

Image Rendering using Wave Theory of Light and Extended Analog Computers

By
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ABSTRACT

This paper introduces a new way to represent light and images using an Extended Analog machine. Instead of using conventional methods of simulating light based on the particle theory, a new method based on the wave theory of light will be introduced. The first section will be an introduction which will cover light sources, diffuse materials, the particle theory of light, the wave theory of light and finally an explanation of the EAC machine that we have designed. The second section will be about the theory behind the EAC design and the third section will explain the implementations for the EAC machine simulation. The last section will discuss the future work and the results from the simulation.

INTRODUCTION

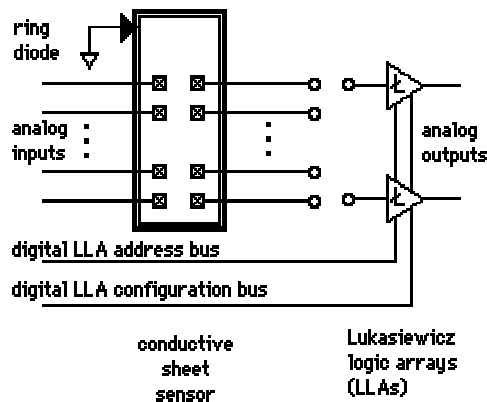
Most real environments consist of surface materials which reflect light diffusely. Object to object reflection between these diffuse surfaces accounts for some of the illumination. The remaining illumination comes directly from the light source. Conventional methods for simulating realistic environments in graphics is called raytracing. Raytracing is based on the particle theory of light, which uses straight rays to represent the light phenomenon. Straight rays preserve most of the properties of 3D computer graphics' drawing roots.

The basic concept used in raytracing is that light energy flows along rays, so that by determining the trajectory of a ray through an optical system, you can find the paths along which energy flows through the system. This model propagates light in straight and infinitely thin rays. In detail, this concept sometimes leads to problems, because rays have zero width, and energy must strictly be considered to flow along tubes of rays, but the simpler ideas are applicable to most systems.

The wave theory of light represents light as waves and has important advantages for complex environments. Since intensity and distribution of light in a scene are governed by energy transport and conservation principles, the particle model of light is not enough to accurately model complex environments. The ray representation assumes an infinite precision in the position of objects and the heading of rays. This assumption leads to unnecessary calculations when rendering a scene, such as an instance where several rays bounce from nearly the same surface point in nearly the same direction. These multiple calculations can be reduced when we use the wave theory of light. Rather than simulating multiple light particles bouncing from light sources and among objects, the illumination is done by representing light as waves. A major advantage to the wave

method is that the resultant surface intensities are independent of the observer's position. Environmental intensities can then be preprocessed for dynamic visualizations. The wave method also eliminates the aliasing problem. The aliasing problem is a well-known problem in graphics. It occurs when 3D primitives (polygons or discrete points/pixels) are projected onto the screen and the data sampling skips important information resulting in an image which is not correct.

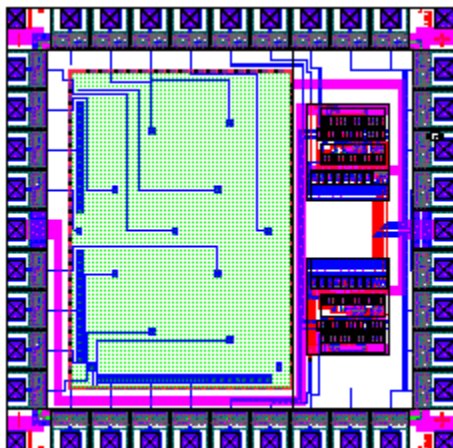
The rendering method will be designed using an extended analog machine (EAC). This EAC will be based on Lukasiewicz Logical Arrays developed by Professor Jonathan Mills. As stated by Mills, Lukasiewicz logic is "a multiple-valued logic with a denumerably infinite number of truth values". Lukasiewicz logical arrays (LLAs) are "arrays of continuous-valued analog circuits of Lukasiewicz implication and negated implication".



"This is the schematic layout of the first KLM. It has a conductive sheet surrounded by a ring diode to restrict current flow into and out of the sheet to the contacts only. Two compact LLAs are available to shape outputs from the sheet. The sheet and LLA connections are made at the output pins of the VLSI circuit, which also permits the sheet and LLAs on the prototype to be tested independently."

J.W. Mills

<http://www.cs.indiana.edu/~jwmills/ANALOG.NOTEBOOK/klm/klm.html>



"This is the VLSI layout of the KLM, created in UNCLE. The conductive sheet is the green area to the left, with probes embedded in it. Two Lukasiewicz logic functional units, in a compacted, efficient form, are at the right."

