Institution: Durham University

Unit of Assessment: Computer Science and Informatics

Title of case study: Stereoscopic Imaging

1. Summary of the impact (indicative maximum 100 words)

This case study involves the development and implementation of novel algorithms that control the mapping of depth from a scene being imaged by a camera to an image being viewed on a stereoscopic display so as to make viewing more comfortable for the human visual system. The algorithms, developed at Durham University between 2003 and 2005:

- are influential in the implementation of software tools supplied to the games industry;
- have reportedly been widely adopted in the 3D movie industry; and
- are used to produce award-winning 3D science movies that have been shown around the world and which have measurable and quantifiable public impact (nationally and internationally) in terms of both significance and reach.

2. Underpinning research (indicative maximum 500 words)

The research relates to methods for controlling the mapping of depth from a scene being imaged by a camera (real or virtual computer graphics camera) to an image being viewed on a stereoscopic display. The challenge is that the human visual system does not find comfortable more than a limited range of depth (the depth budget) on a stereoscopic display, while there may be an arbitrarily large range of depth in the scene being imaged. The depth budget allocation problem has become a central challenge in content creation for all 3D applications.

Between 2003 and 2005, research at Durham University by Dr. Nick Holliman (lecturer) resulted in two new algorithms that allowed different regions of the scene to be represented differently in depth on the 3D display, thus giving content creators control over the allocation of the depth budget. The key insight was that the mapping could be implemented differently in different regions in depth so that each region of the scene could be represented with more or less depth in the final image, e.g., the best depth representation might be given to a main character in a movie or game while lower quality depth could be given to the background or other characters. A piecewise linear algorithm was developed in [1] with a further refinement to smooth the visual appearance of the depth transition at boundaries in [2]. This can perhaps be understood by comparing it with focus-context techniques used in 2D visualisations where a defined area of the scene is given better resolution in the displayed image, whereas in the 3D case a defined area of the scene is given better depth resolution in the displayed stereoscopic image.

To demonstrate the utility of the methods, a number of implementations of the algorithms were developed including: a spread-sheet and scripting language implementation for the popular computer graphics software PoVRay [1]; an OpenGL demonstration of the basic technique operating interactively in a dynamic scene [2]; and an implementation for the commercial computer graphics tool 3DStudioMax [3].

In 2006 a stereoscopic movie “Cosmic Cookery” visualizing the development of structure in the universe during the 13.7 billion years from the Big Bang to the present day was made. In 2010 a stereoscopic movie “Our Cosmic Origins”, relating to how our galaxy took its place in the universe, was made, with a follow-up “Cosmic Origins 2” made in 2012. These movies employed the algorithms from [1, 2] and the resulting stereo image rendering tools; in particular, the stereographic techniques resulting from [1, 2] were used to optimise the stereo effect throughout the movies to match the content in each scene to the average viewer’s visual tolerance levels. The whole process and technical research refinements as regards the making of “Cosmic Cookery” and “Our Cosmic Origins” can be found in [4] and [5] (with the making of “Cosmic Origins 2” following these principles).

A patent was applied for in relation to the algorithms in [1, 2] and was licensed to RealD Inc. in the USA who funded the completion of the filing and subsequent maintenance of the patent rights [6].

3. References to the research (indicative maximum of six references)

[1] N. Holliman, Mapping perceived depth to regions of interest in stereoscopic images, in: Stereoscopic Displays and Applications XV, volume 5291 of Proceedings of SPIE, 2004.

- [ISSN/ISBN: 0277-786X, 0-8194-5194-0; DOI: dx.doi.org/10.1117/12.525853; 61 citations on Google Scholar as of 21st October 2013]

[2] N. Holliman, Smoothing region boundaries in variable depth mapping for real time stereoscopic images, in: Stereoscopic Displays and Applications XVI, volume 5664A of Proceedings of SPIE, 2005.

- [ISSN/ISBN: ISSN/ISBN: 0819456373; DOI: dx.doi.org/10.1117/12.586712; 11 citations on Google Scholar as of 21st October 2013]

[3] B. Froner and N.S. Holliman, Implementing an improved stereoscopic camera model, in: Eurographics Theory and Practice of Computer Graphics 2005 (L. Lever, M. McDerby, eds.), Canterbury, June 2005, pp. 27-34.

- [ISBN: 3-905673-56-8; 8 citations on Google Scholar as of 21st October 2013]

[4] N. Holliman, C. Baugh, C. Frenk, A. Jenkins, B. Froner, D. Hassaine, J. Helly, N. Metcalfe, T. Okamoto, Cosmic cookery: making a stereoscopic 3D animated movie, in: Stereoscopic Displays and Virtual Reality Systems XVII, Proceedings of SPIE Vol.6055A, 2006.

