3D Animation in Three Dimensions

(The Rocky Road to the Obvious)

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ABSTRACT

That animation created using CG modeling and animation tools is inherently three-dimensional is well known. In the middle to late nineties IMAX Corporation began actively exploring CG animated features as a possible source of economically viable content for its rapidly growing network of stereoscopic IMAX® 3D theatres. The journey from there to the spectacular success of the IMAX® 3D version of The Polar Express is an interesting mix of technical, creative and production challenges. For example 3D animations often have 2D elements and include many sequences that have framing, composition and lens choices that a stereographer would have avoided had 3D been part of the recipe at the outset. And of course the decision to ask for a second set of deliverables from an already stressed production takes nerve. The talk will cover several of these issues and explain why the unique viewing experience enabled by the wide-angle geometry of IMAX® 3D theatres makes it worth all the pain.

INTRODUCTION

In late 1995 during the early development phase of our 3D dinosaur film **T-Rex: Back to the Cretaceous** I had been discussing the difficulty and expense of narrative driven and effects heavy films in our format with then head of film Jonathan Barker. In the evening of that same day I took my son to see the just released **Toy Story** from Disney and Pixar, and sitting in the theatre had the sudden epiphany that here was a 3D movie already made and sitting on tapes ready to explode off the flat surface on which it was contained by the simple act of pressing the render button again with the camera moved over slightly. This rosy view of the simplicity and apparent ease with which I imagined we could give new life in IMAX® 3D to already great films was soon tempered by experience. There is a quote that says "experience is something you get just in time for it to be too late to do you any good" but in this case it came too late for it to do any harm because I pitched the idea to Jonathan the next day, emphasizing how easy and inexpensive it would be to do. Jonathan relayed this to IMAX Corporations co-CEO's Rich Gelfond and Brad Wechsler who were intrigued enough to allow a small budget to be allocated to exploring the idea.

It was also around this time that IMAX Corporation began a relationship with Mainframe Entertainment in Vancouver, initially through our Ridefilm division. They agreed to help out with some early proof of concept tests and so a short clip of the **Reboot** villain "Megabyte" punching out through some glass at the audience (Figure 1) became the first experiment. Instead of just rendering a second eye we decided to go back into the animation and set up the camera(s) to emulate the stereo parameters we'd choose if we were shooting a real scene with a real IMAX® 3D camera.

Figure 1 - **Reboot** test.

STEREOSCOPIC GEOMETRY

In stereoscopy, one needs to be mindful of the geometry in which the audience will experience the result - in fact stereographers go to work armed with formulae that provide geometrical mappings between the space in front of their camera to the space delivered by the exhibition geometry. If you are watching 3D on a standard size TV from across the room, for example, it's pretty obvious that you can only bring small things (or miniaturized

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large things) into the space between the TV screen and yourself. Most of the action is placed into a space behind the screen which serves as a window into a 3D world. At the other end of the size scale, in an IMAX® theatre geometry for example, you can pretty much subvert the entire volume of space in the theatre and replace it with an accurate representation of the space that was in front of the camera (Figure 2). This near orthostereo "you are there" immersion has been our predominant stereo philosophy at IMAX® throughout the development of 3D cinematography at the company.

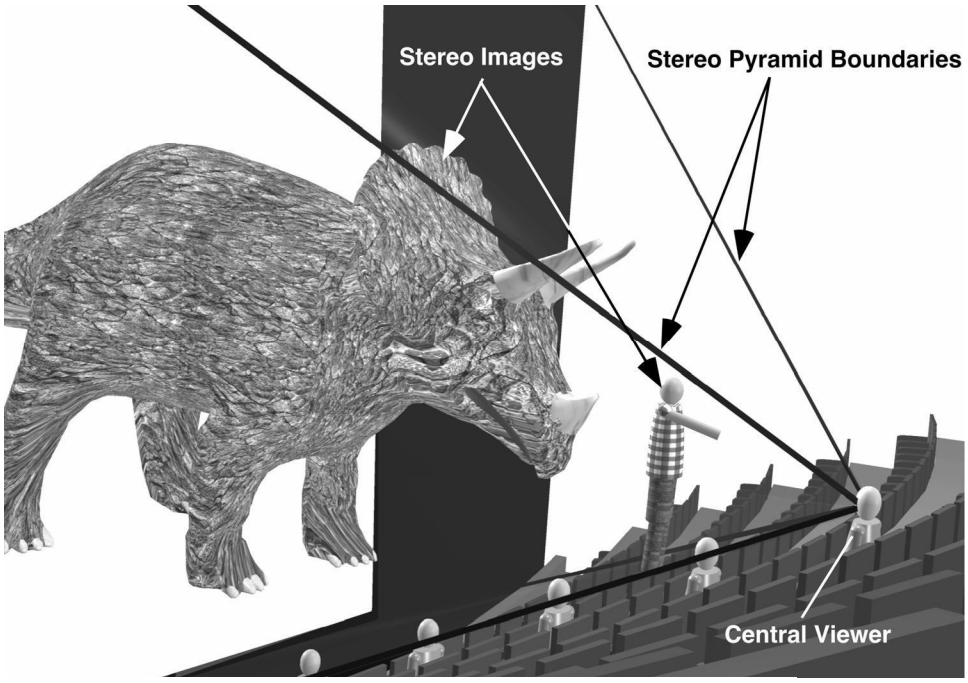


Figure 2 - IMAX® Stereoscopic Pyramid.

