Introduction to Computer Graphics with WebGL

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Lighting and Shading II

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Objectives

- Continue discussion of shading
- Introduce modified Phong model
- Consider computation of required vectors

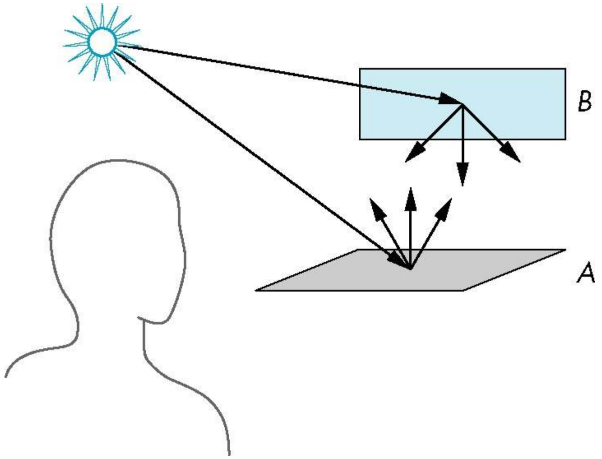
Ambient Light

- Ambient light is the result of multiple interactions between (large) light sources and the objects in the environment
- Amount and color depend on both the color of the light(s) and the material properties of the object
- Add k_a I_a to diffuse and specular terms

reflection coef   intensity of ambient light

Distance Terms

- The light from a point source that reaches a surface is inversely proportional to the square of the distance between them
- We can add a factor of the form $1/(a + bd + cd^2)$ to the diffuse and specular terms



- The constant and linear terms soften the effect of the point source

Light Sources

- In the Phong Model, we add the results from each light source
- Each light source has separate diffuse, specular, and ambient terms to allow for maximum flexibility even though this form does not have a physical justification
- Separate red, green and blue components
- Hence, 9 coefficients for each point source
  - I_{dr}, I_{dg}, I_{db}, I_{sr}, I_{sg}, I_{sb}, I_{ar}, I_{ag}, I_{ab}

Material Properties

- Material properties match light source properties
  - Nine absorbtion coefficients
    - $k_{dr}, k_{dg}, k_{db}, k_{sr}, k_{sg}, k_{sb}, k_{ar}, k_{ag}, k_{ab}$
  - Shininess coefficient α

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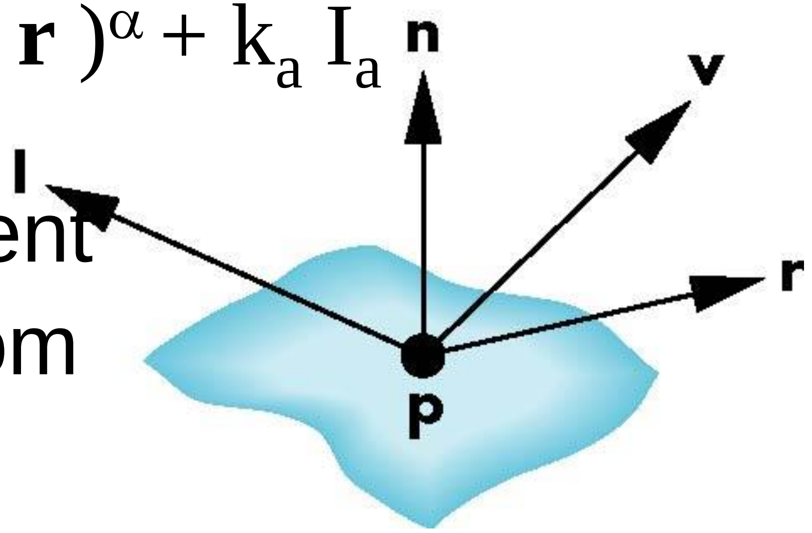
Adding up the Components

For each light source and each color component, the Phong model can be written (without the distance terms) as

$$I = k_d I_d \, \mathbf{l} \cdot \mathbf{n} + k_s I_s (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_a I_a$$



For each color component we add contributions from all sources

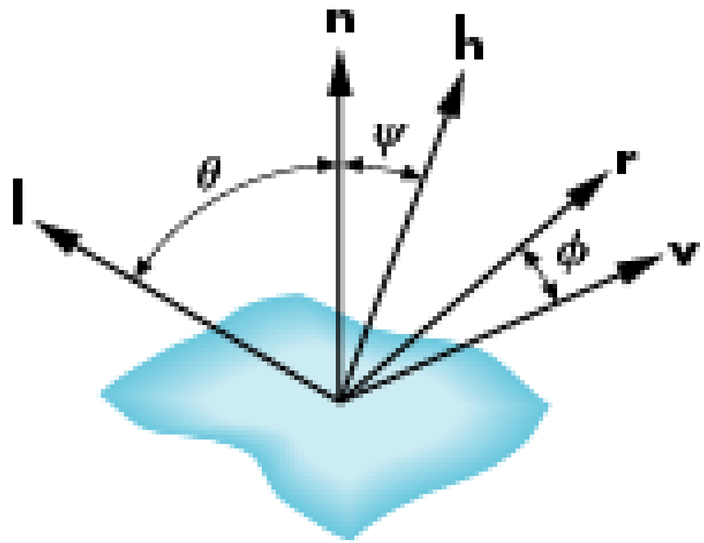
Modified Phong Model

- The specular term in the Phong model is problematic because it requires the calculation of a new reflection vector and view vector for each vertex
- Blinn suggested an approximation using the halfway vector that is more efficient

