

# A Psychophysical Study of BRDF-Based Lighting

Alexander J. Faaborg  
Cornell University, Ithaca NY

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**Abstract** — Subjects were presented with three-dimensional objects rendered with BRDF-based lighting. The subjects were tested to see if (1) the object they were looking at affected their ability to evaluate an objects material and (2) if they were able to tell different materials apart based only on light reflectance. Results showed that even though most subjects felt like they were guessing, subjects were able to correctly evaluate the object's material with about 70% accuracy. Readers should note that this study used a reasonably small sample size that was not very unique demographically.

## INTRODUCTION

Improving at six times Moore's Law, this is a revolutionary time for computer graphics. In just ten years we have moved from two-dimensional Nintendo games to Microsoft's new Xbox console, capable of rendering over 125 million polygons per second. At this blazing pace, graphics technology may actually hit the ceiling of human perception. While we are still far from creating a virtual reality impossible to differentiate from real life, we have reached a stage where researchers are interested in investigating exactly what that would entail.

One of the most important aspects of simulating an environment is correctly calculating the way light reflects off of objects. For many objects, the way light reflects will change as the object is rotated, or the light source is moved. Chris Wynn from *nVIDIA* believes "while the realization of real time computer-generated images indistinguishable from photographs remains as yet unreachd, one piece of machinery that will play an important role in realizing interactive photo realism is the notion of a Bidirectional Reflectance Distribution Function (BRDF) and BRDF-based lighting techniques." (Wynn, 2000). A material's BRDF describes the way light reflects when given the incoming direction of the light, the wavelength of the light, and the location of the viewer.

BRDF-based lighting techniques have been previously used to pre-render realistic images, but recently, graphics hardware has become powerful enough generate BRDF-based lighting in real time. This is also due to new mathematical techniques. Using Normalized Decomposition, the 4 dimensional BRDF function can be projected down to

two-dimensional space, allowing current graphics hardware to implement real time BRDF-based lighting.

As new PC graphics hardware and powerful gaming devices like the Xbox begin to reach consumers, developers will be able to create environments that are increasingly realistic. However, to what extent can humans perceive changes in BRDF-based lighting? Just how accurate do content developers need to be, and can they get away with cutting corners? This experiment tested a subject's ability to detect subtle differences in BRDF-based lighting, using a variety of objects and materials rendered in real time.

## METHOD

### *Subjects*

15 subjects ran in the experiment. The group consisted of 4 female subjects and 11 males. The mean age was 22.7; 12 of the subjects were undergraduate students at Cornell University, enrolled in a 200 level cognitive science course, and the remaining 3 subjects were from the Cornell University psychology department.

All subjects knew that they were being tested on their ability to detect differences in the way light reflected off of three-dimensional objects, and before the experiment subjects received a brief educational overview of BRDF-based lighting.

### *Apparatus*

Subjects were asked to sit at a computer with the monitor at eye level and 50cm from their head. To increase a subject's ability to perceive differences, and make the experiment slightly easier, the lights were turned out in the room. Primary stimuli were presented in 800 pixel by 600 pixel windows, and secondary stimuli in 400 pixel by 600 pixel windows. The experiment was presented on a SONY Trinitron CRT was running at a resolution of 1024 by 768.

Stimuli for the experiment were created using open source code written by the nVIDIA Corporation as a demonstration for computer game developers, based on research conducted by the University of Waterloo. The nVIDIA application was modified to remove menus, control the size, position, and title of the application window, and to load specific three-dimensional objects and materials when opened. For each trial separate executable files were compiled. The interface for loading these executables and

recording data entered by the subject consisted of a full screen PowerPoint presentation with VBA Scripts generating data files for analysis.

Objects were rendered using a Voodoo 5 5500 graphics accelerator from 3Dfx, although the experiment will also work with *n*VIDIA TNT, TNT2, GeForce, GeForce2 GTS and future *n*VIDIA hardware. The application also requires OpenGL drivers and GLUT installed for it to load.

### *Procedure*

To determine if subjects could notice small differences in simulated lighting, three very similar metal materials were selected: objects were rendered with Gold, Bronze, and Anisotropic Gold surfaces. All color was removed from the object's texture maps to ensure that the only variable was the way light reflected off the object. The three dimensional models consisted of a chalice, a teapot, and a groud cup.