The stereography is conceptually much simpler: match the wide angle perspective as closely as you can, keep the two cameras parallel, scale the modeling space with an appropriately chosen camera spacing, be cognizant of the physiological close approach limits - do all of this and you have stereoscopic images that will work well in any IMAX® theatre. Since most of what we shoot/render in 3D is with parallel cameras it follows that we are not trying to establish a stereo window in our compositions, and since that runs counter to the common paradigm in stereo imaging I'll point out again that it's really just all about size. The negative parallax space between the audience and the screen is a pyramid with the screen as its base and the viewer as the apex. In an IMAX® theatre this pyramid is of a size that allows fully scaled virtual worlds to share the theatre space with the audience, an option that is not open to smaller venues.

But although most IMAX® 3D shots have no positive parallax on film, our theatres are aligned with a built-in ~65mm screen divergence. Subjects with zero film parallax get pushed, geometrically at least, to stereo infinity for viewers with the average adult eye spacing.

Some other large format 3D productions have chosen to use camera convergence in the more conventional way, and as a purely stylistic choice it becomes part of a natural and healthy creative exploration of the medium - even if I personally don't find it as interesting. The problem for audiences arises when camera convergence is deployed without attention to the headache-inducing symptoms of excessive positive parallax, the dreaded and all too common wall-eye. One advantage of shooting 3D with parallel cameras, if the frames are ever in digital form, is that a post-production shift can be used to make the stereoscopy accommodate smaller screen venues. The reverse is usually more challenging.

The convergence issue is the topic on which I'm most often challenged. It is a debate that flops back and forward across the divide between the purely technical and physiological, and issues that have to do with style and history and precedent and, of course, the usual sterile arguments from authority. Stereoscopic cinema is an artistic medium, but is unique in

allowing the filmmaker to challenge the audience in a physiological sense, to force them to do unnatural and painful things with their eye muscles. Do no harm should be the only rule.

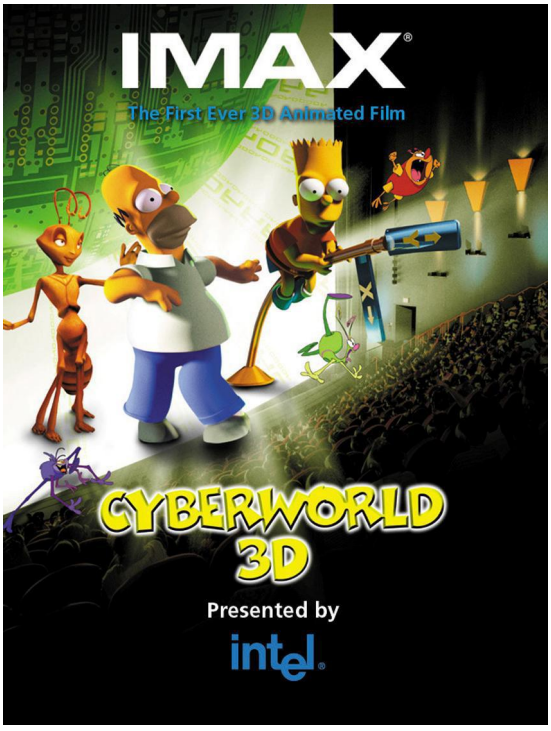
PROOF OF CONCEPT TESTING

Figure 3 - **Sign Of The Seahorse** test.

The Reboot test stimulated enough interest at both IMAX and Mainframe to want to produce a test with a more visually sophisticated piece. Mainframe was then in development on a project called **The Sign of the Seahorse** based on the children's book of the same name by Graeme Base. A few scenes had been taken through to final lighting and we set about creating IMAX® 3D versions of these. It would be difficult to overstate the importance of this test, especially one scene set in an underwater cave with "Pearl" a pink trout who was the heroine of the story. Figure 3 shows a frame from the sequence. There are only two light sources, the glow fish accompanying Pearl and light filtering through from the cave entrance in the distance, the top and sides of the frame rolling off into darkness. Pearl turns briefly to the camera and then swims away towards the entrance. When screened in a full size IMAX® 3D theatre, this frameless depth of field free space enveloped the audience and evoked a remarkable sense of presence in this completely virtual world. IMAX® as a company was convinced that this was a direction worth pursuing.