The Halfway Vector

- **h** is normalized vector halfway between **l** and **v**

$$\mathbf{h} = (\mathbf{l} + \mathbf{v})/\,|\,\mathbf{l} + \mathbf{v}\,|$$

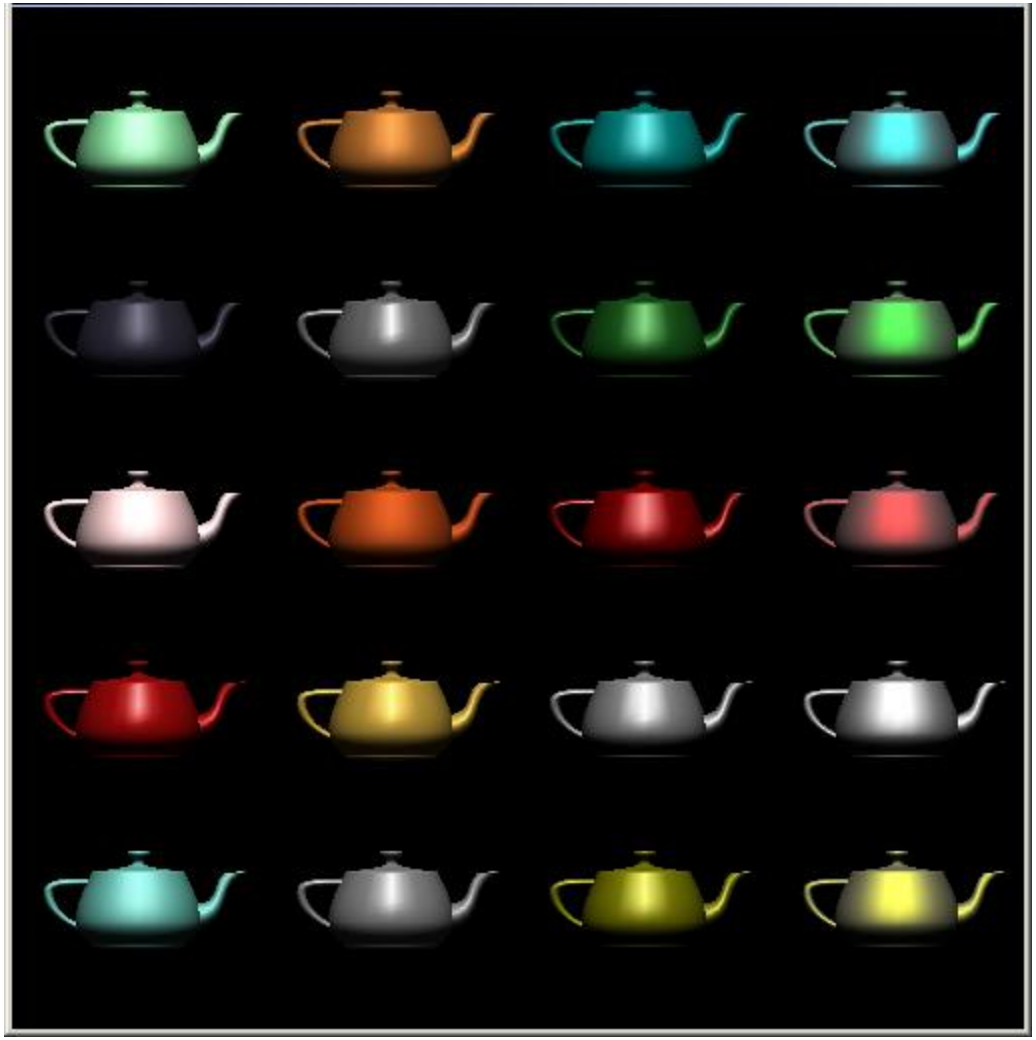


Using the halfway vector

- Replace $(\mathbf{v} \cdot \mathbf{r})^{\alpha}$ by $(\mathbf{n} \cdot \mathbf{h})^{\beta}$
- β is chosen to match shininess
- Note that halfway angle is half of angle between $\mathbf{r}$ and $\mathbf{v}$ if vectors are coplanar
- Resulting model is known as the modified Phong or Phong-Blinn lighting model
  - Specified in OpenGL standard

Example

Only differences in these teapots are the parameters in the modified Phong model



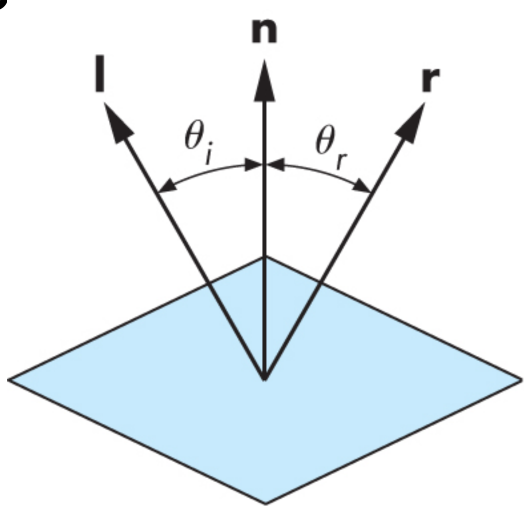
Computation of Vectors

- **l** and **v** are specified by the application
- Can computer **r** from **l** and **n**
- Problem is determining **n**
- For simple surfaces is can be determined but how we determine **n** differs depending on underlying representation of surface
- OpenGL leaves determination of normal to application
  - Exception for GLU quadrics and Bezier surfaces was deprecated

Computing Reflection Direction

- Angle of incidence = angle of reflection
- Normal, light direction and reflection direction are coplaner
- Want all three to be unit length

