CASE STUDY - *Beauty and the Beast 3D*
Benefits of 3D Viewing for 2D to 3D Conversion

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ABSTRACT

From the earliest stages of the *Beauty and the Beast 3D* conversion project, the advantages of accurate desk-side 3D viewing was evident. While designing and testing the 2D to 3D conversion process, the engineering team at Walt Disney Animation Studios proposed a 3D viewing configuration that not only allowed artists to "compose" stereoscopic 3D but also improved efficiency by allowing artists to instantly detect which image features were essential to the stereoscopic appeal of a shot and which features had minimal or even negative impact. At a time when few commercial 3D monitors were available and few software packages provided 3D desk-side output, the team designed their own prototype devices and collaborated with vendors to create a "3D composing" workstation. This paper outlines the display technologies explored, final choices made for *Beauty and the Beast 3D*, wish-lists for future development and a few rules of thumb for composing compelling 2D to 3D conversions.

Keywords: Disney, Beauty, Beast, 3D, Conversion, 2D/3D, Viewing, Monitor

1. INTRODUCTION

The idea to convert Disney's animated classic *Beauty and the Beast* (Figure 1) to stereoscopic 3D began to take shape in late 2007. Walt Disney Studios had become a leader in the rebirth of stereoscopic 3D filmmaking for both animated and live-action films and had embraced advancing the art to a higher level. Owing to the well received Disney Digital 3-D releases of *Chicken Little, Meet the Robinsons, Bolt* and the 2D to 3D conversion of *The Nightmare Before Christmas,* animation films had a particularly strong 3D track record. With that in mind, the engineering team at Walt Disney Animation Studios was asked to study the viability of converting one of its most beloved 2D animated films, *Beauty and the Beast,* from hand-drawn 2D to stereoscopic 3D.

Figure 1. Disney's 2D animated classic *Beauty and the Beast* was first released in 1991 and was the first animated film to be nominated for an Academy Award for Best Picture. Image copyright 2010 Disney Enterprises.

Could a 2D hand-drawn film be compelling in stereoscopic 3D? Could a conversion process uphold the quality and magic of the original film? Within just a few weeks, a study of the film and quick mock-up of the 2D to 3D philosophy provided the answer: yes! It was clear that if converted properly, a stereoscopic 3D version of the film could be striking. The next step, then, was to devise the process and workflow that would convert the film "properly." Focusing on three key project requirements and three key process requirements, the engineering team began designing the software and hardware that would best assist the artists to this end. This included the creation of a "stereo composing" workstation that provided viewing techniques that had not previously been available for stereoscopic artists at their desks.

Not losing sight of the fact that the task at hand was to convert an entire feature length film from 2D planar imagery to stereoscopic 3D, a scale which had seldom been attempted, and that 2D animation can appear flat by nature, the engineering team set about evaluating all existing options for real-time desk-side 3D viewing. It was found that cost effective commercial devices offered sub-standard stereo and image quality while adequate solutions were cost-prohibitive. Therefore, confident that the technology existed to create suitable devices, the engineering team chose to build their own prototype systems while continuing to evaluate all new consumer devices until a satisfactory solution was found. This paper follows the exploration of 3D viewing devices and evolution of consumer devices that led to a successful desk-side 3D viewing configuration. While meeting nearly all requirements and directly contributing to the success of the project, the solution still reveals the need for continued evolution in the field.

To present the engineering process that occurred for desk-side 3D viewing, this paper will first review the project and process requirements that accompanied the design of a "stereo composing" workstation. An assessment of the state of the art of 3D monitors at the inception of the project follows with a description of the prototypes and evaluations performed by the engineering team to arrive at a final configuration. Finally, by evaluating the strengths and weaknesses of the configuration, criteria for potential future development are proposed.

