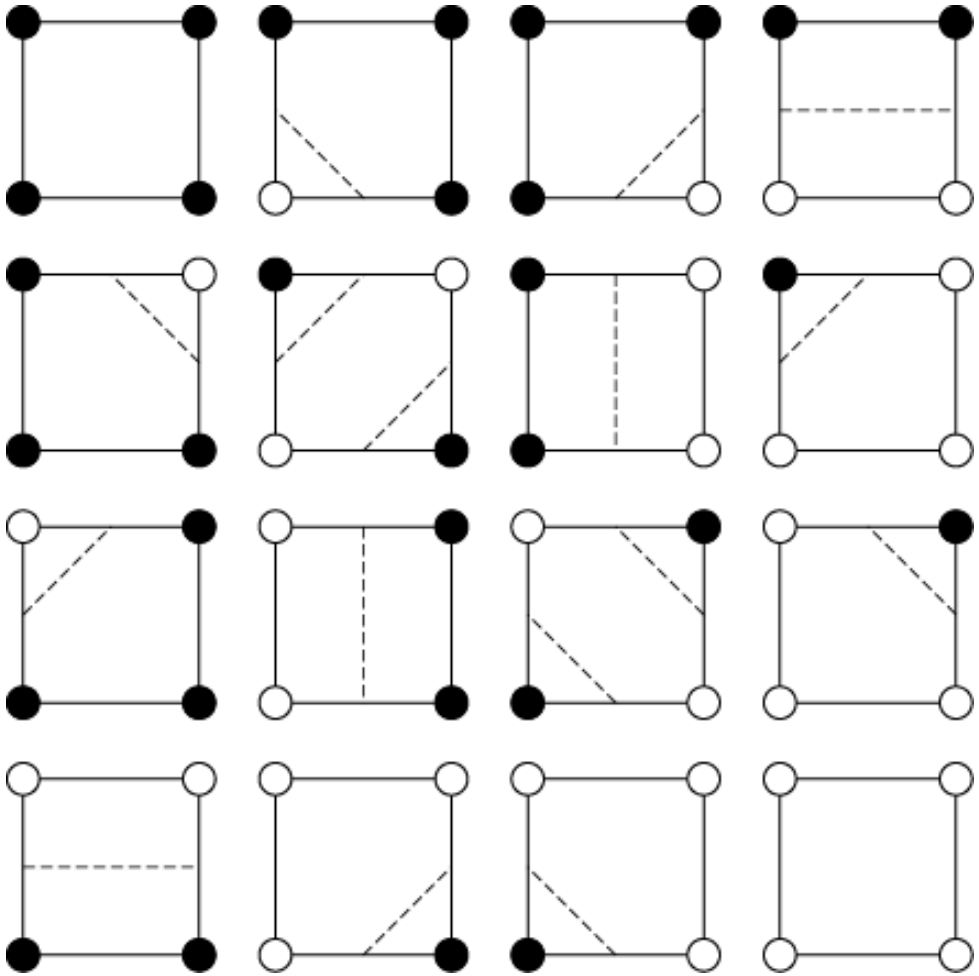
Occam's Razor

- Contour must intersect edge between a black and white vertex an odd number of times
- Pick simplest interpretation: one crossing

