REF2021

Institution: Kingston University

Unit of Assessment: 11 – Computer Science and Informatics

1. Unit context and structure, research and impact strategy

1.1 Unit context and structure

The Computer Science and Informatics Unit of Assessment submission for Kingston University (KU) consists of **22 staff (22 FTE)**, including 9 professors and 3 early career researchers[ECR], all from the School of Computer Science & Mathematics. Research is undertaken in the **Digital Information Research Centre** (**DIRC**), one of KU's research centres of excellence.

DIRC is organised around three non-exclusive research themes: **Communications**, **Vision** and **Security**. Across them, staff conduct research in the following areas:
- **Communications (7 FTEs, 34% of outputs)**
  - 5G networks & mobile infrastructure
  - Wireless & multimedia communications
- **Vision (9 FTEs, 53% of outputs)**
  - Visual surveillance
  - Medical imaging
- **Security (6 FTEs, 12% of outputs)**
  - Cyber & network security
  - Private & public place security

DIRC is managed by its director, Professor **Politis**, and three theme leaders, Professors **Martini**, **Nebel** and **Remagnino** for Communications, Vision and Security, respectively. Supporting KU's Strategic Plan, **DIRC** aims to offer a vibrant and active research environment where staff engage with the latest research and collaborate to produce impactful interdisciplinary quality research on culture, society, and industry. More specifically, to ensure a sustainable research culture, the Centre's director and theme leaders (meeting on a monthly basis) define investment priorities, organise biweekly seminars (internal and external speakers present, and ~20 members attend), put in place mentoring activities supporting, in particular, ECR and research students (**65 PhD, 3 PhD wholly overseas & 13 MSc by Research completions since REF2014**), and support the organisation of scientific conferences. They also coordinate the mandatory training of research supervisors and the dissemination of good research practice, in tandem with the central Research, Business and Innovation Directorate (RBI). Since DIRC's leadership aims to increase and diversify funding sources (**income over £5.6M in cycle**) and increase collaborations with the public and private sectors, the Centre facilitates brainstorming events to respond to the latest funding calls and initiatives, and in order to anticipate the future needs of industry. Moreover, theme leaders facilitate cross-theme collaboration, joint publications, and research grant submissions.

DIRC's expertise in **Computer Vision** and **Wireless & Network Technology** was developed across two decades with applications focusing on health and security. With the rapidly changing and ubiquitous world of digital information, the Unit not only embraced and contributed to the latest technologies (e.g., **Martini** and **N. Barman**[ECR] work on standards), but also anticipated the latest trends (e.g., **Politis**' and **G.C.**[ECR] *'s* white papers). Consequently, these two areas of research have become increasingly entwined which has led to, for example, the creation of innovative solutions to facilitate the live video streaming revolution (ICSUoA11Martini1). In addition, the overarching topic of **Security** was developed into a research theme, supported by the development of new expertise in cybersecurity and collaboration with the Government Communications Headquarters (GCHQ).

DIRC provides an **inclusive and outward looking environment for research development, fostering interdisciplinary and multidisciplinary research to achieve maximum impact in real-world applications**, as illustrated in the three submitted impact case studies (ICSs). It has developed a significant array of collaborators both internationally and across a range of

stakeholders to address the needs of society in its areas of excellence. DIRC's thematic research is complemented by other KU centres of research excellence, in particular the Centre for Engineering, Environment & Society Research (UoA12), and the Interdisciplinary Hub for the Study of Health & Age-related conditions (UoA3), which promote interdisciplinary research and collaboration. Research is also supported through the continuous development of our Research Laboratories and Infrastructures that provide the required resources to undertake internationally leading research.

1.2 Unit research

Following REF2014, the Unit - coordinated by the DIRC director, the head of the School of Computer Science & Mathematics, the School's Director of Research & Enterprise, and the Associate Dean for Research & Enterprise from the Faculty of Science, Engineering & Computing - designed its **research strategy for the next 6 years**. This strategy guided the Unit during the assessed period, which resulted in a vigorous growth of research in terms of visibility, quality and quantity, e.g., 82% of submitted outputs were published in upper-quartile (Q1; Scimago tracked, 2019) journals and average annual external research income increased by 24%. Following the description of the Unit's strategy, which is organised around **priority areas** and **key objectives**, its **achievements** are briefly summarised. Finally, **future research** and its approach to **open research and research integrity** are described.

Priority areas

In this REF period, the Unit built on its existing research strengths, emerging trends, and challenges to define the **four priority areas** on which it focused and invested to produce internationally leading research (examples of such publications are provided in brackets):

- **Machine learning-based computer vision**, including deep learning, in domains such as visual analytics in the context of security in public spaces, processing of images captured by unmanned aerial vehicles, and quantitative medical imaging to aid diagnostics (ICSUoA11Remagnino3). Relevant infrastructure investments include a GPU-farm and a new High Performance Computing facility. (outputs 11-32-1364, 11-17-1842, 11-05-1339, 11-13-1347, 11-22-1355)
- **Ambient intelligence and error resilient 2D/3D video transmission** facilitated by the synergy between the vision and communications themes, and interdisciplinarity embracing health, life sciences, social sciences, and arts (ICSUoA11Martini1). Relevant infrastructure investment includes a Centre for Augmented and Virtual Reality Environments that includes a user experience laboratory equipped to industrial standards. (outputs 11-40-1372, 11-36-1368, 11-11-1345, 11-29-1361, 11-12-1346)
- **Next generation network standards and applications**, including 5G architectures, and creations of ad-hoc network in critical situations (ICSUoA11Politis2). Relevant infrastructure investments include WiMAX/WiFi-Adhoc/LTE testbeds. (outputs 11-38-1370, 11-18-1351, 11-20-1354, 11-48-1376, 11-19-1352)
- **Cyber security**, including smart grid security. This has been underpinned by an £0.9M investment in a new Centre of Cybersecurity Education and Culture to support academic development and included the appointment of two new members of staff, and the purchase of a Quantum Cryptography Analyser. (outputs 11-46-1375, 11-02-1336, 11-49-1377)

Since REF2014, the University supported these identified priority areas by investing over £2.6M through competitively-awarded initiatives. These include the delivery of new infrastructure (*see section 3.2*), 15 PhD scholarships, funding to pump-prime innovative research and support impact activity, and research transformation funding to facilitate international collaborations.

