REF2021

Institution: Aberystwyth University

Unit of Assessment: 11: Computer Science and Informatics

1. Unit context and structure, research and impact strategy

Unit structure and research aims
The Department of Computer Science at Aberystwyth University (AU) is a long established and significant department in the UK, founded in 1970 and celebrating its 50th anniversary in 2020. The Department's expertise is focused on research in applied Artificial Intelligence (AI), as well as contributing to more foundational and theoretical aspects of AI that facilitate successful applications of AI in the real-world. This focus is reflected in our research, impact and people strategies, and also in the structure of the Department's four research groups - **Advanced Reasoning** (AR); **Bioinformatics and Computational Biology** (BCB); **Intelligent Robotics** (IR); and **Vision, Graphics and Visualisation** (VGV).

Whilst we have four research groups in terms of subject areas, owing to the common interests of our staff in applied AI, most of our research-active members are not affiliated to just one group. Instead, the groups are organised in terms of research topics:

- **AR** covers all major areas of Computational Intelligence (CI) and is one of the world-leading groups in CI, particularly renowned for its invention of semantics-preserving approximate techniques for explicit knowledge model formulation and simplification and for its ground-breaking work on data-driven decision support with increased level of automation, efficiency and reliability.

- **BCB** conducts research in data analysis of large-scale biological data, formalisation of biological data, biomedical informatics, genomics, metagenomics, and pharma-genomics, closely working with world-leading specialists in the BBSRC Institute of Biological, Environmental and Rural Sciences (IBERS).

- **IR** is one of the best-known UK robotics groups, carrying out research covering unconstrained environments, tackling both software and hardware. It covers robotics research ranging from aerospace and airspace, through land and water surface, to underwater, with a particular strength in space robotics, currently participating in the ESA ExoMars mission.

- **VGV** undertakes research concentrating on a range of fundamental techniques for analysis of high dimensional data, feature extraction, matching and classification, driven by application areas such as medical image analysis, machine vision for robotics, video and 3D shape analysis and matching. This is the newest group in the Department, strategically planned for in RAE 2008, developed during the REF 2014 period, and fully matured within this assessment period, conducting a significant amount of world-leading and internationally excellent research as evidenced by the returned outputs and an associated impact case study.

The high-level strategic aim of the Department has been and still is to deliver world-leading and internationally excellent research in applied AI, supported by the vitality and sustainability of its research environment. In order to achieve this aim, over this assessment period, the Department's research strategy has three key objectives:

i. To focus resources on research of high scientific quality (substantially strengthening our 75% 4*/3* research output profile awarded at REF 2014) and significant impact (built on our 100% 4*/3* research impact profile last round), delivering methodological solutions to current globally challenging issues relevant to intelligent and decision support systems, while growing our research capacity;

ii. To provide the right environment (with high-quality administrative, infrastructural and capital support) to stimulate and drive progress in our research, investing in collaborations in the UK and across the world, expanding the funding streams and types for research, and promoting open access to research outcomes;

iii. To develop the experts of tomorrow and attract researchers from across the globe, enhancing the development of staff career and research student potential with clear performance standards, while championing for equality, diversity and inclusiveness of our staff and students.

The research strategy of the Department is complemented by its impact strategy, which is focused on promoting and facilitating applications of AI developed through its research and which has always been driving our work over the Department's 50 years history. The Department's research and impact strategies are aligned with the University's Research and Innovation Strategy as outlined in REF5a, and build on its key principles of encouraging ambitious, entrepreneurial research that challenges existing approaches and knowledge; creating a coherent research-led academic environment; and collaborating with external partners, in the UK and globally, both in generating research and in passing on the benefits of research through impact and innovation.

Implementation and achievement of strategic aims
In the assessment period, the implementation of the research strategy has enabled researchers in the Department to:

- undertake cutting edge research across its core strengths in all four groups, and to develop new areas of investigation such as AI applications in healthcare;

- work collaboratively with academic and commercial partners and other end-users of AI systems in the UK and internationally;

- recruit six world-class research fellows (amongst other leading researchers);

- secure over £5.3M in external grant income to support our research;

- attract £2M+ capital investment in state-of-the-art equipment and workshop/laboratory facilities;

- graduate PhD students (double the number for REF 2014) with outstanding academic training and career development;

- become the most gender-balanced department among the leading computer science departments in the UK.

Over this period, our research-active staff have published over 290 peer-reviewed articles in international scientific journals, plus approximately 200 peer-reviewed conference papers. On average, each staff member has produced 9.5 journal articles. According to SciVal 62.9% of our research output includes international collaboration, attracting on average 7.1 citations per such output. Publications are of high quality: 25% are published in the best 10% percent of journals, measured by CiteScore; this is compared to 19.3% on average for the UK.

The 70 outputs returned this round are examples demonstrating that our staff at all stages of their career have produced excellent research results. Amongst these outputs, fifty-one appeared in top journals of an impact factor (IF) greater than 5, including 25 that each have an IF larger than 9; thirty-one have an average number of Google Scholar (GS) citations per year (since publication) larger than 10. Particularly, nine of the outputs returned have each attracted more than 100 citations despite their relative recency. Two papers were selected by IEEE as the

annual Publication Spotlight articles in its flagship journal IEEE Transactions on Fuzzy Systems, with the work specially introduced in IEEE Computational Intelligence Magazine (in 2018 and 2021 respectively). Six papers are the journal version of work that has led to winning best paper awards or competition at esteemed international conferences, while the original conference papers are not returned. Another eight papers have led to special issues at prestigious journals or special sessions or tutorials at foremost international conferences.