In parallel with these tests we had been trying to convince some major computer animation studios to consider their feature film projects as candidates for an IMAX® 3D release. Several very polite meetings later however we had still not elicited enough interest to get the right people into a screening. We were convinced that once the creative leads had seen just how compelling their work would look in this medium we'd be trampled in the rush, and **Cyberworld**, a film designed specifically to showcase the concept, was to be our trigger for the stampede

CYBERWORLD



Originally conceived as a low budget demonstration exercise, **Cyberworld** (a title that was not settled on until close to release) would consist of a collection of existing CG animated shorts rendered into stereoscopic 3D by the original creators of each piece. The contributors to the film were to become partners in its production. At a Birds of a Feather meeting at the 1997 LA SIGGRAPH we showed the **The Sign of the Seahorse** test and called for interested contributors, whether individual animators or larger companies, to send us short standalone clips for consideration. By early fall of that year we had over 200 tapes and some remarkable animation to choose from. Ironically, **Sign of the Seahorse** was not developed further and so never had a sequence long enough to be a stand-alone clip in **Cyberworld**.

Steve Hoban, an independent producer and good friend joined me in putting together a production team based in Toronto. A key event was convincing 20th Century Fox and Matt Groenig and Pacific Data Images (PDI) to allow us to include the Simpsons 3D sequence from the Treehouse of Horror VI. The ambition and importance of the film notched upwards.

Eight separate animation companies in England, France, Germany, Japan, the US and Canada, contributed to the final film with pieces that covered the complexity gamut from clever solo projects like **Monkey Brain Sushi**, animated at Sony Imageworks by Brumbauer, to the feature-level animation comprising the five minutes from **Antz** contributed by Dreamworks and PDI. The goal for each selection, as with the earlier tests, was to create a stereoscopic version that was close to an orthostereo mapping into IMAX® theatre space, and to reframe each piece to fit the aspect ratio of a 15perf, 70mm film frame. Working shot by shot, the procedure was as follows:

- In the original animation files, change the aspect ratio of the camera/viewpoint to 1.4:1.
- Adjust the focal length to get a horizontal field of view between 75° and 80° to match the center row perspective in a typical IMAX® 3D theatre. Animation is frequently rendered with long focal lengths that crush depth and so this step usually makes the entire scene suddenly recede into the distance - so the next step is:
- Move the position of the camera to reframe for a good IMAX® composition.
- Create a second, horizontally separated, camera and choose camera spacing (interaxial, interactual and interocular are often used interchangeably for this parameter) to scale the scene as desired. If the scene has characters, human or otherwise, whose scale is to be preserved then the camera separation should be the equivalent of the average human eye spacing, or ~65mm scaled into the modeling units of the animated scene.
- Render the left and right eye at "high" enough resolution. For **Cyberworld** our target going in was to have everything rendered at least at 3K horizontal, and then we interpolated to 4K for film recording. Not all companies were able to go this high, especially on some of the older pieces, but nothing was rendered at less than 2K.

