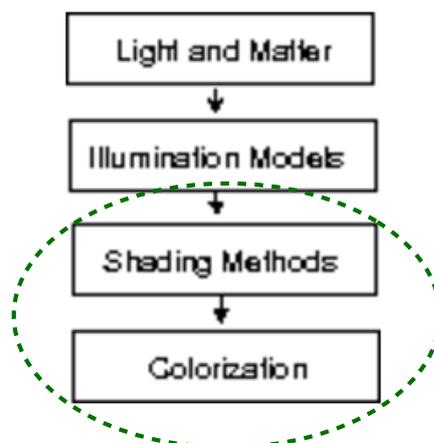


Shading

Luiz Velho
IMPA

Conceptual Framework



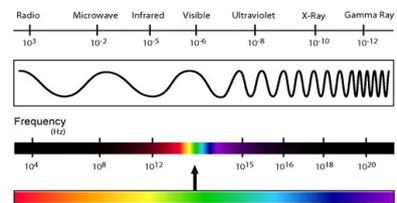
Illumination (Recap)

Study of Light Emission and Propagation

- Light
- Materials
- Transport

Light

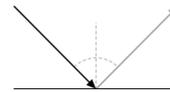
- Dual Model
 - Particle (Photon)
(Radiant Energy)
 - Wave
(Electromagnetic Wave)
- Attributes
 - Energy
 - Wavelength



Transmission

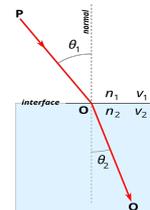
- Geometric Optics
 - Direction
- Interface 2 Medium
 - Reflection

$$\theta_i = \theta_r$$



- Refraction (Snell's law)

$$\frac{\sin \theta_1}{\sin \theta_2} = n_{21} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$$



- Assumptions
 - No Participating Media

Surface Material

- Boundary Interaction
 - Fresnell Equation
(function of angle and wavelenght)
- Types
 - Dielectric (Insulating)
 - Translucent (ex: glass)
 - Metal (Conductors)
 - Opaque (ex: copper)
 - Composite (Pigment + Substrate)
 - (ex: plastic, paint)



glass



Copper

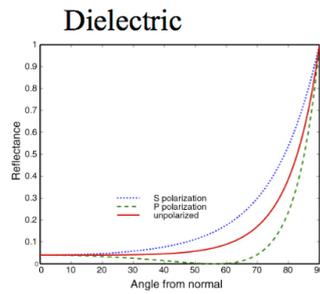


Plastic

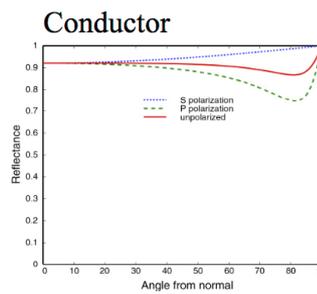
Fresnel Reflectance

- **Solution of Maxwell's equations**

- Depends on: incident angle / light polarization / wavelength



Glass, etc



Metals

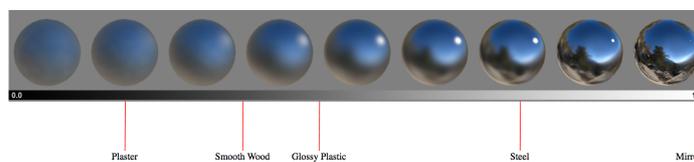
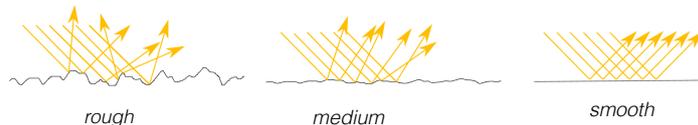
Surface Geometry

- **Attenuation and Scattering**

- Microfacet Model

- **Types**

- Smooth (total transmission / no absorption)
- Rough (partial transmission / partial absorption)