Key objectives

During this period, the Unit identified **capacity building** and **enhancement of international recognition** as its key objectives in pursuing excellence in its research priority areas:

- **Capacity building through external collaborations**

To capitalise on its existing research strengths, increase its available resources and expand its research portfolio, the Unit instigated a set of measures to forge national and international partnerships and consortia:

- o A sabbatical scheme was established, which resulted in two colleagues spending extended periods in overseas institutions (32 months in total), which led to the submission of three proposals to the Qatar National Research Fund (U$D1.6M total) and the award of an MRC grant (£146k). Moreover, many Unit staff (38%) took the opportunity to visit (from a few days to several weeks) overseas research institutions.
- o To supplement externally funded travel grants, £10K was allocated by the faculty to allow leading international academics to spend time (typically a week) within the Unit (26 academic visitors were received during the period). It also hosted over 100 external researchers for extended periods (several months). Finally, funding was made available to invite external speakers to the Unit's biweekly research seminar programme. E.g., Prof. Murroni - IEEE distinguished lecturer - shared his expertise on 'Quality of experience models and methods for broadcasting' (2019).
- o Encouragement and financial support for staff to participate in events supported by non-academic stakeholders such as government departments and agencies. E.g., participation at the Chatham House event - 'Cyber 2015' - led to a close collaboration with GCHQ resulting in the accreditation of Cyber MSc courses and the funding of several PhD studentships. Consequently, KU made a strategic investment of £0.9M in its new Cybersecurity Centre (2018).
- o Monthly meetings between the School's Director of Research & Enterprise with KU's Research, Business and Innovation Directorate to identify research that is sufficiently mature to be considered for future commercial exploitation, and to respond to direct business enquiries. This pro-active and structured approach to knowledge transfer proved particularly successful as exemplified by £2.0M of Knowledge Transfer Partnership (KTP) awards.

All those activities contributed not only to increased success in obtaining external research funding (*see section 3.2*), but, perhaps more importantly, to help broaden the base of researchers and collaborations with external partners, including foreign institutions, SMEs, and large companies.

- **International recognition**

In parallel with building capacity, the Unit made a concerted effort to steadily enhance its reputation in its key areas of research, through international recognition and leadership activities:

- o Staff support in terms of funding and teaching relief to organise international conferences under the auspices of professional bodies such as IEEE. E.g., in 2017 **Martini** chaired the 'Communications Software, Services & Multimedia Applications' symposium at the IEEE International Conference on Communications (ICC'17).
- o Travel and publication fund to increase visibility of research by supporting publication in highest profile journals consistent with 'most appropriate outlet' e.g. targeting open-access Q1 (Scimago) journals
- o Increase the number of staff on editorial boards of journals. E.g., **Remagnino** became Associate Editor of the journal 'IEEE Transactions on Circuits & Systems for Video Technology' in 2016.
- o Engagement with policy making and standards setting organisations. E.g., **Martini** has been active in the IEEE P3333 group - Standard for the Quality Assessment of 3D Displays, 3D Contents and 3D Devices based on Human Factors - making a key contribution to the IEEE P3333.1 standard. She also chaired the IEEE P3333.4 group and is currently chairing the IEEE P3333.1.4 standardization committee on quality assessment of light-field imaging.

Achievements

The following research achievements aim to illustrate the success of the Unit's strategy:

- **Production of bodies of research in the identified priority areas**
  - o **Argyriou** designed a novel end-to-end **3D face reconstruction** approach from a single 2D facial image based on a new CNN architecture. In 2017, it was presented at

the prestigious International Conference on Computer Vision (output 11-05-1339). Moreover, this work had an international reach outside academia (*see Section 4.2*).

   o **S. Barman** produced a body of work focused on the automation of **retinal vessels morphology quantification**. This was applied to the UK Biobank fundus image dataset (over 100,000 retinal images) and contributed to diabetic retinopathy as evidenced by a publication (output 11-22-1355) in the Q1 journal 'Computerized Medical Imaging & Graphics' (2015).

   o **Makris** and **Nebel**'s research on modelling sets of multivariate sequences using nonlinear dimensionality reduction delivered a new approach addressing **stylistic variations in time series**. Published in the Q1 journal 'IEEE Transactions on Cybernetics' (2014), this work (output 11-32-1364) has applications beyond human motion analysis such as autonomous transport and other self-organising areas.

   o **Martini**'s research on multimedia Quality of Experience focused on **medical video streaming ensuring preservation of diagnostic quality**. Her work is a main reference in the European Network on Quality of Experience in Multimedia Systems and Services (Qualinet) Working Group on medical imaging. Publications include (output 11-40-1372) in the Q1 journal 'IEEE Journal of Biomedical and Health Informatics' (2014).

- **Impactful research.** The three submitted ICSs exemplify the significant impacts produced by the Unit's research.
   o 'Intelligent computer vision improving security in crowded public events and agricultural practice on farms' (ICSUoA11Remagnino3)
   o 'Industrial innovations through enhanced multimedia quality of experience' (ICSUoA11Martini1)
   o 'Using ubiquitous networks to produce novel communication capabilities and to improve quality of life' (ICSUoA11Politis2)

They highlight the benefits of a strategy that builds on sustained and focused research efforts in specific areas, a wide range of stakeholders, e.g., telecommunications industry and Home Office ministerial department, using long lasting commercial relationships as the initial step towards economic impact.

- **Publications in high-quality journals** (82% of submitted outputs were published in upper-quartile journals) including the following **IEEE Transactions journals**: Smart Grid, Cybernetics, Image Processing, Services Computing, and Multimedia E.g., **Khan**[ECR] and **Martini**'s research on encoding dynamic vision sensor data was published in 'IEEE Internet of things journal.'

- **Significant increase in both external funding (+24%/year) and PhD completions (+26%)** in comparison with REF2014.

- **Capacity building through external collaborations:**
   o Funding awards from a **wide variety of sources**: EPSRC, MRC, TSB/Innovate UK, EU, NATO, National Institute for Health Research and many foundations and charities, i.e., Nesta, British Heart Foundation, Fight for Sight, and Lausanne Hospital.
   o Collaborations with a range of UK (Buhler UK Ltd, Deltatre Ltd, Entryphone Ltd, Globe Microsystems Ltd, VCA Technology Ltd.) and overseas (Airbus, Cubic Corporation, Deutsche Telekom AG, Google, Instinet, Telecom Italia, and Alcatel-Lucent (now Nokia)) companies.
   o Publications with other research groups: among submitted 55 outputs, 82% include at least one external collaborator (at 51 different institutions), and 45% include at least one international collaborator.

