

Institution: Edge Hill University
Unit of Assessment: 11 – Computer Science and informatics
<p>1. Unit context and structure, research and impact strategy</p> <p>Research in the Department of Computer Science at EHU is carried out within the Department's Research Centre for Data and Complex Systems (CDCS) which incorporates a Visual Computing Lab (VCL). 93% of the Department's academic staff are members of either CDCS or VCL, some are members of both, and all are returned to this UOA. Work conducted within the Centre (led by Bessis) focuses on data analysis and future (disruptive) technologies, and, through the Lab (led by Liu), research in computer vision and graphics.</p> <p>The Department of Computer Science, established in 2012, made its first REF submission in 2014. Since then, the Department has received significant investment and support from the University, enabling growth of the staffing base, with the ambition to further develop its research capacity and reputation, both in terms of quality and quantity.</p> <p>In 2013, the Department had three research groupings with 35% of staff submitted to REF2014 (5 to UOA11 and 1 UOA25). The research and impact strategy set out in the REF2014 submission aimed at overall growth in the research base to achieve international levels of excellence in the areas of big data analytics, visualisation and future (disruptive) technologies. Specifically, the strategy focused on:</p> <ol style="list-style-type: none"> 1. Overall growth of our research-active staff who would be identified for REF2021 submission and our PGR community 2. Income generation by targeting a broad array of external funders 3. Enhancing our impact skills, capacity and capability in order to engage effectively with research users/beneficiaries. <p><i>1. Overall growth of our research-active staff who would be identified for REF2021 submission and our PGR community</i></p> <p>During the reporting period there has been significant growth in both research-active staff and PGR community. The unit has doubled its staffing base with over 93% of staff having significant responsibility for research, hence 19 FTE returned in this submission (see section 2). The unit is well-balanced with a mixture of early career, mid-career and senior researchers. There has also been a growth of staff with research leadership responsibilities achieved through both internal promotions and external appointments.</p> <p>As a result of this growth, the outputs' ratio, income generation (section 3) and international collaborations (section 4) per staff has also increased. To support the growth and strengthen the strategic areas we have increased the critical mass of research active staff in:</p> <ul style="list-style-type: none"> • Data analytics (Awais, Bessis, Korkontzelos, Liptrott, Lyon, Pandey, Raza, Trovati) • Visual computing (Behera, Kumar, Liu, Matthew, Vangorp, Zhang) • Future (disruptive) technologies (Al-Khalidi, Bessis, Gavan, Liptrott, Malik, Pereira, Raza, Wang) <p>This growth in staff with SRR is also reflected in the volume of peer reviewed outputs: from 33 for REF2014 to 206 this cycle (with eight articles submitted appearing in the top 10% of cited articles: January 2021). We are also reporting 9 PhD awards in comparison to zero completions in 2013. It also notable that we have, through external and internal funding, developed a sustainable community of research assistants and post-doc researchers from zero in 2013 to 12 in total across this period.</p> <p><i>2. Income generation by targeting a broad array of external funders</i></p> <p>During the current assessment period, the overall value of successful external bids is £1,7m (section 3) has come from diverse funders, including European Commission (EC) H2020, EPSRC, and Innovate UK, as well as other funding streams: UKIERI/DST, DBE, HEA,</p>

automotive industry, OfS, Erasmus+, Local Enterprise Partnerships (LEP). For a Unit that reported £28K income in REF2014, this is a significant improvement.

3. Enhancing our impact skills, capacity and capability in order to engage effectively with research users/beneficiaries

Our approach was to strengthen, extend, as well as develop new collaborations with research users and develop practices that support researchers to consider how their research can be of benefit to wider society and the economy, something which is central to our ethos. This included presenting our work and capabilities at various academic and non-academic events: e.g. Weather Research and Forecasting (WRF) workshops organised by National Centre for Atmospheric Science (NCAS), UK and US National Centre for Atmospheric Research (NCAR), clinicians and patient-experience groups hosted by NHS trusts (Walton Centre, Aintree Hospital, Alder Hey children's hospital, etc.) and Lancashire LEP. We also communicate our research and impact activities via various media platforms (e.g. BBC NW news, Radio Lancashire). This has enabled us to reach wider audiences while more focused interactions and collaborations at local, national and international levels have extended our circle of users to farmers, the car industry and food suppliers (see also section 4).

All current projects have a detailed impact plan, including identification of beneficiaries and routes to impact. The Department supports these plans in different ways; we have drawn on institutional support: e.g. the University's Research Impact Manager (RIM), invested in a post-doctoral researcher and a Departmental Knowledge Exchange and Enterprise Coordinator (KEE). In addition, we support impact-generation through workshops on planning for impact and sharing best practices. Impact is also a standing agenda item at the departmental away days. Alongside our case studies, other projects are also developing impact: e.g., TYPHON is starting to generate impact on wide range of data analytics industrial users, specifically in car manufacturing (Volkswagen), banking (Alpha Bank, Greece) and national telecommunication carriers (OTE group, Greece).

We were actively involved in establishing the Faculty's Productivity and Innovation Centre (PIC), partly funded by the European Regional Development Fund (ERDF). PIC aims to provide innovation support and advisory services to Lancashire-based SMEs. Our interaction with local and national organisations has led to successful KTPs and consultancies. We designed and delivered bespoke workshops as part of our public engagement and "work-as-partners" approach with UK-based SimCon, UCAR in the US, EU based Eclipse Foundation, resulting in impact generation reported in submitted impact cases.