2. BACKGROUND AND OBJECTIVES

We can begin to see the need for desk-side 3D viewing by reviewing the scope of the *Beauty and the Beast 3D* project as well as the principles of compelling 2D to 3D conversion. From initial engineering tests to the final production configuration, the idea of composing stereoscopic 3D shots without being able to readily observe the results in depth seemed akin to lighting a chromatic film or rendering a chromatic computer graphics image without seeing color.

2.1 Project Requirements

Besides a "stereo composing" workstation, there were three essential requirements for the production. The engineering team addressed these requirements, namely; data, a process and a pipeline, while shaping the stereo viewing objectives.

2D Data. *Beauty and the Beast* was created in 1991 using Disney/Pixar's Computer Animation Production System (CAPS), the award winning digital 2D animation system designed in the late 1980's. This system preserved a complete archive of the film's digital assets, metadata and image processing algorithms. Although access to this data was a great advantage for the project, digital 2D animation assets are organized and assembled more intricately than typical digital and computer graphics assets. This intricacy proved valuable for certain calculations but could be reduced for the majority of the stereo conversion process. Therefore, a number of processes were automated to export and reassemble the data in a format suited to the stereo process and a forecasting and tracking system was implemented. During that early development, as well as the initial feasibility tests, these assets were exported and reassembled manually and stereo tests were viewed using a red/blue anaglyph algorithm.

2D to 3D Conversion Process. Prior Disney Animation stereo 3D releases, including post-renderings of *Chicken Little* and *Meet the Robinsons* and the production-integrated stereo rendering of *Bolt,* were achieved with the aid of the virtual 3D environments used to created each film.[1] Outside of a few hybrid sequences, like the acclaimed Ballroom sequence, *Beauty and the Beast* was not created in a virtual 3D environment. Therefore, a new process was needed to provide artists a method of simulating that environment. More specifically, for a compelling 3D rendition of the film, a Patent Pending system was developed to allow artists to locate 2D planar elements – characters, props, effects, backgrounds – at a simulated virtual 3D depth and to give each element the impression of volume. In addition, the artists could animate the elements, align elements relative to each other and isolate and segment areas of an element. The process was envisioned as a "stereo composing" session where an artist composes stereo 3D and verifies the results on a secondary desk-side 3D monitor much like a commercial artist edits and composites a commercial on a high-end computer system and confirms the results in real-time or near real-time on a desk-side professional broadcast or HD monitor.

Production Pipeline. The third and final requirement of the project was to establish a production pipeline. In addition to the automation and tracking of the data retrieval process and the addition of 2D to 3D stages to the existing production tracking system, stereoscopic 3D quality control tools were needed. These quality control tools included the proposed desk-side 3D viewing device as well as Patent Pending depth continuity, depth markup, depth visualization and layer management software tools. Key to the accuracy and appeal of the shots, these tools played a primary role in allowing artists to "see" what they were doing. Quality control in stereoscopic 3D became fundamental to the pipeline.

2.2 Process Requirements

A successful 2D to 3D conversion process must support and enrich the visual imagery of a film without introducing uncomfortable side effects. This requires truthful re-creation of the scene in depth as well as compliance to the rules of compelling stereoscopy and an awareness of the contributions of the imagery itself. Desk-side 3D viewing devices greatly enhanced the production's ability to identify and uphold the following objectives for the film.

Be Accurate. The foremost principle of good stereoscopic conversion is to accurately represent the objects of an image in depth. This is done by simulating the placement of each object in a three dimensional environment. When mimicking the view of each object from horizontally offset left eye and right eye perspectives, the offset between the object in the left image and the right image, or binocular disparity, indicates the position of the object with respect to the observer. Just as with real-world viewing where the left eye and right eye observe the surroundings from slightly different angles, the brain "fuses" the two views together to recreate a scene and interprets depth using stereo triangulation.

In addition, objects convey the feeling of volume because of the changing triangulation of the points along their shape. For compelling 3D conversion, therefore, rather than flat "cards in space", objects should be given volume to simulate shape. Moreover, in the real world, as in computer graphics rendering, the apparent volume will reduce as the object moves away from the observer. This affect should be recreated in an accurate 3D conversion.