- **National and international recognition:**
   - **External examiners for 70 PhDs (38% overseas)** and delivery of 18 keynote talks at academic venues including the prestigious **Royal Society** (*see Section 4.2*)
   - **Membership of 10 national and 15 international grant review committees** (*see Section 4.2*)
   - **Membership of the editorial board of 25 international publications** including 15 Q1 journals (*see Section 4.2*)

- **Engagement with policy makers and contribution to standards bodies: Nebel**, having spent a week at the UK Parliament as part of a Royal Society Pairing Scheme, provided

written evidence to the House of Lords Select Committee on Artificial Intelligence (2017) to inform national policies on the economic, ethical, and social implications of advances in artificial intelligence. **Martini** contributes to international standards for the International Telecommunication Union (ITU) - ITU standards on Quality of Experience (SG12) – and the IEEE P3333 group. **N. Barman**[ECR] made 9 contributions to ITU resulting in the G.1072 Gaming Quality of Experience standard (01/2020). **Politis** was chief editor of a white paper 'A New Generation of e-Health Systems Powered by 5G' published by the Wireless World Research Forum (WWRF) in 2016. He also contributed to a white paper of the 5G Infrastructure Public Private Partnership (5G PPP) - joint initiative between the European Commission and European ICT industry - on '5G empowering vertical industries' (2016). **G.C.**[ECR] contributed to the white paper 'Connected Vehicles' published by WWRF (2019).

Future research

As cyber-attacks are becoming more and more sophisticated, usage of machine learning approaches has become an essential element of cyber security. Since the Unit developed significant research capacity in those two domains, **machine learning for cyber security,** especially in 5G/6G heterogeneous networks**,** will be included as a future research priority area. Similarly, as original research on multimedia quality of experience showed, machine learning is essential to ensure accurate dynamic response to changes in network conditions. Consequently, it will take an even more prominent role in Communications research, e.g., on **smart mobile ad-hoc networks**. Collaboration with various local authorities has clearly highlighted that the **'smart cities' agenda** is becoming both mainstream and a reality. Consequently, this agenda will be one of the key research topics the Unit will contribute to. Its existing strengths in both visual surveillance and mobile communications leaves it particularly well placed to substantially impact the field.
The Unit has already amplified its efforts to **diversify its research, impact and engagement funding sources**: e.g., research proposals worth £1.6M were submitted to the Qatar National Research Fund and we collaborated with South London local authorities on a successful £6M bid (pending funding allocation) to the London Business rates strategic investment fund, where the Unit will develop an AI-based business intelligence platform to support over 1,000 local businesses. The Unit has also engaged in closer collaboration with industry (e.g., media, visual surveillance, finance, and pharmaceutical) to be able to target, in particular, the various Innovate UK programmes (e.g., £0.48M award for a double KTP with a FinTech company, 2019).

Open research and research integrity

The Unit complies with the University's Open Access Policy, and therefore the REF2021 Open Access Policy and funding bodies' requirements. Consequently, all its submitted research outputs are available in KU's Research Repository (https://eprints.kingston.ac.uk/) to achieve a **Green open access environment as a minimum**. Moreover, thanks, in particular, to KU's funds to support Gold open access, the percentage of submitted publications that are **Gold open access increased significantly** since REF2014 from 5% **to 22%**. The University supports fairness and transparency in research assessment, so does not support the use of unweighted impact factors. **Nebel** contributed to a recent project, translating this to a public-facing set of principles and signature of the Declaration on Research Assessment (DORA).

The Unit also complies with KU's policy on **data sharing and management**, which aligns with that of UKRI. Collectively, these mechanisms promote a culture which supports transparency of research and data sharing. This is exemplified by some of the datasets and source codes that the Unit makes available to the research community. Importantly, when they involve human participants, collection and management of those data adhere to research protocols agreed by the University Research Ethics Committee in accordance with the Data Protection Act 2018 and the General Data Protection Regulation (GDPR). Based on data captured by a motion sensing device (i.e., Microsoft Kinect), **Makris** and **Argyriou** created action datasets for both single player (G3D) and multiplayer gaming (G3Di) (http://dipersec.kingston.ac.uk/G3D/). The publications reporting those datasets were cited over 200 times during the REF period. **S. Barman** produced a dataset of retinal images of multi-ethnic children that allows for the scientific community to train, test and,

most importantly, benchmark computer vision algorithms (https://blogs.kingston.ac.uk/retinal/chasedb1/). The associated publications were cited over 300 times since 2014. **Argyriou** made open source the code of his 3D face reconstruction app on GitHub, where it was in **the world's top 10 downloads for four weeks (2017)**. Those examples illustrate some of the impact that our data sharing culture has on the scientific community.

Through ongoing **training and a rigorous and integrity-driven research culture**, the Unit fosters an environment whereby academic staff and other researchers are actively supported in the many aspects of research ethics, research integrity, and researcher supervision (*see Section 2*).

1.3 Unit impact strategy

Approach to enabling impact

The critical mass and longevity of the Unit's research have resulted in the generation of positive impacts on economy, society, culture, quality of life, health and public policies as illustrated by the two ICSs submitted to REF2014 and the three included in this submission. These outcomes were made possible with the support of KU's Research, Business, and Innovation team (and Impact and Business Development Managers assigned to faculty support) and a focused strategy aimed at ensuring engagement with industry, and national and international bodies by establishing long-term relationships with main stakeholders, participating at decision-making organisations, and exploiting intellectual property opportunities.

The **strategy to ensure the maximum impact of conducted research** is organised around two main objectives:
1. to build trust and foster the establishment of long-term relationships with commercial organisations and main stakeholders.
2. to participate actively in the work of professional organisations and decision-making entities.

Engagement with industry
The strategy is focussed on building trust and fostering the establishment of long-term relationships with industry. This was achieved using various schemes which include KTPs, sponsored PhD scholarships, supply of trainees and job candidates, support of SMEs and organisation of industry relevant events such as the School's annual industrial lectures, IP training, discussion forums and professional workshops. The Unit's applied research, addressing practical problems, is particularly sought by SMEs, illustrated by involvement in 12 KTPs during the period, across a variety of industries including media, visual surveillance, food processing, finance, pharmaceutical, building, safety and security, manufacturing, and software engineering (*see Section 3.1*). The Unit was also a partner in 10 EU funded FP7 and HORIZON 2020 projects, where it collaborates with international companies including Airbus, Deutsche Telekom, Telecom Italia, and Alcatel-Lucent (now Nokia) (*see Section 3.1*).