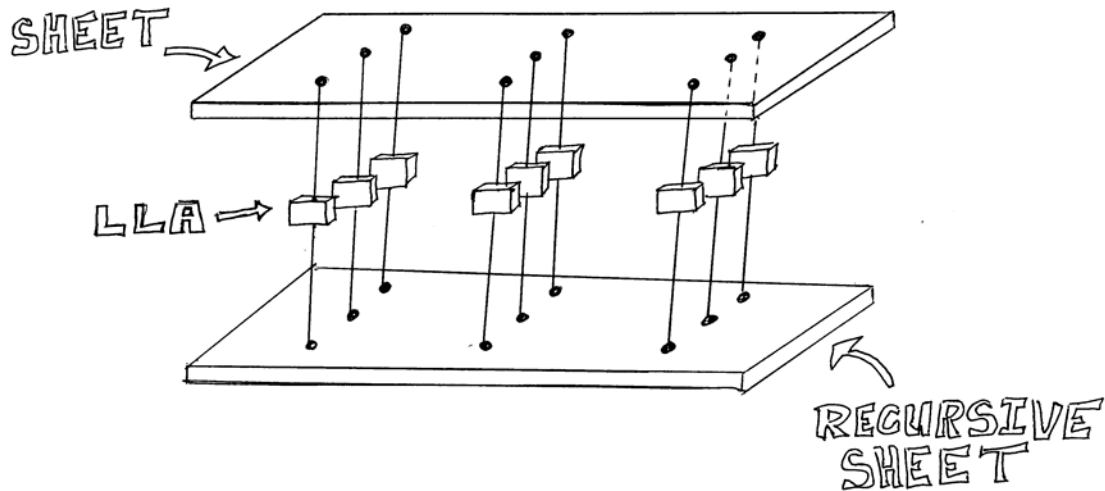
J.W. Mills

<http://www.cs.indiana.edu/~jwmills/ANALOG.NOTEBOOK/klm/klm.html>

For more information on EAC refer to the following website:

<http://www.cs.indiana.edu/~jwmills/ANALOG.NOTEBOOK/klm/klm.html>

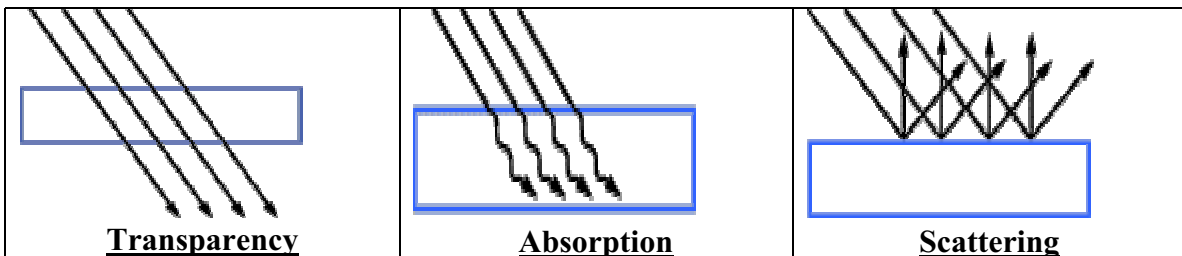
The EAC machine will be made from conductive sheets and LLAs. There will be input/output contacts on each sheet that will equal the number of pixels. Each contact point can be a light source, part of an object, or the medium in which the light travels. Also, each contact point will have an LLA because each contact point may correspond to an object's surface. If it does, the LLA can be used to simulate the material properties of the object at that point. The LLAs are also needed in case we need to change the resistive property of the sheet which has a constant resistive value. To increase it or decrease it we can use the LLAs to scale the current at each pixel contact point appropriately. The wafer will consist of a 2-layered sheet. The first layer is used to simulate the initial light source(s) and the second layer for reflection. To initialize objects in the virtual world we will make the borders of the object sinks into the second sheet. In other words, it will become an input into the reflection sheet. The borders will then be the light source for the second sheet. There can be multiple levels of reflection, but the initial level of reflection is one. If the level of reflection is two, then the wafer would consist of three sheets, the initial sheet and two reflection sheets. Contact points corresponding to objects in the first reflection sheet will serve as inputs into the second reflection sheet. This cycle can go on for many levels. Whenever we want another reflective cycle we add a sheet to the wafer. The final image is rendered by adding the pixel/contact point of the first sheet with the corresponding point on the reflective sheet(s). We then pass this into an analog to digital converter to get the intensity for pixels. We do this for all the pixels to get the final image.



THEORY

In designing the EAC machine, the goal is to accurately simulate the interaction between light and materials. Light is simulated in the machine by adding voltage to a location on the sheet. Since the sheet is conductive the voltage will displace throughout the sheet. Voltage decreases at points further away from the light source. Materials are represented by using sinks and LLAs. Sinks causes current to be sucked out of one sheet

and input into another. The material is then a source of current in the reflective sheet(s). When a light wave hits an object four different things can happen. The wave can be reflected or scattered off the object, the wave can be absorbed by the object, the wave can be refracted through the object, or the waves can pass through the object with no effect. More than one of these events can happen at once. Absorption is simulated in the EAC machine with the sinks. The sinks absorb current out of the system. The amount of current absorbed from the system depends on the material property. Transmission is simulated by using LLAs along with sinks. Sinks are located only at the boundaries of the image. LLAs corresponding to pixels inside the image can be programmed to either allow the current to displace through the material causing transparency or allow no current to pass through the image. This will cause our image to be opaque. Reflection or scattering is simulated using the sink and the reflective sheet. Sinks from the initial sheet become light sources in the reflective sheet. The reflective sheet will have significantly less voltage than the initial sheet. This is accurate because most of the light in a realistic environment comes directly from the light source.