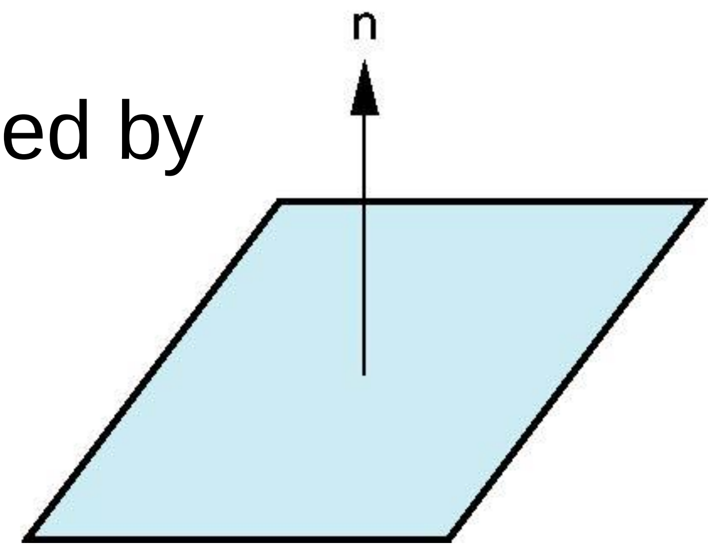
$$r = 2(l \bullet n)n - l$$



Plane Normals

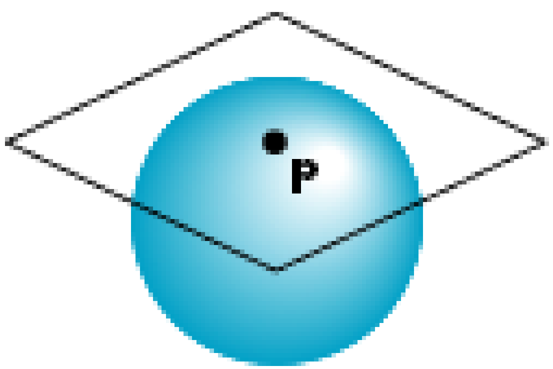
- Equation of plane: $ax+by+cz+d = 0$
- From Chapter 4 we know that plane is determined by three points p_0, p_2, p_3 or normal $\mathbf{n}$ and p_0
- Normal can be obtained by

$$\mathbf{n} = (p_2-p_0) \times (p_1-p_0)$$



Normal to Sphere

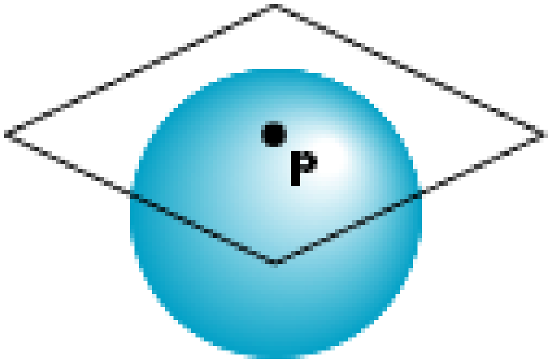
- Implicit function f(x,y.z)=0
- Normal given by gradient
- Sphere $f(\mathbf{p})=\mathbf{p}\cdot\mathbf{p}-1$
- $n = [\partial f/\partial x, \partial f/\partial y, \partial f/\partial z]^T=\mathbf{p}$



Parametric Form

- For sphere

$$x=x(u,v)=\cos u \sin v$$
$$y=y(u,v)=\cos u \cos v$$
$$z= z(u,v)=\sin u$$



- Tangent plane determined by vectors

$$\partial \mathbf{p}/\partial u = [\partial x/\partial u, \partial y/\partial u, \partial z/\partial u]T$$
$$\partial \mathbf{p}/\partial v = [\partial x/\partial v, \partial y/\partial v, \partial z/\partial v]T$$

- Normal given by cross product

$$\mathbf{n} = \partial \mathbf{p}/\partial u \times \partial \mathbf{p}/\partial v$$

General Case

- We can compute parametric normals for other simple cases
  - Quadrics
  - Parametric polynomial surfaces
    - Bezier surface patches (Chapter 11)

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Lighting and Shading in WebGL

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Objectives

- Introduce the WebGL shading methods
  - Light and material functions on MV.js
  - per vertex vs per fragment shading
  - Where to carry out

WebGL lighting

- Need
  - Normals
  - Material properties
  - Lights
- State-based shading functions have been deprecated (glNormal, glMaterial, glLight)
- Compute in application or in shaders

Normalization

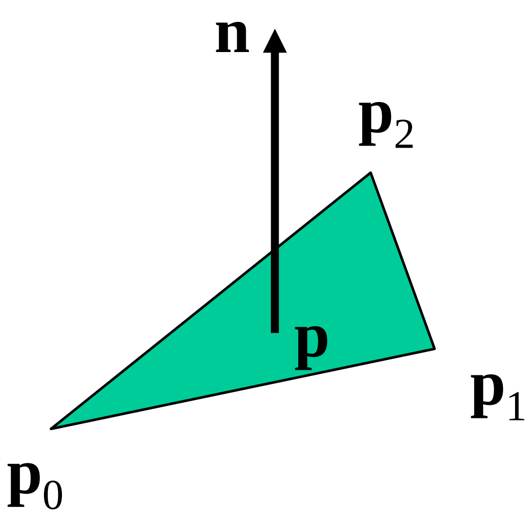
- Cosine terms in lighting calculations can be computed using dot product
- Unit length vectors simplify calculation
- Usually we want to set the magnitudes to have unit length but
  - Length can be affected by transformations
  - Note that scaling does not preserved length
- GLSL has a normalization function

Normal for Triangle

plane $\mathbf{n} \cdot (\mathbf{p} - \mathbf{p}_0) = 0$

$\mathbf{n} = (\mathbf{p}_2 - \mathbf{p}_0) \times (\mathbf{p}_1 - \mathbf{p}_0)$

normalize $\mathbf{n} \leftarrow \mathbf{n}/|\mathbf{n}|$



Note that right-hand rule determines outward face

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Specifying a Point Light Source

- For each light source, we can set an RGBA for the diffuse, specular, and ambient components, and for the position

```
var diffuse0 = vec4(1.0, 0.0, 0.0, 1.0);
var ambient0 = vec4(1.0, 0.0, 0.0, 1.0);
var specular0 = vec4(1.0, 0.0, 0.0, 1.0);
var light0_pos = vec4(1.0, 2.0, 3,0, 1.0);
```

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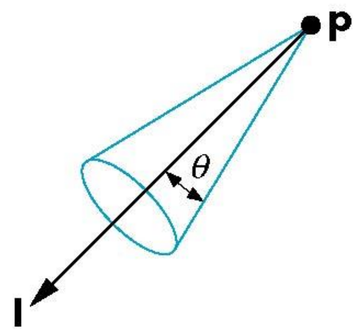
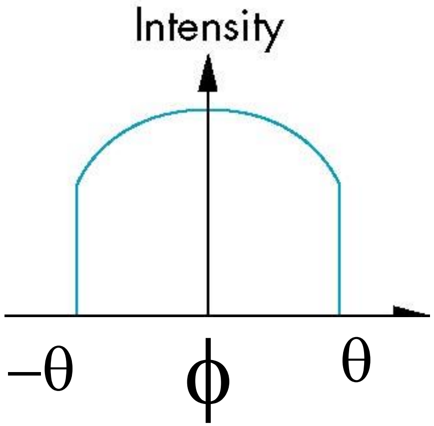
Distance and Direction