Finally, animation and alignment of objects in depth should be simulated accurately. If an object animates forward or backward the depth and volume should adjust accordingly and it should align properly with all other objects in the scene.

Be Compelling. The second set of principles for appealing stereoscopic conversion are the same as for good stereo composition in modern CG or live-action productions, namely compelling 3D creative direction and audience comfort. Rather than the more gimmicky 3D effects exploited in ride films and the 1950's 3D fad, films released in recent years have utilized stereo 3D primarily as if looking into a window of depth. This approach maximizes the immersion of the viewer and minimizes discomfort and was the model for *Beauty and the Beast 3D.*

The first guideline for this approach is to manage the Depth Budget of each shot. The Depth Budget refers to the distribution of depth layers in an image and particularly the closest and furthest objects. In most modern productions shots are not given extreme depth ranges by placing, in the same shot, an object far in front of the screen and an object far behind the screen. In addition, effort is made to avoid excessive "convergence", or turning in of the eyes, to resolve an object far in front of the screen, and "divergence", or turning out of the eyes beyond parallel, to resolve an object far behind the screen. The budget is generally predefined and monitored throughout a production by the stereographer. In the case of 2D to 3D conversion, the Depth Budget should mimic the depth of the original scene but can be scaled for comfort and storytelling and may include subtle adjustments to "rein in" the adverse affects of extreme compositions.

Secondly, the transition in depth from one shot to another, or Depth Continuity, should avoid sharp changes in depth budget where possible. That is, if one shot is very shallow with a focal point behind the screen, and the next shot is extremely deep with a focal point far in front of the screen, the viewer's eyes must quickly re-converge and re-focus for these differing depth budgets. This will likely cause discomfort, especially if occurring often, and so, for best composition, shot transitions should instead move fluidly from one point of convergence and depth budget to the next.

In addition, the depth should be choreographed to mimic the scene but also to support the emotional journey of the story. This is often referred to as the Depth Script. For example, it may be compelling to allow the depth budget to remain smaller in less emotional sequences and grow for more emotional scenes. There are a growing number of techniques and artistic styles in this area, but it should at least be noted that the conversion artist and stereographer should stay consistent and aware of the overall creative affect of their depth composition within the context of the entire film.

Finally, and particularly significant to 3D conversion, it is important to avoid retinal rivalry. Retinal rivalry occurs when one eye sees part or all of an object and the other eye does not. This effect usually manifests itself by making the object appear slightly transparent because it exists in one eye and not in the other. This may occur in any stereoscopic imagery due to image mismatches, such as a lens flare in one camera image and not the other, a background object that is visible to one eye but blocked from another or, in the case of stereoscopic conversion, improper alignment or application of the conversion method. It is therefore important to provide artists with 3D viewing and other quality control techniques to identify these issues and correct them.

Be Smart. Effective and efficient production is also key to a successful stereoscopic conversion. This is primarily achieved by avoiding unnecessary work and ensuring that the most time is spent on work with the most valuable results. For example, the stereoscopic conversion artist should be mindful of the depth cues that already exist in the 2D imagery. Shading, familiar size, relative size, motion parallax, occlusion, linear perspective and atmospheric perspective are fundamental monocular depth cues. [2,3,4,5] In all two-dimensional imagery, particularly 2D hand-drawn animation, these cues are used heavily to convey shape and structure to the observer. Therefore, in this process of adding the binocular cue of stereopsis, or binocular disparity, it is important not to conflict with these depth cues.

Figure 2 is a good example of the use of shading to imply structure. The gargoyles present substantial cues to their shape because of the highlights and shadows in the imagery. An overly complex stereoscopic simulation of their shape, if not completely accurate, will conflict with those cues and could actually diminish the perception of depth and dimension in the image. Additionally, extremely fine details, even if accurate, may be time consuming and lend only a very small amount of added depth perception. Therefore, the ability to verify results quickly on a desk-side 3D viewing device allows artists to quickly arrive at the most effective and efficient stereoscopic rendering.