The three Impact Case Studies returned this round are examples of how our commitment to impact leads to significant practical achievements in a diverse range of real-world applications, including intelligent robotics, health informatics, and decision support for e-commerce. In particular, the research within IR, focussed on unconstrained environments has contributed to various types of impact, including direct contributions to the ExoMars rover mission. We have used our expertise in a wide area of robotics applications to enhance STEM engagement on different levels, from schools and colleges to engagement with the general public. The health informatics case centres around improving patient outcomes and developing commercial benefits via medical image analysis, linking the VGV research to a range of impact aspects, especially around commercial orthopaedics' segmentation software (which was developed by Synopsys), international deep endometriosis standard (adopted by the International Society of Ultrasound in Obstetrics and Gynaecology), MS/stroke segmentation (leading to spin-out company Tensormedical) and stroke rehabilitation and retinal disease treatment. The positive impact outcome ranges from individual patients to groups of hospitals up to international standard. In the area of e-commerce, our work carried out in AR on data mining, in particular fuzzy rough theoretics and associated algorithms, has been exploited to discover e-commerce site usability issues. This application of our techniques has benefitted companies due to increased automation, reduced losses and improved competitiveness, leading to annual savings of more than $86M.

In the assessment period, research capacity in the Department has been reinforced by investment in people, equipment and infrastructure. We have increased our research-active staff number by 12% since REF 2014 (from 24.80 to 27.82 FTEs, note that despite REF 2014 being selective returns, we returned 99+% of our staff then). We have received £2M+ capital funding from HEFCW and other sources for equipment purchase and lab/workshop revamping. Particularly, a host of individual equipment of significant value each has been acquired (see Section 3 for examples), and we have a 170 square-meter mobile robot workshop built and in full use. This is in addition to existing workshops such as MarsYard, where our space robotics research is based, including a half-real-sized Mars rover for the ESA ExoMars mission; an intelligent humanoid robotics lab, where an iCub humanoid robot and a most recently acquired Yumi robot and many hosts of small mobile robots are based; and state-of-the-art engineering and electronics workshops.

Research integrity (governed by the University's Research Integrity Concordat) and research ethics (defined with the University's Research Ethics Framework) are an integral part of all research projects. All research applications are subject to an ethics assessment, where the process is supported by a University online ethical review system that facilitates an efficient, lightweight process that does not create unnecessary barriers to research while ensuring that all research projects adhere to the highest ethical standards.

A notable development for the Department during the assessment period has been the strengthening of connections with cognate subject areas, facilitated by two rounds of University-level restructuring (in 2014 and 2018), leading to the establishment of the Faculty of Business and Physical Sciences. This process involved the coordination and integration of research policies, sharing best practice and strengthening research support and activities that facilitate cross-departmental collaboration (including research 'speed dating' events and sandpits). An outstanding example of joint efforts in conducting interdisciplinary collaborative work is for the development of research on space robotics, with our staff providing expertise on robotics and staff from the Department of Physics offering their in-depth knowledge on planetary science. With a dedicated laboratory (MarsYard) that was originally established within the Department,

we share its use with Physics in support of both Departments' research projects, at the moment most prominently on the ExoMars mission. The laboratory also houses a number of related resources, including a mini-rover, 3D tracking system and simulated Martian terrain. Researchers in the Department are also active participants in Interdisciplinary Research Centres formed by the University with significant internal research funding support, including the Aberystwyth Centres of Excellence for: Space and Earth Monitoring, Rural Health Research (co-directed by Zwiggelaar), and Environmental Microbiology, through which they work with colleagues in Biological Sciences, Geography and Earth Sciences, Physics, Psychology, and Sports and Exercise Science.

The drive to implement our research strategic aims informs all dimensions of departmental management, including staff and research student recruitment, and is embedded in the everyday work of our members of staff through the four research groups. Each group is organised by a coordinator, who in turn are supported by the departmental research coordinator. The departmental research coordinator ensures that all research-active members of staff understand the Department's strategic direction of travel. By organising meetings with short lightning talks they provide new and current members the opportunity to get to know the Department's research and recognise opportunities for collaboration. Other activities include department-wide research meetings/seminars (with the latter periodically presenting talks by invited world-leading academics and industrialists). Particularly, meetings to coordinate research bid preparations involving multiple research groups help the Department to make optimal use of its different research strengths and to exploit synergy effects. These are further complemented by Faculty research meetings that facilitate cross-departmental coordination and collaboration, and one-to-one meetings for research-active staff with the Faculty Associate Dean for Research, Knowledge Exchange and Innovation (Zwiggelaar).

