# CLASSROOM EXPLORATIONS IN 3D STEREOSCOPY (S3D)*


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## ABSTRACT

3D Stereoscopy is a rich and fun interdisciplinary context for engaging students across campus. Students can practice programming and also experience how computing can be used as a tool for exploration and analysis of scientific (or other) questions.


## INTRODUCTION

This paper is a discussion of 3D stereoscopy (S3D) and how it can be used in the classroom. S3D is fun for students, yet not difficult to implement. An instructor might devote a single lecture or multiple lectures depending on the desired depth of the discussion and assignments. S3D is well suited for non-major courses because it has rich connections to other disciplines, e.g. film, animation, cognitive science, neuroscience, mathematics, and visualization. S3D can also serve as a context for learning how to do research. In physics or chemistry labs, students measure and analyze experimental data to confirm, or fail to confirm, a hypothesis. However, computer science students are more likely to implement an application in lab, e.g. a game, database, rather than using or thinking of computing as a tool for exploring and answering some scientific (or other) question. S3D can serve as a context for learning this kind of skill. S3D is also a subset of the broader context of *algorithmic art* which is increasingly being used for teaching programming concepts [3,5]. The exercises here expand on a variety of teaching modules developed by the author and others [10].

## BACKGROUND

For centuries, it has been observed that a scene viewed with both eyes is somehow different from viewing it with one eye. Charles Wheatstone in 1838, however, was the first person to hypothesize that this perception arises when the brain "fuses" the slightly shifted images seen by each eye. Since then, there has been a fascination with how to

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artificially induce this perception. Thanks to new technology, there has been a recent resurgence in S3D. Blockbusters such as Avatar and Up are commonplace in theaters. It would be difficult to find a student today who has not seen such a film. Many excellent websites and books are now available on how to create S3D films artistically and technically. Ongoing research is helping us better understand what causes viewer discomfort and how it can be reduced. Finally, new programming environments have made it easier for students at all skill levels to explore and create their own stereo images.

The first part of this paper presents a set of classroom discussion questions to introduce concepts. The second part presents ways of generating S3D images and offers suggestions for topics that students could explore through programming to better understand the techniques and challenges of S3D.

## DISCUSSION QUESTIONS

### Question 1: What is the difference between 2D vs 3D vs S3D?

Most students do not understand the difference between 2D, 3D, and S3D. 2D animated films (e.g. Disney's Fantasia) are generally hand drawn. All of the information is created and stored in 2D. Changing the viewpoint means completely redrawing everything.

In 3D and S3D films, scenes and objects are created and stored in 3D (i.e. points have xyz components rather than just xy). A 3D movie is "rendered" by projecting the 3D scene down to the 2D screen of the virtual camera. One advantage of modeling in 3D over drawing in 2D, is that once the scene is modeled, it can viewed from any position and angle simply by moving the camera and having the computer re-render it. Confusion between the terms 3D and 3DS arises because, until several years, 3D referred to movies which were only *modeled* in 3D (e.g. Toy Story I), whereas, 3D now often refers to *Stereoscopic 3D* (in this paper we use the term S3D). S3D animated films are both modeled in 3D and rendered using two rather than one camera, where each camera corresponds to the image seen by a separate eye. In the theater, the rendered images from each camera are viewed, e.g., with polarized glasses, so that each eye sees just one image. The viewer's brain fuses these images together to give the perception of binocular vision. Films such as Pixar's Up are both 3D and S3D.

### Question 2: What are Monoscopic Depth Cues?

Non-stereoscopic types of information that enable our minds to interpret distances of objects are referred to as monoscopic depth cues. These cues include relative sizes (objects far away are smaller), occlusion (one object in front of another), atmospheric affects (objects near the horizon are hazier), cast shadows, and motion parallax (objects farther way seem to move more slowly). A good description of each of these, and more, can be found in Mendiburu [9].

### Question 3: What does it mean to *Perceive* Depth?

Stereo blind people generally function quite well because monoscopic cues provide enough *information* for interpreting 3D space. However, these cues do not provide the *perceptual* experience of depth. Oliver Sacks [13] writes: "All of these cues, acting together, can give a sense of reality and space and depth. But the only way to actually perceive depth - to see it rather than judge it - is with binocular stereoscopy". Sue Barry [1] grew up cross-eyed and did not experience stereo vision until her late forties. She functioned normally, for the most part, because she learned to read the monoscopic cues. After her vision was corrected she said "when I first learned about stereopsis in college, I wondered if I could imagine this way of seeing. Now I had my answer. I could not. Stereopsis provides a distinctive, subjective sensation, a quale" where by "quale" she means "the raw feel of sensations such as the subjective quality of 'pain' …". Monoscopic depth cues may provide enough information to navigate our 3D world, but these cues do not offer the same experience.

### Question 4: Is S3D a Gimmick?

Is S3D just a gimmick for making more money at the box office? Film critic Roger Ebert believes so. In fact, he felt so strongly about this that he wrote the article "Why I Hate 3D (And You should Too) [6], where he claims that S3D is "a waste of a perfectly good dimension", "adds nothing to the experience", etc. There are good reasons to both agree and disagree with him.

