Institution: University of Cambridge

Unit of Assessment: 9 – Physics and Astronomy

Title of case study: Geomerics: Cambridge University spin out revolutionises lighting in video gaming

Period when the underpinning research was undertaken: 1.1.2000-31.12.2005

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Anthony Lasenby	Professor of Astrophysics and Cosmology	1987-date
Professor Michael P. Hobson	Professor of Astrophysics	1994-date
Professor Joan Lasenby	Professor of Image and Signal Analysis	1994-date
Dr Chris Doran	EPSRC Advanced Fellow	1996-2004

Period when the claimed impact occurred: 1st Aug 2013 - date

Is this case study continued from a case study submitted in 2014? Y

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

Cambridge University spin-out Geomerics is based on research by Professors Michael Hobson, Anthony Lasenby, Joan Lasenby and Dr Chris Doran in geometric algebra. In December 2013, Arm acquired Geomerics for GBP13.4 million**.** Geomerics' prize winning and revolutionary lighting technology:

1. Is integrated into Unreal, Frostbite and Unity game engines *as "the most advanced lighting system the games industry knows"*, reaching >1.5 million games creators with >2 billion end-users globally.
2. Was used by major games publishers to (a) remake the iconic 90s game Final Fantasy VII, delivering stunning graphics at unrivalled quality per man-hour (b) upgrade some of the biggest blockbuster franchises in gaming history (including FIFA, which alone has 45 million players generating revenue of >USD 1.2 billion annually).
3. Underpinned the production of the ground-breaking, BAFTA-award-winning game Hellblade:Senua's Sacrifice. Developed by a Cambridge-based Independent Games maker in collaboration with clinicians/patients, the game has profoundly changed players' lives.

2. Underpinning research (indicative maximum 500 words)

Geometric Algebra (GA) is a mathematical framework which incorporates several independent mathematical frameworks such as linear algebra, vector calculus and differential geometry. It provides a unified mathematical language for the neat description of physical systems. GA research carried out by the Astrophysics Group (Physics) and the Signal Processing Group (Engineering) at Cambridge between 2000 and 2005 (with a secondary contribution from researchers based in Arizona State University) led to the formation of the spin-out company Geomerics. The main focus of the research was fundamental theoretical physics but the methods developed proved more widely applicable. The groundwork for this widening of application was laid in a five year EPSRC Advanced Fellowship awarded to Chris Doran in 1999. The Fellowship was awarded to investigate ways that GA could be exploited in the fields of computer graphics and computer vision. This research was conducted in collaboration with

Anthony Lasenby and Joan Lasenby, and during this period the research was broadened to include applications to rigid body dynamics and electromagnetism **[R1].** The outcomes of this research were a series of results demonstrating how algorithms based on GA could solve problems in graphics and vision faster and more robustly than traditional techniques.

The research that led to the breakthrough product ***'Enlighten'*** in 2007 was carried out jointly by staff at Cambridge University - Anthony Lasenby, Joan Lasenby and Mike Hobson - and Geomerics' internal team led by Chris Doran. 'Enlighten' computes photo-realistic lighting in real-time on games consoles. This was viewed as a difficult problem because in the real world light bounces many times on its journey from source to eye and those interactions need to be captured for a complete physical model. Modelling on a games console increases the difficulty further for two reasons (1) computational resources are limited and (2) updates need to be extremely fast so there is no noticeable time lag in a game. GA proved an optimal mathematical framework for this physics problem giving accurate models which could be computed at speed. One significant challenge encountered was surface mapping (unwrapping a curved surface to a 2D planar map). Anthony Lasenby used his research on conformal geometric algebra to guide the development of new algorithms for unwrapping geometry that minimised distortion **[R2,R3]**. A second major challenge was de-noising. Mike Hobson had developed image reconstruction techniques based on wavelets for the analysis of astronomical images **[R4,R5]**. He applied similar techniques to compress images and speed up calculations. Joan Lasenby and her team then used foundational work on conformal geometric algebra **[R2]** to produce the first real-time lighting model. These strands of research provided the technical advances which allowed the development of Geomerics' prize winning Enlighten software.

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

R1. * Geometric Algebra for Physicists, CUP (2003, Paperback Edition 2007) (C. Doran and A.N. Lasenby), ISBN-13: 978-0521715959

R2. Surface evolution and representation using geometric algebra, The Mathematics of Surfaces IX, Proceedings of The Ninth IMA Conference on the Mathematics of Surfaces, Cambridge, U.K., p. 144, (2000) (A.N. Lasenby and J. Lasenby), https://doi.org/10.1007/978-1-4471-0495-7_10

R3. Recent applications of conformal geometric algebra, in Computer Algebra and Geometric Algebra with Applications, 3519: pp.298-328 (2005) (A.N. Lasenby), ISBN: 0302-9743

R4. * Maximum-entropy image reconstruction using wavelets, Monthly Notices of the Royal Astronomical Society, Volume 347, Issue 1 (2004) (K Maisinger, M.P. Hobson and A.N. Lasenby) https://doi.org/10.1111/j.1365-2966.2004.07216.x