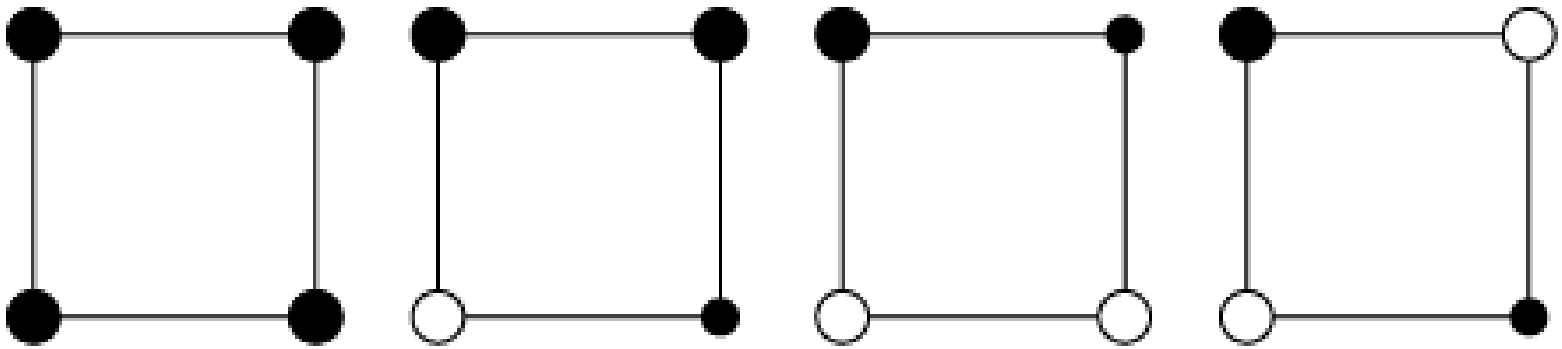


16 Cases



Unique Cases

- Taking out rotational and color swapping symmetries leaves four unique cases
- First three have a simple interpretation