Barry [1] wrote that "When a normal binocular viewer closes one eye … he or she still uses a lifetime of past visual experiences to re-create the missing stereo information". Thus, even though a film may be viewed on a 2D screen, a skilled cinematographer can trigger the perceptual experience of stereo in the viewer's mind, assuming that the viewer is able to experience stereo in the first place. Why go to the trouble then of using S3D?

S3D also introduces severe cinematographic limitations. According to Mendiburu [9], "monoscopic depth cues have virtually no range limitations, sterescopic perception hits a limit when objects are too far away". Mendiburu [9, p. 21] shows a figure displaying the"stereopsis comfort zone" for S3D. Objects outside of this rather narrow zone can cause discomfort and confusion, thus putting severe restriction on what a director can do. S3D is also limiting because some computer graphics techniques, e.g. bump mapping, do not work in S3D. Finally, stereo also takes your brain more time to process, so images must be presented for a longer time on the screen.

While we agree that, under certain conditions, one can perceive depth without S3D and that S3D introduces limitations, few people who view an S3D film will say there is no difference with a normal film. S3D can and should be a very effective tool in a cinematographer's tool chest and, a necessary tool in numerous scientific applications. It took many years before film makers understood how to use sound or color effectively, and it may be many years before we fully understand how best to use S3D.

### Question 5: What are the Causes of Eye Fatigue and Nausea

Improvements over the years have led to S3D movies which cause much less eye fatigue and nausea than early 3D movies. The discomfort is, in part, due to the lack or inconsistency of proprioception, i.e. "the sense of movement and spatial orientation arising from stimuli within the body" [9]. For example, your eyes' lenses are focused on (accommodation) and aimed at (convergence) the screen, while perceiving objects that elsewhere. Also, as your head moves from side to side in the theater, there is no motion parallax because the left and right images of the film do not change. These and other effects can cause confusion in your brain which leads to discomfort and nausea.

**Question 6: When are Monoscopic Depth Cues Not Enough?**

Monoscopic depth cues can dramatically fail as in the case of solar flares. In 2006 NASA launched twin spacecraft Solar Terrestrial Relations Observatory (STEREO) [15] to take stereo images of the sun. Monoscopic cues provide little information - all one can see is the sun's uniformly mottled surface texture thus making it impossible to pick out the flares. When stereo is turned on, however, the flares immediately pop out. Stereo viewing is also proving to be very effective in teaching and research about the physical world, e.g. in medical education [19] and chemistry (e.g. VMD [17]).

## STEREO FORMATS, IMAGE GENERATION, EXERCISES

There are numerous formats for implementing S3D: parallel/free viewing, anaglyph, wiggle, lenticular, polarized, etc.. Descriptions of these formats, sample images, and other information may be found in [2,4,18]. We focus on parallel free-viewing and anaglyph because they are simple and inexpensive. Anaglyph requires cheap red/cyan glasses. Typically, one stores the left eye image in the red color channel and the right eye in the green/blue channels. In parallel free-viewing, images are placed side-by-side with the left-eye on the left and right-eye on the right (reversed for cross-eyed free-viewing). Free viewing does not require glasses but requires the viewer to fuse two images. This can take practice and can be uncomfortable to view for any length of time. Fusing is sensitive to size, separation, and distance of the images. Alternatively, one can generate the left and right eye images in separate files and then use the freely available Stereoscopic Player [16] which will convert and display the images in most any format you wish.

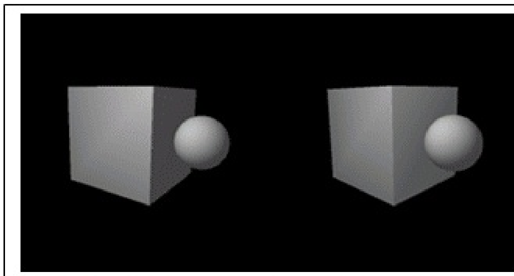
Fig 1: Parallel Free Viewing (side by side)

There are many examples of stereo images available online. However, it is educational to create one's own. To do this, one needs a way of modeling a 3D world, specifying the two cameras, and rendering the images for each eye:

**Computer Science Majors:** A 3D computer graphics class for majors could include a short exercise that takes a scene they have already modeled, and renders images from two parallel cameras separated by the inter-ocular distance. This could easily be done either using OpenGL [14] or an existing ray tracer or a ray tracer students have written themselves.

**Arts & Animation:** Students who have some experience with 3D software packages such as Autodesk Maya can use the built-in 3D stereo camera that allows one to generate stereo output in a number of different formats including anaglyph.

**Non-majors:** Students in programming classes for non-majors can use environments such as Processing [12] which includes OpenGL libraries for rendering 3D scenes. The syntax is significantly simpler than writing a typical OpenGL program in C or Java. For example, Gilbertson [7] posts a Processing program containing only about 40 lines code that generates side-by-side images. Fig 1 displays the output. Students could be given this or similar code and asked to modify the image drawn, or to vary the parameters such as size or inter-ocular distance. Creating a 3D scene and varying stereo parameters can motivate the use of a variety of programming concepts such as functions, transformations, and loops. Alternatively, one could use the ray tracing program POV-Ray [11] for generating the images.