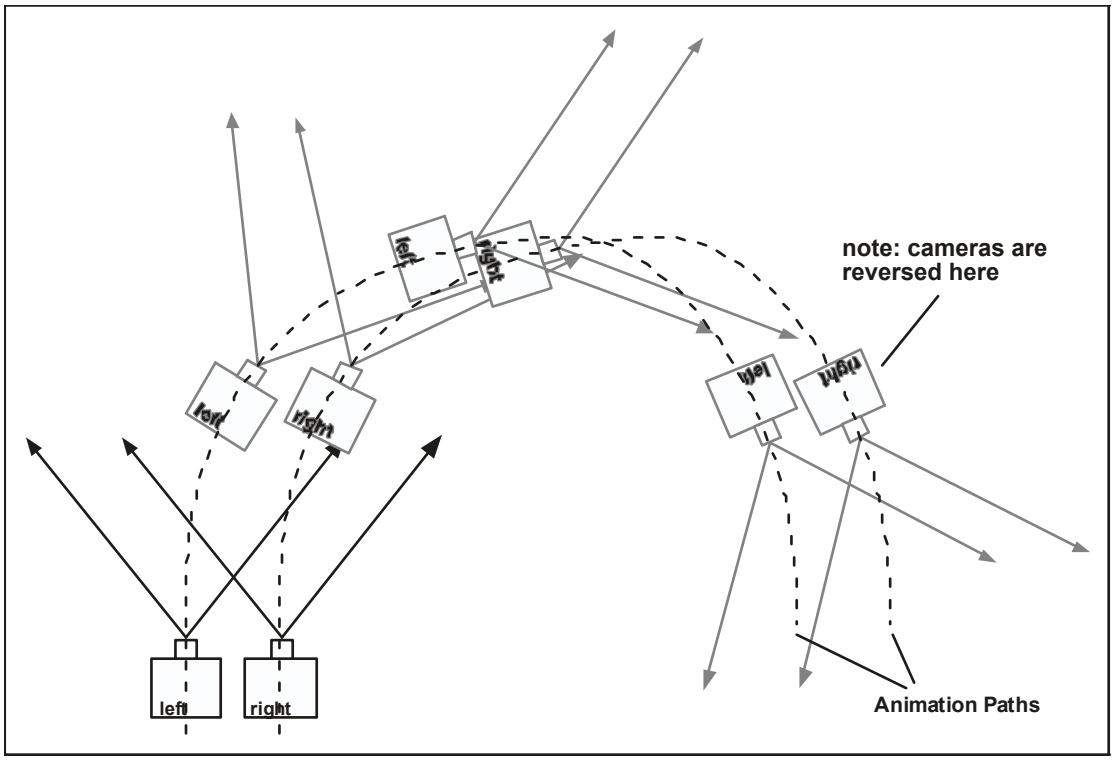


Figure 4 - Cloning Animation Paths.

These operations were just the starting point – every individual shot can (and most often do) have issues that require further interventions. All of the tests we had conducted previously had locked camera positions, and camera motion can cause serious problems if you simply clone a second camera with all of the animation curves still attached.

Figure 4 shows how disastrous it can be for each camera to be following horizontally shifted versions of the same animation if the cameras are rotating to have their direction of view always point along the direction of motion. As the cameras progress they begin to separate, change spacing, and even switch places so that right becomes left and vice versa.

A related issue is what happens if the camera motion includes a tilt or rotation around the direction of view as shown in Figure 5. This has the effect of vertically separating the two camera images, and therefore the on-screen images.

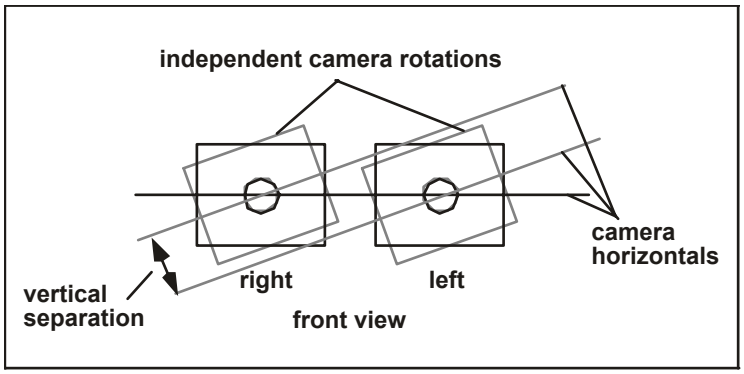


Figure 5 - Camera Rotation.

Cameras need to stay locked in a relative position that mimics a real 3D camera, and the strategies for doing this vary with the animation package in use.

Since all of the sets and the characters in an animated scene have to be painstakingly built out of geometric forms, only things that are actually likely to be in view are built, and only the parts of characters that you are going to see are animated. Changing the field of view as massively as was usually the case with the pieces in Cyberworld meant that many sets had to be filled out, lighting of scenes had to be re-addressed, and some new animation performed. The best example of this was in the five minute clip from Dreamwork's ANTZ. The two sample frames in Figure 6 show the difference between the original framing (in the red box) and the framing for Cyberworld (the full image).

In this case the set was fairly complete because there were a lot of shots inside the "bar" at the ant colony, but in the shot at the left Z (voiced by Woody Allen) and Princess Bala (voiced by Sharon Stone) are seen in the original only from the waist up, so the leg movements were never animated and had to be so for the reframed version.

The frame on the right in Figure 6 also illustrates another very common issue – a framing where the foreground characters are part of frame within a frame to direct your attention into the shot. Characters like this are often so close to the camera that they would be difficult to fuse in 3D if shot with the default camera separation, and since people are not strongly sensitive to brief changes in camera separation, the fix for situations like this is to reduce it until the shot is comfortable to view. One of the things we learned during Cyberworld is that animating the camera separation can get you out of a lot of stereo comfort binds, as well as being a useful tool for effects, like large changes of scale.

An issue that is especially important for foreground objects in 3D is depth of field. This is a property of lenses that you can't avoid when shooting with a real-world camera and has become part of the grammar of film as a device to suggest depth and to define or change where the director wants your attention. In CG animation, depth of field is something that is added to emulate the look of film, but in 3D there is no need to "suggest" depth and because a 3D image sets up the illusion of real space, depth of field can seem more like pathology than grammar. For animation to be presented in 3D it's better to turn it off altogether, but because things in the real world tend to soften out in the distance for atmospheric reasons, soft backgrounds are much less objectionable than soft foreground.

Many CG animations have 2D elements - painted backgrounds are common and even some foreground elements in shots where camera motion won't reveal them. 2D backgrounds are rarely obvious as such in shots rendered into 3D if they

are composited into the scene with zero parallax, but 2D foreground objects need to be fixed either by replacing with real geometry or, and more commonly, by wrapping them as textures on to some simple geometry.