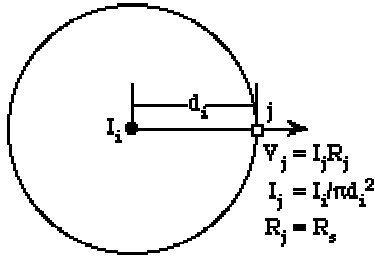
IMPLEMENTATION OF SIMULATION

The simulation for the EAC Machine is written in C++. There is a class called `ConductiveSheet` that simulates the conductive sheet. The class has the functions: `AddSource` (to add light sources to the sheet), `AddSink` (to add sinks to the sheet) and `VoltageAt` (gets the voltage at a specific pixel).

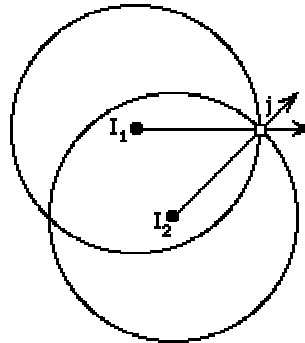
The sheet can be modeled as an ideal infinite plane with constant current flowing into or out of it, spreading radially from each point.

What is the voltage at j , V_j ?

- I_i = an input current source or sink
- j = a unit square of the conductive sheet
- d_i = the distance between I_i and j
- R_s = the sheet resistance



$$V_j = R_s I_i / \pi d_i^2 \text{ for } d_i > 0$$



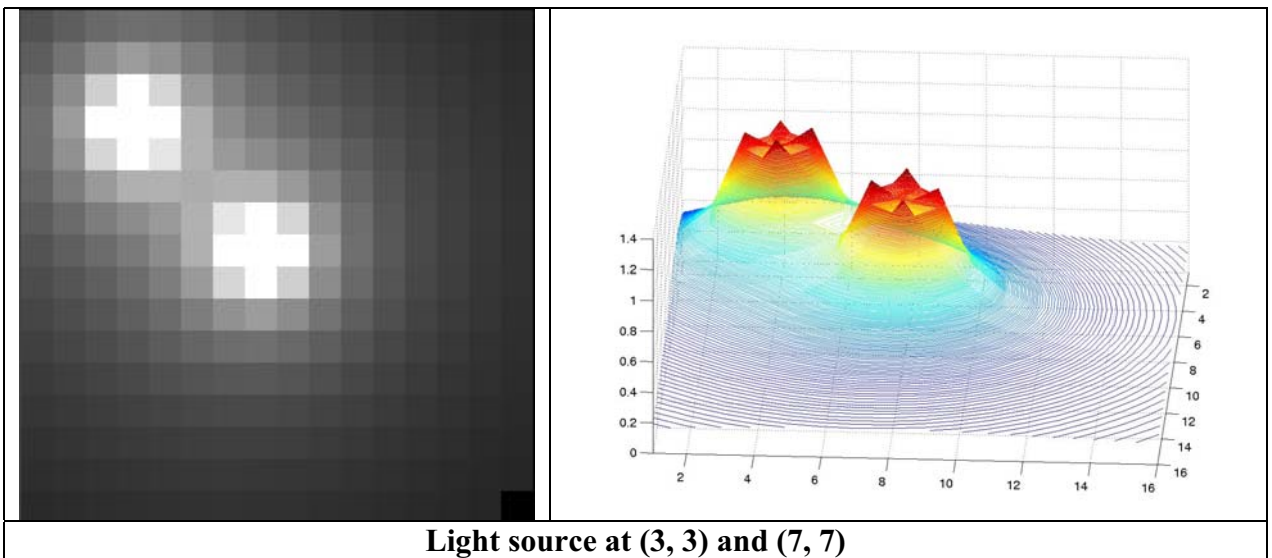
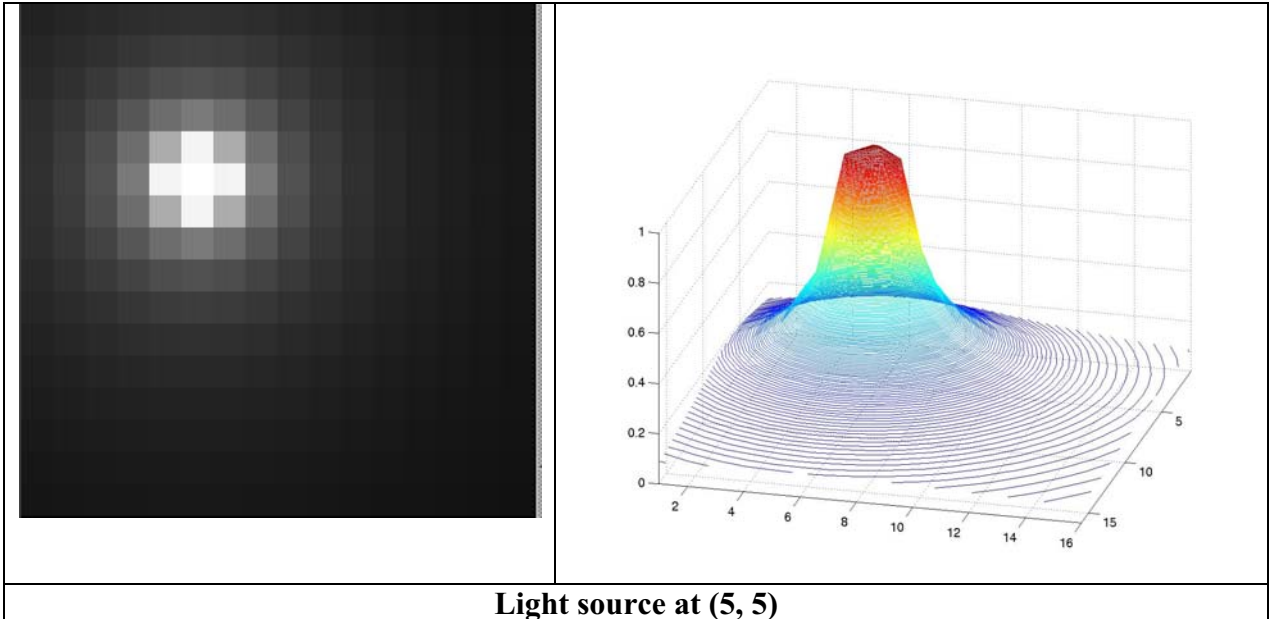
$$V_j = R_s / \pi \sum_{i=0}^n (I_i / d_i^2) \text{ for } d_i > 0$$