To promote research and cherish research impact, the Department provides incentives for research-active staff, which include the following: staff members can buy themselves out from non-research activities; staff are allocated a part of the overheads on externally funded projects; and staff have regular opportunities for sabbatical research leave (one semester in every eight). Particularly, staff can use their accumulated overheads allocation as they see fit (for research purposes) and this tends to be used for open access publications, PhD funding, and travel for collaboration and conferences, to supplement such support offered by the University/Faculty and the Departmental central fund.

The Department has engaged with the open science agenda and is committed to open access publishing and open data, through 'gold' or 'green' route. Article processing charges are generally covered from research grants, or through University accounts for UKRI-funded research and as part of JISC agreements with publishers, with targeted additional funds provided by the Department. Over the period, the Department has covered open-access publication charge to the value of approximately £45K. Where funds are not available, green open access publishing is facilitated by the AU Research Portal, with staff required to deposit pre-production manuscripts on acceptance. Staff have made substantial contributions to scientific and engineering applications of AI techniques through providing open-access free software packages. For instance, Jensen and MacParthalain have contributed a host of programmes implementing the data-driven model learning and feature selection algorithms (developed by AR, including user manuals) to Weka, the world's largest open-access repository for machine learning and data-mining software. Also, through international collaboration, Shen has contributed to the international digital image processing community with the first, real-world, large-scale underwater dataset, covering a diverse range of underwater scenes involving different objects and object motions. Such contributions have helped standardise the development and implementation of follow-on research in the relevant areas, providing reference benchmarks.

Future strategic aims and goals
For the next REF assessment period we aim at further reinforcing our research in applied AI, with an emphasis on improving our research environment. We will strengthen the leadership in

Intelligent Robotics and Health Informatics, while increasing investment in areas where we plan to expand in response to social and economic demands. We are currently recruiting a Reader/Chair in Bioinformatics and a Lecturer in Cyber Security, and we will be appointing a Chair in Intelligent Robotics shortly. We plan to use the momentum generated by the UKRI Centre for Doctoral Training in AI, Machine Learning and Advanced Computing (AIMLAC) to increase PhD student numbers. Its inherent interdisciplinarity and close cooperation with industry partners will help us continuing work with external partners and forging new partnerships. We are also engaging with the newly founded £40.5M Aberystwyth Innovation and Enterprise Campus to forge new collaborations nationally and internationally. These activities will aid in our endeavour for gaining research funding from a wide range of sources, including but not restricted to UKRI, Leverhulme, Royal Society, Horizon Europe, COST, and industry. One particular area we plan to focus on is AI in space data science and engineering, based on our existing strength in space robotics and the world-leading research experience on planetary science from our sister Department of Physics. This will be reinforced with strong support from international academic collaborators and industry, as evident by the recent award of one of the only five Strategic Partner Acceleration Awards granted by the Welsh government, for us to lead the establishment of an international joint centre for AI in space data science and engineering.

To further strengthen our future research, the Department has placed the following KPIs in place for staff on Research and Teaching contracts. On average, each full-time member of staff will aim to: produce 1.5 journal/conference papers per year, at 3*/4* level; graduate 1.5 PhD students every four years; and hold a grant of £200K+ over a 3-year period. This KPI setting is realistic based on our historical profiles in each of the three aspects, with a provision for gradually increasing our research student numbers and income.

As a department focussing on applied AI, we will continue to deliver research with significant social and economic impact, especially targeting pressing global challenges. For instance, AR has been working with international collaborators (e.g., Beijing University of Chemical Technology and Fujian Business University, as well as their local companies and authorities), exploiting the ideas of real-time road-user feature extraction, selection, classification and tracking over dynamic temporal windows in a noisy environment. This has led to the development of intelligent transportation management and traffic surveillance systems, which based on initial deployment feedback, have helped to significantly improve public safety and security. VGV has started collaborative research with clinical staff on cleft lip and palate. The collaboration involves (clinical) researchers from Birmingham Women's and Children's NHS Foundation Trust, Hospital Dental Service in NHS Tayside, and the Dental School at the University of Dundee. We are exploring 3D computer vision and machine learning techniques for the analysis and classification of children's cleft lip and palate data which is expected to inform surgical staging. IR's research on autonomous driving off-road and on ill-defined tracks has led to work on projects funded by the Defence Science and Technology Laboratory and QInetiQ, using one of our autonomous track solutions as part of QinetiQ's solution to the Autonomous Last Mile Resupply. This has since gained considerable interest in the precision agriculture and farming community, where general off-road (in field) and on track autonomous navigation is seen as solving problems of the farming community facing staff, time and funds constraints, by automating tasks such as weed control, seeding, monitoring of animals, etc. A further direction is based on our involvement as part of one of the largest EU research consortiums to develop a mechanistic and actionable definition of how the brain generates action, using a set of elementary interactions, and to translate this knowledge into novel technological solutions to control robotic mobility. We are extending our work on health informatics (BCB and VGV) to the analysis of movement of stroke patients via data from wearable and mobile devices, to monitor and assess their recovery. This research also offers great potential to join forces with our existing success in MRI brain segmentation to make a systematic contribution to improving public healthcare.

2. People

Staffing strategy and staff development
The recruitment of research-active staff and policies and practices for staff development are informed by the Department's research strategy, with the aims of strengthening the vitality of the research environment, by appointing and enabling world-class researchers, and of ensuring the sustainability of the research environment, by training and equipping the research leaders of the future. Recruitment takes into account the strengths of our research groups, as well as areas for strategic development, including emerging research themes. We recruit on all levels, developing promising early career researchers (ECRs) and employing more established senior researchers to provide leadership for our groups.