Figure 2. The highlights and shadows in this image provide strong depth cues. A good 2D to 3D conversion should add binocular disparity without conflicting with those cues. Image copyright 2010 Disney Enterprises.

In addition, to achieve the most appealing stereoscopic 3D results, the artist should be aware of the stereoscopic composition at all times and how it might differ from but enhance the 2D imagery. One of the most exciting qualities of stereoscopic 3D filmmaking is that shots that could appear ordinary or even cluttered in 2D planar viewing may transform into highly immersive imagery when viewed in stereo 3D. Crowd shots are a good example of this change. The added dimension of depth opens up the space between characters and objects and more clearly focuses the attention of the viewer on the subject as well as other interesting features that may have been lost in the details. Figure 3 provides an example of a crowd shot that, while true to the style of Disney artistry and expertly composed for focus and space in 2D, still becomes even more compelling when converted to stereo 3D. The sign on the left of the image also illustrates an image feature that is easily overlooked in the 2D imagery, but is surprisingly apparent and appealing in the stereoscopic 3D version of the shot.

Figure 3. For cross-eyed viewing; a well composed 2D crowd scene is even more compelling when 3D exposes additional space, focus and details not as apparent in the 2D image. Image copyright 2010 Disney Enterprises.

The ballroom scene in Figure 1 provides a final example of the influence of desk-side stereoscopic viewing on effective and efficient production methods. The initial version of this shot was composed by the engineers without the CG elements but with the aid of the desk-side 3D viewing prototypes described in this paper. Rather than creating a sophisticated representation of the entire sequence, it was found after just a few minutes of trial and error, that effective treatment of the chandelier in the early stage of the scene and effective treatment of Belle and the Beast in the second half of the scene provided an appealing stereoscopic rendition of the shot without conflicting depth cues and with minimal effort. Although standard depth and volume was applied to all other objects in the final composition, it was clear that less complex techniques could be used for those objects, improving efficiency and avoiding viewer discomfort.

3. DESK-SIDE 3D VIEWING DESIGN

The engineering team envisioned a workstation for 2D to 3D conversion in which changes in depth could be observed in real time. This design mimicked high-end finishing systems such as commercial production suites or editing bays where an artist alters footage or composites in software and the result displays almost immediately on a high-quality secondary monitor. This "stereo composing" approach suggested the need for an accurate, reasonably priced secondary desk-side monitor that would connect directly to the output of the 2D to 3D conversion software and provide comfortable long-term 3D viewing. In addition, it was preferable that the stereo quality duplicate the movie-going experience of the audience as closely as possible.

3.1 Existing 3D Viewing Pipeline

A typical digital production viewing pipeline includes the monitor at each artist's desk along with centralized review stations for higher-quality daily or weekly reviews and a fully equipped theatre for final approvals. For the stereo 3D renderings of *Chicken Little, Meet the Robinsons* and *Bolt,* anaglyph red/blue was used for desk-side viewing, active shutter systems were used for daily and weekly reviews and a RealD cinema system[6] with circular passive eyewear and a silver screen was used in the hybrid 2D/3D theatre capable of interchangeable monoscopic and stereoscopic viewing.[7] The anaglyph and active shutter systems provided sufficient yet cost effective solutions for computer graphics-based stereo productions because the digital assets for these films were already represented in a virtual 3D world. Artists could assemble each shot using their virtual 3D viewer and spot-check the results in an anaglyph viewer and at review stations. However, for *Beauty and the Beast 3D*, artists would need to observe and analyze the stereo 3D output frequently while "composing" stereo from 2D planar imagery. Therefore the preference was to provide artists comfort and quality on par with final theatrical output. At the time, passive circular polarized systems were prevalent in U.S. cinemas and the eyewear was relatively comfortable with little perceivable discomfort when looking away from the stereo screen. Given the quality and comfort of this technology, the engineering team felt the most effective production pipeline would be to convert all viewing stations, including desk-side and centralized review, to circular polarized passive devices.