Engagement with governmental departments and policy makers
In parallel with enterprise partnerships, the Unit recognises the importance of engaging with other types of stakeholders such as standards bodies, governmental departments, and policy makers (*see Section 4.2*). Police, security, and safety services have relied on the Unit's expertise through being a collaborative partner in many funded projects involving security organisations, e.g., H2020 MONICA *(ICSUoA11Remagnino3)*. The Unit was also highly active in transferring the product of its research to standards bodies (ITU, WWRF, and IEEE Multimedia Interest Group).

Unit impact

The quality and variety of impacts generated by the Unit is illustrated by its ICSs; all of them relied on successful collaborations with industry and public/standard bodies, including the City of Bonn, the EU, IUT and IEEE:

1. **Research in computer vision and artificial intelligence** (**Remagnino**) led to: **safety and security** benefits in large public events through the deployment of the 'MONICA' platform in 5 European countries, with over 140,000 end-users; bringing **industrial benefits and strategic redirection** to a UK SME; **driving forward drone operations** with a UK SME specialised in unmanned systems; and harnessing 5G to provide **welfare improvement and cost savings** in farming. (ICSUoA11Remagnino3).

2. **Research in multimedia quality of service and experience** (**Martini** & **N. Barman**[ECR]) was adopted by both a UK SME and a multinational company. First, the creation of innovative video door phone systems by Entryphone Ltd resulted in **additional cumulative sales** of £0.4M and increased profit margins. Second, the integration of video streaming quality monitoring in Deutsche Telekom's networks enabled the company to offer cloud gaming services. This is essential to its **competitiveness** since cloud gaming is predicted to represent up to 50% of 5G data traffic by 2022. (ICSUoA11Martini1).

3. **Research into methods for building ubiquitous Mobile Ad-Hoc Networks, machine learning** and **quality of service in streaming** (**Politis**, **Argyriou** & **Martini**) led to: **economic benefits** to an international company through the development of an advanced radio gateway supporting emergency responders; a network and software solutions SME; the deployment of Ubitech's (a network and software solutions SME) gaming platform in nine institutions in five countries supporting children with cerebral palsy, leading to significant **health benefits for over 1,000 of them**; and finally, contribution to new **technological standards and EU 5G policy**. (ICSUoA11Politis2).

In addition to these selected ICSs, the Unit's research has consistently benefitted its industrial partners, e.g., Innovate UK assessed all its contribution to KTPs very positively. Besides generating economic impact, health and social care were areas of particularly impactful research. E.g., **Philip**'s body of work on mobile healthcare (m-health) brought positive health benefits to diabetes patients through interdisciplinary and international collaborations (e.g., with Pharmacy and Chemistry at KU, Chemistry and Forensics at Nottingham Trent University, Biochemistry at Basrah Medical College in Iraq, Applied Medical Sciences at Dammam University in Saudi Arabia, Royal College of Surgeons in Ireland, consultants at various NHS Trusts, and foreign hospitals in Germany, Greece, Ireland, and the Netherlands). It includes: a social robotic platform supporting behavioural change in children; a social network-based system contributing to both social behavioural change and better disease management; and, a telehealth solution, where a vest with wearable sensors and a patient hub capture physiological information for smarter management of diabetes as a comorbidity.

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2. People

2.1 Staff and promotion of equality, diversity and inclusion

The staffing strategy of the Unit is guided by its commitment to Equality, Diversity, and Inclusion (ED&I). Kingston was one of the first 8 UK institutions to be awarded a **Bronze Race Equality Charter** in 2015 (renewed in 2019). Its ED&I work on academic career progression was recognised by **The Guardian Award for Diversity Initiative** in 2014. Moreover, members of the Unit were instrumental in the School of Computer Science & Maths achieving an **Athena Swan Bronze Departmental Award** in recognition of its commitment to advancement of gender equality in academia (2019). The School prides itself on a strong representation of female professors in the leadership – from Head of School to theme leader and Director of Research & Enterprise (2014-2019, now Professor of Computer Vision). The Unit's submission adheres to KU's REF 2021 Code of Practice, and to the underpinning principles of transparency, consistency, accountability, and inclusivity. The University's staffing policy supports flexible working and study leave, promotes health and wellbeing and provides support for staff with caring responsibilities within the Unit. Among the Unit's 22 FTE membership, there are 4 female staff (18%). While this figure is slightly lower than that of the HESA Benchmark 2014/15 for ITCS (IT, systems sciences & computer software engineering) academic staff (22%), they made a significant contribution, 35%, to the submitted outputs. In terms of BAMEs, the Unit returns 7 staff (32%), which compares very favourably to the HESA Benchmark of 12%.

During this REF period, the **staffing strategy** focused on recruiting junior academic and postdoctoral staff offering original research in its research priority areas, supporting staff research activities and skill development, and rewarding the quality of their overall research output by promotion.

- **Recruitment and induction**
  The Unit is committed to ensuring transparency within its recruitment process through training its staff and offering, e.g., refresher opportunities every three years. All recruitment panels comprise mixed gender. We also minimise any potential bias within the recruitment process by ensuring all Chairs have undertaken Unconscious Bias and Fair Recruitment & Selection training in the last three years. This process served particularly well our ED&I commitments since among the four new Lecturers who joined the Unit, three are from Black, Asian or minority ethnic backgrounds. To ensure that new staff feel welcome and supported, in addition to the formal University's induction process and introductions to their new colleagues, each new staff is placed with more experienced colleague in shared offices with this person acting as a "buddy" in the short-term helping with any day-to-day questions. Moreover, they are assigned a research mentor for their first years and encouraged to join research groups that align with their interests. Furthermore, BME and female staff are offered to join the Beyond Barriers Mentoring Scheme which aims to maximise their potential. Finally, to support early research activity of academic staff, new appointees have a 30% reduction in their teaching hours during their first year.