### Exploring Monoscopic Cues

Before diving into stereoscopy, students can experiment with exercises that explore monoscopic depth cues. For example, the left side of Fig 2 was created in Processing by drawing an image of a figure repeatedly in a nested for-loop. There is no sense of depth. In the middle image, the size decreases with height, thus making the higher figures appear to be farther away. This effect is intensified by on the right by making the higher figures lighter. One can also use animation and loops to experiment with how parallax gives the illusion of depth. Fig 3 shows a snapshot of an animation of 4 planes moving to the right with the smallest plane moving the slowest. This gives the illusion of 4 equal sized planes at different depths. If the order is reversed, i.e. with the smallest on the bottom and going the fastest, the illusion breaks down.

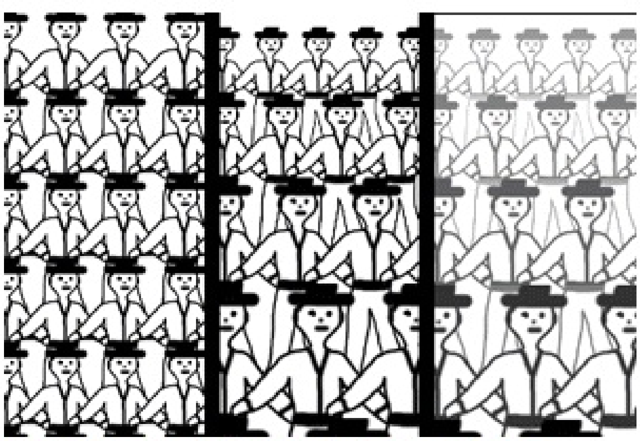

Fig 2: Size and Atmospheric Depth Cues.

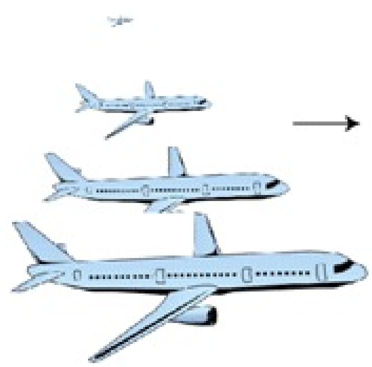

Fig 3: Parallax Depth Cue.

### Exploring Stereoscoptic Parameters and their effect on Perception

If the basic code is provided (e.g. in OpenGL, Maya, POV-Ray, or Processing), then students can vary parameters, record what happens, and analyze the results. Chapter 5 of [9] gives excellent explanations and figures showing how stereo parameters should affect depth perception. Below are just a few examples of what could be explored:

**Inter-ocular distance:** Changing the inter-ocular distance makes objects appear to move forward or back, and can even make an image uncomfortable to look at. The typical rule-of-thumb is that the inter-ocular distance should roughly be 1/30th of the distance from the camera to the foreground.

**Convergence Angle:** The convergence angle of the cameras (parallel or converging) changes the apparent distance of the screen and its relative position to the objects.

Screen Size: Changing the screen size and/or seat location changes the effective inter-ocular distance and can dramatically distort what is seen.

**Comfort Zone:** Placing items inside and outside of the stereoscopic comfort zone can result in strange effects, particularly at the edges, generating what are known as window violations.

**Alignment:** Poor left/right vertical alignment can make it difficult or impossible to fuse the images, which is what happens for stereo-blind people who suffer from strabismus (crossed eyes).

**Stereograms:** Random dot stereograms are images that look like random colors/textures, but are actually pairs of side-by-side stereo images. They are actually easy to generate. Figure 4 shows an example where the central square has been shaded gray (for illustration purposes). When fused, the gray area sits in front of the background. It was generated by creating an image of random dots, duplicating it for each eye, and then for one of the eyes, shifting the grayed area slightly left or right.

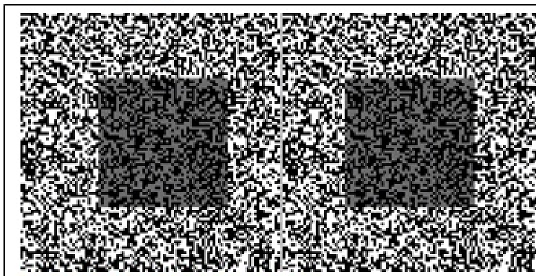

Fig 4: Random Dot Stereogram

## CONCLUSIONS AND FUTURE DIRECTIONS

3D Stereoscopy is a rich and fun interdisciplinary context for engaging non-majors and for providing students with the experience of using computing as an exploratory tool. Readers who want to learn more are encouraged to read Mendiburu [9] and Beech [2]. Future work includes expanding these concepts and exercises into teaching modules that others could use more conveniently in a wider range of classes than so far has been tried. Student data then needs to be collected to measure the effectiveness of the modules on student learning, skills, and satisfaction.

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