- The source colors are specified in RGBA
- The position is given in homogeneous coordinates
  - If w =1.0, we are specifying a finite location
  - If w =0.0, we are specifying a parallel source with the given direction vector
- The coefficients in distance terms are usually quadratic (1/(a+b*d+c*d*d)) where d is the distance from the point being rendered to the light source

Spotlights

- Derive from point source
  - Direction
  - Cutoff
  - Attenuation Proportional to $\cos^{\alpha}\phi$





Global Ambient Light

- Ambient light depends on color of light sources
  - A red light in a white room will cause a red ambient term that disappears when the light is turned off
- A global ambient term that is often helpful for testing

Moving Light Sources

- Light sources are geometric objects whose positions or directions are affected by the model-view matrix
- Depending on where we place the position (direction) setting function, we can
  - Move the light source(s) with the object(s)
  - Fix the object(s) and move the light source(s)
  - Fix the light source(s) and move the object(s)
  - Move the light source(s) and object(s) independently

Light Properties

```
var lightPosition = vec4(1.0, 1.0, 1.0, 0.0 );
var lightAmbient = vec4(0.2, 0.2, 0.2, 1.0 );
var lightDiffuse = vec4( 1.0, 1.0, 1.0, 1.0 );
var lightSpecular = vec4( 1.0, 1.0, 1.0, 1.0 );
```

Material Properties

- Material properties should match the terms in the light model
- Reflectivities
- w component gives opacity

```
var materialAmbient = vec4( 1.0, 0.0, 1.0, 1.0 );
var materialDiffuse = vec4( 1.0, 0.8, 0.0, 1.0);
var materialSpecular = vec4( 1.0, 0.8, 0.0, 1.0 );
var materialShininess = 100.0;
```

Using MV.js for Products

```
var ambientProduct = mult(lightAmbient, materialAmbient);
var diffuseProduct = mult(lightDiffuse, materialDiffuse);
var specularProduct = mult(lightSpecular, materialSpecular);
 gl.uniform4fv(gl.getUniformLocation(program,
                "ambientProduct"),       flatten(ambientProduct));
 gl.uniform4fv(gl.getUniformLocation(program,
                "diffuseProduct"),       flatten(diffuseProduct) );
 gl.uniform4fv(gl.getUniformLocation(program,
                 "specularProduct"),       flatten(specularProduct) );
 gl.uniform4fv(gl.getUniformLocation(program,
                 "lightPosition"),       flatten(lightPosition) );
gl.uniform1f(gl.getUniformLocation(program,
                "shininess"),materialShininess);
```

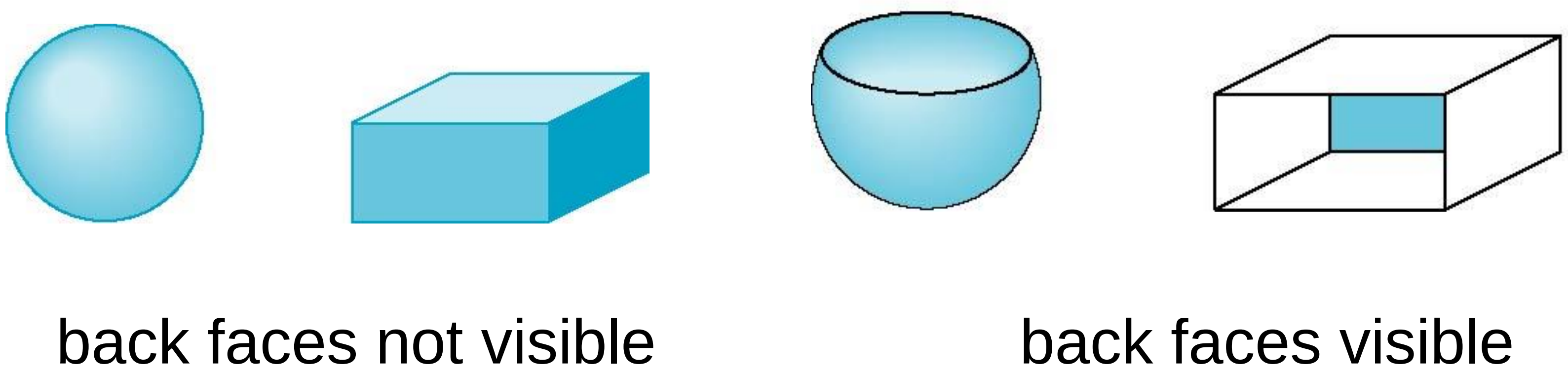
Adding Normals for Quads

```
function quad(a, b, c, d) {
    var t1 = subtract(vertices[b], vertices[a]);
    var t2 = subtract(vertices[c], vertices[b]);
    var normal = cross(t1, t2);
    var normal = vec3(normal);
    normal = normalize(normal);

    pointsArray.push(vertices[a]);
    normalsArray.push(normal);
      .
      .
      .
```

Front and Back Faces

- Every face has a front and back
- For many objects, we never see the back face so we don't care how or if it's rendered
- If it matters, we can handle in shader



Emissive Term

- We can simulate a light source in WebGL by giving a material an emissive component
- This component is unaffected by any sources or transformations

Transparency

- Material properties are specified as RGBA values
- The A value can be used to make the surface translucent
- The default is that all surfaces are opaque
- Later we will enable blending and use this feature
- However with the HTML5 canvas, A<1 will mute colors