Complementing our engagement with research users, significant efforts have been made to formalise our interdisciplinary work. Our researchers are active members of the University's three interdisciplinary institutes resulting in internally and externally funded projects ranging from the use of disruptive technologies for healthcare to being part of Erasmus+ funded projects. We have also led the development of an interdisciplinary Data Science for STEM research centre (led by **Bessis**) which brings together expertise mainly from Biology, Geography and Computer Science. Established in 2018, the Centre has been involved in collaborative, interdisciplinary projects supported by NERC, Royal Society and Natural Science Foundation of China, Indian Institute of Science, Tirupati, Birmingham Children's Hospital. In addition, we have recruited a number of PhD students co-supervised by Computer Science, Geology and Biology via the Graduate Teaching Assistant (GTA) programme.

Externally, we have established new collaborations and strengthened existing links with other institutions, focusing on interdisciplinary research, through MOUs, including ETH Zurich and NHS institutions (Liverpool-based Walton Centre, Aintree and Alder Hey, etc.).

Building on recent performance and staffing investment, our future aspiration is to create an inspiring environment attracting and retaining high-profile scholars, and supporting ECRs to progress into established careers, maximising their potential as research leaders. We will continue investing in AI and data science. The post-REF2021 period will focus on excellent research in the areas of digital health, autonomous systems and future of mobility. Our post-REF2021 strategy is to:

1. Establish a Data Science Research Institute to support growth of interdisciplinary research alongside subject-based research
2. Grow the number and ratio of successful, externally funded bids to sustain relevance and significance of our research
3. Expand collaborations with internal and external research organisations, businesses and communities to co-produce research of high impact
4. Scale up our PGR and PDR community into a doctoral/post-doctoral training college to enhance sustainability and vitality of our research environment and to contribute to the development of the next generation.

1. Establish a Data Science Research Institute to support growth of interdisciplinary research alongside subject-based research

The vision for this institute is to become a partner of choice, world-renowned hub of expertise working together with external research entities, businesses and communities to influence policies locally, nationally and internationally. It will create critical mass and ensure future sustainability within the University by reaching out to other research units across the University, including Sports Sciences, Psychology, Medical School and Engineering department (currently being established). We will develop our existing research groupings (CDCS and VCL) into smart analytics and visual computing themes. While maintaining their identity, they will work in greater synergy. With specific reference to smart analytics group, we will be researching on NLP, Bayesian networks, AI, knowledge representation and reasoning methods, machine learning, distributed processing and AI, predictive analytics within the context of smart business analytics (industry 4.0, cyber-physical systems, smart manufacturing and autonomous transportation). Visual computing group will focus on visual analytics, augmented and virtual reality, image processing, object recognition contributing to advancing digital health and smart vehicle systems with assistive technology.

2. Grow the number and ratio of successful, externally funded bids to sustain relevance and significance of our unit's research

Since REF2014, we have invested in training, peer-reviewing and mentoring. We recruited and developed existing staff into research leadership roles and supported ECRs to progress to mid-career researchers (section 2). The result is that we now have a critical mass of experienced academics who will be able to provide mentoring and other relevant support to the less experienced staff and ECRs. We shall increase the internal collaborations ensuring all staff, whether as independent or pre-doctoral researchers, are involved in research projects. We will use internal funding sources as pump primers. We will expand a network of peer-buddies involving internal and external subject experts to peer-review, mentor and collaborate. We will encourage staff to target a wide range of key funders suitable to the level of staff experience and expertise. The target is to double our current income and have all staff with at least one successful external bid. Working together with the best external collaborators and increasing the number of externally funded projects from the key funders will have a direct impact on the quality of the research. Responsible metrics, such as successful bids and recognition from the community through careful use of citations, will help inform the measurement of research quality at departmental level. More successful external grants will support increase in recruiting PDRs and help retaining completing PGRs to sustain continuity. Our commitment to Athena Swan principles and wider equality, diversity and inclusion (EDI) will put greater emphasis on balancing workload to increase quality and effective productivity.

3. Expand collaborations with internal and external research entities, businesses and communities to co-produce research of high impact

Our commitment to increasing public engagement and impact generation will be supported by partnering and collaborating with world-leading researchers, organisations and industry locally, nationally and internationally. This will include strengthening existing collaborations (section 4).

The unit will seek to increase existing collaborations with R&D organisations, including STFC, Alder Hey Children's Hospital, Walton Centre, Birmingham Children's Hospital and with industry.

We will strengthen our strategic position in the HealthTech cluster Sci-Tech Daresbury and Liverpool Health Partners (LHP). By leading research and innovation in collaboration and partnership with local, national and international businesses, organisations and academia we will be in a strong position to support a local technology science park where research can be co-produced with such partners. Within these settings we will have research users and beneficiaries informing our research and impact activities.

4. Scale up our PGR and PDR community into a doctoral/post-doctoral training college to enhance sustainability and vitality of our research environment and to contribute to the development of the next generation

We will continue to build capacity in terms of supervision, completions and widening PGR and PDR communities. It is our ambition that, by building on our existing collaborations with UK, China, Japan, India and European universities, and networking with new communities, businesses and industry with a number of key partners to establish a training college which will support peer exchange, mentoring and co-production of knowledge. This will enable our unit to foster both interdisciplinary and subject-based PGR and PDR community from diverse backgrounds energising and enhancing our research environment.