- **Research support**
  Supporting the career development of all staff and strengthening the Unit's research is addressed through several mechanisms:
  - The annual appraisal process is organised around a flexible menu of personal research objectives designed to both challenge and develop an individual's activities according to the Unit strategy. To support staff, all appraisers are required to attend appraisal training before undertaking them and appraisees are also encouraged to participate in training.
  - The organisation of specific research and enterprise training seminars. The topics that were covered during the period include KTP funding, Horizon 2020 briefing, the Global Challenges Research Fund, fast track impact, GDPR & research data, legal contracts & negotiations, Intellectual Property Rights protection, research management, and publication masterclasses.
  - A staff development fund provides resource to support research objectives by funding, i.e., specialised equipment, conference/networking event attendance, and sabbaticals (**S. Barman** - 8 months at the Institute of Neuroscience in Marseille, France, 2018; **Al-Fagih** - 24 months at Hamad Bin Khalifa University in Qatar, 2018-2020).
  - The work allocation system is a metric-based methodology used to ensure that academic staff's teaching commitment does not prevent development of their research. This methodology explicitly rewards research success, i.e., publications in high-quality journals, grant awards, and PhD completions, with teaching relief. The system also recognises the time associated with research student supervision (2hrs/week) and FTE contributions to funded projects.
  - A research activity mentoring programme supports ECR and academic staff aiming to increase their research activity. Based on frequent meetings, the scheme encourages personal progress monitoring, esteem building and engagement with the research community and research users. In particular, the scheme supports ECRs to apply for KU's First Grant Scheme that is intended to provide pump-priming grants to initiate work on research projects that will, in-turn, result in a high-quality application for external research funding. E.g., one female academic (**Al-Fagih**), ECR at the time, was successful in achieving a First Grant in 2017/18, publishing two Q1 and five Q2 papers and submitting two large external grants (2019 and 2020) since. A direct impact of this programme was the sustained increase of the number of research awards (+24% annual income compared with the REF2014 period).
  - Support for research grant applications. All applications are internally peer-reviewed by two senior colleagues (at least one from the Unit) before submission. The application is

coordinated and supported by KU's Research, Business, and Innovation service (RBI), which deals with all pre- and post-award processes. They include identification of appropriate funding opportunities through horizon scanning (issuing of a monthly funding alert), support in finding suitable industry partners if necessary, budget preparation, and application submission. Moreover, RBI works with funders to provide necessary information for the applicants on Terms & Conditions of Grants/Awards before submission. If applications are unsuccessful, RBI encourages applicants to collect any official feedback from the funder and advise them on how to enhance and/or change the focus of their application so that it becomes suitable to other funders or schemes. Additional support is provided in sharing good practice events and grant writing sessions, especially in response to calls fitting ongoing research.

- **Career progression and promotion**
  All staff are given equal career/promotion and internal funding opportunities, irrespective of their contract. Moreover, they are permitted to work flexibly/remotely for at least one day per week, and for longer durations by arrangement with their Head of Department. Staff are encouraged to participate in leadership programmes (Stellar HE and Diversifying Academic Leadership, Leadership Foundation) and a female leadership development programme (Aurora). Three staff attended Leadership programmes and two female staff completed the Aurora programme during this REF period. Moreover, all staff can access KU delivered courses free of charge, e.g., Masters/MBA, and budget is available to support staff wishing to study at a higher level and attend short courses, conferences, and travel to enhance their career progression. Staff also apply externally for funding projects that strengthen their international recognition, e.g., **Martini** received internal investment of £20k to develop an international transmission standard by an international professional body (ICSUoA11Martini1).
  A significant portion of the Unit's staff (45%) was promoted in recognition of their research excellence during the current assessment period: **N. Barman** from Research Associate to Lecturer, **Al-Fagih** to Senior Lecturer, **Philip** to Associate Professor, and **Argyriou**, **S. Barman**, **Khaddaj**, **Makris**, **Martini**, **Nebel** and **Politis** to Professors. They all play a major part in strengthening the research culture, developing valuable research collaboration, producing research outputs, supervising PhD completions and attracting substantial external research income. 40% of promotions in the period were women (including two to Professor).

Visiting Scholars contribute to both the vitality of the research culture and the Unit's engagement with the international research community, industry, and national and international bodies. They regularly give research seminars, advise researchers, contribute to journal publications, serve on the committees of international events organised by the Unit, and facilitate collaborations with their organisations. Moreover, Visiting Professors - four are currently active, and constitute a diverse VP base – not only allow direct contact with decision makers in national and international bodies, but also act as role models for students and staff alike. Professor Monekosso (Leeds Beckett University) conducts research in sensor data analytics for human activity recognition, behaviour analysis and automated sensor failure detection. Professor Velastin (University Carlos III, Spain) is an expert in computer vision and video analytics (security, safety, traffic analysis, machine learning). Professor Hatton is Professor Emeritus of Forensic Software Engineering. Professor Qanadli (Head of the Cardio-Thoracic and Vascular Unit, Lausanne University, Switzerland) is a key partner in a large clinical trial (500 sample data set) currently conducted with **Dehmeshki** to achieve both European (CE) and Food & Drug Agency (FDA) certifications of his computer aided system for detection and monitoring of aortic abdominal aneurysm.

2.2 Postgraduate Researchers

The Unit embraces the vision behind the UK Concordat to Support the Career Development of Researchers. Consequently, alongside the University, it has developed specific mechanisms to **support its Postgraduate Researchers' career** development with a view to developing them as both independent researchers and attractive candidates for future posts.

The increasing quality of research has attracted more and higher quality PGRs. Moreover, to recruit the strongest students, the Unit invested **around £1M during the REF period on PGR support**. Consequently, there was a significant increase (33%) of doctoral completions compared to REF2014 (the annual average of 7.4 a year increased to 9.9). This growth and the improving completion rate were supported by additional supervisor and student training, annual monitoring of supervision teams, and the provision of additional computing resources. The opening of the £55M University's Town House Project (2020), which incorporates extensive and state-of-the-art library and seminar facilities, provides further research-orientated space. Best practices in supervision are promoted and guide the development of individual training programmes. Most importantly, **PGRs are embedded within a supportive research community** which facilitates interdisciplinary exchanges via, for example, seminars, cross-faculty conferences, and science communication competitions. ED&I commitments naturally include PGRs; with a current female population of 24%, it is in line with the corresponding HESA Benchmark 2014/15 (26%).

The Graduate Research School provides **compulsory training in core multidisciplinary/transferable skills** (e.g., research methods, ethics, intellectual property, personal development portfolio planning, and thesis writing skills) and acts as a centre for further support/guidance. PGRs are also encouraged to attend specialist MSc courses that are relevant to their research area. Among them, the MSc's in Networking & Data Communications, Network & Information Security, and Game Development, with its Machine Learning & Artificial Intelligence component, support directly DIRC's three research themes. Moreover, specialist training outside KU is offered if required. In addition to those subject-specific training opportunities, DIRC organises biweekly both a reading group and a seminar series including internal and external speakers. PGRs are also financially supported to present their research at international conferences and in open access journals. **The Unit's PGRs routinely publish their research in high quality international (Q1) venues**.