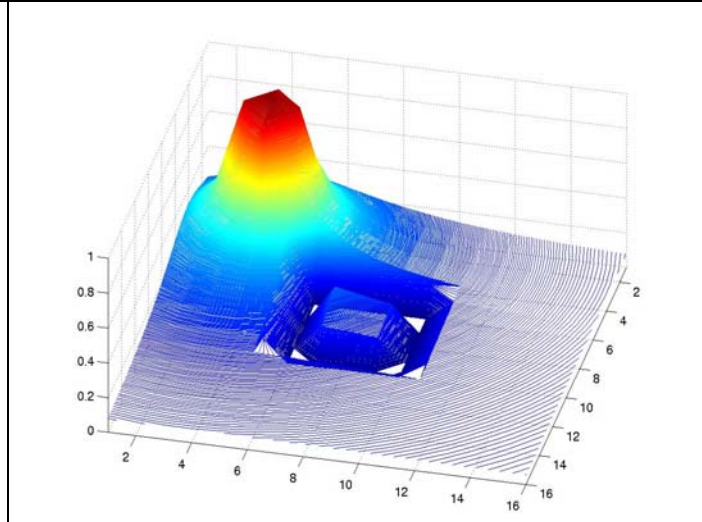
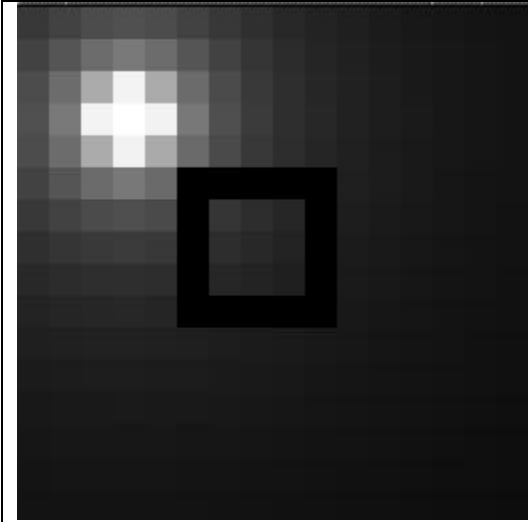
There is also a class that simulates the LLAs. The location of the light source(s) and material(s) must be known initially and the material properties of all the objects in the scene must also be known initially. Sinks corresponding to the boundaries of the material(s) are added to the sheet. Once all the information about the scene has been programmed, the voltage from all the light sources are then added to the sheet in the appropriate locations. The final pixel intensity is calculated by adding the pixel in the initial sheet with its corresponding pixel in the reflective sheet. The resulting pixel intensities are then displayed using an OpenGL program. The OpenGL program simply uses the pixel intensities from the simulation to set the RGB values for the square representing the pixel. The intensities for the reflection sheet have to be amplified to display the result. To amplify the intensities the image pixel with the highest intensity is found and the remaining pixel intensities are divided by this intensity. This allows us to scale up the reflection intensities so we can visualize the result.