Our unit is committed to the principles of open research concomitant with the University being a signatory to DORA. We use university's Open Access Policy and Open Research statement to encourage open access beyond the requirements of REF and promoting good data management practices, though DMP-online. Complementing Research Office (RO) support, our Department makes considerable efforts to promote OA ethos. It is discussed in individual performance review meetings and at departmental away days and other gatherings. When possible, we use open source software such as, Tensorflow, OpenAI/Gym, Python, ROS, Gazebo etc. as well as making source code and generated data available in repositories such as GitHub and University's data repository. For instance, all source code and API, including a standalone NLP tool developed as part of CROSSMINER (impact case study) are made available for developers via GitHub and downloadable from Eclipse Foundation, while datasets generated by medical image processing related projects are released for research purposes only.

We are committed to the principles of the Concordat to Support Research Integrity supported by University-wide policies and procedures (REF5a). Complementing University processes, we are encouraging greater consideration of the broader ethical/moral dimensions of our work through staff and PGR training. Research integrity and ethical scrutiny is ensured via comprehensive research ethics review and approval processes at the Department and University level.

2. People

Staffing strategy and staff development

A key research objective has been to invest in leadership and grow the research-active staffing base. 5 (FTE 5.0) out of 14 (FTE 12.9) eligible academics were submitted in REF2014 plus one submitted to UOA25, in contrast to 19 out of 20.4FTE in REF2021. 19 staff now have a PhD, compared with 4 previously. There were two readers providing research leadership in REF2014 compared with two readers (**Korkontzelos, Trovati** – both promoted to professor in August 2020) and three professors (**Bessis, Liu, Pereira**) in REF2021, including one female. This has been achieved by both focused and enhanced recruitment and staff development strategies. New staff have been appointed on permanent contracts at all levels, including two professors (one as HoD), two senior lecturers and nine ECR lecturers. During the census period, we also had 12 post-doc researchers recruited to work on various externally funded research projects. The unit's plan defined the new appointment requirements, which, in return, contributed to the strategic growth of the areas of data analytics, visual computing as well as future internet and (disruptive) technologies.

Given the significant number of appointments and ECRs, induction and development have been crucial. Departmental induction includes a meeting with the Director of Research who helps to identify short-term research objectives as well as ensuring staff are aware of research support

resources and governance compliance. The unit's staff development strategy was revised with a stronger emphasis on supporting staff at all levels pursuing research careers, including undertaking PhD studies. There are regular research seminar series and research mentoring schemes (both university and departmental level) to identify areas for development, which are further discussed during probation and performance and development review (PDR) meetings. These inform researchers' 3 to 5-year research plans outlining their professional development needs and requirements, which are agreed with the HoD. Staff development is informed by the national Researcher Development Framework providing training opportunities for all career stages. The institutional Research Development Programme (RDP) provides a professional development framework for planning, promoting and supporting the career development of researchers through a range of activities.

All staff are encouraged to apply for internal seed funding and Conference Travel Grant, particularly ECRs who are prioritised, and are supported to gain experience in writing and submitting internal and external grant proposals (see section 3). When applying for internal funding, experienced researchers are encouraged to include at least one ECR with a brief description about how the ECR(s) will benefit or be supported if successful. The University also organises a biennial ECR conference. The Department organises events with participants from industry and research communities to celebrate and discuss their research accomplishment, societal engagement and impact. One of the successful KTP projects (BEC Ltd.) was initiated at this event.

All ECRs are encouraged to attend bid writing workshops provided through the RDP. ECRs are mentored by an internal or external expert with similar research interest. They are encouraged to write joint proposals with senior colleagues. Successful bids such as CROSSMINER, TYPHON, CHARM, PERSIST (section 3) all had ECR and mid/senior-career researchers co-writing bids. At more senior level, training on project and people management, and large grant applications is also available.

The Department has a dedicated budget for staff development and supports staff with flexible working arrangements, traveling to attend external events and conferences. It offers opportunities to staff for teaching relief, and study leave through various MOU agreements.

Examples of training attended by our staff include certification courses on Deep Learning, CAVE open source software, SAS programming. Our staff have also benefited from attending KTN meetings, Advanced HE leadership courses such as Aurora and Leadership Academy: attending KTN meetings has contributed to three successful KTP projects.

Our revised recruitment and collaboration strategy has resulted in a noticeable internationalisation of the Department. We have attracted and retained academics from European, Chinese, South-Asian and other heritage bringing wider diversity to our unit. We recognise our gender imbalance and our Athena Swan action plan has initiatives to tackle this, not least through targeting female potential applicants. We are also taking action to help increase the pool of suitable candidates in the long term by encouraging under-represented groups to consider Computer Science disciplines as an active area to study.

Research students

The University has made a significant investment in GTAs and since 2012 has funded PhD studentships annually across the University (REF5a). Since 2014 we have had 8 MRes and 19 PhD students (15 GTAs or otherwise supported by departmental scholarships). In contrast to zero completions reported in REF2014, the current period has seen 9 PhD awards. This has helped to create a community of PhD researchers with mutual support.

Our scholarships have enhanced our international profile with 65% of our students from EU/international: in REF2014 the profile of our five PhD registrations was 4 UK:1 international. While PGR recruitment process is managed by the Graduate School (GS), we promote the opportunities among our networks and are part of the shortlisting and appointment panels (REF5a).

Although we have been successful in broadening our research student demographics, more work remains to be done to address female/male student ratio, as well as attracting students

with other under-represented characteristics. This will be achieved as part of our Athena Swan action plan and other initiatives developed and managed by the Department Equality and Diversity Committee (DEDC) working with the University EDI Steering Group.