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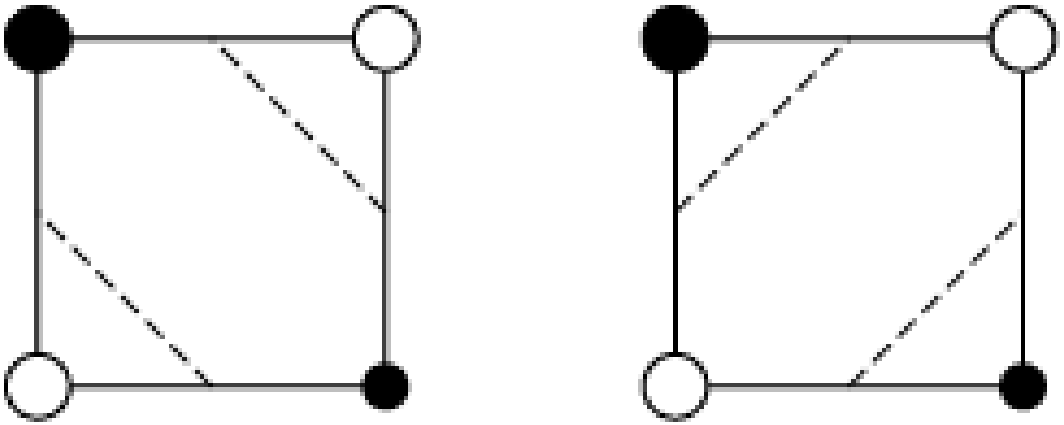
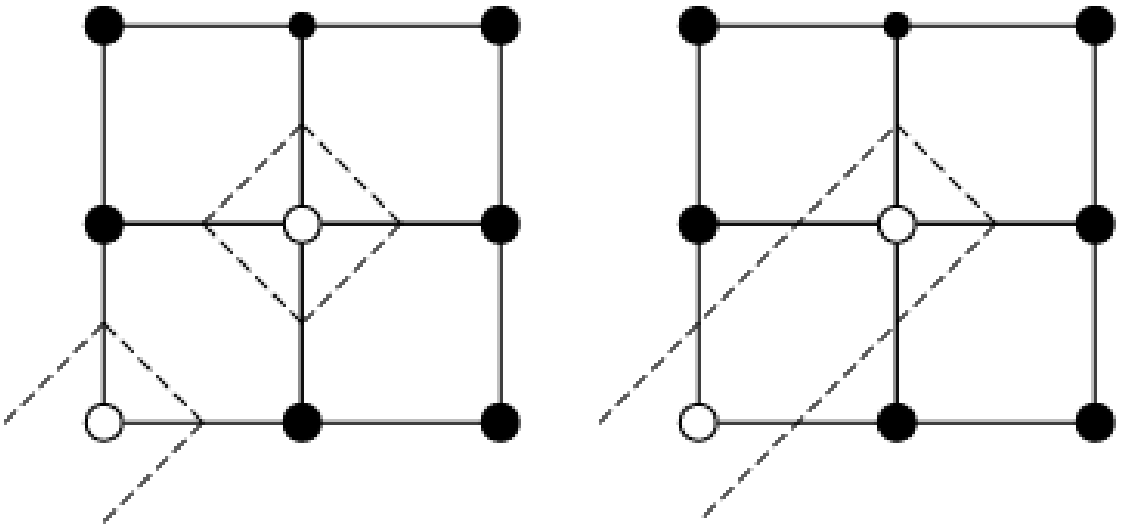
Ambiguity Problem