3.2 3D Viewing Options

At that time, however, few circular polarized desk-side viewing devices existed. Figure 1 lists the available technologies along with an overview of their characteristics in the areas of viewing quality, ergonomics and cost. The viewing quality includes stereo quality (representing depth sensitivity, similarity to theatrical-quality output, and degree of cross-talk between left and right eye output), image resolution and color quality. Ergonomics includes viewing angle and long-term viewing characteristics. Viewing angle represents the angle from center both vertically and horizontally that an artist or group of artists can move while maintaining acceptable stereo sensitivity. Long-term viewing relates to eye fatigue and comfort of the eyewear when used on a production potentially requiring two or more hours a day of stereo viewing for anywhere from 4 to 12 months. Finally, the average entrance cost for each technology is shown.

Table 1. Analysis of available desk-side 3D viewing technologies in late 2007.

Viewing Method	**Viewing Quality**			**Ergonomics**		**Entrance Cost****
	Stereo Quality	**Image Resolution**	**Color Quality**	**Viewing Angle**	**Long-term Viewing (2+ hrs)**	
Anaglyph Red/Blue	Fair/Good	Good/ Excellent	Poor	Good	Poor/Fair	<<$200 (--ES)
Active Shutter	Good	Good/ Excellent	Good	Good	Fair	<$1K (-gES)
Linear Passive Line-Interlaced*	Good	Fair	Good	Poor/Fair	Fair	<$2K (MGES)
Circular Passive Line-Interlaced*	Good	Fair	Good	Poor/Fair	Good	<$2K (MGES)
Linear Passive Full-resolution	Good	Good/ Excellent	Good	Good	Fair	$5K+ (MGES)
Circular Passive Full-resolution	Good	Good/ Excellent	Good	Good	Good	$5K++ (MGES)
Auto-stereo*	Good	Fair/Good	Good	Fair	Good	$5K++ (MG-S)

* Not readily available in early 2008 at project start.
** Entrance Cost includes any of: stereo-capable monitor (M), high-speed monitor or graphics card (g), stereo-capable graphics card (G), specialized eyewear (E), specialized playback software (S).

As discussed, both anaglyph and active shutter systems have very low entrance costs and suitable stereo quality. However they are not optimal for long term viewing because of eye fatigue and recurring discomfort whenever looking away from the stereoscopic display due to the filtering mechanisms unique to each eye. For anaglyph, the unique filtering of red and cyan per eye also results in poor color quality. Filtering is more subtle for active shutter, but some artists report sensitivity to the “flipping” of the active shutters during extended wear. Active shutter also requires a battery which can run low with extended viewing and impede the switching action which causes discomfort and extra maintenance. In addition, at the time, active shutter generally required heavier eyewear than other technologies.

Passive line-interlaced and full-resolution devices utilize either linear or circular polarization. Linear passive systems filter each eye with perpendicular polarization which causes discomfort when looking away from the stereo monitor. Circular passive systems utilize clockwise/counterclockwise polarization which generally does not cause discomfort when looking away from the stereo monitor. Auto-stereo has the advantage of no eyewear but is horizontally line-interlaced so viewing angle depends on horizontal resolution and number and quality of horizontal viewing zones.

3.3 3D Viewing Selection

Circular passive full-resolution technology was particularly appealing because of its high stereo quality and long-term viewing characteristics. But at the onset of the project only theatrical systems and a few dual monitor desk-side devices were available and they did not meet the desired size and/or cost requirements. Therefore, the engineering team, spearheaded by Disney design engineer Ron Gillen, took on the challenge of designing and building a circular passive desk-side device to meet those requirements and provide 3D viewing for the "stereo composing" workstation.