Despite the significant growth of research student numbers and awards, we remain in capacity-building stage. Most PhD positions to date have been funded internally which has helped in capacity and reputation building. This is changing with five PhDs registrations supported by external collaborations with contributions to supervision or tuition fees (e.g. the NHS, ETH Z, UASWS (with Swiss army) and Precision Decisions Ltd.). Other examples include funded MRes as part of the UK-India Education and Research Initiative. Business and industry partners participate in our end of year shows at which PGRs present their research, which encourages students to consider how to communicate their research to research users and potential employers.

Building on these, with an improved supervision capacity and overall reputation, we aim to increase externally-funded PhD opportunities. Growth of our research student base is part of our post-REF2021 research strategy which will be achieved through collaborations with leading organisations and a doctoral training college (section 1).

We are developing a research environment with an embedded culture of nurturing and supporting research students from enrolment to graduation, preparing them for research and other relevant careers. While GS provides most of the formal monitoring and support mechanics, implementation of those mechanisms within the Department's environment is overseen and managed by the unit's PGR coordinator (**Pereira**). She acts as a direct link between the GS and our unit, managing students' annual appraisals, allocation of mentors, providing training activities for the supervisory teams and holding biannual informal forums with the PGR community.

A strong supervisory team is the heart of the PGR students experience. To that end, all project teams including interdisciplinary cross-departmental ones meet monthly. Students also benefit from 1-2-1 weekly meetings with their DoS, and with other supervisors as and when needed. In semester 1 students, with their supervisory team, complete their annual learning and skills needs analysis and plan for any methodological and subject specific training and development activities.

Students' conference attendance and other training needs identified as part of their personal development plan are supported by the departmental budget and the GS PGR bursary scheme. Our students have benefited from training courses such as NLP Summer School, GPU-based analytics and data science, British Machine Vision Summer School, and presenting at international conferences world-wide. All students have peer reviewed conference outputs before their PhD final viva and some have their work published in IEEE, Elsevier and Springer journals.

In order to prepare our students for their academic careers, they can enrol on PGCert in Teaching and Learning in HE and are allocated teaching/lab hours to give them practical skills. 60% of PhD graduates are in academic positions in the UK universities (York, Liverpool, UCLAN, LJMU), while the remaining 40% are working in as either postdoctoral researchers (St. Andrews, Edge Hill) or in industry (Talk-Talk).

Equality and diversity

Our commitment to EDI is underpinned by the University's commitment to be an equal opportunities employer. As such, all recruitment panel members have necessary training, including on unconscious bias. All recruitment panels, whether for staff or PGRs, must have at least one female and one male member (REF5a). In addition to meeting key national benchmarks, listed in REF5a, we hold a departmental Athena Swan bronze award, one of the 23 bronze holder computer science departments at the time of award. We have departmental DEDC that oversees the implementation of the Athena Swan action plan and wider EDI activities, such as staff and research student recruitment strategies, staff surveys, equal access across all careers stages to research opportunities, staff development and flexible working, etc. Our ethos and commitment to EDI for staff and students is reflected in the successful completion

of OfS-funded TechUP Women IoC project that trained and upskilled 100 women from diverse social, economic and educational backgrounds.

The academic staff (both, T&R and research only, including GTAs) contract allows high degrees of flexibility in working patterns (e.g. PT to FT and vice versa, role change, career break, etc.). These mutually agreed with line manager flexible arrangements include study leave, working from home and identification of office hours.

During the current census period, one colleague transferred to FT after long-term childcare commitments and was supported to register on PT PhD studies. This type of support is embedded within the culture of the Department and all staff are encouraged to complete further training or undertake a PhD to support their progression within academia. The Department has supported 4 academics [3F, 1M] in various ways, including workload adjustment and financing, to undertake their PhDs externally. Staff with caring responsibilities have also been supported to travel for conference attendance with those for whom they care.

The University has a dedicated team of professionals ensuring a supportive and healthy environment for all staff and PGRs providing various training and tools to manage mental wellbeing, disability, bullying and harassment, and address additional barriers, such as caring responsibilities. Furthermore, open and honest dialogue is encouraged during the probation and PDR meetings, as well as via peer support, 1-2-1 meetings and occupational therapies. In addition, there is informal support via coffee mornings and, in lockdown, via monthly research cafes. Despite the strictures imposed by COVID-19, all research projects have continued as a result of the support the Department has been able to offer (e.g. remote access to labs, laptops etc.).

REF submission development reflected our commitments to EDI. Identification of staff with SRR [3F:16M], as well as appointing our UOA coordinators complied with the University's REF code of practice. All senior staff were encouraged to nominate themselves for the UOA coordinator role, 2 [1F:1M] were selected by the University's REF panel. Once outputs were deposited in the University's repository, staff nominated their strongest for peer review: after self-assessment, each was reviewed by two or more internal and external reviewers (random selection). Peer-reviews were disseminated among the authors to ensure transparency. All staff were invited/encouraged to take part in the peer reviewing process, including ECRs and staff without SRR [1F:1M], to aid personal development. REF submission was prepared by the Unit's REF team, consisting of 2 UOA coordinators, HoD and Admin Manager [2F, 2M]. The team met regularly and reported to the Department's Research Committee with senior, mid-career and early career researchers, as well as a PGR representative. REF was a standing item at monthly Department meetings keeping whole UOA informed and involved in the construction of the REF submission. With respect to our REF submission, colleagues are equally likely to be identified as having significant responsibility for research regardless of their gender or ethnicity.