At every stage of this process the decisions about what to invest time on are driven entirely by judgment calls on what works for the particular shot. Have we squeezed the most intimate, compelling 3D possible out of the set-up? Is it comfortable and visually clean (i.e. no obvious artifacts)? During the Cyberworld production a few of the contributors set up small stereoscopic screening rooms so that they could see their work as they went, but most of the decisions happened at IMAX's Technology Centre outside of Toronto where we had a very good 3D digital screening room, with couriered tapes and me flying from place to place serving as a conduit for the learning that was going on in every location. This was a system that worked only because we were on a relatively relaxed schedule, and all future projects have depended on a good in-house digital 3D screening room with free access for the digital artists working on shots.

With the various segments loosely connected by an original animation from SPIN Entertainment and directed by Colin Davies, **Cyberworld** was released in November 2000 and is still playing in some IMAX® 3D theatres. It has grossed nearly $27M which is an impressive showing for what started as a technology demonstration project. More importantly it taught us that while taking high quality computer animation to IMAX® 3D was not as straightforward as I had naively imagined at the outset, it was not nearly as difficult as most of the contributors initially thought it was going to be.

The visual success of Cyberworld did not have the worlds major animation studios rushing their flagship projects into IMAX® 3D quite as quickly as we'd hoped. There were a lot of discussions and lots of financial modeling, and several possible projects came close but were ultimately passed. Every cutting edge CG animated film pushes the boundary of the possible, of the artists, of the software tools, of the physical infrastructure. Attaching the increased demands of a high-resolution stereoscopic version to be generated contemporaneously is asking a lot of even the most courageous producer, and given that at the time we were still wedded to the idea that it was necessary to reframe everything and render two new high resolution frames for every frame of the original production, the reticence was probably well founded. There were also debates about the likely final cost of doing something that no one had yet tried and proposed budgets tended to be well padded to reflect the uncertainty.

SANTA VS THE SNOWMAN

Steve Oedekerk, the incredibly prolific comic writer, producer and director was the first to take the plunge with **Santa vs. the Snowman**, an animated holiday special produced for television in 1997 and directed by John Davis. This was also the seed project for a new animation studio that Steve had set up in San Clemente and when I arrived in April of 2001 to help get the project going the entire infrastructure of a CG studio was still being installed. The approach was identical to **Cyberworld**, re-lensing and reframing all of the shots etc., except that everyone was in the same room and it was all on one software architecture (LightWave 3D).

The approach to changing the field of view in a scene usually starts by looking at the set-up for a shot from a top view and guessing at a new

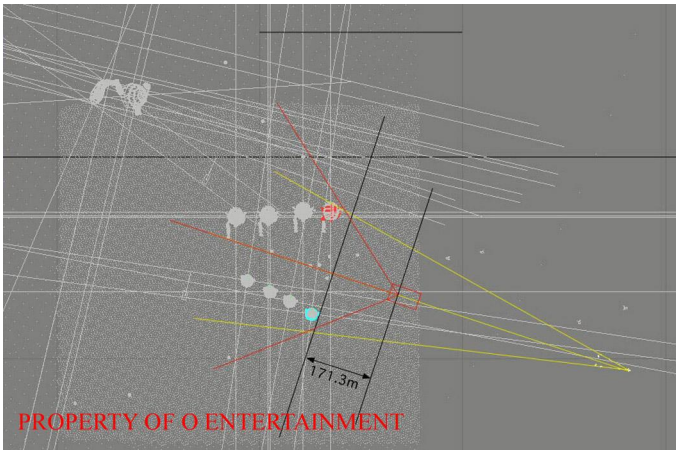
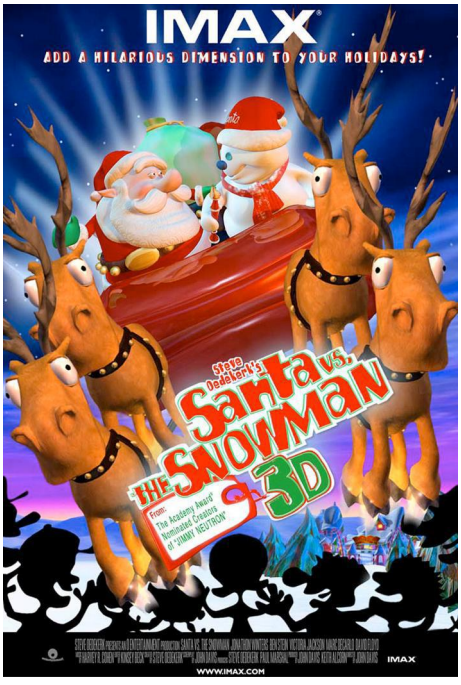


Figure 6– Changing the field of view.



position for the wider camera that gets as close as possible as the director's original intent for a shot. The screen grab in Figure 6 shows an example in which the yellow lines indicate the original camera field of view, and the red lines the IMAX® wide angle view.

Figure 7 shows what the before and after rendered frames look like.