Local Illumination

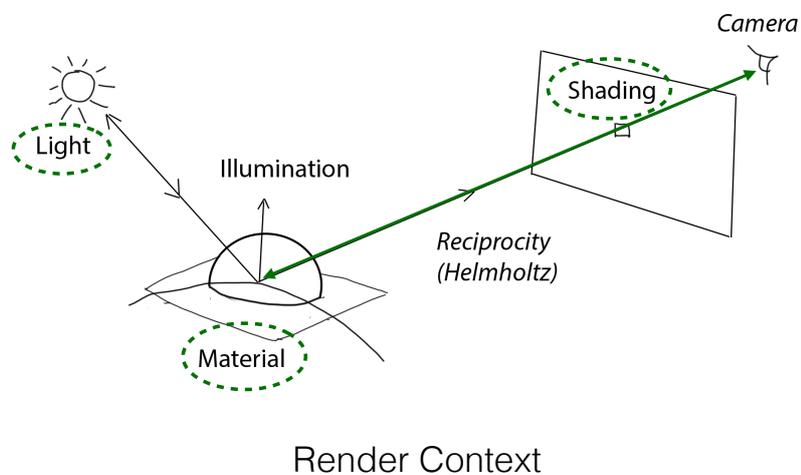
Illumination Mechanisms

- Light Transport
 - Coherent 
 - Incoherent 
- Bidirectional Transport Function

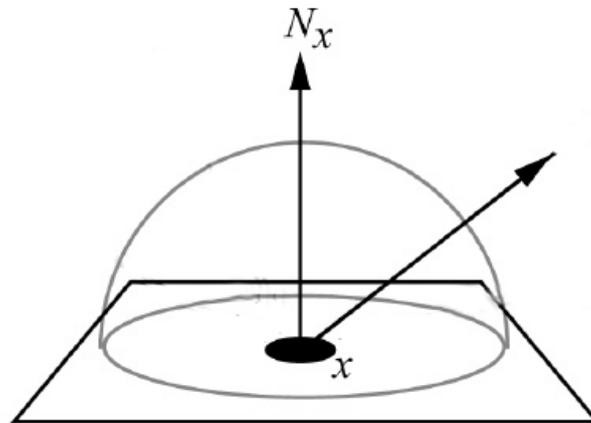
R_M and T_M

Model (recap)

- **Data Driven Computation**



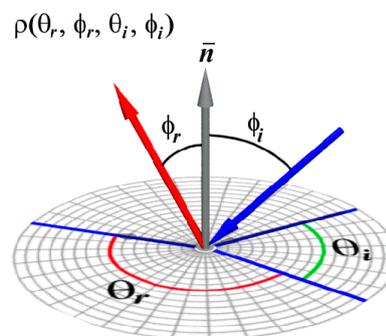
Illumination Hemisphere



- **Tangent plane at point X**

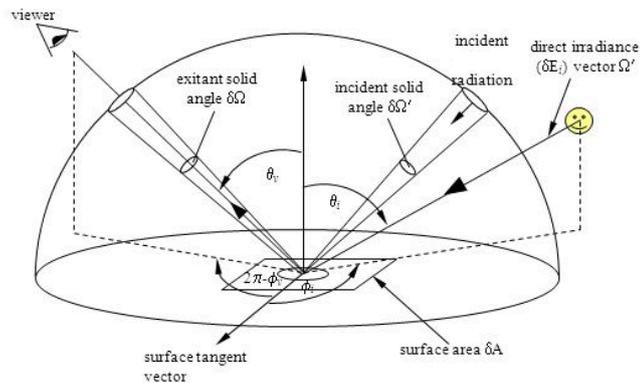
Scattering

- **Bidirectional Reflectance (Transmittance) Function**



Transport Computation

- **Solid Angles / Area Differential**



Configuration of viewing and illumination vectors in the viewing hemisphere, with respect to an element of surface area, δA .

BRDF Representation

- **Analytical Models**

- Phenomenological / Physical

Bases Functions

- **Measured BRDFs**

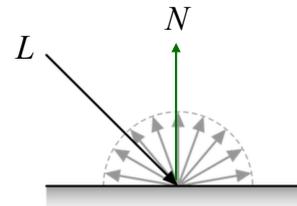
- Sampled Data

Interpolation / Fitting

Local Illumination Models

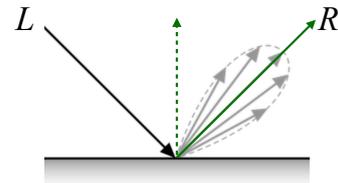
$I = \text{Dif} + \text{Spec} + \text{Trans}$
 Pure Diffuse