4. PROTOTYPES AND EVALUATIONS

The first prototype targeted full resolution, highly accurate circular passive stereo 3D viewing with a viewing area large enough to imitate the depth sensitivity of a full size theatre screen. This lead to a comparison between projector-based designs and LCD monitor-based designs. Although a projector-based system best emulated the theatre experience, it became clear that the space requirement to install several of these stations was prohibitive. It was also clear after a few tests that the alignment of a projector-based system could be difficult to maintain. By contrast, a method was imagined for a sufficiently large, full resolution monitor-based system with simplified alignment methods.

4.1 Dual Monitor Prototype #1

The fundamental design of the system used beam-splitter glass in a technique similar to teleprompter systems. As shown in Figure 4, two display devices, in this case LCD monitors Display A and Display B, are secured in a position at 90 degree angles to each other and facing inward. Display A displays the left eye image and Display B displays the right eye image, horizontally flipped. The viewing area extends straight out from Display A. A pane of beam-splitter glass with anti-reflective coating facing Display A and mirrored coating facing Display B is installed between the two monitors at a 45 degree angle to each. The image from Display A passes directly to the observer through the glass while the image from Display B is mirrored and reflected to the observer. This results in a composite of the two images. In order to separate the left and right eye images, circular polarization is applied to each image, one clockwise and the other counterclockwise. Because LCD monitors already have linear polarization, circular polarization can be achieved by applying a quarter-wave plate on the LCD panels of each device. The mirror will flip the polarization to achieve the correct clockwise/counterclockwise polarization between left and right and the observer will perceive stereo depth when wearing circular polarized eyewear. A rendering of the proposed device can be seen in Figure 5.

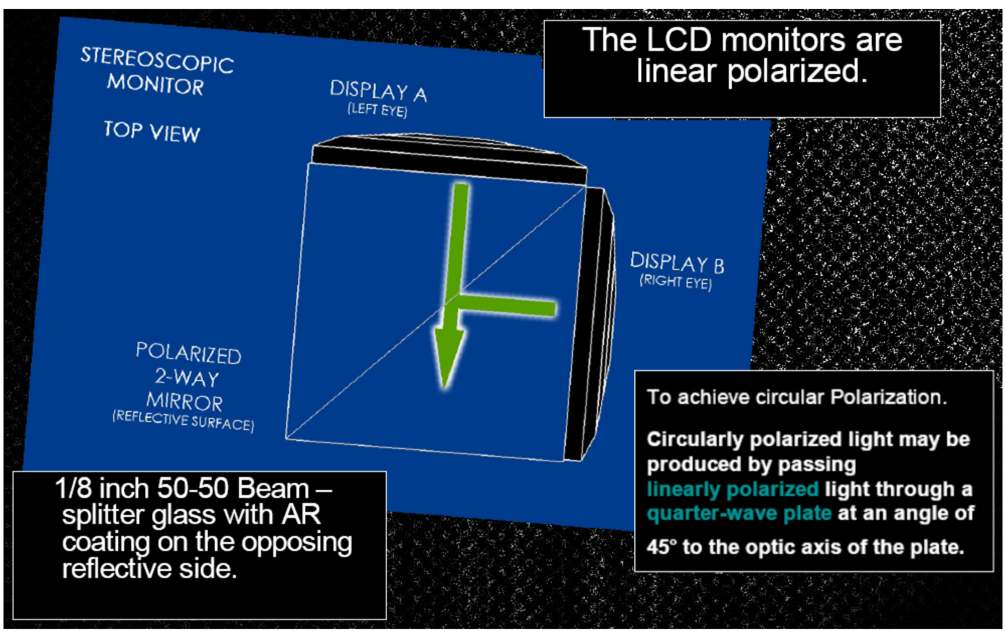

Figure 4. The circular passive prototype used beam-splitter glass and reverse polarized images from two precisely aligned LCD monitors for stereoscopic viewing. Courtesy Ron Gillen. Image copyright 2010 Disney Enterprises.