The Department currently has 29 (Cat-A) research-active staff, including:

• 4 Professors,
• 2 Readers,
• 4 Senior Lecturers,
• 12 Lecturers and
• 7 independent Research Fellows.

During the assessment period, the Department appointed 1 Professor (Han), 1 Reader (Tsakiris), 5 Lecturers (Anjos, Hunter, Khan, Miles, Zarges), 6 Sêr Cymru II COFUND Research Fellows (Akanyeti, Chao, Daykin, Lan, Li, Qu), and 1 Marie Skłodowska-Curie Fellow (Dagdia). The highly competitive Sêr Cymru II COFUND programme was introduced by the Welsh Government to attract world class talent to Wales, and the Department was the one that across all discipline departments in all Welsh universities, has been able to attract the largest number of such outstanding fellows. The Department has in general a very good staff retention record; over the period only five academic staff on a permanent contract left the Department, mostly for promoted appointments elsewhere: Gkoutos and Liu (appointed to Chair at Birmingham and Edgehill University respectively); Tuci (appointed Associate Professor at University of Namur, Belgium); He (appointed Associate Professor at Nottingham Trent University); Neal (moved to public service sector). In addition, Lee retired in 2018 after 47 years of distinguished service; Barnes passed away; and Dagdia was appointed Associate Professor at Versailles Saint-Quentin-en-Yvelines University, France after completion of her fellowship.

All research-active staff in the Department benefit from the support for professional development, reflecting University policies described in REF5a. There is a yearly review meeting with each member of staff where strategy and goals for the next year are discussed, with their performance evaluated and contributions appreciated. Each member of staff has an opportunity of one semester research leave every four years, requiring a detailed research plan including expected outcomes prior to taking up the sabbatical and a formal report right after the leave, with both being scrutinised by the research committee where the Department's HoD, Research Coordinator and two of our Professors sit.

For the next REF period, the Department will continue to strengthen our cohort of research-active staff to further build capacity in new and existing areas. Recruitment is currently underway for a Lecturer in Cyber Security, a Reader/Chair in Bioinformatics and a Chair in Intelligent Robotics will be appointed shortly, to provide leadership in BCB and IR respectively. Also planned is to appoint a Reader in the area of Space Data Science and Engineering, where we intend to develop an interdisciplinary sub-unit based on existing world-leading strength in space robotics in our Department and the expertise in planetary science within the Department of Physics.

Equality, diversity and inclusiveness
Principles of equality, diversity and inclusiveness (EDI) are at the heart of our approach to staff recruitment and development. We are proud of our diverse research community, in which 41% of

research-active staff are women and 28% are of non-white ethnic background, with individuals originating from 9 different countries. A recent analysis by CrowdStrike (which examined gender balance across the leading UK and USA universities) ranked the Department as having the highest representation of women among teaching and research staff in all considered computer science departments in both the UK and the USA. The inclusive research environment is the product of the Department's strategic and proactive approach to EDI issues over a sustained period. The Department is fully aligned with AU's Strategic Equality Plan and AU-wide EDI initiatives as outlined in the institution-level document REF5a. It has a dedicated and very active Equality Champion, and all our female Cat-A staff have won research grants during this REF period.

EDI is indeed addressed in all aspects of academic life in the Department. For instance, given the large number of quality outputs produced by our staff, in the process of selecting and ranking research outputs for this REF return, the selection panel included three observers covering different aspects of inclusiveness and diversity, namely gender, ethnicity and Welsh language (with one observer for each aspect). The Department was the first at AU to receive the Athena Swan Bronze Award, and our staff have contributed to work on the University's Athena Swan application and provided advice on the process to a good number of computer science departments nationwide. Members of the Department participate as both mentors and mentees in the University's female academic mentoring programme, have engaged in initiatives for, and organised, International Women's Day and Black History Month, and are active in the University's Women in Research network. Through these activities they have provided leadership on equality issues in the University and contributed to representing EDI concerns in University policy and strategic planning. Unconscious bias training is mandatory for all staff.

We are the unique representation of all Welsh computer science departments participating in the EPSRC's Inclusion Matters programme with a project on 'Challenging Different Forms of Bias in Physical Science and Engineering Research', that involves reverse mentoring as one important element. Through initiatives such as this, members of the Department are prominent in championing EDI issues within the discipline more broadly. For example, Dee was an originator for the annual BCSWomen Lovelace Colloquium that the Department involves in organising annually; it is regularly attended by more than 120 female undergraduate and taught postgraduate students from all over the UK. She has been recognised by Computer Weekly as one of the most influential women in UK IT. In 2016, Dee received the BCS John Ivinson award for voluntary service. In 2018, she was entered into the Computer Weekly hall of fame for those who have made a lasting contribution to women in technology and received a Suffrage Science award, one of the six awards given every two years for women in computer science.