An explicit part of the PGR monitoring process is to ensure that supervision teams engage their students in these training programmes. Moreover, students are encouraged to become involved in organising events to develop leadership and research organisation skills. E.g., in 2014 a Unit PGR took the initiative to organise the first University-wide PhD conference. PGRs are now expected to present their work at that event and compete to represent KU at the UK-wide Vitae Three Minute Thesis® competition (in 2019, the representative was from the Unit). They are also **encouraged to take part in competitions and events organised by learned societies and the industry**. E.g., a PGR was awarded a prize in the Biochemical Society's Science Communication 2016 competition, and two PhD students won the first prize for their solution to the challenge 'classification of construction site images' (sponsored by Sir Robert McAlpine Ltd) at ProjectHack3.0 (2019). **All those initiatives contributed to the significant increase of PhD degrees awarded during the period, i.e., 65, when compared to REF2014's, i.e., 37.**

As part of their career planning, in discussion with supervisors, they may take on limited teaching duties to gain experience in delivering education and improving their communication skills. Indeed, PGRs and postdoctoral researchers are offered opportunities to engage in teaching alongside experienced academics, assisting in within-laboratory teaching and portions of classroom delivered materials. They are supported and encouraged to engage with the opportunities for HEA recognition and training appropriate to their roles. The success of those schemes can be exemplified by researchers moving on to take up academic positions and fellowships at competitive UK and international universities, such as Surrey, Oxford, Pennsylvania, and National University of Sciences & Technology in Pakistan.

3. Income, infrastructure and facilities

3.1 Income

Steady growth of research income and increasing success in raising both nationally and internationally competitive external research funds can be attributed to several factors. Most important is the maturity of the Unit – it produced 195 external research funding applications during

the period - and its engagement with the research community, users and industries across the UK, Europe, and the world. The total research income of £5.65M from new and continuing projects in the current period is substantially greater than that accrued over REF2014, corresponding to a **growth of 24%** in the annual average income. This is particularly significant in the current climate of reduced public research funding and unease regarding the participation of UK institutions in EU Programmes. **43% of Unit's income is from 10 collaborative EU programmes**, addressing visual surveillance, and wireless & multimedia communications for health and security (Table 1).

Table 1. Research funding from EU programmes

	Prog.	Project title [partners]	Income	Period	Unit's theme
1	FP7	ADDPRIV (Automatic Data relevancy Discrimination for a PRIVacy-sensitive video surveillance) [10]	£178k of €0.4M KU	2011-2014	Vision & Security
2	FP7	CONCERTO (Content and cOntext aware delivery for iNteraCtive multimEdia healthcaRe applicaTiOns) [11]	£206k of €0.4M KU	2011-2015	Communications
3	FP7	PROACTIVE (PRedictive reasOning and multi-source fusion empowering AntiCipation of attacks and Terrorist actions In Urban EnVironmEnts) [10]	£196k of €0.3M KU	2012-2015	Communications & Security
4	FP7	PROTECTRAIL (The Railway-Industry Partnership for Integrated Security of Rail Transport) [31]	£30k of €0.1M KU	2010-2014	Vision & Security
5	FP7	SALUS (Security And InteroperabiLity in Next Generation PPDR CommUnication InfrastructureS) [17]	£199k of €0.3M KU	2013-2016	Communications & Security
6	FP7	SIAM (Security Impact Assessment Measures - A decision support system for security technologies) [8]	£161k of €0.3M KU	2011-2014	Vision & Security
7	FP7	WELCOME (Wearable Sensing and Smart Cloud Computing for Integrated Care to COPD Patients with Co-morbidities) [13]	£265k. New €8.3M award (€0.6M KU shared with UoA3)	2013-2017	Communications
8	H2020	AEGLE (An analytics framework for integrated and personalized healthcare services in Europe) [14]	£165k. New €6.1M award (€0.5M KU shared with UoA3)	2015-2018	Communications
9	H2020	MONICA (Management Of Networked IoT Wearables - Very Large Scale Demonstration of Cultural Societal Applications) [30]	£586k. New €17.6M award (€0.9M KU)	2017-2019	Vision & Security
10	H2020	QoE-NET (innovative Quality Of Experience maNagement in Emerging mulTimedia services) [7]	£414k. New €2.9M award (€0.5M KU)	2015-2018	Communications

Although historically there was an important reliance on EU Programmes, the Unit diversified its sources of incomes, resulting in new awards with headline value £4.52M during the period. Consequently, despite the award of a limited number of H2020 grants, its income grew during the REF period. Indeed, the last few years showed increasing success in attracting funding from UK Research Councils (Table 2). As a result, **18% of income is from 2 continuing and 4 new**

EPSRC and MRC projects and Industrial Case Studentships (with BAE systems, Legion Ltd and Roke Manor Research Ltd).

Table 2. Research awards from UK Research Councils

	Prog.	Project title	New Award	Period	Unit's theme
1	EPSRC	DARE (Distributed Autonomous and Resilient Emergency Management System)	£1.2M (£363k KU)	2017-2020	Communications & Security
2	EPSRC	IOSIRE (The Internet of Silicon Retinas: Machine-to-machine communications for neuromorphic vision sensing data)	£561k (£280k KU)	2017-2020	Vision
3	MRC	Classification of oral lesions using deep learning for early detection of oral cancer	£147k (£89k KU)	2018-2020	Vision
4	MRC	Automated retinal microvascular quantification as a predictor of cardiovascular disease risk in later life	£149k (£83k KU)	2014	Vision

In line with KU's mission of supporting business innovation through knowledge transfer of its expertise, technology, and world-leading research (9% 4* in REF2014), the Unit applied for funding to **Innovate UK** schemes from which it was awarded **19% of its income:**

- **10 Knowledge Transfer Partnerships** - including 3 'double' KTPs - with the following companies: Cubic Defence UK Ltd (former Vocality) [D], Deltatre Media Ltd, Factbook Ltd, Globe Microsystems Ltd, VCA Technology Ltd, Entryphone Ltd[D], JPY Plc, Selectamark Security Systems Plc, Lerch-Bates Ltd, and Instinet Global Services Ltd[D]
- **5G Testbeds & Trials Innovate UK Programme**
  5GRIT - 5G Rural Integrated Testbed, £2.1M (£180k for KU), (2018-2019)
- **Agri-tech catalyst round 9 scheme** (IUK & the Department for International Development) Bee Smart: Improving yields for cashew growers in Ghana with smart pollination management, with Agsenze Ltd, £427k (£150k for KU), (2020-2023)

The remaining income is derived from a **variety of sources** including:
- **Overseas organisations:**
  - **NATO** (WITNESS - Wide InTegration of Sensor Networks to Enable Smart Surveillance and MIDAS - Control of Team of Mini-UAVs to Support Counterterrorism)
  - **US Department of Homeland Security**
- **UK organisations:** Home office Centre for Applied Science & Technology, SouthWest London Academic Network, and National Institute for Health Research
- **Private companies:** Google, Siemens AG and DOCOMO Communications Laboratories Europe GmbH, and Buhler UK Ltd plus 11% of income from KTP and RCUK partners
- **UK and European Charities:** Linde Real Fund, Fight for Sight, NESTA, Leverhulme Trust, Council for Assisting Refugee Academics, British Heart Foundation, and Lausanne Hospital

3.2 Infrastructure and facilities

During the period, research was supported by investment exceeding £2.6M by KU. It comprised **£1.6M funding** for the acquisition of new infrastructure and facilities all co-located in a single building to foster collaborations (described below), and in addition, a combination of research capital, pump-priming and faculty studentships over the period (£1M).