- Diagonally opposite cases have two equally simple possible interpretations

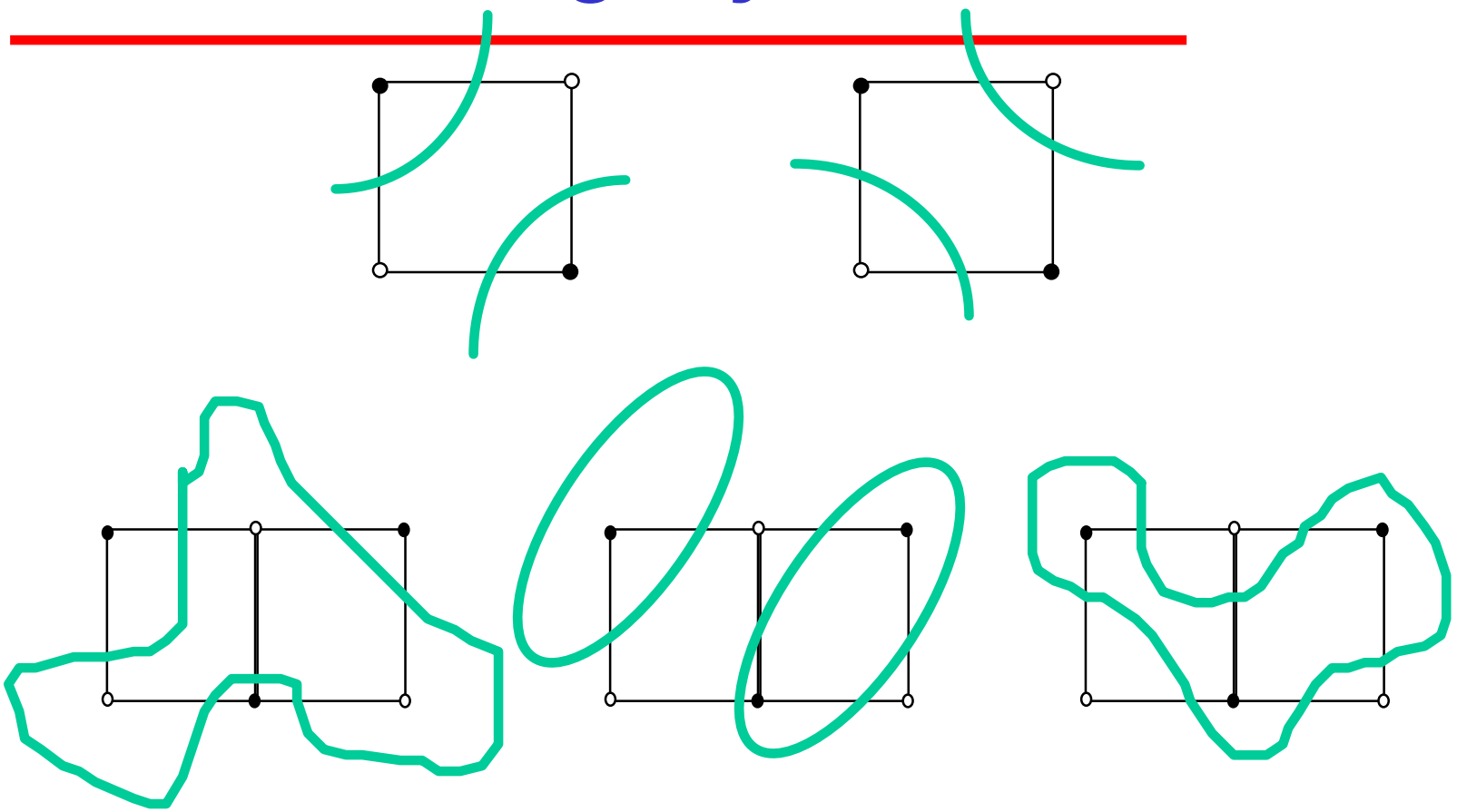


Ambiguity Example

- Two different possibilities below
- More possibilities on next slide



Ambiguity Problem

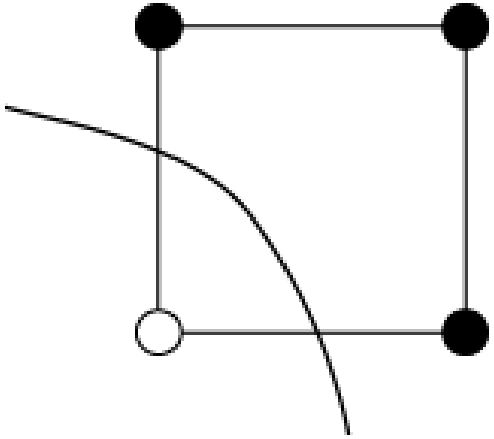


Is Problem Resolvable?

- Problem is a sampling problem
  - Not enough samples to know the local detail
  - No solution in a mathematical sense without extra information
- More of a problem with volume extension (marching cubes) where selecting “wrong” interpretation can leave a hole in a surface
- Multiple methods in literature to give better appearance
  - Supersampling
  - Look at larger area before deciding

Interpolating Edges

- We can compute where contour intersects edge in multiple ways
  - Halfway between vertics
  - Interpolated based on difference between contour value and value at vertices