The Department has an excellent track record in retaining and developing ECRs; five of the eight ECR staff members returned last round are also returned this round (whilst the other three are now serving as Head of Data Science at Wandera or as an Associate Professor elsewhere). ECRs are assigned an experienced mentor who helps them develop their own research plan embedded in the context of the research group(s). For example, since joining the Department as a lecturer, Akanyeti has worked very closely with Shen, and in his second year after joining us, he was awarded a prestigious two-year Sêr Cymru II COFUND fellowship. During his fellowship, Akanyeti has won research grants of a value totalling £115K and recruited seven PhD students. Another distinguished achievement that our ECRs have made is demonstrated by the success of Miles receiving a £1.16M EU grant for her work on advanced media production, mentored by Tiddeman. ECRs also have access to the University's Research Fund (of a typical size of £5-10K per grant) as a valuable source of pilot funding to enable them to develop ideas and prepare external grant applications. Akanyeti's success directly benefitted from this scheme. ECRs are further supported with earmarked PhD studentships jointly funded by the Department and the Faculty. In addition, two members of staff (Aubrey, Shaw) successfully applied for participation in the Welsh Crucible, a competitive HEFCW-funded scheme for early and mid-career staff to develop future research leaders.

The quality of researcher support and professional development in the Department has helped established staff members to take on positions of research leadership within the University, including as Pro Vice-Chancellor for the Faculty of Business and Physical Sciences (Shen), Head of the University Graduate School (Zwiggelaar) and Faculty Associate Dean for Research, Knowledge Exchange and Innovation (Zwiggelaar), as well as to be successful in the highly competitive academic promotions (e.g., Tiddeman to Reader, Clare and Dee to Senior Lecturers) and in external appointments (e.g., Gkoutos, Reader, and Liu, Senior Lecturer, to Chair in other British universities). Senior researchers in the Department have been externally recognised for the quality of their research and their contributions to computer science and engineering, including the election of Price (2015) and Zwiggelaar (2020) as Fellows of the Learned Society of Wales, joining Lee (elected in 2014) and Shen (2012, who is an elected Council member of the Society).

Research students
The Department is committed to developing and supporting the next generation of researchers and to growing a vibrant and sustainable graduate school. We had 46 PhD students (including 3 jointly supervised with a sister department owing to the interdisciplinary nature of their work; totalling 44.5 doctoral awards) graduate over this assessment period, double the absolute number and a 38% increase in the annualised rate of awards compared to REF 2014, with another 35 currently on-going students; this indicates a significant increase in PhD numbers over the late part of the assessment period and reinforces the uptrends. Further expansion of the PhD cohort is a continuing priority for the next REF period, supported by our participation in the UKRI CDT in AI, Machine Learning and Advanced Computing (awarded in 2019). The University and Faculty provide both full and partial scholarships annually to applicants for them to study with us. This is strengthened with departmental scholarships that are offset against the fees for excellent international students; over the assessment period, we have awarded well over 20 such scholarships. There are also sandpits for ECRs to obtain seed funding from the University Research Fund to help them kickstart the supervision over PhD projects, typically involving an interdisciplinary topic. Another innovation during this period has been the introduction of the University's Professional Doctorate (DProf) scheme that allows qualified professionals to study for a doctorate while staying in employment. Despite this being a recent scheme, the Department has recruited five DProf students. In addition to training the students, this scheme provides supervisors in the Department great opportunities to establish and deepen our ties with industrial partners. One example is a research DProf project looking at how digital automation within a hospital setting may affect satisfaction levels of patients.

The Department has a rigorous PhD selection and admission process in place. For individual applicants, this involves detailed discussion between the departmental PhD selector and the appropriately identified supervisors, which is supported by interviews. For competitively funded studentships (e.g., for the UKRI AIMLAC CDT), there is an initial shortlisting process followed by formal interviews and selection by a panel consisting of experienced supervisors.

Every PhD student is assigned at least two supervisors in the Department (or for interdisciplinary projects, at least two supervisors across the two departments). All supervisors are required to undertake frequent training/re-training, including UKVI matters. One important aspect taken into consideration when selecting supervisors is inclusiveness and diversity (in particular, with respect to gender and ethnicity). A recent initiative taken by the Department has enabled the University to introduce a ring-fenced PhD studentship competition for early career supervisors, administered at the Faculty level.

All PGR students receive centrally provided research training, with modules supporting their research and skills development, preparing them for their career. Modules on offer range from public engagement to grant development workshops, and from leadership to developing their first peer-reviewed publication. In addition, responsible research, EDI, ethics and data management plans form the core of a compulsory induction module. An added benefit of the research training provision is the peer-based teamwork and networking with students from different disciplines (e.g., Arts, Humanities and Social Sciences) and universities (e.g., modules

shared with the UKRI CDT). Students are encouraged to participate in scientific conferences and disseminate their results, with support from a conference fund maintained by the Faculty while the Department covers the cost for PGR students to attend specialist training courses.

Progress is monitored via an annual report submitted to a review committee and also via interview by an independent panel of experienced supervisors. All PGR students are expected to attend the departmental research seminar programme as well as seminars within their research group. The Department also organises a one-day workshop (as part of the monitoring process) each year for all research students to present their work to fellow students and staff, with a prize for outstanding presentations in years 2 and 3. We also have an annual prize competition for the best first-year report. At University level, PhD students have the opportunity to attend and participate in an annual PGR conference, which also incorporates the local competition for the national Vitae 3MT event.