RESULTS

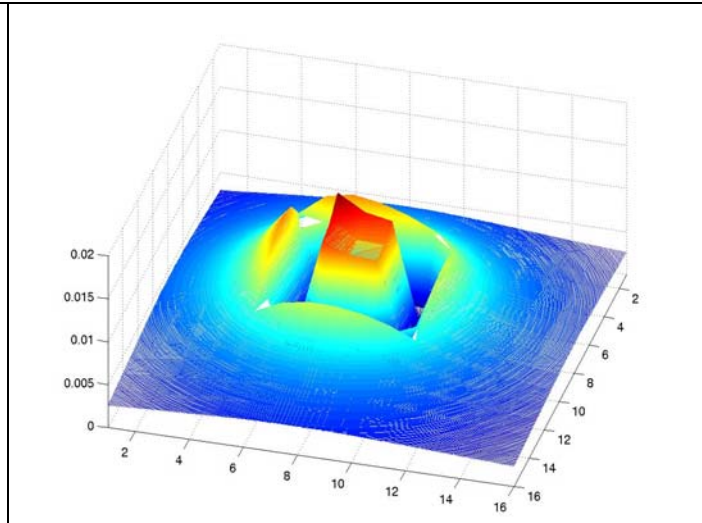
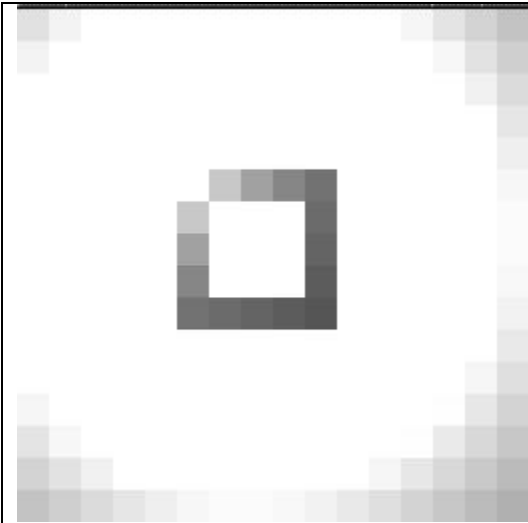
The results from the program simulating the EAC machine shows that light and material interaction has been represented accurately. Keep in mind that these images are only a small, simple sample of an environment. These images have a 16 x 16 grid of pixels. The contour maps of the data from the simulations also help us verify the interaction with light and materials. Notice that the contour map (below images) for the initial sheet has a limit from zero to about one. The upper limit of the reflection sheet is

equivalent to the image pixel on that sheet with the highest intensity. One can see from the OpenGL images and contour maps that light is represented accurately. Light displaces as we get further away from the source.

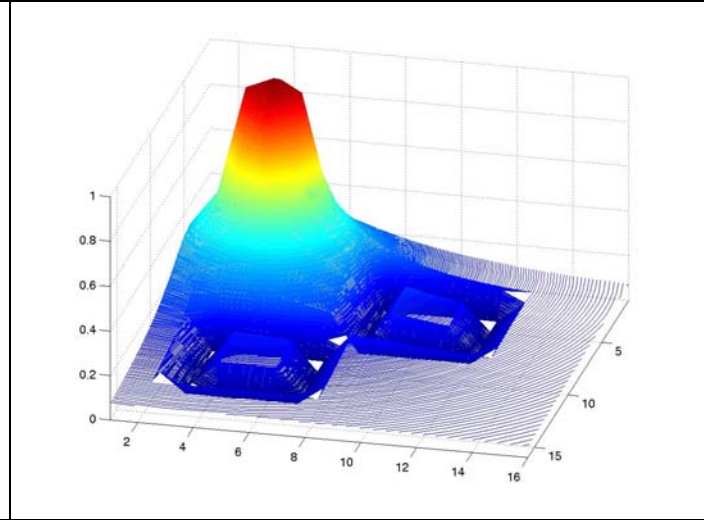
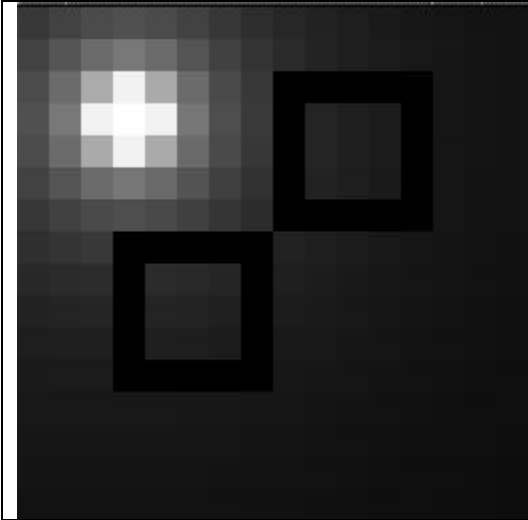