Since 2009, the Unit has had access to a dedicated 20-node **Linux High Performance Computing facility** (200 processor cores & 20TB storage). It was essential to the development of machine learning-based classifiers in areas including protein bioinformatics, action recognition,

people tracking and big data processing. Since this important resource was becoming outdated, KU **invested £0.52M in 2018/19** to replace the previous facility by a state-of-the-art one following the Unit's specifications. Delivered in 2019, it offers significant improvements in terms of connectivity (10 Gbps Ethernet), processing units (Xeon® Scalable Processors at 2.1 GHz), number of cores (768), memory (8GB memory per CPU Core) and useable storage capacity (80TB). Moreover, to boost further research quality across the three themes (especially projects using Deep Learning), **£50k was invested in 2017/19 to build a 24 GPU-farm** based on NVIDIA Titan**.**

The Unit also invested £53k in a customised facility to further its activities in advanced research in computer vision and digital communications to become a leading institution for Mobile Virtual Reality and Connected Living. The **Centre for Augmented and Virtual Reality Environments (CAVE) opened in 2017**, equipped with cameras, projectors, motion capture sensors and specialist workstations & software to facilitate research in the domain of real-time data integration and analytics – with applications ranging from medical diagnostics to smart cities, ambient assisted living – to gaming and user experience. It includes a high-performance display (Sony's BVM-X300) as an essential part of the set-up for achieving an effective visual interface and High Dynamic Range workflow. As it complies with the next-generation ITU standards embracing 5G and ITU-R BT.2020 broadcast standard, it is essential in our contribution to relevant standards bodies.

Furthermore, KU allocated **£0.9M in support of a new Centre of Cybersecurity Education and Culture (2018/21)**. The centre specialises in providing intelligence for live threats using state-of-the-art technology and strategies to combat cybercrime. It offers research in physical, network & cybersecurity, a GCHQ Masters qualification, and partnerships with the Home Office, the security industry, and communities. An additional £100k was invested in a fully equipped Cyber Security lab, which promotes state-of-the-art research contributing directly to the Security theme (2019).

The Unit also supports the Communications theme with LTE/WiFi-Adhoc testbeds to enable experimental evaluation. In addition, it invested £25k in 2019 in a Quantum Cryptography Analyser to pioneer **Internet-of-Things data security using quantum key cryptography for post-5G and 6G mobile Networks**.

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4. Collaboration and contribution to the research base, economy and society

4.1 Collaborations and interdisciplinary research

Over the last decade, the Unit enhanced networks of collaborators across the full range of stakeholders in their respective disciplines. There were 258 collaborations in the period (defined as a relationship with an external entity that led to a peer-reviewed co-authored paper submitted to REF2021 and/or a funded research project). They include partnerships with academic institutions in the UK, Europe, America and Asia (Cambridge, Oxford, UCL, Imperial College, EPFL, ETH, Bologna, New York, Pennsylvania, British Columbia, Nanjing, and Yonsei in Korea), research organisations (Francis Crick Institute, Fraunhofer-Gesellschaft, French National Centre for Scientific Research, and UK Biobank), multinational companies (Airbus, Cubic Corporation, Disney, Deutsche Telekom AG, NTT Docomo Inc, Dolby Laboratories Inc, Google, and Telecom Italia), and 33 SMEs (e.g., VCA Technology, Vocality, Ubitech, Entryphone, Blue Bear Systems Research Ltd, which are introduced in the ICSs).

As impact in real-world applications often relies on **interdisciplinary research**, the Unit collaborates with academics from very different fields, especially in the areas of medical and biomedical sciences, to ensure real-world impact. Evidence of interdisciplinary leadership is provided by substantial investments from non-traditional computer science funders (e.g., £0.5M from MRC and medical charities) and publications in scientific journals in non-UoA11 disciplines (e.g., Nature, Physics, Developmental Cell, Ophthalmology, and Hypertension). In addition to **Philip**'s work already described in the 'Unit Impact' section, interdisciplinary research is exemplified by the activities of the following members.

S. Barman's research in medical imaging analysis addresses the early detection of oral cancer and the association of retinal microvascular morphology with cardiovascular disease risk. Her MRC & British Heart Foundation funded retinal vasculometry work involved collaborations with various clinical UK research groups, i.e., Integrative Epidemiology at UCL Institute of Ophthalmology, the NIHR Biomedical Research Centre at Moorfields Eye Hospital and the Institute of Public Health at University of Cambridge, and the UK Biobank Eye and Vision Consortium. Her MRC funded project on classification of oral lesions for cancer detection, involves an international partnership with US and Asian institutions including department of Oral & Maxillofacial Pathology, Radiology & Medicine at New York University, Cancer Research Malaysia, Faculty of Dental Sciences at University of Peradeniya in Sri Lanka, and the department of Oral Medicine & Radiology at BP Koirala Institute of Health Science in Nepal.

Hoppe conducts research in medical imaging in close collaboration with researchers from the MRC Laboratory for Molecular Cell Biology and Department of Physics & Astronomy at UCL, and the Francis Crick Institute. This leads him to design novel segmentation and tracking algorithms addressing the real-life challenge of processing wound time-lapse images. Their output permits quantitative analysis, providing important insight about the wound healing process (Nature Physics doi:10.1038/s41567-019-0618-1, 2019).

Makris investigates the distinction of liver lesions by analysing images produced by contrast-enhanced ultrasound imaging. His research is performed in partnership with three other institutions, each providing their unique expertise to address this interdisciplinary challenge: Department of Radiology at King's College Hospital, Perelman School of Medicine at University of Pennsylvania (USA), and Radiology & Imaging Research Centre, Evgenidion Hospital, National and Kapodistrian University (Greece) (Ultrasound in Medicine & Biology, output 11-25-1386).