Thanks to the motivational encouragement and supervision arrangement offered by our dedicated staff, and supported with world-class research facilities, over the assessment period, we have a 100% success rate for students to complete their degree within their approved registration period. All 46 PhD graduates within this assessment period have been successful in gaining their post-degree employment upon graduation and a number of them have been able to produce an outstanding quantity of top-quality publications from their studies. For example, Diao (graduated in 2014) first-authored three and second-authored another three articles in leading computer science journals, including two in IEEE-TCYB (IF= 11.079, attracting 168 and 88 GS cites respectively) and two in IEEE-TFS (IF= 9.518, with 66 and 58 cites respectively), with another conference paper receiving the best paper award at FUZZ-IEEE 2012 (top international conference on fuzzy systems), selected from the 305 papers that were accepted globally for presentation at the conference. Li (2020) first-authored six and co-authored another five leading journal articles, including four in IEEE-TFS and two in IEEE-TCYB; she also received a best conference paper award (from the 16th Annual Workshop on CI); both examiners of her dissertation have been deeply impressed and would like to nominate it for a national/international best dissertation award.

Within the period, our PhD students (Akpokodje, Diao, Jin, Li, Xu, Yang, Zhang) have collectively won seven best paper (including finalist) or competition awards at international conferences. For example, Akpokodje received best PhD student paper at the 6th International Conference on Cloud Computing and Services Science (2016); Zhang is a finalist for the best paper award at the 2020 World Congress on Computational Intelligence (the largest and foremost biannual international event in the field), selected from 1,819 accepted papers worldwide; and Xu is the winner of the internationally renowned Competition on Constrained Real Parameter Optimisation, organised by CEC-2019 (which is the most important annual international conference in evolutionary computation). Additionally, our students have received 10 Outstanding Student Paper Travel grants from IEEE over this period. Historically, this is the largest number of such awards granted to students from a single academic department.

A significant number of our recent PhD graduates have already demonstrated a great potential in making a very successful academic career. For instance, Naik (2015) and Chen (2017) are now a Senior Lecturer at Aston University and Huddersfield University respectively; and Jin (2015) and Lu (2016) are now a Professor and HoD at Chongqing University of Science and Technology and Chongqing Jiaotong University respectively. The most remarkable is Nicholls (2018), now an ECR at Birmingham, who has rapidly developed and automated the digital infrastructure needed to coordinate the acquisition and sharing of SARS-CoV-2 virus sequencing data for the COG-UK consortium, with continued support from his PhD supervisors at AU. This is a major responsibility for this early career stage, but one that Nicholls was excellently skilled to do. The subsequent analysis of the data that this infrastructure then enabled has influenced government policy and public health. Owing to his exceptional achievement, he has now been nominated for a Dillwyn Medal, awarded to outstanding ECRs across all fields, by the Learned Society of Wales.

3. Income, infrastructure and facilities

Research income

The vitality of the research environment in the Department is underscored by success in obtaining external research grant income to support and facilitate our work. In total our research-active staff have participated in winning more than £10.1M in external funding (with more than £5.3M of this going to AU) over this REF period from a wide range of different sources. The most significant sources for research income are UKRI/Royal Society (22% of funding), EU (47%), government bodies/local authorities including health (17%) and industry (12%). The participation in the UKRI CDT in AIMLAC is currently the greatest single grant. Of a particular note is that the Department is the one across all discipline areas in all Welsh universities that has been awarded with the largest number (six) of independent world-class research fellowships that are funded under the prestigious Sêr Cymru II COFUND programme. Another noteworthy example is the EPSRC Inclusion Matters grant. In addition, in support of our research, staff have also been successful in receiving eight KESS research studentships within the assessment period, through collaboration with industry (e.g., Hywel Dda University Health Board; Bond Digital Health; RHE Global; Hafren Scientific; Welsh Water; and Wales Coastal Monitoring Centre).

Examples of external funding received over this period include:
- Advanced media production (EU, £1.16M, Miles and Tiddeman);
- Centre for Doctoral Training in Artificial Intelligence, Machine Learning and Advanced Computing (UKRI, £5.4+M, £800K to AU, Zwiggelaar and Shen);
- Developmental algorithms for robotics: Understanding the world of objects, interactions and tools (EPSRC, £560K, Shen, Lee and Shaw);
- Geographical data and earth observation for monitoring (EU, £300K, Labrosse);
- Benchmark scenario planning in primary production: Creating sustainable change (TSB, £290K, Neal);
- SeqInfo: Big data stringology algorithms for 2nd and 3rd generation sequencing (EU, £164K, Clare and Daykin);
- Optimised framework based on rough set theory for big data pre-processing in certain and imprecise contexts (EU, £138K, Zarges);
- Co-Production of alternative views of lost heritage (AHRC, £125K, Tiddeman);
- ExoMars Mars terrain simulator (UK Industry, £115K, Labrosse);
- Network-aware evolutionary coordination for ariel backbone (UK Industry, £110K, Wilson);
- FuzzyBot: Dynamic fuzzy rule interpolation for humanoid robot control (UK Government, £110K, Shang); and
- Dynamic modelling of plant growth with computer vision (EPSRC, £100K, Dee).