3. Income, infrastructure and facilities

Income

Over the assessment period, this UOA's strategy has been to build progressively from local to national and to international funding bids. This strategy has achieved a significant increase in successful applications from broad range of external funders (e.g. Innovate UK, European and National Research Councils and EC H2020), with total income for our unit of £1,012,496 compared to £27,663 income reported in the previous REF period (representing a 3560% increase). This strategy has been supported and enabled by the University through investments ranging from new facilities and infrastructure, to the recruitment and development of staff. This in turn has helped improve our national and international reputation as well as increasing the quality and quantity of external funding applications; in all 42% of submitted staff have secured external funding in the REF period.

Innovation is at the root of this strategy; the unit's focus on data analysis and visualisation, disruptive technologies and computer vision have played a crucial role in guiding income-

generation plans, as well as informing the commitment to collaborative work with national and international academic and business partners.

Collaboration with university networks means that we led work packages on two major EC H2020 European projects (CROSSMINER and TYPHON). These projects directly relate to the CDCS data analysis, visualisation and disruptive technologies research. Specifically, CROSSMINER enables the monitoring, in-depth analysis and evidence-based selection of open source components and facilitates knowledge extraction from large open-source software repositories. TYPHON, on the other hand, provides an industry-validated methodology and integrated technical offering for designing, developing, querying, evolving, analysing and monitoring scalable hybrid data persistence architectures that meet the growing scalability and heterogeneity requirements of the European industry from the domains of automotive, earth observation, banking, and telecom. Both projects were part of larger consortia with an overall value of €8,987,625. Partners included: University of York, UK; University of L'Aquila, Italy; Centrum Wiskunde and Informatica, Netherlands; Athens University of Economics and Business, Greece; Bitergia, Spain OW2 consortium, France; Frontendart, Hungary; Softeam, France; Unparallel, Portugal; Eclipse Foundation, Germany, Centrum Wiskunde and Informatica, Netherlands; University of Namur, Belgium; Volkswagen AG, Germany; GMV, Spain; Alpha Bank, Greece; Institut fur angewandte Systemtechnik Bremen GmbH, Germany; Contemporary Learning Management Systems, Greece. Income from these projects supported 6 post-doctoral positions.

In terms of industrial collaboration, while the impact of TYPHON on research-users in banking, car manufacturing and telecommunication industries will emerge in coming years, the CROSSMINER platform has already been integrated with Eclipse Foundation, and other industrial users. The EHU-based team's Sentiment Analyser is now been used by UNPARALLEL, Portugal and SoftTeam, France, who also integrated EHU's Emotion Detector into their operations. These are just a few examples of industrial links generated by CROSSMINER which are further detailed in our impact case-studies.

We have also been successful in obtaining three Innovate UK KTPs; all three linked to the activities of CDCS, providing innovative solutions ranging from data visualisation to SMART, cloud-based customer insight systems. While two KTP projects are still ongoing the one completed in 2017 was rated as 'Outstanding' by Innovate UK.

VCL enjoyed success of winning UKIERI funding for the CHARM project the aim of which is to become a successful real-time unobtrusive monitoring of complex human activities as they progress, using a sound and widely applicable context-aware recognition framework. This is a collaborative project with the Indian Institute of Science, Bangalore, Indian Institute of Technology, Madras and University of Bristol. The project is led by EHU.

Other income sources of over £300k include funders such as the Joint Academic Development Centres Grant, Department of Business, Erasmus+, OfS, as well as industry and NHS.

Some of these successful projects were the direct result of University and our unit's investment in pump-priming funding for external income, training and mentorship. We received around £110k internal funding from the University's RIF, half of which was used for pump priming, leading to two of the KTP projects and the UKIERI funding. Over 40% of staff were supported through internal funding. In addition, as detailed in section 2, the Department supports staff writing grant applications with flexible working arrangements, providing financial support for traveling when required in order to attend external meetings. The RO produces costings, supports research data management plans via DMP online and assists with IP issues.

In addition to the direct links from funded projects to impact described above, there are clear connections between income, knowledge generation and produced outputs. Some of the outcomes of CROSSMINER and TYPHON have been published in *Knowledge-Based Systems*, *Neurocomputing* and *Expert Systems with Applications*, Elsevier, and the most recent UKIERI funded project has already seen a publication in *IEEE Transactions*.

Building on our successes and experience we will continue generating external income by targeting funders such as UKRI and Leverhulme, as well as industry, governmental and NGOs,

such as NHS. We will aim to secure funds with good overhead rates to support sustainability. We will continue using internal RIF opportunities for pump-priming projects, as well as supporting new external collaborations and joining larger consortia.

Infrastructure and facilities

The Unit and the University as a whole (REF5a) have actively invested in high-spec physical infrastructure, dedicated hardware, and specialist software as well as in organisational structures.

The Department is now based in the Tech Hub, a £13m investment funded by £10m from the University and £3m from the Lancashire Local Enterprise Partnership (LEP) to support implementation of the LEP's strategic plans for our region, specifically focusing on productivity, innovation and internationalisation of the region.