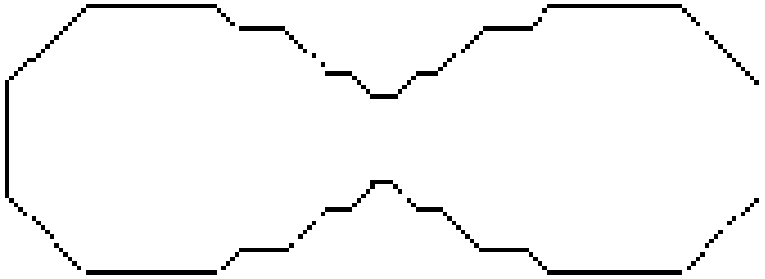


Example: Oval of Cassini

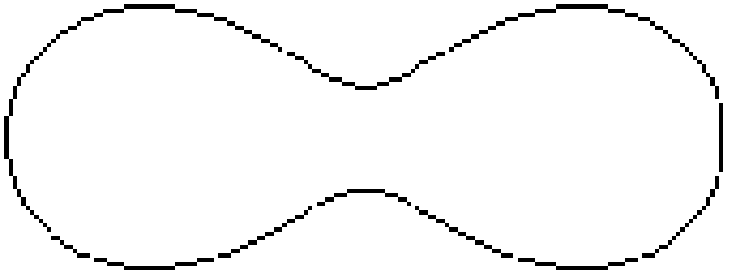
$$f(x,y)=(x^2+y^2+a^2)^2-4a^2x^2-b^4$$

Depending on a and b we can have 0, 1, or 2 curves

midpoint intersections

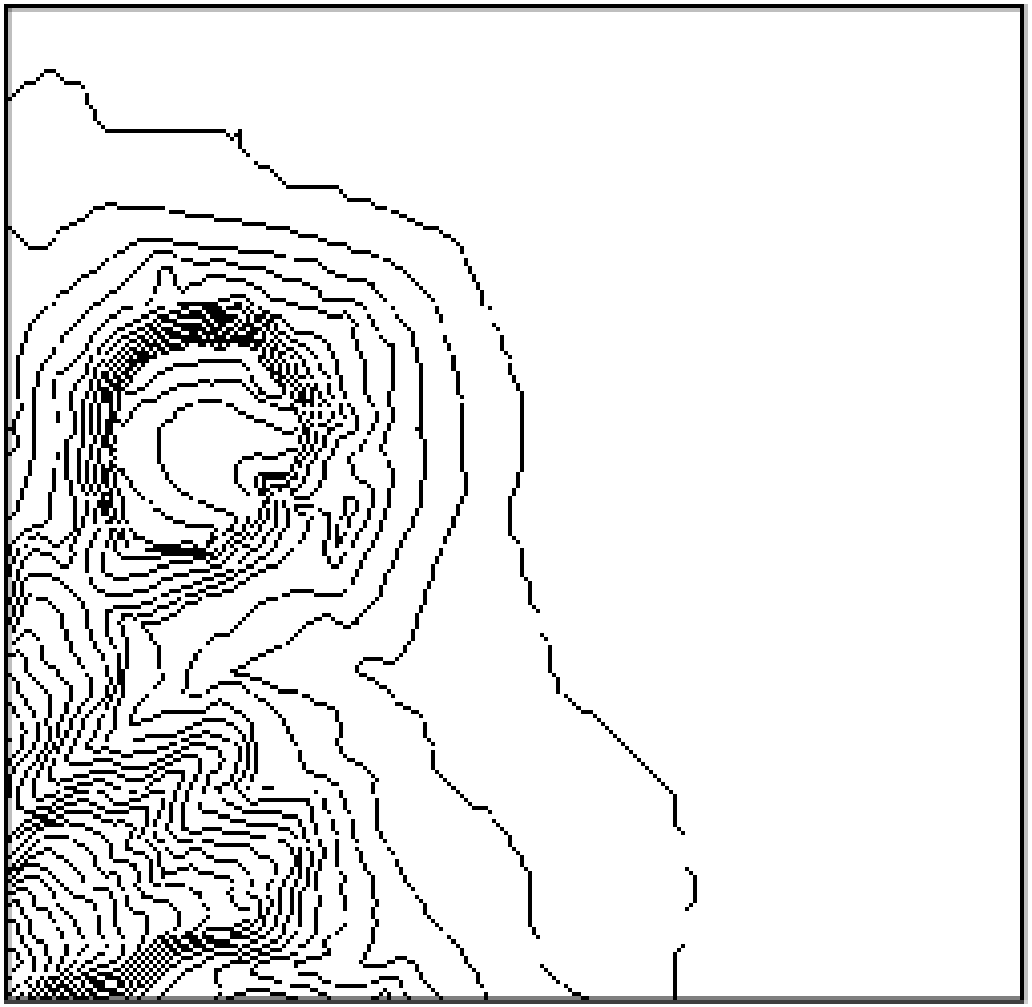


interpolating intersections



Contour Map

- Diamond Head, Oahu Hawaii
- Shows contours for many contour values



Marching Cubes

- Isosurface: solution of g(x,y,z)=c
- Use same argument to derive method but with a cubic cell (8 vertices, 256 colorings)
- Standard method of volume visualization
- Suggested by Lorensen and Kline before marching squares
- Note inherent parallelism of both marching cubes and marching squares