The majority of the grant holders named above- Miles, Shaw, Clare, Daykin, Zarges, Wilson, Shang and Dee- are women.

The further growth of external income to sustain a wide range of research activities is a departmental priority for the next REF period. The objective of expanding research income is strongly backed by Departmental, Faculty and University support for research development. For example, the University Research Fund offers pilot funding (of a typical size of £5-10K per grant) to support research staff developing ideas and preparing external grant applications. Since the formation of the Faculty (in 2018), our staff have won six such grants. All grant applications are supported by an internal peer review process and by a Research Development Officer at the Faculty level designated from the University's Department of Research, Business and Innovation. Planning for grant applications is also enabled by annual review meetings, sabbaticals and workshops and sandpits, especially in relation to facilitating larger collaborative proposals. Our most recent research fund-raising activities have led to a significant number of successful applications over the final academic session of this REF round (Aug. 2019-July 2020); most notable examples are: FoodBioSystems: biological processes across the Agri-Food system from pre-farm to post-fork (BBSRC, £2.4M) and South West and Wales Doctoral Training Partnership II (AHRC, £1.35M); Zwiggelaar is overseeing the delivery of both projects.

In addition, he is contributing training aspects on responsible research and innovation aspects, which are transferred from his experience with the UKRI AIMLAC CDT.

Research infrastructure and facilities
The Department has excellent research facilities that support our work in different research groups and has benefited from capital funding by the University and external sources (mainly HEFCW). This supports and adds to the Department's rolling programme of investment in new research equipment, allowing us to conduct research of the highest quality in areas that are part of our strategic growth vision. Apart from the existing major facilities such as the MarsYard, the humanoid robotics lab, and the state-of-the-art engineering and electronic workshops, examples amongst the many newly acquired facilities and equipment that have been made during this assessment period include: a 170 square-meter purpose-built mobile robot workshop; an outdoor Mars rover lab; a multi-material high-accuracy 3D printing machine to support research in soft robotics and space robotics; a SPARUS II, underwater robot; a virtual reality lab; a Yumi robot working as a process control and diagnostic rig; a local big data storage; a flow estimation environment; a submarine robot for environmental monitoring; and a transcranial magnetic stimulation (TMS) machine stroke lab.

Each of the above-listed relatively larger and newly acquired lab facilities and equipment requires at least a monetary support of £100K, summing up to a sub-total of capital investment worth £1.58M, excluding a separate investment of £440K for the building of the aforementioned workshop. In addition, we participate in Supercomputing Wales (£15M total), much of our data-intensive applications that require very significant computing resources (carried out in all our groups) makes use of this invaluable facility, whilst we also run our own GPU farm to support computationally heavy tasks and experiments.

Our researchers benefit from the excellent research infrastructure and facilities. For instance, VGV benefits from the virtual reality laboratory that supports research in virtual and augmented reality, and from the TMS lab for their medical imaging work. AR benefits from the process control and diagnostic rig for their model-based reasoning work in support of intelligent decision-making. BCB benefits from the big data storage for their plant gene sequence analysis. IR benefits greatly from our robotics laboratories and state of the art engineering and electronics workshops that enable the production of our own hardware to support our research. We are proud to have contributed to hardware that will fly to Mars as part of the ESA ExoMars mission. Of particular note is that the Department owns a large number of different robots, ranging from robot manipulators and a robotic submarine to large all-terrain vehicles and swarms of robots.

There is a strong connection to our research-led teaching activities where we ensure that each student who is enrolled on a robotics-related study scheme gets their own robot for modules in the first and second year to improve engagement. A dedicated member of staff is available for all researchers to offer training and support, in order to make use of the Supercomputing and GPU farm resources.

We also benefit from a physical sciences library dedicated to the Faculty, which we share with our sister Departments. All important journals in our specialist area are available and the full online access to the IEEE and ACM digital libraries provide our researchers with indispensable immediate and convenient access to relevant publications in their fields of research. We also enjoy free access to the National Library Wales that is located adjacent to our campus.

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

Collaboration
All four research groups contribute to the vitality of international research in their areas and have collaborated with researchers in more than 50 countries all over Europe, North and South America, Africa, Australia, and Asia, most notably China. According to SciVal 62.9% of our

research output involves international collaboration, of high quality: 25% are published in the best 10% percent of journals, measured by CiteScore (as compared to 19.3% on average for the UK).

The research in AR has been developed in cooperation with national and international academic collaborators including those from Universities of: Adelaide, Deakin, La Trobe, RMIT (Australia); Beijing Chemical Tech, Dalian Maritime, Fujian Business; North China Electric Power, Northwestern Poly, Sun Yat-sen, Tiajing, Xiamen (China); Coimbra (Portugal); DTU, Southern Denmark (Denmark); École Polytechnique, Lorraine, Paris-North (France); Institut Superieur de Gestion de Tunis (Tunisia); Michigan State (USA); Passau (Germany); Stellenbosch (South Africa); Yuan Ze (Taiwan); as well as those from Birmingham, Cardiff, Lancaster, Loughborough, Nottingham, Oxford, Sheffield, and Swansea. We work with many industrial companies, for a diverse range of real-world applications (e.g., e-commerce; transportation; crime-prevention; and diagnosis, for both physical and biomedical systems) that require novel data-driven learning-based solutions for problems such as feature selection, rule interpolation, classification and prediction, evolutionary optimisation, modelling and simulation. Our work has strong support from major companies and government organisations, nationally and internationally (e.g., Candela, Huawei, MoD, QinetiQ).