The Tech Hub offers state-of-the-art technology housed in specialised labs such as the Computerised Augmented Virtual Environment (CAVE) and the Connect Space, which provide access to specialised hardware and software which is regularly updated and includes new robotic technology, 3D printers, augmented reality tools, NVIDIA GPU cards, IoT kits, video conferencing facilities, as well as specialised software such as SAS, MATLAB, Simulink etc. In addition, we have two HP (up to 32 GB GPU memory, 2560 GPU cores and 24 CPU cores each) and one custom build AI (96 GB GPU memory, 4608 GPU cores and 20 CPU cores). There are laptops for all staff, PGR students and PDRs for research remote working, which proved particularly effective during the COVID-19 pandemic. Over 10 of these are high-end RTX laptops which are used for GPU intensive applications. The Department has also invested in two technical staff, with highly specialised knowledge and practical skills to support access to the departmental infrastructure, as well as providing training for users on the use of the different tools, kits and instruments. All researchers from PGR students to project PIs have equal access to the unit's research infrastructure and facilities, monitored and supported by technicians.

The CAVE has been used not only by the unit's research staff but colleagues across the University, especially those from Biology and the Medical School, for projects from metabolic pathway data visualisation in VR to medical education in collaboration with NHS. In addition to sharing some of our research facilities, we have been successful in receiving in-kind GPU donations from NVIDIA, contributing to our research projects in image processing and autonomous vehicles.

All facilities have been actively used in unit's different research projects. For example, TYPHON, CROSSMINER, the KTPs and UKIERI projects have been supported by high-end analytics servers, video conferencing facilities, SAS, MATLAB, etc. In addition, CHARM has also been supported by NVIDIA GPU cards and NVIDIA Jetson Nano and other IoT kits available in the Department. In the context of the CHARM project several advancements have been made in the area of Human Activity Recognition and Monitoring and have been accepted for publication in IEEE Transactions and IEEE AVSS.

This combination of infrastructure and specialist facilities has enabled the exploration and subsequent initiation of collaborative research projects in AI, data analytics and visual computing with local, national and international organisations. During the last 3 years, these have generated over 30 peer reviewed outputs. This has motivated and facilitated high-calibre partnerships with internationally renowned institutions and organisations such as ETH Zurich, the NHS, FPT tool – SimCon and Precision Decisions Ltd. Furthermore, the available infrastructure and facilities have informed research proposals as well as new PhD projects. This includes the PhD project *Hospital Data Analytics for Business Intelligence* in collaboration with Innovation Hub at Alder Hey Children's Hospital, which has been supported by departmental facilities, including the CAVE. This has also led to a new project proposal on "Prediction of A&E Attendance", which will be carried out in collaboration with the newly established Edge Hill University Medical School and Alder Hey Innovation Hub.

This strategic investment has also enabled the creation of the University's Data Science STEM Research Centre, a collaboration between the Biology, Computer Science and Geography departments, and intended to promote and generate highly impactful collaborative research. This development has resulted in a number of publications and research projects, as discussed

in Section 1. More specifically, **Zhang** is leading *Exploration and Enhancement of Land Management Strategies Using Hyperspectral Imagery and Big Data Analytics* (internally funded project, in collaboration with University of Port Harcourt, Nigeria, Lancaster University and Nottingham Trent University, £23,000, 2020–2021), which aims to design novel Big Data Analytics methods and techniques to analyse hyperspectral images (HSIs). This will provide landscape and scenery information, which can be applied to resource management, Earth observation, mineral exploration, and land management strategies. A research assistant position was funded by this project. **Zhang** has also been collaborating with the Geography Department on a NERC *Assessing the Nature and Causes of Coastal Dune Evolution* funded project (2018 – 2020, £354,354). Furthermore, **Bessis** is currently supervising a PhD project with the Swiss army aiming to combine IoT technology and wireless sensor networks in order to create a data aggregation adaptive quality of service that can be applied to various emergency management scenarios.

Although our current needs for research facilities and infrastructure are met, in order to support our ambition to grow both subject base and interdisciplinary research as well as our PGR and PDR community (future objectives 1 and 4, section 1), we aim to invest in specialist equipment for data analytics, health informatics and autonomous vehicles and transportation.

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

We believe people are central to successful collaborations. There are various activities organised by the University and our unit to stimulate, foster, create and maintain new and existing research collaboration networks, as well as strengthen links with the University's research institutes.

We plan for and support development of strategic relationships with diverse communities at local, national and international level which serves to enrich our research. As described later, our approach has been successful in addressing national and international initiatives, such as data science, AI and industrial strategy.

In our unit, research collaborations, networking and partnerships with external academics are important drivers for growth, capacity and reputation building. Collaborations are encouraged and supported by RIF and from the departmental budget. We have developed working relationships with academics in Italy, Greece, Germany, Spain Switzerland, USA, Canada, Nigeria, China, Japan and India, as well as in the UK. A large number of our outputs are co-authored with colleagues from across the world. All staff returned have at least one output with external collaborators. Examples of collaborations and networking with academic colleagues in other institutions, locally, nationally and internationally with successful outcomes include:

- Two EC H2020 projects (**Korkontzelos** and **Bessis**) on data analytics were collaborations with academics from University of York, University of L'Aquila (Italy), University of Namur (Belgium) and Athens University of Economics & Business, **Korkontzelos** acting as the lead academic for Edge Hill.
- **Bessis** collaborations with University of Bahrain on cybersecurity of IoT based healthcare application resulted in successful grant from Department for Business, Energy & Industrial Strategy.
- **Behera**, **Bessis** and **Liu**'s collaboration with academics in Indian Institute of Science (IISc), Bangalore and Indian Institute of Technology (IIT), Madras led to securing the UKIERI/DST funding supporting post-doctoral positions at Edge Hill and in India and 2 MRes scholarships for our unit.
- At the local and national level **Behera**'s work on image recognition also emerged as part of collaboration with colleagues from universities of Liverpool and Leeds and resulted in joint publications, and received national media coverage.
- **Liu** and **Zhang** (ECR), have an extensive network of academics from the UK (e.g. Brighton, Cranfield, Cardiff, Loughborough, Liverpool, York, Northumbria, Portsmouth, Aberystwyth universities), USA (Texas A&M University--Corpus Christi) and China (e.g.