For each three dimensional model, 6 trials were created. Each trial consisted of first showing the subject a primary object, and then two secondary objects. The subject's task was to determine which of the two secondary objects was identical to the primary object. This was a forced choice. There was no time limit, and the subject was able to rotate the object using the mouse, as well as move the light source. Some subjects viewed the secondary objects simultaneously, and some viewed then separately; this is elaborated in the discussion. The 6 trials for each three dimensional model consisted of presenting each of the three possible material combinations (gold v. bronze, anisotropic gold v. gold, anisotropic gold v. bronze) twice. The order in which these objects were

presented, the side each secondary object appeared on the screen, and which of the two objects would be the primary object was all randomized during the creation of the experiment. With 3 different models and 6 trials for each, there were 18 total trials. The object order was first chalice, then teapot, concluding with the cup. Images of the stimuli are included with this report.

After all subjects completed the experiment, they were each asked to rate their performance from 1: always knew exactly which secondary object was the primary, to 10: always guessed which secondary object was the primary.

## RESULTS

### *Determining if Some Subjects had a Disadvantage*

Due to an unexpected error some of the subjects viewed the secondary objects simultaneously, and some separately (see discussion). Because of this, 9 of the 15 subjects may have been at a disadvantage in the experiment. To determine if this was the case, the results of those 9 subjects were compared to the remaining 6 subjects using an un-paired t-test. There was no significant difference between the two groups performance scores. For this reason, and the fact that the error should theoretically have made the experiment more difficult for some subjects, we felt that including all 15 subjects in the analysis was a conservative decision.

### *Determining if the Shape of the Three Dimensional Object Altered A Subject's Ability to Detect Differences in Reflectance*

The three-dimensional objects were not presented in a random order, so it is possible subjects were able to improve as the experiment progressed. In addition, the shape of certain objects may have affected a subject's ability to notice differences in how light reflected. Hypothetically the chalice could have been the easiest object since it contained the largest flat surface. To ascertain if any of these events occurred, a 2-way contingency table test was run comparing all subjects scores on each of the material combinations across the three objects. In each of the material combinations, there was no significant difference in performance scores. Due to this, the object the subject was viewing was disregarded in further analysis.

*Determining if Subjects Could Discriminate Between Materials*

With 15 subjects doing 2 material combination trials for each of the 3 objects, each material combination had a total of 90 data points. Each of these 90 data points represented either a correct or incorrect response. For each of the three material combinations, the 90 data points were analyzed using a one-sample sign test. The following results were found:

Material Combination	Percent Correct	Significance
Gold v. Anisotropic Gold	67%	$p < .001$
Gold v. Bronze	68%	$p < .001$
Bronze v. Anisotropic Gold	72%	$p < .001$

## DISCUSSION

### *Weaknesses and Limitations of Experiment*

The most substantial error with the experiment involved how the subject loaded the secondary objects. The experiment directions explained that to view both applications at the same time, the subject must use the alt-tab feature of Windows, but the experiment neglected to specifically state that the subjects must do this. Because of this omission, confusion surrounding how to use alt-tab, and the fact that subjects did not read all the directions, 9 of the 15 subjects viewed the secondary stimuli one at a time, instead of simultaneously. Curiously, this did not seem to impact results, as there was no significant difference between the groups' performance scores. This may be due to a small sample size. Both groups contained subjects that did well, and subjects that did poorly; possibly implying that whatever skill or technique is needed to detect a difference between the lighting is perhaps not dependant on seeing the objects at the same time.

The second limitation of the experiment had to do with the brightness of the CRT being used. The experiment was developed on an LCD screen producing 210 cd/m<sup>2</sup> of luminance. The brightness of the SONY Trinitron CRT is not known, but it was clearly less, causing the experiment to be considerable more difficult than originally intended. To help compensate for the difference, subjects were asked to conduct the experiment in the dark.

## *Conclusion*

From the darker CRT to the unexpected event of more than half the subjects viewing the secondary stimuli independently, it was expected that subjects would not be able to detect the subtle differences in reflectance. When asked if they felt as if they were guessing during the trials on a scale of 1 to 10 (where 10 is completely guessing), the average score reported was 7.6. However, despite the difficulty of the experiment, and the introspection of the subjects, the results showed that they were in fact capable of perceiving subtle differences in lighting with about 70% accuracy. This implies that human perception may actually be more acute than we consciously realize.

This study is only a singular probe into the massively complex realm of human visual perception and psychophysical analysis of computer rendered graphics. However, if we are to eventually generate simulated environments that are indistinguishable from reality, we must first be able to map exactly how robust human perception truly is.

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## STIMULI

The following screen shots are attached:

- ✎ A chalice trail from the actual experiment
- ✎ Chalice Stimuli before color was removed from the texture maps
- ✎ Grayscale Chalice, Teapot and Cup stimuli used in the experiment