Pixel-for-pixel accuracy between the composited left and right images was achieved using an alignment mechanism inspired by automobile headlight adjustors. Small screws were installed behind each corner of the monitors as well as the beam-splitter glass allowing them to be tilted in any direction in fine increments. In addition, both monitors could be shifted and locked side-to-side in a running track for proper horizontal alignment. For best results, with a test grid displayed on both monitors, one monitor is positioned in a neutral position and the other monitor is adjusted side-to-side for horizontal alignment. Then, that second monitor is tilted appropriately using the "headlight adjustment" screws for final vertical and perspective alignment. If necessary, the beam-splitter glass could also be adjusted.

Figure 5. A rendering of the dual-monitor stereo device shows left and right monitors with beam-splitter glass between. Notice the right eye image is flipped horizontally. Image copyright 2010 Disney Enterprises.

To complete the design for the "stereo composing" station the artist workstation needed to feed the left and right eye images to the device through its graphics card and in-house and 3rd party software. This required two quad-buffered monitor outputs from the graphics card. In addition, because the output from the right monitor is reflected, the right eye needed to be flipped horizontally before output. Dual-output, quad-buffered graphics cards were typical for high-end computer graphics workstations at that time. Therefore, the configuration was achieved by adding a low cost single output graphics card to feed the primary 2D software "composing" monitor while the dual-output card fed the stereo 3D device. The engineering team then collaborated with high-end graphics software providers to add stereo output to their device drivers and display windows. By SIGGRAPH 2008[8] in August, several commercial computer graphics software companies were reporting stereo output capability. The capability spread quickly within months.

4.2 Dual Monitor Prototype #2

Prototype #1 was utilized for three *Beauty and the Beast* stereo conversion tests - a shot each from the ballroom sequence, finale and opening song - leading to final project approval. Two 28" LCD monitors were used which provided sizeable stereo viewing analogous to the stereo quality observed in the theatre. The device also provided outstanding long-term viewing comfort, viewing angle, image resolution and color quality. It's only drawbacks included nominal image bleeding related to the thickness and reflectivity of the beam-splitter glass and an overall footprint that remained fairly large. Therefore a second prototype was devised using smaller 19" LCD monitors. This version could be mounted above the desk or be kept to the side. The device had the same advantages of Prototype #1 except for slightly reduced stereo quality as compared to stereo viewing in the theatre. Figure 6 shows both the 28" and 19" prototypes located to the left of and above, respectively, the primary software monitor and comprising the "stereo composing" workstation.

4.3 Commercial 3D Viewing options – 2008/2009

Starting in mid-2008, several new LCD-based commercial stereo devices also became available. In sizes ranging from 17" to 46", these devices featured either linear or circular passive polarization that reversed on alternating scan lines.

The scan lines from the left and right eye were then interlaced per frame to line up with the polarization providing stereo output but effectively cutting the vertical image resolution in half. While this caused degradation of the image for all 17” to 24” devices, those devices capable of one-to-one pixel resolution of 1920x1080 or higher faired better than those with lower pixel resolution. It was also found that the degradation was much less apparent for 46”+ devices. Further evaluation revealed that the smaller LCD devices also had a limited vertical viewing angle. This characteristic varied greatly between manufacturers and did not necessarily reflect the price of the units. Viewing was sufficient in the “sweet spot” in front of each monitor, but positions sometimes as small as 15 degrees above or below center caused pixel discoloration, banding or even reversed stereo polarity.

However, as shown in Table 1, all of the devices demonstrated very accurate and adequate stereo quality and good color quality. Moreover, the devices benefited from lower entrance cost as compared to the dual monitor full-resolution prototype systems, falling quickly between $300 and $2000 for 17” to 24” units. In addition, circular interlaced devices required only one graphics card output because the alternating scan lines are combined and output through one connection. This eliminated the need for the second graphics card in stereo workstations. By the end of 2008, several of these commercial devices became realistic options.