Chinese Academy of Sciences, Zhejiang University, Shandong University, Beijing Institute of Technology, Tianjin University) leading to a publication of a textbook entitled “3D Imaging, Analysis and Applications”, a book entitled “RGB-D Image Analysis and Processing”, both published by Springer.

- **Pereira** and **Bessis** collaboration with colleagues from Durham, York and Nottingham resulted in a successful TechUp Women project funded by IoC/OfS establishing partnerships with industry. The TechUp Women project was a winner of one of the Impact Awards in 2020.
- **Bessis** and **Korkontzelos** have been visiting scientist and research collaborators, ETH Zurich, Switzerland. **Bessis** also has collaboration with UASWS (with Swiss army). Both collaborations have resulted in PhD projects.

We are also beginning to host external or visiting academics during their study leave and aim to develop this further in the coming REF period to enhance collaborations and the identification of joint research projects. We have hosted three academics from Nanchang Hangkong and Harbin Engineering universities, China, contributing to our research seminars and co-authoring conference and journal outputs.

As part of the existing projects, various industrial partners are actively collaborating with the Department, such as R&D for car manufacturing (**Trovati**, **Bessis**), Volkswagen and Eclipse (**Korkontzelos**, **Bessis**) Jaguar Land Rover Automotive PLC (**Behera**), as well as NHS (**Pereira**, **Trovati**, **Liu**, **Behera**, **Zhang**, **Lyon**).

Furthermore, the Department’s active involvement with the University’s PIC has facilitated the strengthening of existing links with local SMEs and the creation of new ones, which has led to a KTP (Country Range Group Ltd.) and a number of consultancy projects and co-productive research. It is through these activities that we develop relationships with key research users and beneficiaries. For example, at the international level, we maintained a close relationship with key beneficiaries of the software quality assurance project, NCAR, US that has implemented changes in the WRF software regression testing. This work also led SimCon Ltd to improve their Fortran code analysis tool and increase their customer base. Equally, CROSSMINER’s impact has been achieved through co-production approach and has led to the development of an NLP tool for the Eclipse Foundation user community.

Furthermore, at the national and local level, we are working with different industries whose research and innovation needs inform our research activities. A recently completed project is *Forecasting Fine-Grained Regional Weather for Precision Agriculture by Integrating Global Weather with Local Weather Sensors Data*. This project was completed in collaboration with its major user, Yorkshire-based Precision Decisions Ltd, that provide UK farmers with weather forecasting solutions. Another project on data capture analysis and visualisation as part of one of our KTPs, graded by Innovate UK as “outstanding” has helped Bi3 Ltd acquire new partners, get established on a new market and increase their customer base.

We have successfully responded to national and international priorities and initiatives (e.g. Big Data PPP: research addressing main technology challenges of the data economy) through funding calls by EC H2020, UKRI and Innovate UK. In addition, we have had representation and presence at local, national and international boards, committees and societies, such as: Digital Health Board, Lancashire and South Cumbria and HealthTech Cluster (**Pereira**, **Bessis**), LEP and LHP (**Trovati**), RCUK/Royal Society invited meetings and European Research Network for Cognitive Computer Vision System (**Behera**), the LEP LCR Digital & Creative Board and international advisory committees for many conference and symposiums (**Bessis**), etc. This helps us to monitor closely national and international priorities and initiatives and, by working with diverse communities and industry partners, drive those initiatives. Our work in collaboration with a car manufacturing R&D on developing a model encapsulating standards and cyberthreats in the automotive industry is responding to the Industrial Strategy.

Considerable efforts have been made to showcase our work via the media. ‘Be Curious’, **Behera**’s project in partnership with the University of Leeds for demonstrating the role robotics and AI in health and social care has received a wide media coverage, including BBC News,

Daily Mirror, The Times, The Sun, Daily Mail, The Metro and ITV. It was also presented at Science and Media museum in Bradford partnering up with CBBC's Operation Ouch. **Behera** was invited to take part in UK Parliament week for the exhibition of Robotics and AI.

Our unit's contribution to and recognition by the research base can be demonstrated in several ways. Senior academics are engaged with journal editorships, delivering keynote speeches, supporting grants committees, etc. while ECRs and PGRs supporting conference/workshop organisations, serving on programme committees and delivering invited lectures.