Nebel's collaborative research in bioinformatics led to 16 joint publications during the period. It was conducted with a variety of departments, including Pharmacology, Biochemistry, Plant Sciences, and Statistics at University of Oxford, Bioengineering at Nice Sophia Antipolis University (France), Pharmacy at University of Patras (Greece), Biological Sciences at University of Trieste (Italy), Computational Medicine at Autonomous University of Barcelona (Spain), and Pharmacology at University of Illinois (USA). That work was supported by grants from the British Council, the EU, the Royal Society, and the Polish National Centre for Science, and led to participation in international protein structure prediction contests (CASP11 & 12).

Remagnino has been a Visiting Researcher at the Royal Botanic Gardens, Kew, since 2010. This collaboration led to the production of an interdisciplinary body of work in plant classification, e.g., 'Multi-organ plant classification based on convolutional and recurrent neural networks' was published in IEEE Transactions on Image Processing (2018).

4.2 Contribution to the research base, economy and society

Contribution to research base

Unit members contribute to **their academic and research communities** through a variety of activities including journal edition, membership of national and international grant review committees, membership of learned societies, advisory boards, chairing conferences and giving invited talks. Moreover, they serve as reviewers for hundreds of journals and conferences (due to space constraints, this is not detailed in this document).

Funding committees: Unit members serve on relevant UK funding committees, including EPSRC, BBSRC, MRC, British Council, National Institute for Health Research, Cancer Research Wales, Newton Fund, UK National Commission for UNESCO, and UK Research & Innovation. **Nebel** and **Remagnino** are Full Members of the EPSRC Review College, **S. Barman** is a member of UKRI Future Leaders Fellowships Peer Review College, and **Martini** is a member of the EPSRC Prioritization panel. As evidence of international reputation, Unit members participate in international grant review committees of the EU, e.g., **Mellor** and **Politis** are expert reviewers for

H2020 programmes (INNOSUP and, 5G & Beyond 5G), and 15 non-UK national funding bodies from Europe (Belgium, Cyprus, Finland, France, Greece, Italy, the Netherlands, Portugal, & Switzerland), the Americas (Canada & Chile) and Asia (Qatar). **Nebel** is a member of the Computer Science Evaluation Group for the Discovery Grants Program of the Natural Sciences & Engineering Research Council of Canada (NSERC) (2019-22).

Journal editorial boards: Unit members serve on the editorial boards of 25 different journals including 15 upper-quartile journals, including IEEE Transactions on Cybernetics, IEEE Transactions on Circuits and Systems for Video Technology, IEEE Transactions on Human-Machine Systems, IEEE Transactions on Multimedia, IEEE Transactions on Systems, Man and Cybernetics, IEEE Journal of Biomedical and Health Informatics, IEEE Signal Processing Magazine, IEEE Vehicular Technology Magazine, IEEE Access, BMC Bioinformatics, PLOS One, and Neurocomputing.

PhD examinations: Unit members examined 70 doctoral theses including for the universities of Oxford, Edinburgh, and Imperial College, and 26 overseas.

Keynote speakers: Unit members delivered 17 keynotes at international conferences. Furthermore, **S. Barman** was invited to give a talk at the **Royal Society** on 'The transformative potential of data and image analysis for eye care', where she presented her retinal image analysis system (2018).

Conference contributions: The Unit supports hundreds of conferences by joining their programme committees and chaired over 22 conference committees. Exploiting his multi-disciplinary research activities within computer vision and healthcare, **Makris** chaired the IET Human Motion Analysis for Healthcare Applications conferences (2016-2019). As an expert in e-Health and 3D Multimedia Technologies, **Martini** chaired the programme committees of 3DTV Conference (2014), and the International Conference on Mobile Medical Multimedia Technologies, Applications and Services (2016) and chaired 4 international workshops.

Involvement in learned, national, international and industry-led societies: Unit members contribute to the research base, economy and society through their activity in over 20 different societies. They naturally include memberships of IEEE (and Senior IEEE) (**Martini** is chair of the IEEE P3333.1.4 standardization committee, was chair of the IEEE P3333.4 group and was Vice-chair of the Multimedia Communications Technical Committee of the IEEE Communications Society (2014-16); **Philip** is privacy sub-group chair for IEEE P2933 Standard Working Group on Clinical IoT Device and Data interoperability with TIPPSS (Trust, Identity, Protection, Privacy, Safety and Security)), British Machine Vision Association, IET (**Makris** is chair of the Vision & Imaging Network since 2017) and Fellows of both the Institutes of Physics, and Mathematics & its Application. Moreover, **Hunter** is a member of the British Standards Institute and International Electrotechnical Commission committees working on International Standards for Automatic Speech Recognition systems; other colleagues are involved in more specialised associations such as the Climate Vulnerable Forum, and National Institute for Health Research Central Commissioning Facility. Finally, some act as experts in industry-led societies. **Politis** is chair of two working groups of the WWRF and of the e-Health Vertical Industries Platform. **G.C.**[ECR] contributes to the 'Cybersecurity' workgroup of the WWRF.

Contribution to economy and society

As detailed in section 3.1, over three-quarters of income involve collaborations with companies, a third of which directly benefiting UK SMEs (Innovate UK programmes). Moreover, **Politis** is the director and co-founder of Ubitech Limited; a 10-people R&D company in wireless communications and machine learning that exploits outcomes of his research.

This demonstrates the Unit's ability to apply its innovative research to practical problems, contributing to economy and society. This is further illustrated by its three ICSs. They detail not only the economic benefits provided to both SMEs and multinational companies (Deutsche

Telekom and Cubic Corporation), but also enhanced security at public events, ecological benefits, better welfare for livestock, and health benefits for disabled children. Moreover, research applied to health contributed to better treatments, especially to diabetes and cancer patients.

Finally, the Unit is keen to **engage with and inform the public** through a variety of activities including talks at KU's 'Cafe Scientifique', local scientific societies and schools, scientific advice to the national press (The Economist magazine, and The Sunday Star), science festivals and outreach using KU's two state-of-the-art portable laboratories ('Labs in a lorry'), which attended over 100 events (e.g., Big Bang Fair, Festival of Science, and New Scientist Live) reaching over 10,000 individuals. **Argyriou** released a free app demonstrating his research on 3D face reconstruction from a single 2D facial image (ICCV17): it received over 1M uploads and the code was in the world's top 10 downloads at GitHub for four weeks (2017). **Nebel** published popular science articles in The Conversation (UK, France & España) about his research: 'DNA techniques could transform facial recognition technology' (2017) attracted 23,000+ readers and was republished in Scientific American. In total, those articles attracted over 48,000 readers (86% from overseas).