- [ISSN/ISBN: 0277-786X; DOI: 10.1117/12.646644; 6 citations on Google Scholar as of 21st October 2013]

[5] Nicolas S. Holliman, Cosmic origins: experiences making a stereoscopic scientific movie, in: Stereoscopic Displays and Applications XXI, Proceedings of SPIE Vol.7237, 2010.

- [ISSN/ISBN: 0277-786X; DOI: doi:10.1117/12.840957; 1 citation on Google Scholar as of 21st October 2013]

[6] N. Holliman. Method and apparatus for generating a stereoscopic image, US patent 7983477 B2, July 19, 2011. (Priority from Dec 18th 2003 GB 0329312.3)

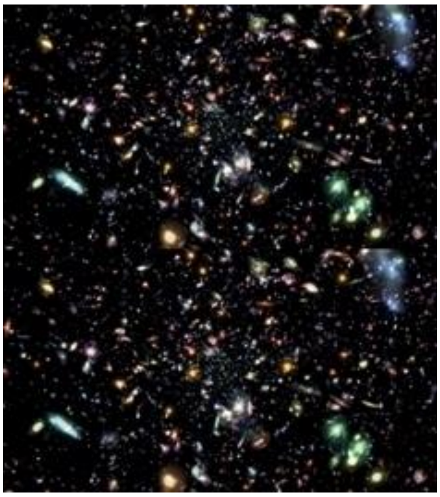
- [12 citations on Google Scholar as of 21st October 2013]

4. Details of the impact (indicative maximum 750 words)

Public outreach

From 29th June 2009 – 4th July 2009, the “Cosmic Origins” movie was presented at the Royal Society’s Summer Exhibition in London. The Royal Society reported 6,000 visitors, including post-16 students, the general public and VIPs, and estimated that around 2,500 people watched the movie [S1]. The movie was invited back to be shown at the Royal Society’s 350th Anniversary Summer Exhibition at the South Bank in 2010. A week-long viewing of the movie was also staged in Durham in October 2009 which attracted 650 undergraduate students and staff. More than 1,000 visitors a year have seen the movie in the Durham Visualisation Laboratory and the Durham 3D lecture theatre. In total, more than 10,000 viewers have seen the movie around the world. The 3D version of the movie on YouTube has now attracted more than 12,770 views [S2]. The movie “Cosmic Origins 2” was shown at the Royal Society’s Summer Exhibition in London from 2nd July 2013 – 7th July 2013 where there were 13,040 visitors in total of whom 4,000 were estimated to have viewed the movie [S3].

We regularly receive requests from outreach centres, museums, schools and universities for our movie to use in external activities, e.g., Centre for Life, Newcastle; Adler Planetarium, Chicago; Observatoire de Paris; and The Baraket Observatory, Israel (and most recently at the Thai National Science and Technology Fair in September 2013 in Bangkok, attended by over 1.2 million visitors). In 2010 “Our Cosmic Origins” won first prize for a computer graphics movie competition at the Stereoscopic Displays and Applications conference, held in Silicon Valley, California, beating competition from leading international groups including Walt Disney’s 3D version of Sleeping Beauty [S4].



Still from “Cosmic Origins” showing Milky Way

The informal impact on viewers is overwhelmingly positive with viewers often reporting that they have never seen such high quality 3D and that they have a new and enhanced understanding of the underlying science. In order to *formally quantify* this positive impact and to demonstrate both reach and significance, an audience response experiment was devised. A one-group pre-test-post-test quasi-experimental procedure was designed which measured naive viewer response by asking them to rate their agreement on a 100 point scale with statements presented before and after viewing the film [S5]. These statements were as follows.

Please rate your impression of
Q1: the viewing experience 3D films can provide
Q2: how well 3D films can convey complex visual information
Q3: how comfortable you think viewing 3D films can be
Q4: how natural the sensation produced by viewing 3D films can be.

The experiment was undertaken first in Durham and then in York and overseas in Twente. Table 1 details the audience response results at each of the three sites. An improvement in audience response was found for all questions at all sites (although the York response to Q3 was not statistically significant) [S5]. Table 2 summarizes the audience response results by collapsing the data at all three sites (Durham, York and Twente) into one result for each statement. All statements show improvement in audience response and all are statistically significant [S5]. A sample of informal comments is as follows:

"<3D> sometimes gives me headaches, this didn't and was very dazzling and informative especially the part showing the Milky Way and Andromeda colliding."
"One of the best 3D films I have seen for quality"
"Film seen today was noticeably more comfortable to watch than normal 3D films"

This confirms that the impact of our research has both significance and reach, and is changing awareness of, attitudes to, and understanding of 3D films and the experience they provide to viewers both nationally and internationally.