Bessis is founding editor-in-chief of *International Journal of Distributed Systems and Technologies*, IGI and has co-edited Springer books, including *Big Data and IoT: A Roadmap to Smart Environments* which was in top 25 in AI Amazon list, with over 145,000 downloads and over 250 citations. He has also acted as area editor of *EAI Endorsed Transactions on Cloud Systems (ToCS)*, EU and associate editor of *International Journal of Big Data Intelligence, Inderscience; Big Data and Cognitive Computing, MDPI*, and *Sci, MDPI*. In addition, **Bessis** co-edited several special issues in top ten SC journals, including titles such as *Data Science for the Internet of Things, IEEE Internet of Things Journal; Data Science for Cyber-Physical Systems, ACM Transactions on Internet Technology (TOIT), ACM; and Industrial Internet of Things (IIOT): Where we are and what's next? IEEE Transactions on Industrial Informatics (TII)*. **Pereira** is an editor-in-chief of the *International Journal of Intelligent Computing Research* and was Guest Editor for the *International Journal of Space-Based and Situated Computing*. **Behera** is member of the editorial board of *American Journal of Engineering and Applied Sciences* and *Journal of Mechatronics and Robotics* and also acted as a lead guest editor of a special issue *Big Data and Artificial Intelligence - International Technology and Science Publications (ITS)*. **Trovati** and **Korkontzelos** have co-edited a special issue: *Data Science for Industry 4.0. Theory and Applications*, Sci MDPI while **Trovati** also co-edited *Theory, Algorithms, and Applications of Big Data Science; Services Computing* and *Tsinghua Science and Technology Journal* and Cloud Computing and Big Data applications; **Korkontzelos** was guest editor of MDPI Special Issue on *Natural Language Processing for Social Media*. **Pandey** has been a guest editor of special issues of *Neural Computing and Applications*, Springer. While **Liu** has been named as the most influential scholar award honourable mention, AMiner.org in 2020, he has acted as associate editor of several IEEE conference proceedings and, in 2017, received the best associate editor award at the IEEE International Conference on Robotics and Automation. He is also an associate/area editor of Elsevier's *Neurocomputing and Pattern Recognition Letters* journals.

Further examples of our unit's contribution to the scientific community include: Founding Member of the IEEE Communications Society Technical Subcommittee on Big Data Processing, Analytics & Networking, and member of Technical Subcommittee on Internet of Things, Expert on the Advisory Board of the EC H2020, R&I on IoT integration and platforms (**Bessis**); Remote Expert Evaluator for H2020 FET-Open Challenging Current Thinking (**Wang**); Reviewing research proposals for funding for: the National Fund for Scientific and Technological Development, Chile, the Research and Innovation Funding Agency of the Flemish (Belgian) Government (**Korkontzelos**), Sinergia funding instrument of the Swiss National Science Foundation and Medical research Council (**Pereira**); RCUK – Biotechnology and Biological Sciences Research Council (**Behera**); SER CYMRUII Fellowship grant for Welsh government and next generation correspondence technique for 4D space-time surfaces, Leverhulme Trust (**Liu**); National Centre of Science and Technology, Republic of Kazakhstan (**Malik**) and EPSRC Fellowship Grant Application (**Bessis**).

Our contribution to supporting the research base through involvement in conferences and journal reviews can be exemplified by: **Bessis** chairing/co-chairing EUSPN 2015-2020 and ANT 2014-2020 organising and co organising over 40 of conferences and workshops in the areas of IoT, cloud computing and data analytics. **Pereira** acting as a general chair of ICITST 2017 organising and contributing various IEEE conferences and workshops (e.g. CAS2010-1017, AINA, FiCloud). **Liu** was a programme co-chair for VSIP 2020 and Area chair for British Machine Vision Conference 2019, 2020 and IEEE International Conference on Robotics and Automation, 2014, 2015, 2017-2019; **Behera** chaired British Machine Vision Association (BMVA) Symposium on Human Activity Recognition and Monitoring in 2017, while **Wang** acted as a Web Chair for IEEE ICC, 2019 and **Kumar** was a local organising chair for Chair for IEEE RoMAN 2019.

Collectively, staff in our unit were involved in a very large number of conference programme committees. We have been reviewing for international journals, including: IEE journals, including Transactions on Wireless Communications, Transactions on Communications, Transactions on Signal Processing, Transactions on Mobile Computing, ACM/IEEE Transactions on Networking, Transactions on Vehicle Technology, Access, Communication Letters, Transactions on Image Processing, Transactions on Intelligent Transportation Systems, Artificial Intelligence Reviews, Access, Transactions on Cybernetics, plus Information Science, Soft Computing, Elsevier, Neurocomputing Pattern Recognition, Computer Vision and Image Understanding (CVIU),.

Several keynotes have been delivered at large and influential international conferences such as ICloT 2019, ICRASET 2018 (**Behera**) International Conference on Computer Graphics and Animation (**Liu**), BigComp 2015 (**Korkontzelos**).

Members of our unit have influenced institutional and departmental policies and decision making. Specifically, **Bessis** has been a QAA subject specialist in over 10 occasions for UK, Greek and Cypriot HE institutes reviewing the infrastructure, facilities, resources and support available to staff and students undertaking research. **Pereira** and **Bessis** have served on the readership and professorship conferment panels in the UK and internationally for universities such as, Coventry, LJMU, MMU, Bradford, Brighton, UCLAN, Middlesex, Bedfordshire, Gloucester, Staffordshire, De Montfort, King Saud University, ATEI of Crete, Polytechnic University of Bucharest, Sheffield Hallam etc.

Collectively, **Behera Bessis, Korkontzelos, Liu, Pereira,** and **Trovati** have acted as external PhD examiner for over 40 UK and overseas universities, including York, Loughborough, Swansea, Reading, Strathclyde, Sheffield, Jaypee, Thapar, Seville, TUDelft and Fribourg and over 20 research degree examinations in India, Pakistan, Spain, Switzerland, the Netherlands, Slovakia, etc.

Looking at the post-REF2021 research strategy we will aim to develop leading collaborations with key partners to increase impact and contribution to society.