# The Science of Images:
# A Cross-disciplinary Introduction to the Field of 3-D Computer Graphics

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## Abstract

Students choosing to specialize in the study of computer graphics often come from two disparate groups – the mathematically-inclined students who are often most interested in the computer programming aspects of the field, and the artistically-inclined students whose interest lies more in design and image construction. If these two groups are to learn as part of one community, they need to develop (at least) a common background and language. This paper presents an approach to achieving this goal and discusses a particular course, The Science of Images, which has been taught for several years in this pursuit.

## 1 Introduction

As computer graphics establishes itself as a discipline distinct from both graphics design and computer science, certain problems are bound to arise. One of the most central issues is how educators can most effectively deal with the variety of backgrounds presented by incoming students. These students may exhibit strength primarily in the arts, or they may have a more technical, less aesthetic background. The challenge is to offer these students an introductory experience that is both engaging and equalizing so that they may continue their studies energized, but with a common background.

This need was articulated in (at least) two forums held at SIGGRAPH 2002. Cox raised the issue of disparate backgrounds in several of the questions around which she focused her forum [Cox 2002] while Bertoline and Laxer discussed the cross-disciplinary nature of computer graphics as they attempted to describe a knowledge base for the discipline [Bertoline and Laxer 2002]. In this paper, we will describe the approach we use in teaching an introductory computer graphics course that addresses both of these concerns.

Various versions of the course have been offered on different campuses including liberal arts schools, small universities and research institutions. The particular version, which we call "The Science of Images", was inspired by the course described by House and Levine [House and Levine 1994]. Similar to their course, the Science of Images is designed in the classic liberal arts tradition, providing students with a foundation in computer graphics concepts. The list of topics was developed from those found in a traditional graphics course taught in a computer science department but with references to algorithmic details and programming removed. In place of programming, the "hands-on" experience is provided through the use of Discreet's 3D Studio Max [discreet]. The Science of Images has been offered the past five years at St. Bonaventure University with the laboratory component of the course originally funded in part by a National Science Foundation grant (ILI-IP 9551854).

## 2 Objectives and Details Of The Course

The original objective of the course was to provide students outside of the sciences with an opportunity to learn how computer generated images are created. As part of this objective, students studied topics found in a traditional computer graphics course for majors such as:

- Transformations in 3-dimensional coordinate spaces;
- Modeling with geometric primitives;
- Color theory;
- Light and its interaction with surfaces;
- Motion and kinematics.

In addition, students broadened their experiences in computer graphics by acquiring an understanding of:

- Why transformations have their respective effects through the use of numerical coordinates and scalars applied to the coordinates;
- How smooth shading is accomplished through interpolation;
- The effects of changes in lighting parameters such as fall-off through the use of a simplified illumination equation;
- Motion and its visual effects in animation, including effects of rates of change.

Over time, the target audience was expanded to include computer science majors who desired a less technical introduction to the field. The effects of this expansion are discussed in Section 4 of the paper.

Although the students are not implementing algorithms as would be expected in a computer science-based course, they are expected to develop an understanding of the basic scientific principles involved. Concepts are discussed using informal, descriptive methods versus precise mathematical notation. They are made of aware of some of the underlying mathematics and science of computer graphics albeit not in a rigorous way. Consider, for the example, the importance of

the order of application of transforms. It is well known that a translation followed by a scale transformation does not have the same effect as scaling first and then translating. Students in the Science of Images are made aware that the transformations perform arithmetic operations on the coordinates of the object being transformed but without introducing matrices, as would be done in a graphics course for computer science majors. Instead, they are taught that scaling is done through multiplication while translating is done through addition. With that knowledge, they accept the importance of order of operations by recognizing that $ab + c$ is not necessarily the same as $a(b + c)$.

The current text for the course is The Art of 3-D Computer Animation and Imaging, 2nd Edition, [Kerlow 2000]. The book does a good job of addressing core concepts in a manner that can be appreciated by all students in the course. Tutorials are used to demonstrate other concepts and everything is augmented through work in a formal laboratory setting. A complete set of course materials is available at http://web.sbu.edu/cs/hunkins/cs126/ [The Science of Images].

## 3 Hands-On Experience

"Hands-on" experience is an integral part of The Science of Images. The students are required to complete three major projects in the course. The projects are incremental, each one building upon its predecessor. The main goals for the three projects are respectively:

- Model the geometry for a 3D world;
- Add lighting, materials and camera to their 3D world;
- Animate their 3D world.

The course materials [The Science of Images] contain the detail requirements for each project.

As noted, students use 3D Studio Max to model and render their worlds and animations. They acquire experience in the use of the software through closed lab sessions. Eleven of the fourteen scheduled labs are devoted to learning how to employ particular graphical techniques using 3D Studio Max, which is accomplished through tutorials that come with the software package. The remaining three lab sessions are provided for students to put "finishing touches" on their projects. Students are expected to do the major portion of their projects outside of the closed lab periods. The following assessments by students point to the success of having students take responsibility for learning the software through guided assistance.

*"I like the structure. Each lab built and added onto the previous ones. Projects helped to learn the techniques without a structured list of what to do."*

*"Fun but sometimes frustrating for me because I couldn't get everything to work out as planned."*

*"The fact that most of the labs were tutorials helped to learn the interface. If we hadn't done those, I don't think I would have learned things as well and probably would have become frustrated. The projects were basically an extension of labs but better because it was dealing with themes/topics we chose."*

Although 3D Studio Max is not the focus during classes, it is used from time to time in lesson presentations to demonstrate high-level concepts such as morphing and material animation. However, a powerful tool such as 3D Studio Max may cause distraction when we want to focus on an underlying graphics concept. In this case, we use tutorials during lecture that focus on specific concepts in computer graphics. The tutorials help separate abstract concepts from the manipulative overhead associated with complete image generation. There are several suites of tutorials that serve this purpose including Rosalie Wolfe's TERA [Wolfe 2000] and the suite produced by Hunkins and Levine [Hunkins and Levine 2002].