Table 1: Durham, York, Twente: Cosmic Origins: Small Screen Projection

	Q1:Experience		Q2: Complexity		Q3: Comfort		Q4: Natural		
Location, Film	**Mean change**	**p-value**	**Mean change**	**p-value**	**Mean change**	**p-value**	**Mean change**	**p-value**	**n**
DU, UK, CO	8.42	0.001	14.3	4E-06	10.2	0.006	13.4	0.000	19
YK, UK, CO	12.5	0.002	14.8	2E-07	4	0.184	12.5	0.020	17
TW, NL, CO	6.65	0.000	11.4	0.004	7.65	0.0167	13.1	0.077	17

Table 2: Impact all sites: Durham (UK), York (UK) and Twente (NL)

Q1:Experience		Q2: Complexity		Q3: Comfort		Q4: Natural		
Mean change	**p-value**	**Mean change**	**p-value**	**Mean change**	**p-value**	**Mean change**	**p-value**	**n**
8.01	**0.000**	13.63	**0.000**	7.22	**0.022**	11.50	**0.005**	53

<u>Commercial impact in the games industry</u>

RealD is a leading global licensor of 3D technologies and currently supplies the most widely used technology for watching 3D movies in cinemas. As of September 2013, its market capitalization was around $337 million [S6]. The original GB patent application based on our research was licensed to RealD Inc. in the USA who funded the completion of the filing and subsequent maintenance of the patent rights for [6]. This was then extended into a new variation of the method granted to RealD as US patent US 8,300,089 B2. The ideas in this patent have been subsequently developed by RealD so as to yield software for computer graphics systems in the form of the RealD Game Developer Toolkit [S7]. A presentation on this development was described in Durham at the Higginson Lecture in 2010 by the Chief Scientist at RealD. As is acknowledged by RealD, "*RealD believes the teachings of* [Holliman's] *patents provide useful contributions to the field of stereoscopic production. The detailed description in the patent application identified a technical problem with 3D depth visualization varying on different size displays, and proposed a specific solution to that problem. Recognizing that problem, RealD has further developed this field of technology, and been granted additional claims in this technical landscape on other solutions. The patents stemming from Dr. Holliman's patent application indeed have made a contribution to the IP base of RealD*" [S8].

Commercial impact in the movie industry

The fundamental concept in research paper [1] has been widely adopted in the movie industry for controlling the stereography in motion pictures, as is noted in patent US 8,300,089 B2 [S9].

- "*This approach* [Holliman's] *is applicable within the context of computer graphical (CG) generation of content and is routinely used in Hollywood content generation for scene enhancement, as discussed by Rob Engle in Beowulf 3D: A Case Study: Proc. SPIE vol. 6083"*

and has been applied in several movies, as noted by a former Chief Technical Officer of RealD in his personal blog [S10]:

- "*The first place I read about the idea was in a paper by Nick Holliman given at the SPIE Stereoscopic Displays and Applications Conference, in which Nick suggested changing the distance between the cameras or lenses for different parts of the scene. … And indeed this technique has been used, and is being used, by stereoscopic supervisors such as Phil McNally and Rob Engle. Phil used it on 'Meet the Robinsons', and Rob used it extensively on the 'Beowulf'*."

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] The Royal Society collected its own feedback during the Summer Science events in 2009 and 2010 which has not been disseminated to the exhibitors: see Exhibition Manager, Royal Society.
[S2] YouTube channel "OurCosmicOrigins" viewing statistics for the three movies in both 2D and 3D form (http://www.youtube.com/user/OurCosmicOrigins last accessed 21st October 2013).
[S3] Feedback supplied by the Royal Society (received from exhibition@royalsociety.org on 23rd August 2013).
[S4] See http://www.stereoscopic.org/2010/preface.html (last accessed 19th September 2013).
[S5] Durham University seed-corn project to collect impact-related evidence for case study: *Algorithms for Stereoscopic Camera Control: Evaluating Impact,* together with two resulting reports.
[S6] See http://www.bloomberg.com/quote/RLD:US (last accessed 19th September 2013).
[S7] The RealD Game Developer Toolkit: http://reald.com/content/game-developer-toolkit.aspx (last accessed 19th September 2013).
[S8] Letter from Vice-President, IP & Legal Affairs, RealD Inc. to Head of Legal Support, Durham University, 24th July 2013.
[S9] Stereoscopic depth mapping, US patent 8300089 B2, 30th October 2012.
[S10] http://lennylipton.wordpress.com/2008/03/20/the-sculptural-cinema/#more-41 last accessed 19th September 2013)