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Polygonal Shading

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Polygonal Shading

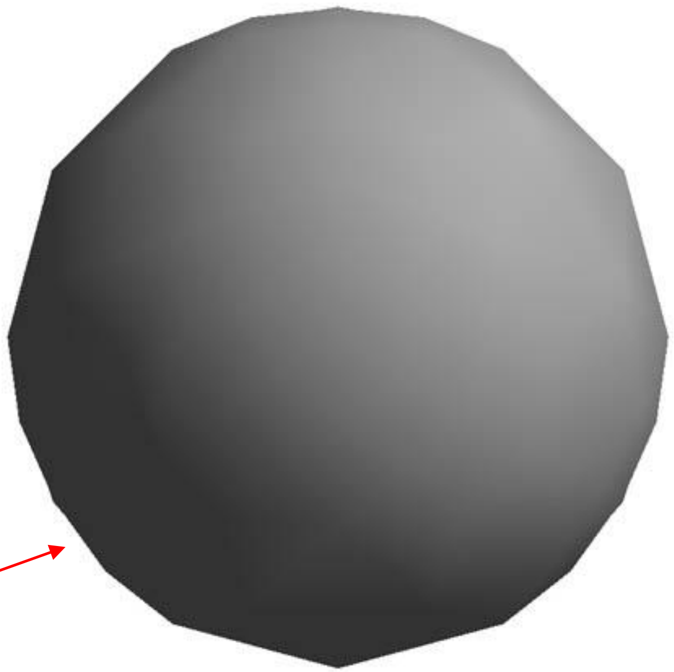
- In per vertex shading, shading calculations are done for each vertex
  - Vertex colors become vertex shades and can be sent to the vertex shader as a vertex attribute
  - Alternately, we can send the parameters to the vertex shader and have it compute the shade
- By default, vertex shades are interpolated 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)

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

Smooth Shading

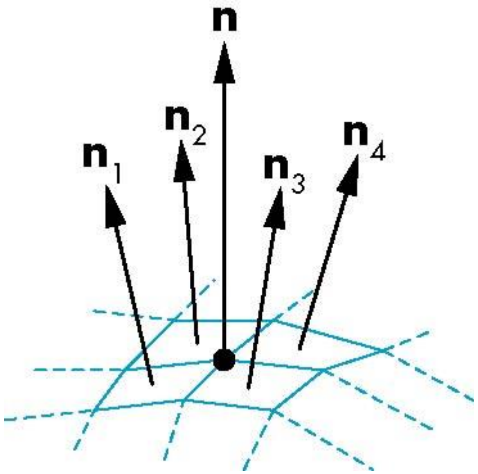
- We can set a new normal at each vertex
- Easy for sphere model
  - If centered at origin $\mathbf{n} = \mathbf{p}$
- Now smooth shading works
- Note *silhouette edge*



