Research Assessment Exercise 2020
Impact Case Study

University: The Chinese University of Hong Kong
Unit of Assessment (UoA): 11 Mathematics and Statistics
Title of case study: Development of novel mathematical methods to significantly improve efficiency and accuracy for computer graphics and medical imaging industries

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

Professor Lok-Ming Lui's group has revolutionized conventional methods for 3D imaging with 30% enhancement in efficiency and real-time high-precision texture mapping of 3D objects for the first time. This technology was exploited by Geometric Informatics to launch a new 3D scanner series with market-leading inimitable high-precision and develop an algorithm which is adopted by Blizzard, Siemens, and Intel. Impact on medical diagnosis is exemplified through BrainNow Medical technology, with the development of a cutting-edge diagnostic tool for Alzheimer's disease with ~90% accuracy. Public awareness about Lui's pioneering contributions on Computational Quasiconformal Geometry and its applications is aroused via media interviews.

(2) Underpinning research (indicative maximum 500 words)

The research reported in this case study was undertaken by Professor Lok-Ming Lui (Department of Mathematics, CUHK [2010-]). Methodologies to manipulate and analyze 3D geometric objects accurately and efficiently have been lacking. The efficiency of capturing and quality of analysing 3D geometric shapes were confined. During 2014-2018, Lui's group had developed effective mathematical models and fast computational algorithms to resolve the constraints of manipulating 3D geometric shapes. More specifically, Professor Lui's team have pioneered research in the development of Computational Quasiconformal Geometry (CQC), leading to an emerging interdisciplinary field. CQC provides a useful tool to process and study 3D shapes, thus contributing to develop effective 3D tools for computer graphics and medical image analysis.

The key findings of this case study are two-folded:
(1) This research has **solved the surface registration problems with high-precision** by creating a meaningful pointwise correspondence between two related surfaces that matches important geometric information. Using CQC, Lui has novelly developed accurate and efficient registration algorithms for surfaces with complex structures [3.2], whose efficiency and accuracy cannot be achieved by other methods. Surface registration allows users to compare different surfaces systematically. This finding has been successfully applied to shape analysis and surface matching, respectively for developing medical diagnostic tools and building 3D cameras (Detailed in section 4).
(2) Another research highlight was the **development of efficient algorithms for surface parameterization** to transform a complex surface to a simple shape, such as a planar rectangle or unit sphere, with least distortions. Conventional computational algorithms for surface parameterization are usually time-consuming which limits the practicability in applications. To resolve this limitation, Lui has developed much faster algorithms to compute conformal/quasi-conformal parameterizations, while significantly improving the accuracy [3.4] (Figure 1). He also developed a fast algorithm to compute an optimized conformal parameterization, **"Teichmuller parameterization"**, when extra constraints are enforced [3.3, 3.5]. The computation of QC parameterization in real time (less than a second) was achieved, which can be applied to various industrial applications, such as texture mapping of 3D geometric objects in the real world[3.1, 3.3] (Figure 2).

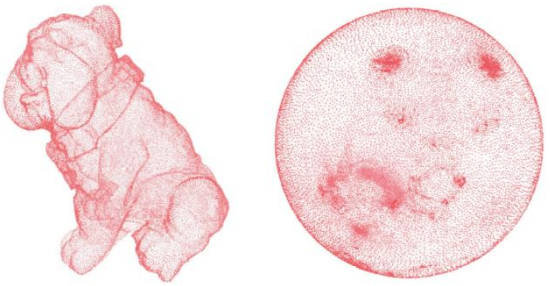

Figure 1: Example of surface parameterization. Left: a 3D point cloud surface representing a dog captured by a 3D camera. Right: Quasiconformal parameterization of the point cloud surface onto a simple domain (unit sphere). By transforming the complex surface onto a simple domain, computation on the surface can be carried out much more efficiently.

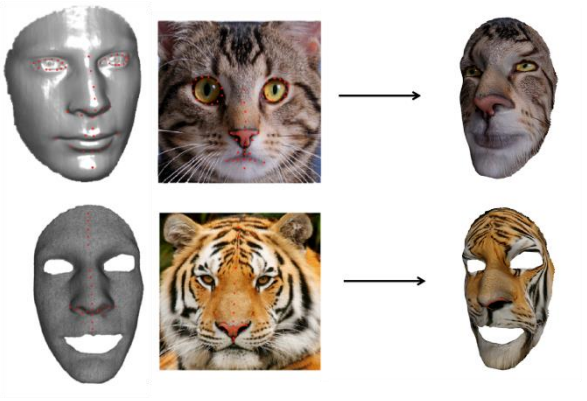

Figure 2: Example of texture maps on surface meshes. Left: Two raw 3D meshes representing human faces. Right: 2D images are mapped onto the surface meshes through quasiconformal parameterizations for surface textures. Accurate texture mapping is crucial in computer graphics for realistic visualization of 3D models.

Lui's innovation has first-time enabled effective manipulation of 3D shapes. The research achieved accurate manipulation and analysis of 3D shapes, which has been applied and revolutionised the framework in computer graphics and medical image analysis.