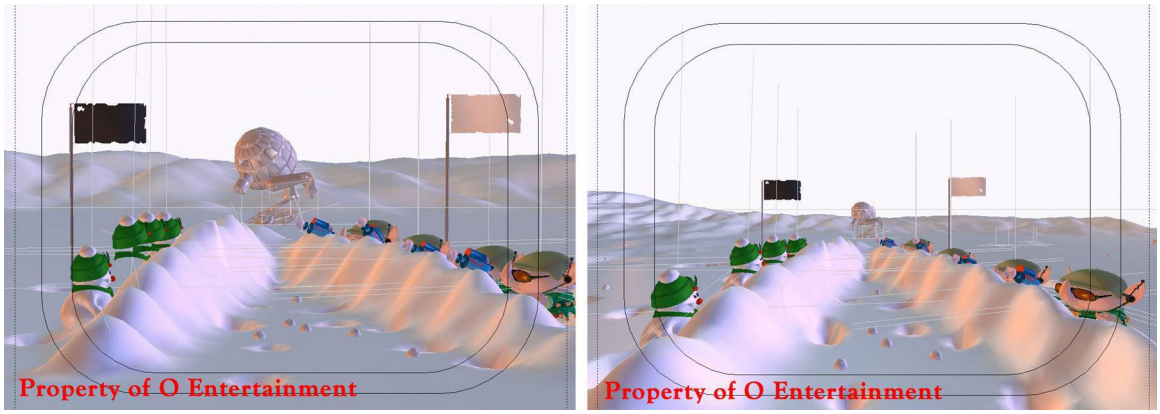


Figure 7 – Before and After field of view change.

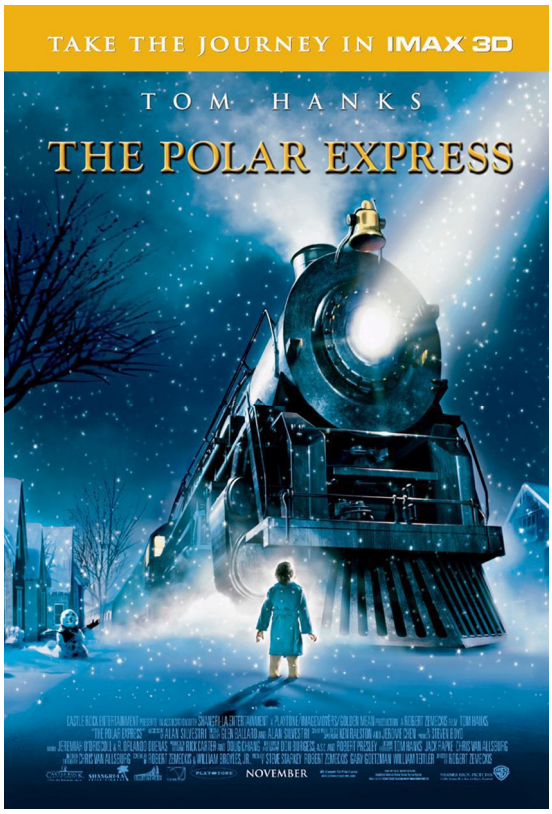
Once that's done you look at what else may have been "broken" by the new field of view. The revealing of non-existent sets or non-animated characters has already been mentioned. In this scene note that the threatening igloo "walker" has been taken far back and away from the action in the new perspective, a problem that was fixed in this shot by moving the animation path of the walker closer to the camera.

I mentioned earlier that one of the discoveries during **Cyberworld** was that we could freely animate the camera separation to keep the stereo comfortable without audiences being aware that anything unusual is happening. In **Santa** there were a lot of shots where we did this - over-the-shoulder shots, camera moves through scenes where foreground objects got very close etc. were finessed with animations in camera separation. I think that once you have established a 3D space there is a perceptual continuity that wants to hold on to the current interpretation of parallax cues for an amount of time that varies with the degree of variance from the average. I'm not sure if this has been studied by anyone, but if not it might make a good R&D project.

Santa vs. the Snowman was released for the 2002 Holiday season, and has continued to play at several IMAX® theatres around the world at this time of year, including again in 2005.

During the same period as these animated projects were produced, IMAX® had also been working hard on the digital enhancement of 35mm feature films to the point where they could be successfully recorded on large format film and deliver a much richer visual experience than the original version. This system rolled out under the name IMAX® DMR and the majority of the films released this way have been day and date releases of Warner Brothers projects. It was natural then that when in 2003 Rober Zemeckis' **The Polar Express** started production there would be conversations about the possibility of a simultaneous release in IMAX® 3D. The breakthrough had come at last.

THE POLAR EXPRESS



The Polar Express is a film in which all of the action, including facial expression, was motion captured on a sound stage and then that data imported into the CG environment at Sony Pictures Imageworks to drive the animated characters through the warm, painterly world illustrated in Chris Van Allsburg's book. The workload for the IMAX® 3D version was therefore going to fall on Imageworks, but of course there was some convincing to do first.