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;
}
```

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

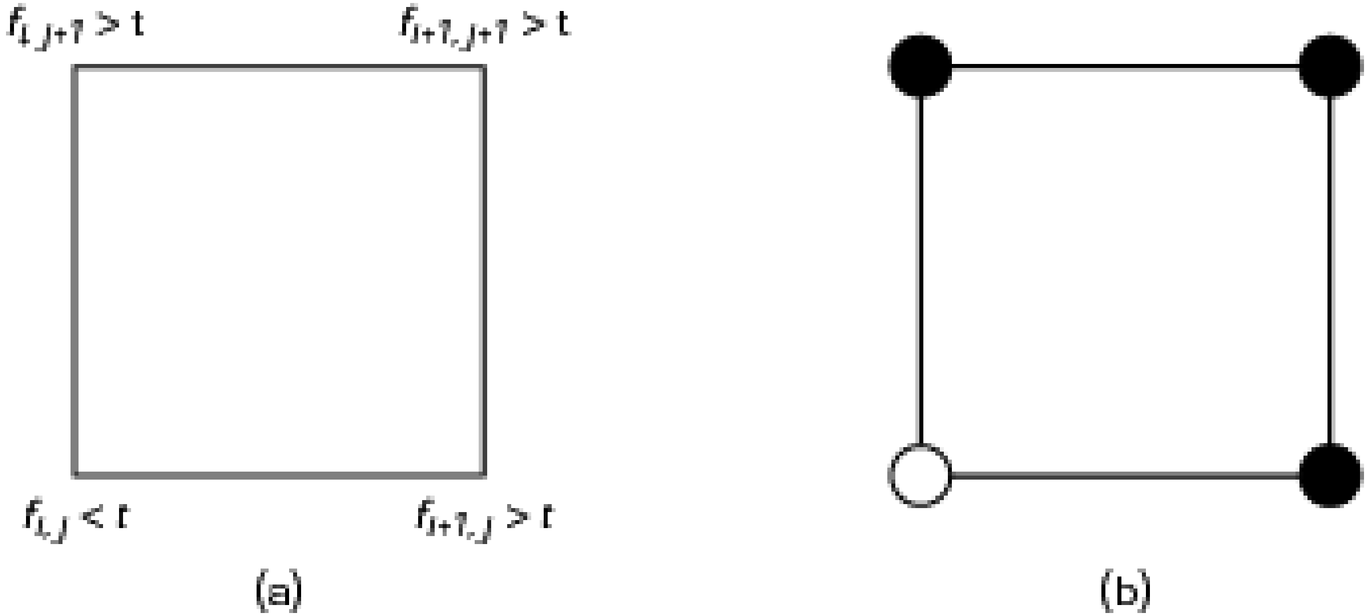
Height Fields and Contours

- 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

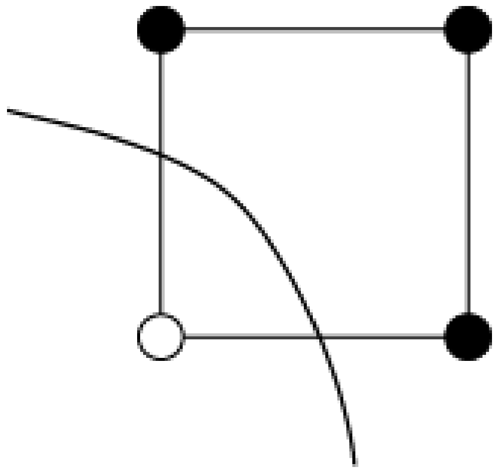
- Displays isocurves or contours for functions $f(x,y) = t$
- Sample $f(x,y)$ on a regular grid yielding samples $\{f_{ij}(x,y)\}$
- These samples can be greater than, less than, or equal to t
- Consider four samples $f_{ij}(x,y)$, $f_{i+1,j}(x,y)$, $f_{i+1,j+1}(x,y)$, $f_{i,j+1}(x,y)$