(Lambert's law)
 $k_d \langle N, L \rangle$



Specular

(Phong Approximation)
 $k_r \langle R, L \rangle^n$

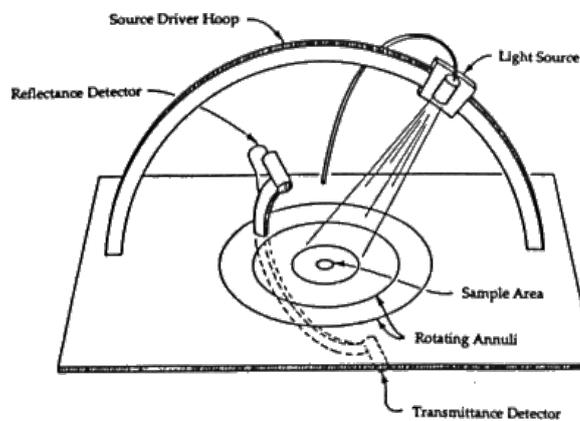


Transmitted

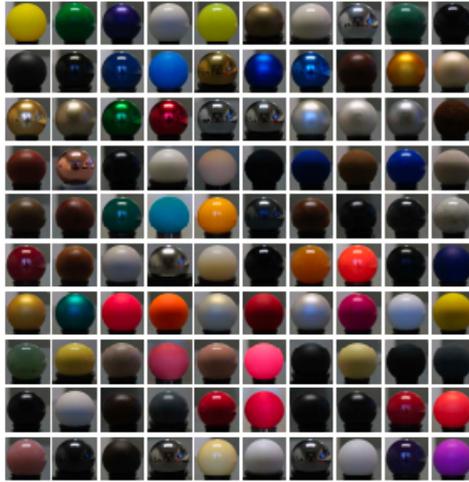
$k_t \langle T, L \rangle^m$

Measuring BRDFs

- Apparatus



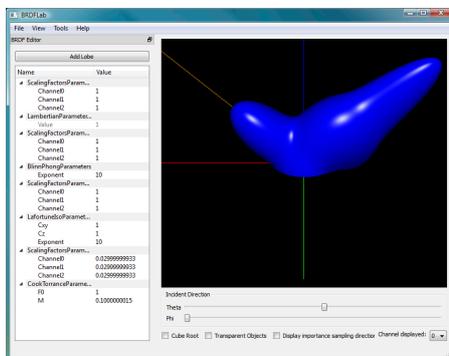
BRDF Measured Data



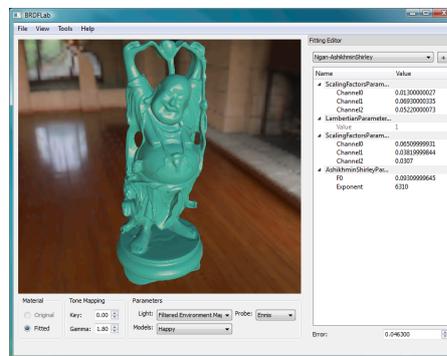
- **MERL BRDF database**

BRDF Lab

- **Design BRDFs**
 - Analytical Models and Measured Data



Display BRDF



Rendering

Materials

Material Types

- Constant
- Matte
- Metal
- Plastic

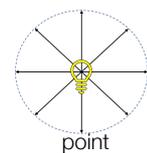
Boundary Interactions

- BRDF

Light Sources

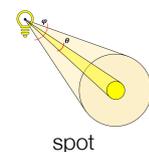
Types

- Directional Light
- Point Light
- Spot Light



Light Coupling

- Visibility



Shading

Colorization Function

- Partition

$$\text{Image} = \cup_i P_i$$

- Domain (continuous)
 - Patches
 - Polygons
 - Micropolygons *
 - Pixels
- Shading
 - Sampling
 - Interpolation

Interpolation Methods

- Flat Shading
 - Constant
- Gouraud Shading
 - Color, Linear
- Phong Shading
 - Normal, Linear

Coloring Functions

- Tone Mapping

Shading Methods

ACKNOWLEDGMENTS

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3. R. G. Cook, "A Ray-Traced Perspective of the Fast Fourier Transform," *IEEE Trans. Comput. Graph. Appl.*, pp. 20-26, Mar/Apr 1979.
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5. J. C. Foley, "A new method for hidden-surface removal," *IEEE Trans. Comput. Graph. Appl.*, pp. 20-26, Mar/Apr 1979.
6. J. C. Foley, "A new method for hidden-surface removal," *IEEE Trans. Comput. Graph. Appl.*, pp. 20-26, Mar/Apr 1979.
7. J. C. Foley, "A new method for hidden-surface removal," *IEEE Trans. Comput. Graph. Appl.*, pp. 20-26, Mar/Apr 1979.
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9. J. C. Foley, "A new method for hidden-surface removal," *IEEE Trans. Comput. Graph. Appl.*, pp. 20-26, Mar/Apr 1979.
10. J. C. Foley, "A new method for hidden-surface removal," *IEEE Trans. Comput. Graph. Appl.*, pp. 20-26, Mar/Apr 1979.