The first tests happened in late summer 2003 at a time when there were no shots completely finished, but there was one short sequence that had been finished "enough" to serve as a character finish and motion illustration for the director. This was from the scene where the sleeping hero boy hears the train and gets up to look out of his bedroom window. In this early phase the strategy of reframing and changing the aspect ratio still seemed like a good starting point, so one of the goals of the early tests was to find out what would be involved as well as to let Robert Zemeckis see what the 3D version might be like. The people at Sony Pictures Imageworks were helpful and cooperative, and even though they were rightly nervous about the whole proposition they made me very welcome at their facility as we set up this first test. Figure 8 shows sample frames from the sequence in their original aspect ratio.

One part of the first test was to use the existing frame as one eye and render the second eye using a camera offset (being mindful of all of the camera motion gotcha's mentioned above). The action in this film was shot on a stage and the Director chose lenses whose focal lengths give much wider fields of view than is common in animation. It was decided that enlarging the field of view even more would add an almost gratuitous level of complexity to the project, and so we confined the second part of the test to opening up the aspect ratio to match the IMAX® frame. We then had to render both left and right eyes. The reframed shots are shown in Figure 9.

Figure 8 – First test frames from **The Polar Express**

The wide shot in the bedroom shows one of the common problems, missing scenery – in this case a large unadorned wall space and no ceiling. Even as we screened these tests for Robert Zemeckis, the production staff at Sony were warning that such a massive change to shots would make a simultaneous release very problematic.

Figure 9 – Test frames at 1.43:1 aspect ratio

These tests were followed by a couple of months of scheduling and budgeting during which it became apparent that creating a 3D version with the current framing was going to be very challenging and that going back and revisiting each shot was not a practical option. The production group also raised a concern that the test we had done was very tame in terms of camera motion and that there might be a strobing issue in IMAX with other, more typical sequences. To address these concerns and to provide a dry run using the procedures that Sony planned to use if the project was green-lit, a second test was designed around a very fast motion sequence.

In this sequence the hero boy pulls the emergency brake to stop the train to allow the hesitant lonely-boy character to get on. The cutting is fast and there is a whip pan inside the carriage. There is also a pull back through the emergency brake handle as illustrated in Figure 10 where we had to do some quite extreme animation of the camera separation. The sequence suggested by the production had four shots, but it was followed by a shot in which the train comes straight at camera and which I asked Sony to add as a cleaner ending. Figure 11 shows the first and last frames of that fifth shot.

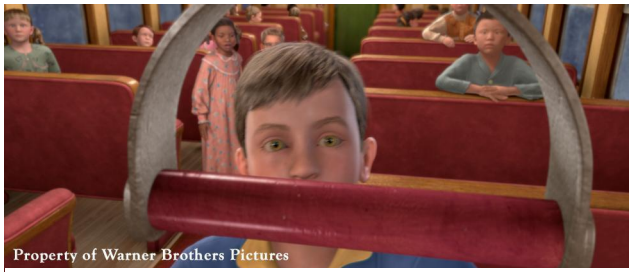


Figure 10 – **The Polar Express** strobe test

In 3D the business end of the cow-catcher stops a few feet from your nose and when we screened this for Robert Zemeckis in March 2004 he turned in his seat as it ended and said "I think you guys are going to be busy". Strobing was not an issue, the 3D was magic and we had our green light.

Sony Pictures Imageworks assembled an IMAX® team headed by Producer John Clinton and with CG Supervisor Rob Engle as my primary interface for the stereography who became if anything even more of a perfectionist than I am. The rules of engagement for this team were to operate strictly independently of the main production - the IMAX® 3D version could not be allowed to jeopardize the primary schedule. Rob figured out effective fixes for all of the elements that were two dimensional in the original version – a 2D swirling snowstorm mapped on to a three dimensional cone being one of the more complex and completely transparent fixes.

Figure 11 – The clincher!

The goal was to try and use as much as possible of the material that had already been rendered as one frame in the film as one eye of the stereo pair. The exceptions were shots that needed both eyes re-rendered for one of a number of reasons: foreground or midground depth of field issues, shots that looked "off-center" in 3D, and shots that had 2D cheats that needed to be attached to geometry to work in 3D for example. Sony had set up a small digital 3D screening room aligned to infinity convergence per the IMAX® spec which gave them a place to see stereoscopy as the audience would and a place for approval screenings.

A series of film output wedge tests demonstrated that the image quality was more than holding up to the interpolation to large format. **The Polar Express** was rendered and delivered to IMAX at 1828 x 778 where it was taken to 4096 horizontal pixels and run through the IMAX DMR® sharpening tools before film recording by DKP 70MM Inc., IMAX Corp's wholly owned post-production facility who also handled all the film post through to print production.