*Ambient Reflection* and *Diffuse Reflection*, two tutorials from the Hunkins and Levine suite illustrate how students are exposed to core concepts separate from the primary software package. Both of these tutorials focus on color determination using a simple Phong Illumination Model. The user of the ambient reflection tutorial controls the color of an ambient light as it shines on swatches of material while viewing the effects of the simple computation. The diffuse reflection tutorial helps students understand the effects that omni lights and surface normals have on the image. The student can manipulate the lights and the normals in a simple scene and acquire an appreciation of how smoothing across an edge is achieved through the simple illumination model. Using such tutorials, a student can concentrate on the effect created through the computations or she can acquire an appreciation of how the effect is achieved – depending upon her inclination. Most likely a mixture of both lessons will be learned

## 4 Benefits of One Course for Both Audiences

The difficulty of designing courses for students with disparate backgrounds is well known. The problem becomes increasingly difficult when the students may have entirely different views about technology. Still, there are examples where such courses have been implemented, and flourished, providing not only a background, but also building a sense of community [Hayes and Sharma, 2003]. Anecdotal evidence also shows that when different groups come together around a shared vocabulary and shared experiences, cooperation increases. By bringing students into a single classroom and a single laboratory, working on the same projects, The Science of Images creates an environment that encourages this sense of commonality.

In addition to providing a common experience, The Sciences of Images pays particular attention to the lessons that mathematically-inclined students could learn from those of an artistic bent and vice versa. Through these lessons, we hope to achieve the common background and viewpoint that will facilitate future cooperation between the disparate groups.

Examples of "artistic concepts" to which are covered include:

- Effects of lighting and placement of lights (e.g. backlighting) on a subject;
- Use and effects of warm vs. cool colors and different material types on viewer perception.

Examples of "technical concepts" which may be new to those students coming from an artistic background include:

- Non-commutativity of transformations and the importance of center-of-mass;
- The use of splines in modeling and motion planning.

There are also lessons that both groups will learn, albeit in different ways. A good example of this is:

- The concept of exponentials and how they affect specular reflections.

At St. Bonaventure University, The Science of Images was originally intended for students majoring in areas outside of the sciences including computer science. However, many of our computer science majors elected to take the course as a university free elective. The experience of having students from both the computer science and the visual arts traditions was very positive and has affected the further development of the course. The following two comments, in response to a survey question about who the course should target, point to the value of a mix of students with disparate backgrounds. The first comment is from a computer science major; the second is from a non-major.

> *"I think everyone should be allowed to take the course. There may be an intimidation factor but also if the non-cs majors have trouble, then the cs majors may be of assistance. I think the course works for a heterogeneous group."*

> *"I think anyone should be allowed to take the course. It's fun and interesting and not too difficult to understand. At first I was a little nervous to take the class because I am not that advanced when it comes to computer skills. Not to mention I was the only girl in the class filed practically with computer science majors. But I stuck it out and found the class a great learning experience that allows everyone to work at their desired level and still accomplish all requirements."*

Although The Science of Images was originally conceived of as a single elective for a student, we have had recently a number of students express an interest in continuing to explore the field of computer graphics, and particularly computer animation. Students from each of the last three offerings have subsequently engaged in independent study projects, extending their work from this class. In each of the last two years, the project has been a group effort. Both cases have had computer science majors work on a team with non-computer science majors to develop animation projects. Last year's group modeled our campus and created a virtual tour; they developed highly specialized roles based upon their respective talents. The project was so successful that two of them – one computer science major and one visual arts major – were hired as a team by our development office to do further work to aid with fundraising. This year's group has chosen to create a short fictional animation; the modeling work, story boards, and technical coding are being shared by students whose prior backgrounds included both technical and artistic inclinations.

## 5 Transferability

While the version of the course currently taught at St. Bonaventure is the one discussed herein, the course has been taught at several other schools as well. Not surprisingly, each school has its own set of pre-requisites, degree of cooperation among departments, and target audience for the course, The common elements are that the course has been offered multiple times at each school and it has been well received by students with both artistic and technical backgrounds. The students with artistic backgrounds understand more mathematics and fundamental graphics concepts than they would have anticipated, while the technically oriented students find themselves paying more attention to aesthetics than they customarily do in their other work. Frequently students with different backgrounds assist each other in the labs and share helpful hints when completing major projects.

## 6 Conclusions

As computer graphics matures as a discipline, it is attracting a set of students whose abilities and inclinations are ever more diverse. We believe that the needs of this group are best served through a course that can serve as a single, unifying introduction to the field. We have implemented such a course, The Science of Images, and taught it successfully. Some details have been provided in this paper; others can be found on the web [The Science of Images].

It is our experience from teaching The Science of Images to students of disparate backgrounds that the students benefit from the mixture of backgrounds. As students are exposed to, and adopt, a common vocabulary with a common set of examples upon which their understanding is based, the gap between the two cultures diminishes. Informal collaborations evolve where the technically oriented student may assist others with "coping with the software system", while the more artistic student may provide helpful suggestions on how to make a project more visually appealing. In addition to observing this positive interaction among students while teaching The Science of Images, we had the opportunity to see it extend into further work. In both cases, we have been impressed and excited to observe how each student brings a unique set of skills to the project at hand. Regardless of the background a student started with, we believe that all of these students are well-prepared to work as part of a computer graphics team.

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