- These samples 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

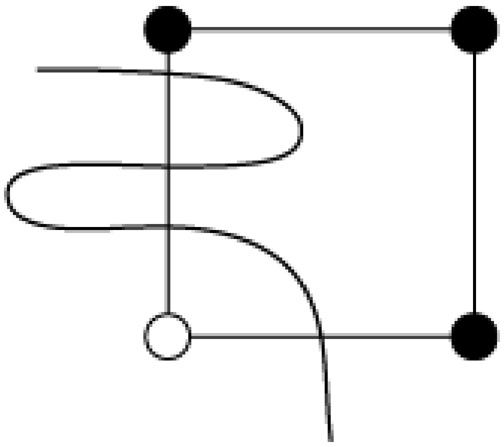


Occam's Razor

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

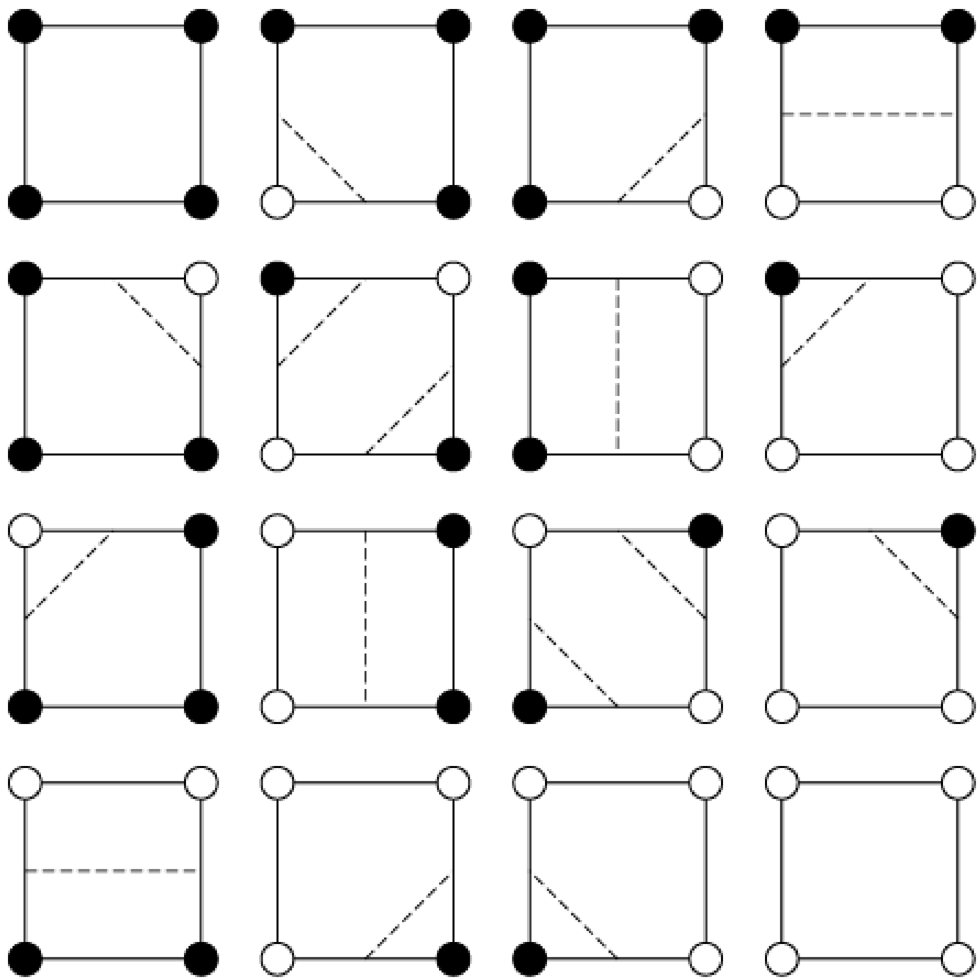


(a)



(b)

16 Cases



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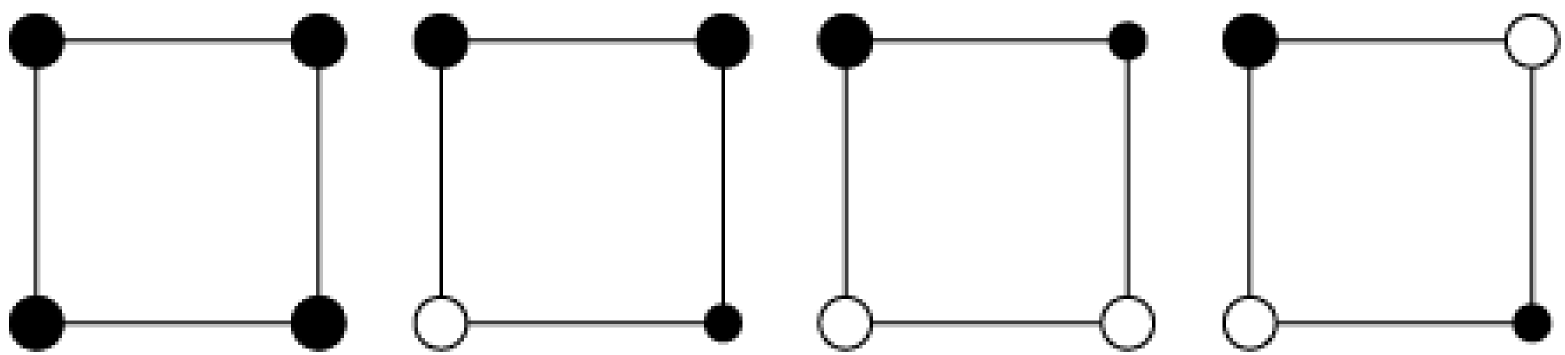
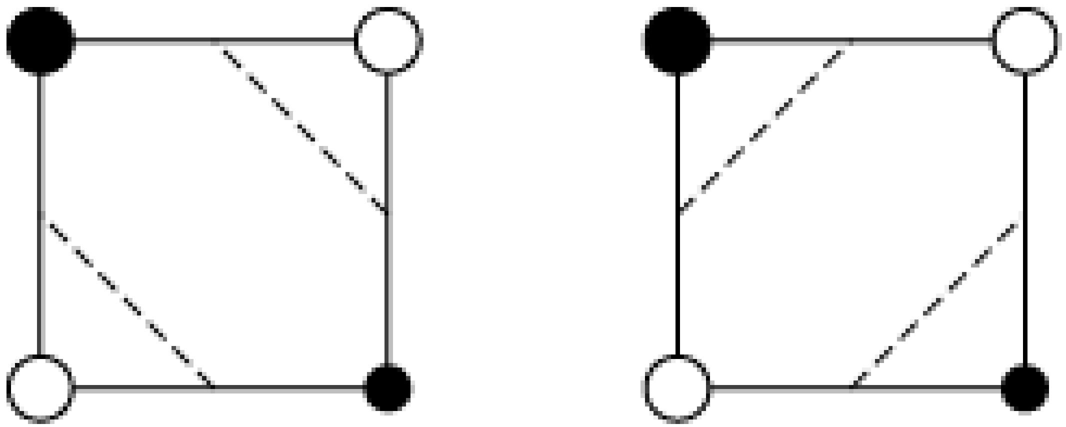
Unique Cases

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



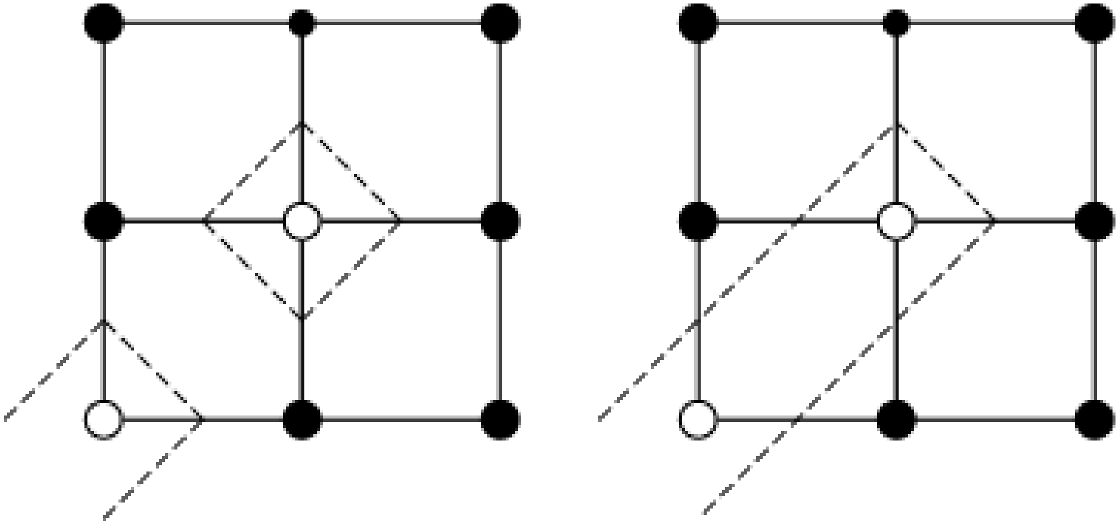
Ambiguity Problem

- Diagonally opposite cases have two equally simple possible interpretations

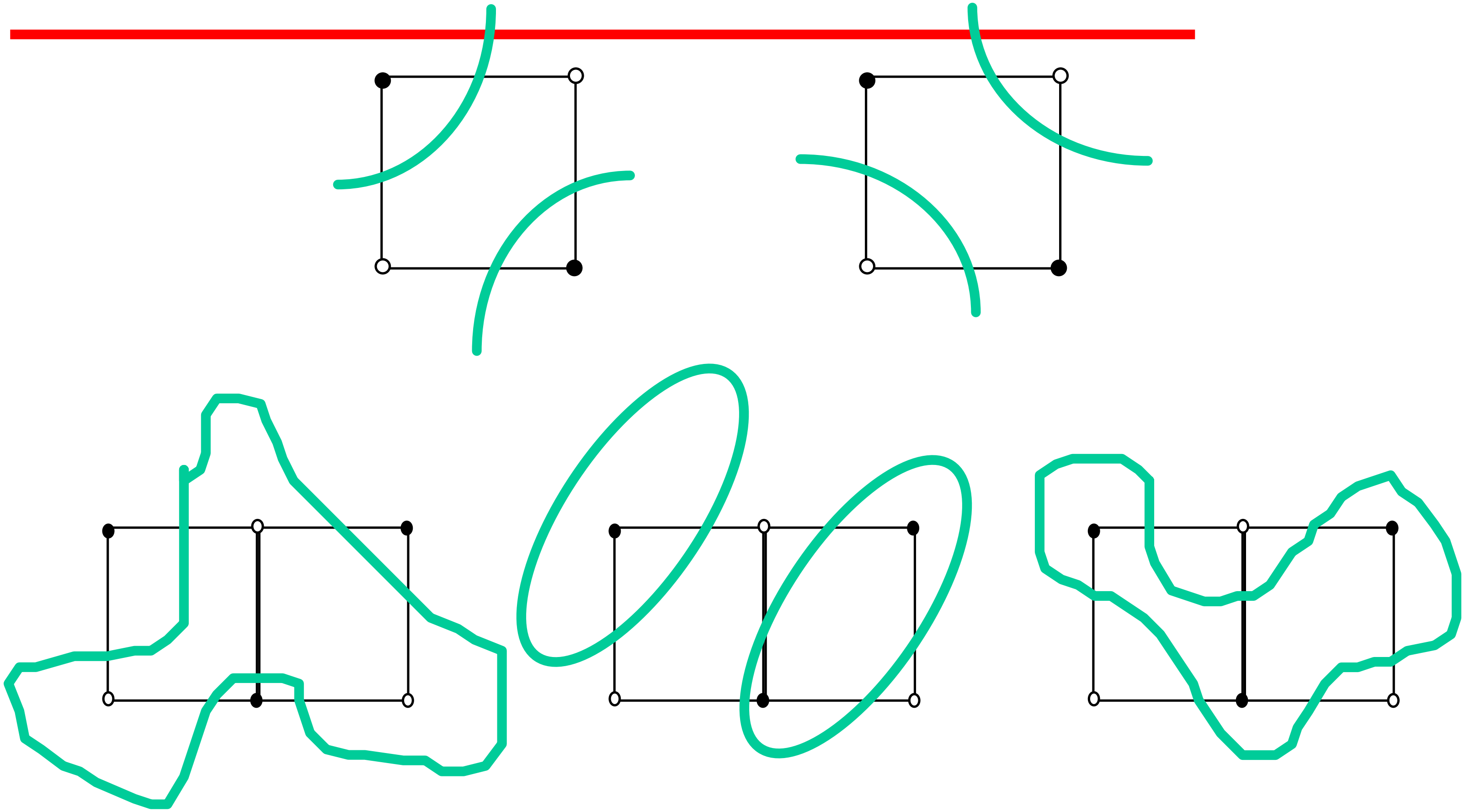