R5. * Combining maximum-entropy and the Mexican hat wavelet to reconstruct the microwave sky, Monthly Notices of the Royal Astronomical Society, Volume 328, Issue 1 (2001) (P. Vielva, R.B. Barreiro, M.P. Hobson, E. Martínez-González, A.N. Lasenby, J.L. Sanz, L. Toffolatti) DOI: 10.1046/j.1365-8711.2001.04693.x

Reference R1 is an academic textbook based on extensive theoretical physics research by Anthony Lasenby and Chris Doran. It was published by Cambridge University Press and is aimed at both highly-specialised researchers and students. Research outputs R4 and R5 have been through a rigorous peer-review process. References marked * best represent the quality of the underpinning research.

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

Cambridge Research leads to award-winning spin-out Geomerics

Geomerics was spun out in 2005 from research carried out by University of Cambridge Professors Michael Hobson, Anthony Lasenby, Joan Lasenby and Dr Chris Doran (first full-time CEO). Chip-design giant Arm, acquired Geomerics in Dec 2013 for GBP13.4 million **[E1b]**, and said of Geomerics ***"The innovative technologies being developed by Geomerics are already revolutionizing the console gaming experience and are set to rapidly accelerate the transition to photo-realistic graphics in mobile…The acquisition expands Arm's position at the forefront of the visual computing and graphics industries"*** **[E1a].** The Financial Times reported a surge in Arm Holding's share price of 5.45% on acquisition of Geomerics **[E1c]**. In November 2013, Geomerics won a tools and technology award from The Independent Game Developers' Association (TIGA) for its product Enlighten **[E2]**. TIGA awards are some of the most prestigious in the computer games industry. In May 2017, Japanese company Silicon Studio acquired licensed rights from Arm/Geomerics to license, develop, and provide worldwide technical support for Enlighten **[E3a]**.

Geomerics' Unrivalled Technology widely adopted by the Video Games Industry

Geomerics' Enlighten software simulates indirect light in a virtual environment in real time**.** It represented a pivotal technical advance for the games industry as a whole. Highlighted in The Guardian, Enlighten ***"subtly, almost imperceptibly, creates a coherent, plausible environment. Without it, you get a sort of scenic equivalent of the Uncanny Valley - everything seems flat and unreal"*** **[E4a].** In 2015, Enlighten was integrated into the unity game engine as a default lighting solution. It was specifically highlighted by Unity as one of two key innovations in Unity's fifth major release of its games engine **"*the biggest thing of Unity 5.0 is our new physically-based unified shading system and the new Geomerics' Enlighten real-time global illumination engine. If you haven't heard of Enlighten yet, it's the most advanced lighting system the games industry knows and is used for some of the most beautiful games today, across many art styles*" [E5a]**. Over 50% of all mobile, PC and console games globally are made on Unity for end users by third party creators. Unity has 1.5 million monthly active creators working in 190 different countries/territories. As of June 2020, Unity has 2 billion monthly active end users. Unity has also expanded beyond gaming, facilitating activities as diverse as movie production and collaborative building design in architecture **[E5b]**. Enlighten is also integrated into two other major games engines: Unreal (2011) and Frostbite (2010). It is used both by four of the largest video games publishers on the planet: Electronic Arts (EA), Activision Blizzard, Square Enix and Take 2 Interactive in major games franchises, and also by highly-successful Independent Games Makers as shown below.

<u>Remake of an Iconic Video Game</u>

Enlighten was selected by Square Enix for the remake of Iconic 90s video game Final Fantasy VII. Remake producer Kitase Yoshinori said ***"After investigation, our teams selected Enlighten as the most advanced third-party global illumination technology available and made the decision to utilize the technology for the remake. Its quality per man-hour is unrivaled and will enable us to deliver the highest fidelity version of Midgard [game setting] to our fans"*** **[E6a]**. Amanda Yeo – journalist with the technology news website Mashable - commented on the upgrade: ***"Final Fantasy VII Remake's most obvious update is the graphics. The newly resurrected game's photorealistic art and detailed world are generally stunning"*** **[E7]**. Launched in April 2020, 3.5 million copies of the remake were sold worldwide within three days yielding revenue of USD 210 million **[E8]**.

Underpinning technology for ground-breaking game Hellblade which has had a profound effect on players' lives

Enlighten enabled the production of Hellblade:Senua's Sacrifice by Cambridge-Based Independent games maker, Ninja Theory. This mainstream, action-adventure game was widely praised for its ground-breaking portrayal of mental illness. Wellcome-Trust funded, the game was developed in collaboration with Cambridgeshire patients/clinicians to include scenes depicting patient-recalled visual/auditory hallucinations. Enlighten played a key role in allowing scenes to be lit in dramatically different ways to reflect the changing state of mind of the central character **[E3b]**. Of its five BAFTA games awards, one was for artistic achievement **[E4b]**. Advisory clinician Paul Fletcher said of the game ***"one of the most powerful and eye-opening experiences of working on Hellblade was just what a phenomenal role a game experience can play in representing mental distress and allowing it to be communicated to others"*** **[E6b]**. Messages of thanks were received by the production team for making the game including ***"Thank you, @NinjaTheory, for Hellblade: Senua's Sacrifice. It saved my son's life. After playing it through, he asked to go to the hospital for help. He couldn't take everything he'd been dealing with & had a plan to kill himself. The game changed his plan."*** **[E6b]**.