Continuous Shading of Curved Surfaces

HENRI GOURAUD

Abstract—A procedure for computing shaded pictures of curved surfaces is presented. The surface is approximated by small polygons in order to solve easily the hidden-surface problem. For the shading of each polygon, a method is proposed to find discontinuities of color and shading across the surface and a correct appearance is obtained in order to achieve good efficiency. The method is described by means of a flow chart which makes possible a hardware implementation of this algorithm.

Index Terms—Curved surfaces, curved surfaces, surfaces, hidden-surface removal, shading.

INTRODUCTION

SINCE computers have been used to produce pictures of three-dimensional objects, one of the main problems has been the hidden-surface problem, at which a picture could be produced and the realism of this picture. On one hand, color-key tables make the display line drawings very efficiently; on the other hand, images with hidden parts removed and with shading take a long time to compute. In 1963 Robert [1] developed the first program capable of removing hidden lines. Several years later other algorithms performing the same task have been developed by Gathery [2], Robert [3], and Levner [4].

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among others. Their algorithms solve the hidden-line problem for structures composed of planar polygons. Two algorithms developed by Gouraud [5] remove hidden lines for objects made of quadratic surfaces. In 1967 shaded images were introduced by the University of Utah (Romer [6], Warnock [8], Watkins [9]), General Electric (Romer [10]), MAGI [11], and IBM (Dyer [12]). More recently, Brookings and Kerby [13] presented an algorithm producing shaded pictures with shadows and movable light sources. General Electric built for NASA the first hardware capable of generating and shading shaded pictures. Combining the work of both Warnock and Romer, Watkins recently developed a fast algorithm which will shortly be implemented in hardware at the University of Utah.

Realism beyond the obvious hidden-surface removal is obtained by shading each object in black and white or in color. In the General Electric system a fixed color is assigned by hardware to each of the different polygons composing the scene. The potential for changing this color from frame to frame exists, but the author is not aware of its use. This scheme gives a "cartoon-like" appearance to the generated images. Appel developed a system to produce shaded images on a digital plotter. The shading of a particular polygon is computed only as a function of the orientation of this polygon. This could become confusing in the case of parallel polygons, but is avoided in this particular case.

Illumination for Computer Generated Pictures

BU TONG PHONG

University of Utah

Abstract—The quality of computer generated images of three-dimensional objects depends on the shading technique used to paint the objects on the computer monitor screen. The shading algorithm used depends on the method for modeling the object, which also determines the hidden-surface algorithm. The various methods of object modeling, shading, and hidden-surface removal are then compared. Several shading techniques corresponding to different methods of object modeling and the related hidden-surface algorithms are presented here. Human visual perception and the fundamental laws of optics are considered in the development of a shading rule that provides better quality and increased realism in generated images.

Key Words—Phong's computer graphics, graphic display, shading, hidden-surface removal.

CR Categories—3.20, 3.41, 6.2

Introduction

This paper describes several approaches to the production of shaded pictures of solid objects. In the past decade, we have witnessed the development of a number of systems for the rendering of solid objects by computer. The two principal problems encountered in the design of these systems are the elimination of the hidden surfaces.

and the shading of the objects. Until now, most effort has been spent in the search for fast hidden surface removal algorithms. With the development of these algorithms, the programs that produce pictures are becoming increasingly fast, and we may now turn to the search for algorithms to enhance the quality of these pictures.

In trying to improve the quality of the synthetic images, we do not forget that the aim is to display the object existing in a mind's eye to reality, with realistic shading and shading. We hope only to display an image that approximates the real object through shading to provide a certain degree of realism. This involves some understanding of the fundamental processes of the human visual system. Unlike a photograph of a real world scene, a computer-generated shaded picture is made from a numerical model, which is stored in the computer as an objective description. When an image is then generated from this model, the human visual system makes the final subjective analysis. Obtaining a close image correspondence to the eye's subjective interpretation of the real object is thus the goal. The computer system can be compared to an artist who paints an object from his imagination and not from direct observation of the object. But unlike the artist, who can correct the painting if it does not look right to him, the computer that generates the picture does not receive feedback about the quality of the synthetic images, because the human visual system is the final recipient. This is a subjective domain. We must at the outset define the degree of realism we wish to attain, and the certain goals to be accomplished. Among these goals are:

1. "Real-time" display of dynamic color pictures of three-dimensional objects. A real-time display system is one capable of generating pictures at the rate of at least 30 frames a second.
2. Representation of objects made of smooth curved surfaces.