3D approvals at the digital screening room at Sony were in two phases – a stereo camera approval based on flat shaded versions of the shots and finally a fully finished pre-delivery approval as shown in Figures 12 and 13 respectively.

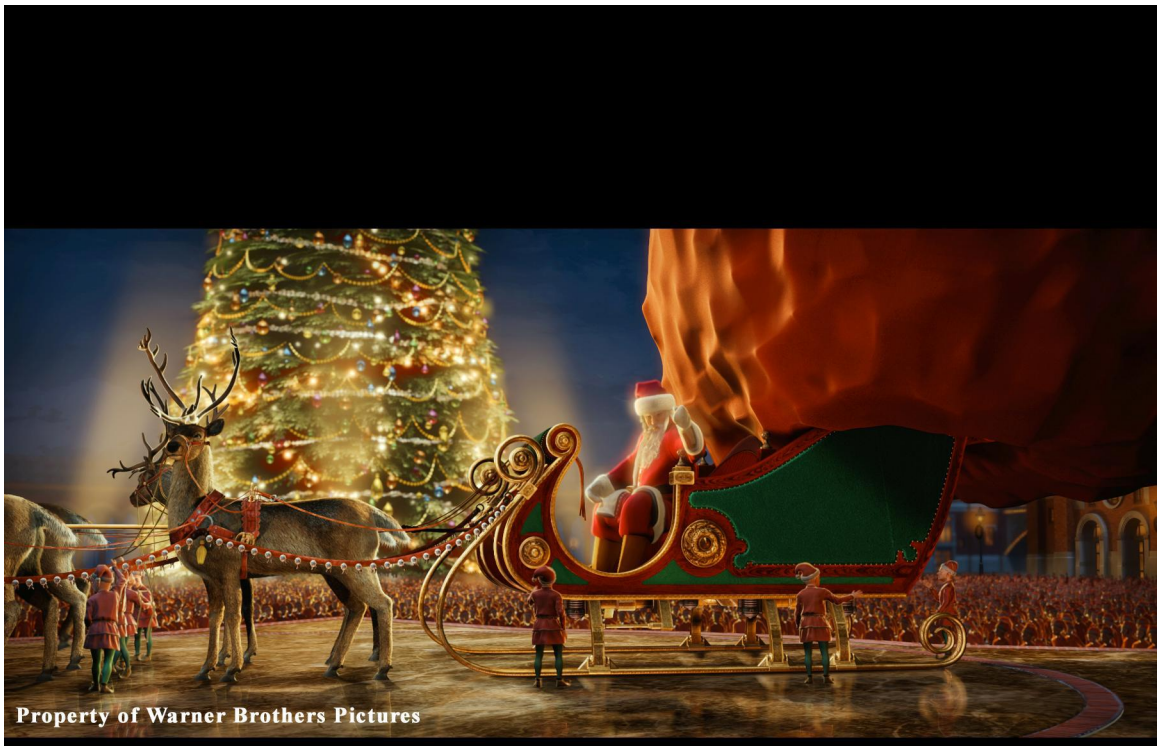
Figure 12 – Flat shaded "camera" approval frame.

Figure 13 – Final render approval frame.

The Polar Express was a remarkable achievement, with the team at Sony Pictures Imageworks creating optimal stereoscopic versions of 780 shots in just five months, and the team at DKP 70MM Inc. processing and recording nearly 300,000 4K frames in a few weeks.

The 2.4:1 frame was placed within a 1.43:1 IMAX® frame offset down from the centre to bring the horizon into line with large format theatre seating geometry. The impact of the letter-boxing on the experience disappear within seconds of the film opening. I have watched the film with people who didn't notice. Reviewers raved about the sensation of being

actually **in** the movie and the added authenticity that the animated characters get from the dimensionality and solidity that the 3D version provides.



The Polar Express IMAX® Framing

CONCLUSION

A great family film combined with the fully immersive stereoscopic experience that so far only IMAX® 3D has been able to deliver, and on 11/2% of the screens it gathered nearly 20% of the film's total domestic gross during the 2004 Holiday season. In 2005 the re-release in IMAX® 3D has added more than $12M to the total and its run is not over. It is also generally acknowledged that the success of **The Polar Express** has been a strong influence in Hollywood's renewed interest in 3D as a way to entice fading audiences back into theatres. If you are a 3D movie aficionado this is great news provided that it is not used as gimmicky dressing on otherwise bad movies as has happened during past 3D revivals in the 50's and 70's.

It has been ten years since **Toy Story** opened and a long journey to get to where the rest of the world finally gets the epiphany too. For IMAX Corporation 3D continues to be a major focus as it has been since the mid 80's. In 2006, I will be primarily occupied with the IMAX® 3D versions of **Ant Bully** directed by John Davis and **Happy Feet** directed by George Miller, both from Warner Brothers and both to be opened day and date with the regular theatrical release. We are also hoping to soon unveil our first live action 3D conversion to IMAX® 3D audiences – the next trans-dimensional adventure.