Upgrading Major Video-Games Franchises

Enlighten is now employed in major gaming franchises: FIFA; Battlefield; Need for Speed; Overwatch; Star Wars Battlefront; Final Fantasy; XCOM; Streetfighter and Plants versus Zombies. In October 2013, Electronic Arts released Battlefield 4, one of the first big titles developed using Geomerics' software. It sold 7.3 million copies and was widely praised for its graphics, with games reviewers referring to *its* ***'jaw dropping lighting effects… The lighting is arguably the best we've ever seen in a video game… and this is all possible thanks to Geomerics' Enlighten engine'*** **[E9]**. The FIFA games Franchise began using Enlighten in FIFA 17. A Business Insider article titled **"*The graphics in 'FIFA 17' are the closest thing we've seen to a real game on TV"*** directly compared it to FIFA 16 noting ***"The lighting in general is more photo-realistic and more dynamic"*** **[E10a]**. In the first 3 months of release, FIFA17 recorded 17% more sales volume than FIFA 16 **[E10b]**. Games using Enlighten from the FIFA video-games franchise alone generated revenue of over USD 3 billion for Electronic Arts (2017-2019) **[E10c]** and engaged over 45 million players **[E10d]**.

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

E1. **Arm acquisition of Geomerics coverage: (a)** Arm Press Release after Geomerics Acquisition (pages 1-4 of PDF) together with **(b)** Arm Annual Report 2013 (pages 5-128 of PDF. See specifically note 19 on page 107 for acquisition figure) **(c)** Financial Times (page 129 of PDF) **(d)** Cambridge Network (page 130 of PDF) **(e)** ElectronicsWeekly.com (pages 131-132 of PDF) **(f)** Electronics Europe (page 133 of PDF) **(g)** invezz.com coverage of Arm Acquisition of Geomerics and surge in share price of Arm of more than five percent following the acquisition ((pages 134-135 of PDF).

E2. **TIGA Awards (2013)** See bottom of final page

E3. **Silicon Studio Materials: (a)** Press release covering the acquisition of licencing rights for 'Enlighten' by Silicon Studio from Geomerics (2017) See page 1 of PDF.**(b)** Silicon Studio presentation detailing the role of Enlighten in the making of Hellblade: Senua's Sacrifice. See pages 7-12 of PDF.

E4. **The Guardian Articles: (a)** ***"Becoming Enlightened"***, by Keith Stuart, The Guardian, 5 February 2008 **(b)** ***"Hellblade: Senua's Sacrifice dominates at video game Bafta awards"***, 13 April 2018

E5. **Unity Software Materials: (a)** Unity blog entry highlighting Enlighten as one of two key new features in major release of the games engine Unity 5.0, 18 March 2014. See page 2 of PDF **(b)** Unity IPO statement file with the United States Securities and Exchange Commission, 24 August 2020. See pages 8, 9, 17 and 19 of PDF.

E6.	**GamesBeat Articles: (a)** ***"Square Enix, Geomerics make Enlighten lighting-tech pact after bright results in FFVII Remake"*****.** Detailing deal struck between Square Enix and Geomerics for Final Fantasy VII remake including quotes from the remake director, 6 July 2016 **(b)** ***"How Hellblade: Senua's Sacrifice changed lives with its thoughtful portrayal of mental illness"*** which is based on a keynote presentation by Advisory Clinician Paul Fletcher at the International Game Summit on Mental Health, 26 October 2019
E7.	**Mashable review Article** by journalist Amanda Yeo about the Final Fantasy VII remake, 6 April 2020
E8.	**Square Enix Article** with sales figures for Final Fantasy VII, 21 April 2020
E9.	**GamingBolt Review** of Battlefield 4 by Yadu Kiran, March 2013
E10.	**FIFA Franchise Materials: (a)** Business Insider article comparing FIFA 16 and FIFA 17 games, FIFA 17 employed Geomerics' Enlighten software, Sept 2016. See pages 1 and 2 of PDF **(b)** Sales figures for both games from article on trefis.com. See page 7 of PDF **(c)** FIFA Franchise Sales Figures (2017-2019) from SuperData annual reviews of Digital Games and Interactive Media. SuperData is a provider of market intelligence on free-to-play and digital games and part of Nielsen Holdings plc a large information, data and measurement firm. See pages 9,10 and 11 of PDF **(d)** Electronic Arts, Financial Results Report 2019 giving player numbers for FIFA 18 and FIFA 19 games. See page 12 of PDF.