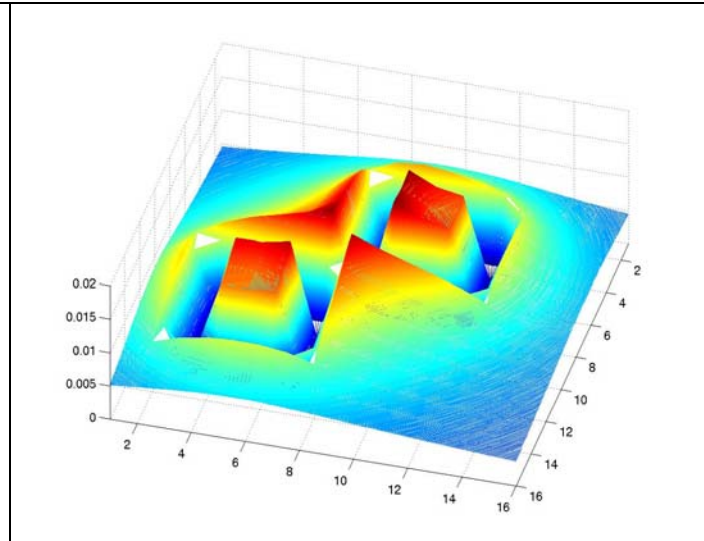
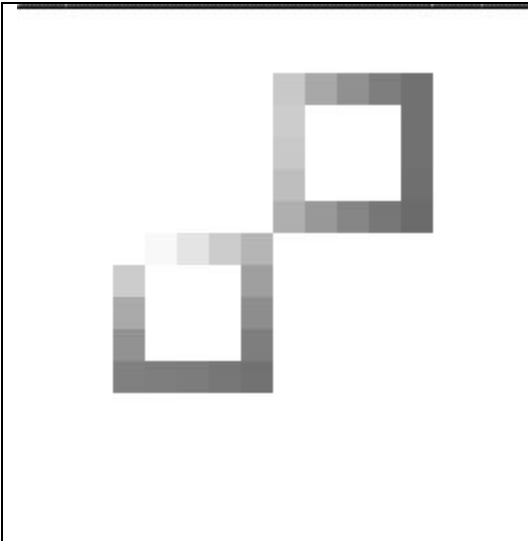
Light source at (3, 3), material center at (7, 7) -> initial sheet



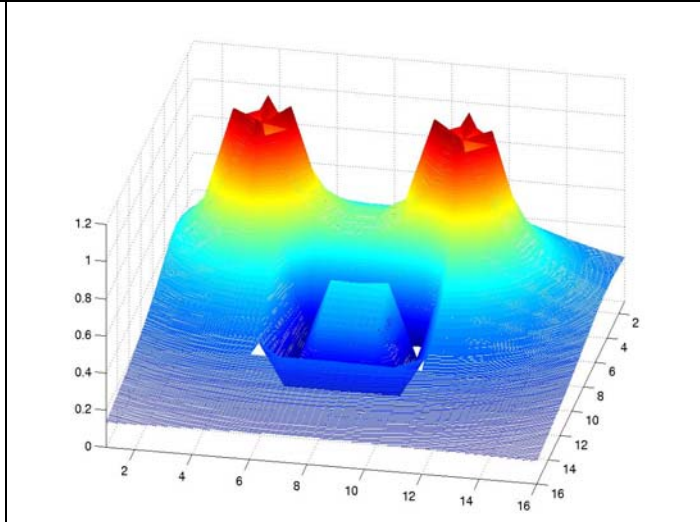
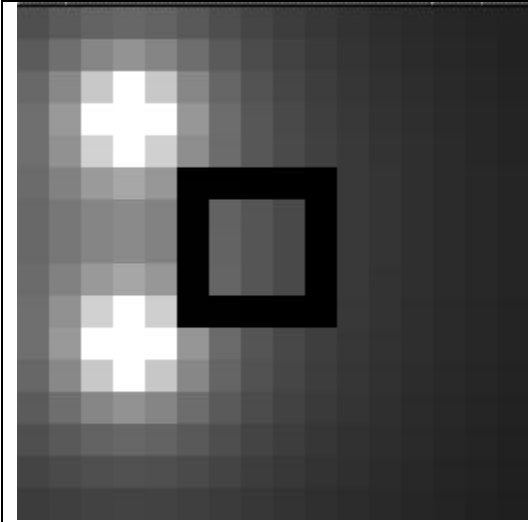
Light source at (3, 3), material center at (7, 7) -> reflective sheet