Ambiguity Example

- Two different possibilities below
- More possibilities on next slide



Ambiguity Problem

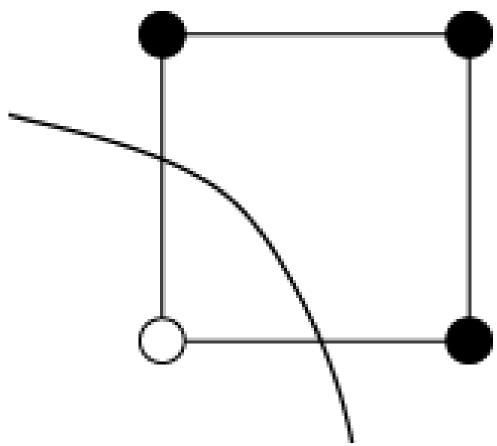


Is Problem Resolvable?

- 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

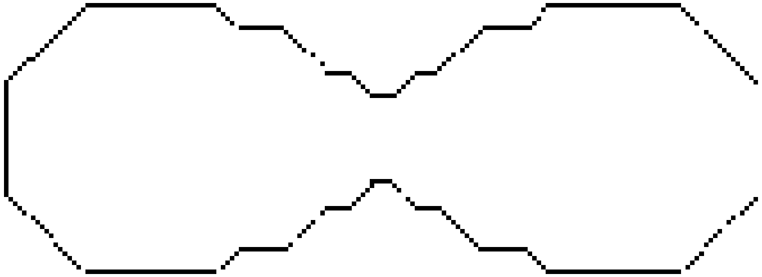


Example: Oval of Cassini

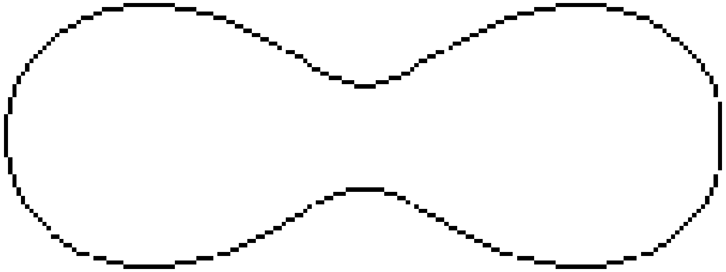
$$f(x,y)=(x^2+y^2+a^2)^2-4a^2x^2-b^4$$

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

midpoint intersections

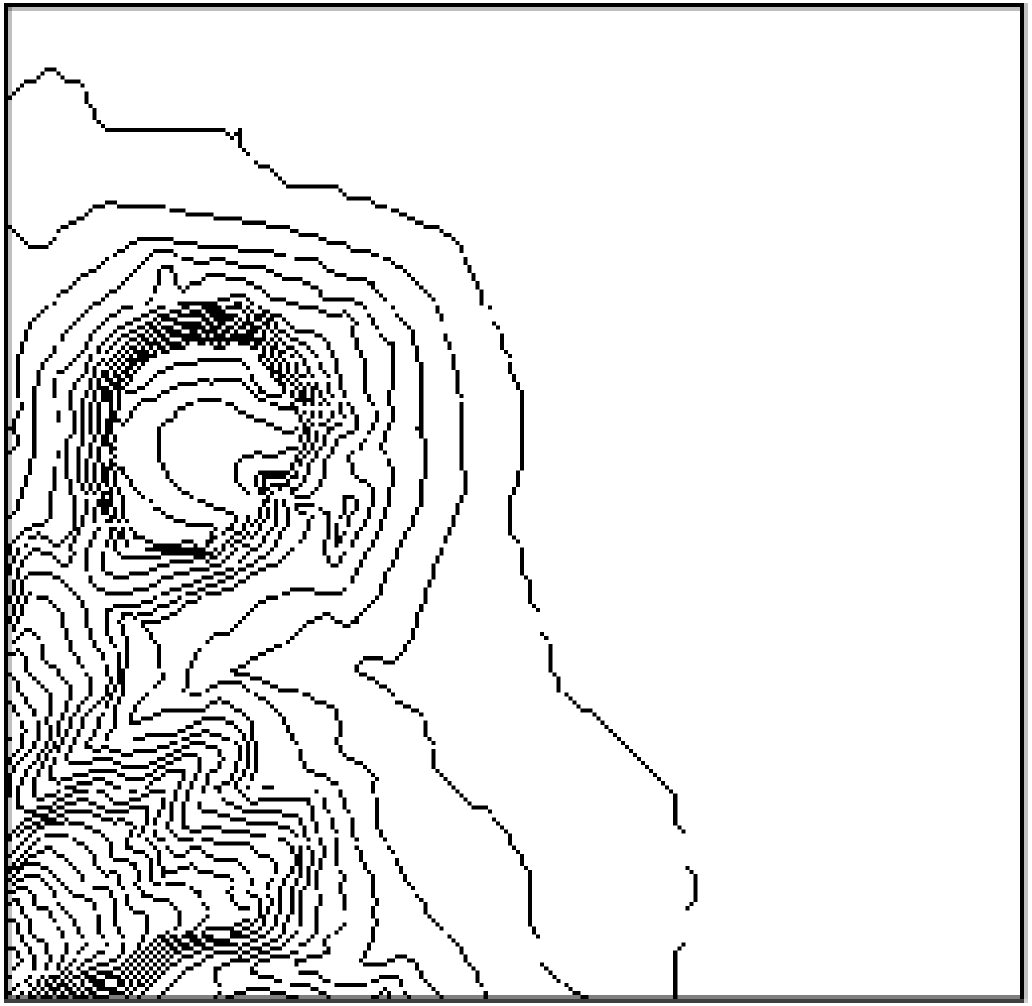


interpolating intersections



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