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

[3.1] L.M. Lui *et al.*: Texture map and video compression using Beltrami representation, SIAM Journal on Imaging Sciences, Vol. 6, No. 4, 1880–1902 (2013)

[3.2] L.M. Lui *et al.*: Landmark and intensity based registration with large deformations via quasi-conformal maps, SIAM Journal on Imaging Sciences, 7(4), 2364-2392 (2014)

[3.3] L.M. Lui *et al.*: Teichmuller mapping (T-Map) and its applications to landmark matching registrations, SIAM Journal on Imaging Sciences, 7(1), 391–426 (2014)

[3.4] L.M. Lui *et al.*: FLASH: Fast Landmark Aligned Spherical Harmonic Parameterization for Genus-0 Closed Brain Surfaces, SIAM Journal on Imaging Sciences, 8(1), 67-94 (2015)

[3.5] L.M. Lui *et al.*: TEMPO: Feature-Endowed Teichmuller Extremal Mappings of Point Clouds, SIAM Journal on Imaging Sciences, 9(4), 1922–1962 (2016)

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

Pathway to impact

Lui's research established a novel generic method for 3D geometry processing and shape analysis. His research was adopted widely in research and industries, pursuing multiple pathways to impact. First, Lui's software tools are available online [5.1] since 2013. They are not only used by researchers in academia but also developers in industry. The technology was also **exploited by Geometric Informatics** and **BrainNow Medical technology Ltd.** for the development of 3D imaging technology and diagnostic tool to detect Alzheimer's disease,

respectively.

Details of impacts are described as follows.

Impact on 3D imaging industry

The major impacts of Lui's research has been to transform the development of 3D scanners by:

Innovation in texture mapping: Development of 3D scanning device

Conventional approaches of 3D scanners partition the surface mesh into simply-connected patches and the texture map is obtained in a patch-by-patch manner, which is highly inefficient and leads to unnatural artefacts. Lui's quasiconformal algorithms [3.1, 3.3] provide effective tools for Geometric Informatics to generate high-precision texture map in their real-time high-resolution 3D geometry capture systems, "**GV3 series**". The GV3 series have been **purchased by tens of thousands international customers including U.S.A., Singapore, Japan and mainland China.**

The CTO of Geometric Informatics revealed the efficacy of the Lui's innovation and its impacts on **GV3** series, *"the **accuracy (of GV3) is improved from 65% to 95%** when comparing with the conventional **patch-wise texture mapping**. **This level of accuracy is almost impossible using other methods** ... parameterization is global and it saves computational time **from 5 minutes for a high-resolution mesh to less than a second…**"* [5.2]. By adopting Lui's methodology, texture mapping of 3D objects with the highest precision is now possible to be obtained in real-time for the first time.

Improvement in surface reconstruction: Advancement of 3D scanning device

3D scanner conventionally used Iterative Closest Point (ICP) method to align patches, which are erroneous especially when there are noises. Using Lui's quasiconformal registration algorithms [3.2], patches can be aligned accurately, which improved the accuracy of surface reconstruction of 3D scanner. According to Geometric Informatics, *"the mapping techniques proposed… can be used to align/stitch meshes capturing the 3D geometric object from different angles. **The accuracy of the alignment is improved from 60% to 95% (….. error is reduced from 40% to 5%)**… is a key ingredient for our product to achieve fast and accurate 3D image acquisition"* [5.2].

Giving a foundation for new algorithm development

Geometric Informatics developed the "**All-purpose Mapping Algorithm**", which is based on Prof. Lui's conformal/quasiconformal methods [3.4]. This ingenious algorithm has been adopted by various renowned companies: "*For example, **Blizzard** is using it for texture mapping, **Siemens** is using it to develop the virtual colonospy machine and **Intel** is using it for mesh generation*" [5.2]. The industrial collaboration with Geometric Informatics demonstrated the successful knowledge transfer of Lui's research findings and impact exerted on 3D imaging industry.

Impact on medical diagnosis

Conventional diagnostic methods usually analyse anatomical shapes from 2D medical images. It is crucial to develop a more accurate medical diagnostic tool by analysing 3D anatomical structures more precisely. Teichmuller map proposed by Lui has induced a natural shape distance for the shape analysis of 3D shapes. Lui's research inspired BrainNow Medical technology Ltd. to develop a cutting-edge diagnostic tool, for the world's first ever, based on geometry of anatomical structures. In 2018, the company has adopted Lui's methodology for the shape analysis of hippocampal surfaces to diagnose early Alzheimer's disease (AD) in order to intervene the neurodegeneration before the symptoms occur. The goal is to develop

an accurate and low-cost diagnostic tool for early detection of AD, as the conventional diagnosis for AD relies heavily on structural and functional magnetic resonance imaging (MRI), which are time-consuming and expensive. As reported by the company Director, "*Using the conventional and commonly-used volumetric based method ... accuracy can only achieve up to 70%. The quasiconformal approach* ***dramatically improves the accuracy to 85-90%*** *... is being integrated to our diagnostic system to improve the diagnostic accuracy*". 50% more medical professionals are expected to adopt this confined prototype for early AD diagnosis due to the enhanced accuracy [5.3].

Impact on public engagement

Prof. Lui's excellent research was recognized by the "Morningside Silver Medal of Mathematics" in 2016. His accomplishment was reported in local newspaper, *Wen Wei Po* and *Skypost*, which aroused public awareness about the significance of his pioneering contributions on Computational Quasiconformal Geometry and its applications to medical imaging, computer visions and graphics [5.4].

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

[5.1] Free Software derived from Lui's research (2019)
https://www.math.cuhk.edu.hk/~lmlui/software.html

[5.2] Acknowledgement letter from Geometric Informatics Ltd. (2019)

[5.3] Acknowledgement letter from BrainNow Medical Technology Ltd. (2019)

[5.4] Media coverage on Morningside Silver Medal of Mathematics (2016)