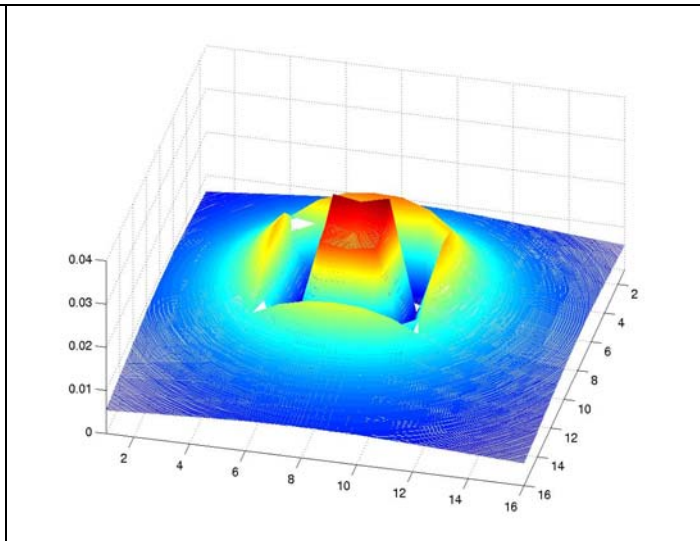
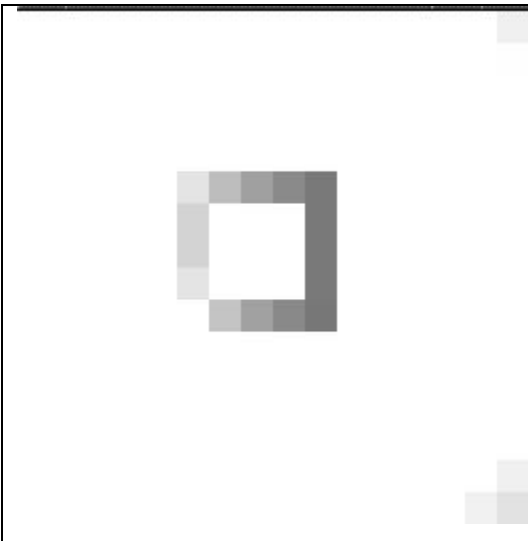
Light source at (3, 3) and material center at (9, 5) and (4, 10) -> initial sheet



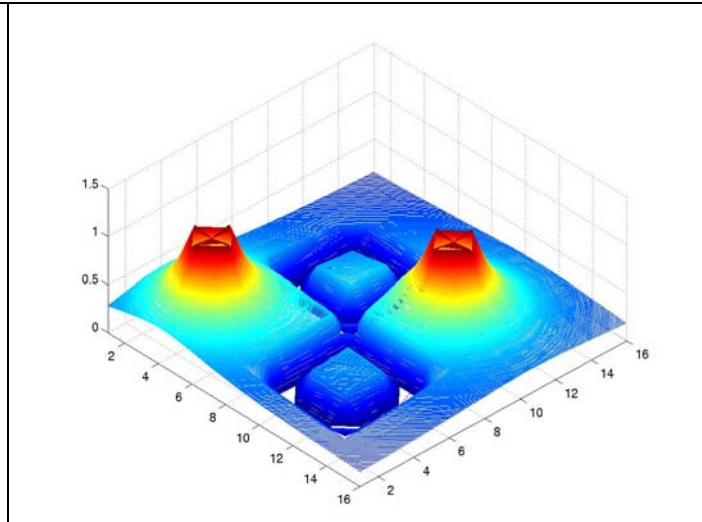
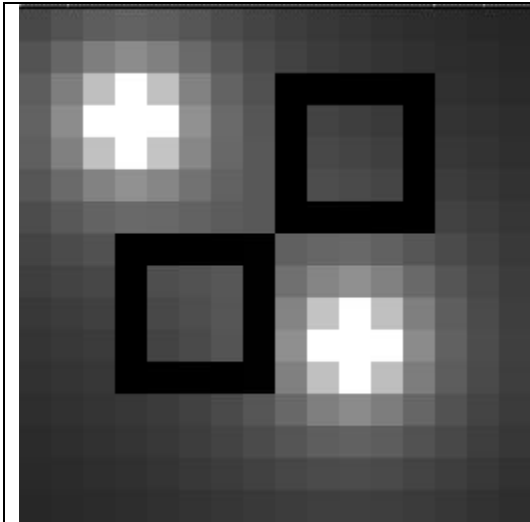
Light source at (3, 3) and material center at (9, 5) and (4, 10) -> reflective sheet