Figure 6. “Stereo composing” workstations were created using 28” Prototype #1 desk-side (a) and 19” Prototype #2 overhead (b) to closely mimic theatrical viewing quality. Images copyright 2010 Disney Enterprises.

5. FINAL CONFIGURATION

As has been shown, there are a number of criteria for consideration when defining effective stereo 3D viewing. Each production should analyze those criteria based on their specific needs. For the magnitude of stereoscopic 3D work required for *Beauty and the Beast 3D,* it was decided that the most vital qualities were stereo quality and long-term viewing comfort. Once those requirements were successfully met, cost, image resolution, viewing angle and color quality influenced the final decision for each unique stage of the pipeline. In this case, the research revealed that circular polarized devices provided the best long-term viewing comfort and that the full-resolution prototype devices and several of the line-interlaced LCD devices exhibited good stereo quality. Therefore, the choice was made to take advantage of the low entrance cost of 22” LCD circular passive line-interlaced devices for the numerous artist “stereo composing” stations and the improved viewing angle and pixel resolution of 46” LCD circular passive line-interlaced devices for the centralized review stations.

Though the stereo quality and image resolution of these devices was not as high as the large 28” full-resolution prototype device, artists were given stereo feedback far more effective and comfortable than the previous anaglyph red/blue and active shutter solutions. In short time, artists were able to "mentally calibrate" the translation between stereo quality on the LCD devices and that of the final theatre presentation. In addition, for the desk-side configurations, artists were generally able to find and maintain a viewing angle in the "sweet spot" of the device. These devices complemented full-resolution theatre viewing and proved an important tool for the successful 2D to 3D conversion of *Beauty and the Beast*.

6. FUTURE REQUIREMENTS

Just as the viewing technologies described here evolved quickly over the duration of this project, the specifications continue to grow and mature and new technologies are emerging. It is hoped that improvement continues in a number of areas and that advanced solutions are developed offering new benefits to stereoscopic viewing and production.

6.1 Continued Evolution

As an initial target, it is believed that the optimal device would offer full image resolution for each eye with at least a 45 degree above/below center viewing angle, and maintain the LCD-like footprint and price point well below $2000. In addition, stereo quality for these desk-side devices should continue to improve in the areas of more discernable depth values and dynamic range, elimination of cross-talk, and direct correlation to the stereo quality of cinema systems. Long term viewing will benefit from advancements such as non-tinted lenses (eliminating brightness and color degradation) non-reflective lenses, prescription lenses, and fitted eyewear. Auto-stereo devices with adequate viewing zones would also provide excellent long-term viewing if such devices became practical for office, home and theatrical viewing.

6.2 Future Innovation

Promising new technologies are emerging that utilize alternative methods to portray binocular disparity or advanced display technologies including laser and hologram-like devices. These technologies are encouraging and will also be evaluated using the criteria in Table 1. In addition, it is hoped that future stereoscopic display devices will be aware of the depth characteristics of the images it displays. In the home this would allow viewers to adjust depth just as they now adjust color. For the stereoscopic artist, this information could feed various on-screen depth evaluation tools.

ACKNOWLEDGEMENTS

The author would like to thank the 3D display team of Ron Gillen, Bert Faerstain, Rik Bomberger and Jeff Sickler and the process development team of Evan Goldberg, Matt Schnittker, Joe Longson and Kimberly Rios for their remarkable work and engineering talent. Many thanks also to Jim Hurrell, Elena Driskill and Lewis Siegel for their contributions. For the numerous evaluation units thanks to the Resources team of John Readick and Natalie Acosta and from Disney Home Entertainment, Mike DeValue. And finally, to Robert Neuman, Stereoscopic Supervisor, and the sequence leads, artists, technologists and production management team of *Beauty and the Beast 3D* many thanks and great work!

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