3. Elimination of discontinuities in the effect of digital shading techniques.
4. The most important consideration is trying to attain these goals in the object modeling technique.

Existing Shading Techniques

Methods of Object Modeling

Image quality depends directly on the effectiveness of the shading algorithm, which in turn depends on the method of modeling the object. Two principal methods of object description are commonly used:

1. Surface definition using mathematical equations.
2. Surface approximation by planar polygonal meshes.

Several systems have been implemented to remove hidden parts for mathematically defined curved surfaces [1], [2], [4], [5] with these systems, each hidden part at each point of the surface can be eliminated, and the result:

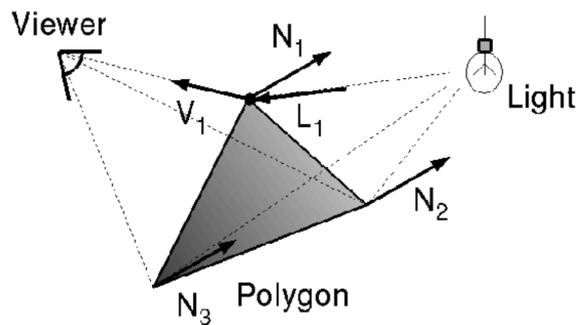
Gouraud Diffuse Shading

Phong Specular Shading

Gouraud Shading

- **Illumination Sampling**

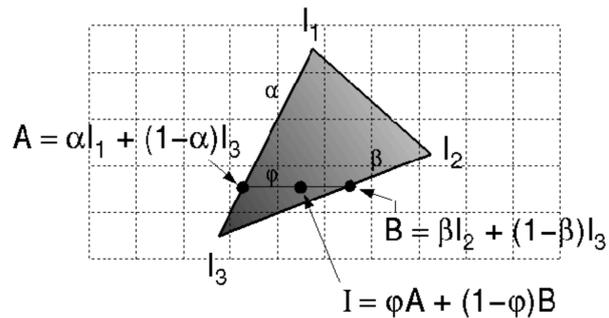
- One lighting calculation per vertex
 - Assign pixels inside polygon by interpolating colors computed at vertices



Gouraud Colorization

- **Colorization Function Reconstruction**

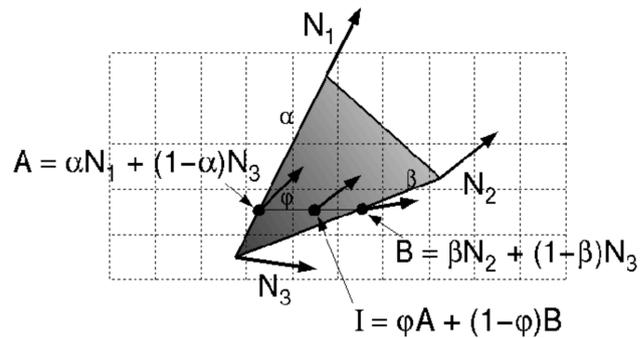
- Bilinearly interpolate colors at vertices down and across scan lines



Phong Shading

- **Geometry Reconstruction**

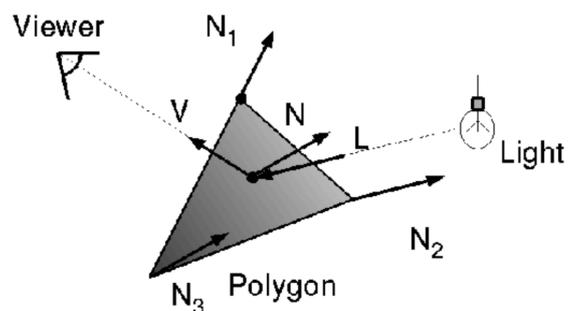
- Bilinearly interpolate surface normals at vertices down and across scan lines



Phong Shading

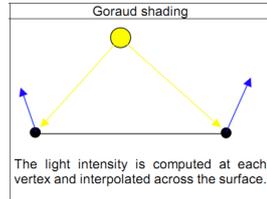
- **Illumination Sampling**

- One lighting calculation per pixel
 - Approximate surface normals for points inside polygons by bilinear interpolation of normals from vertices

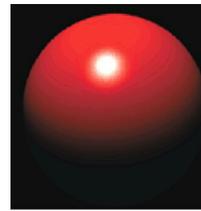
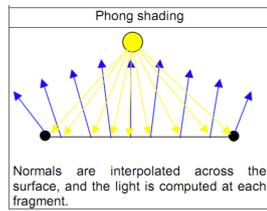


Comparison

- Diffuse vs. Specular Materials



Gouraud



Phong