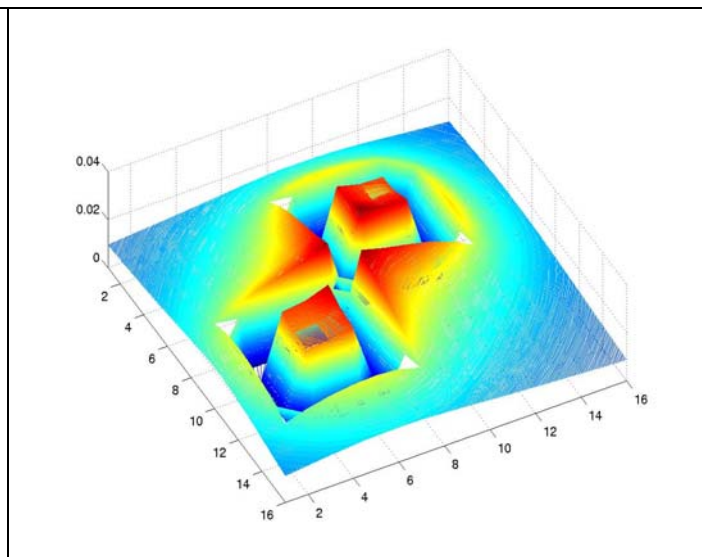
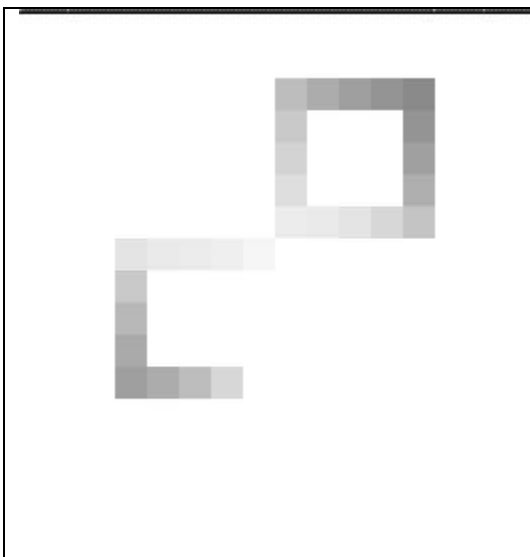
Light source at (3, 3) and (10, 3), material at (7, 7) -> initial sheet



Light source at (3, 3) and (10, 3), material center at (7, 7) -> reflective sheet



Light source at (3, 3) and (10, 10), material center at (9, 5) and (4, 10) -> initial sheet



Light source at (3, 3) and (10, 10), material center at (9, 5) and (4, 10) -> reflective sheet

In these images we see that objects are represented very well. The objects are squares. The boundaries of the objects take current out of the system. This creates several important effects. It causes a shadow-like effect to the neighboring pixels in the environment. The pixel intensities at the boundaries represent the intensity of the material. Notice that these images are transparent because pixels inside the image allow currents to displace through the material. The contour map shows that pixels inside the image that are closer to the light source have a higher intensity than pixels further away from the light source. This is very important, especially when designing a 3-D image rendering EAC machine. The reflective sheet shows that the images are acting as a light source. These images show that the diffusive property of the environment is accurately simulated. When the initial sheet and the reflection sheet are added together we get

object to object illumination. Since we have accurately simulated global illumination we do not need to have global ambient or background illumination.

CONCLUSION AND FUTURE WORK

This project is just an introduction into the concept of image rendering using the wave theory. Currently we have light to object interaction and object to object interaction. The project proves that light and material interactions can be simulated using an EAC machine. Now that this has been proven, detailed implementation of the material properties will be part of the future research.

This project proves that image rendering using an EAC is very similar to image rendering using radiosity methods. The radiosity method is a theoretically rigorous method that provides a solution to diffusive interaction within a closed environment. The solution is view independent, just like our implementation using wave theory. This method is based on subdividing the environment into discrete patches, or elements, over which the light intensity is constant. Because of this it is difficult to include specular reflection as part of the solution. Radiosity is very accurate but there is a high processing cost. This is where the EAC machine has an advantage over both the radiosity method and the raytracing method. In raytracing, rays are cast into the environment by discretizing the image. Rays can then be cast at the rate of 1 per pixel or n per pixel. These involve a lot of calculations per pixel. The amount of calculation in the radiosity method depends on the amount of discrete patches the environment is divided into. It takes fractions of a second to get the results from an EAC machine.

Image rendering using the wave theory of light and EAC is very promising. There are many issues to deal with in order to design an EAC machine that simulates a real environment very accurately. For instance, the current design only deals with black and white color. There is only one intensity value for each pixel. We need three intensity values for each pixel, one value for red, one for green and one for blue, to accurately represent a realistic environment. With three intensity values we will have more control over how to represent the material properties. The machine will then simulate the interaction with light and objects even more accurately. LLAs can be used to set the RGB values that will be absorbed and reflected. Research needs to be done on how to increase the accuracy of the representation of shadows in the system. Currently, the image casts a shadow on all neighboring pixels. It should only cast shadows on neighboring pixels that are opposite the light source. Also, the representation of specular reflection needs to be represented in the system. We can solve this problem with additional LLAs or we can have the EAC machine calculate the diffuse values in our environment and then use conventional raytracing algorithm to calculate other illuminations, such as specular reflection and shadows, in the system. With research and testing the future goals can be accomplished because the conductive sheet naturally simulates light and the LLAs representing the images pixels are programmable and adaptable.

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