Staff in BCB work very closely with the BBSRC-funded Institute of Biological, Environmental and Rural Sciences (IBERS), which is also an integrated part of AU, and their wide-reaching international academic and industrial partners. Moreover, we work closely with bioinformaticians in Queens University Belfast and University of Birmingham on metagenomics and with Hywel Dda Health Board on data management and analytics for lung disease, also on a biobank information management system. We also work with industrial partner Bond Digital Health on systems for self-management of chronic lung disease; with industrial partner Dwr Cymru Welsh Water on anomaly detection in water treatment; with research groups in South Africa (Stellenbosch and Cape Town) on genome variation analysis; with University of Sydney on diagnostic tools for early pregnancy complications and endometriosis; with researchers at the Alan Turing Institute and the Universities of Warwick and Edinburgh on NLP/text analysis of scientific publications and their non-academic impact; and with colleagues at Harvard University and University of Florida on fish modelling thorough analysis of biological data and fluid-dynamics.

The research within IR has been developed through international collaboration within academia (e.g., Paris Descartes and Karbala) and with industsrial partners (e.g., Airbus, QinetiQ, Dstl, Lego Foundation, IIT). We have particular strong connections to QinetiQ (often in joint collaboration with the Defence Science and Technology Laboratory), recently generating £288K of direct research income in projects in the area of robotics around navigation, autonomous vehicles, and data management. Our work involves interdisciplinary collaborations with biologists (animal tracking and vegetation estimation), geographers (survey of rivers in New Zealand and of the icecap in Greenland) and psychologists (infant development). Supported with EPSRC funding, we also actively engage with domestic collaborations of course, e.g., to model how children learn from play, we worked with psychologists from the Universities of Cambridge and Cardiff.

The research within VGV has been developed with support from international academic collaborators, which include UPenn, Girona, MIT, Namur, Macquarie, Minnesota, Max Planck Institute (Leipzig), Bern etc., and from industrial collaborators such as QinetiQ, Unilever, RHE Global. It involves interdisciplinary collaborations with radiologists (cancer staging and detection), psychologists (face modelling and perception), geologists (VR for Mars missions), geographers (survey of the Rees river in New Zealand to measure movement of sediment during flood events, survey of the icecap in Greenland to measure ice movement), marine biologists (video-based classification and analysis of killifish, lobster and crab), plant biologists (plant 3D capture and phenotyping), and archaeologists (3D reconstruction and Augmented Reality). We also actively engage with domestic collaborations, e.g., for a virtual heritage project, we worked with archaeologists from the University of Bangor, Manchester Metropolitan University and the University of Central Lancashire to digitise and maintain cultural heritage assets.

To encourage international collaboration and exchanges, our staff have continued to be active in securing a range of grants in support of such activities over this assessment period. For example, we play the leadership role in a COST Action (Jansen) in the area of nature-inspired optimisation. This has helped to establish an extensive range of new international research collaborations (with colleagues in: France, Portugal, Spain, Croatia, Ireland, Czech Republic, Italy, Leiden, Norway and Slovenia), particularly through the two international industry workshops (in Denmark and Portugal respectively; participating companies included Zenzero, UK; Thales Group, France; AVL, Croatia and Hispasec, Spain) that we organised, facilitating cooperation between academic and industry partners and improving impact. We are involved in the Horizon 2020 Marie Curie RISE program on brain inspired solutions for intelligent navigation and robot mobility (Akanyeti), a large consortium including world-renowned industrial partners (e.g., BWM, Mathworks) and world-leading academic partners (e.g., Max Planck and Donder Institutes). We have won a number of Newton Fund grants, including those co-sponsored by British Council (Liu), by Royal Academy of Engineering (Shen), and by Royal Society (Zwiggelaar). Whilst these recently completed Newton Fund projects were all in collaboration with Chinese partners, the most recently funded one (Shen) is to support academic exchanges with Thai academics and industrialists, to help develop their research and innovation capacity for long term sustainable growth.

In this assessment period, we welcomed many academics and industrialists to visit us, either on a longer-term basis (e.g., six months or one year) or through an opportunistic stay (ranging from a couple of days to a few weeks), from all over the world. Longer-term visitors were typically involved in co-implementing a dedicated research project or a significant workpackage of a much larger project, whilst short opportunistic stays were often for delivering an invited seminar, discussing a joint project proposal or co-authoring a publication. We have hosted a large number of such visitors, including the following senior academics, who stayed with us for at least half a year: Ai and Li, Northwestern Poly; Li, Sichuan; Cao and Lin, Xiamen; Jie, Electronic Science and Technology; Zhang, Shanghai; Zhu, Quanzhou Normal, all being from China, and Quek from Nanyang Technology, Singapore.

In recognition of the national strategic importance and existing success of international collaboration, Welsh government has recently granted us one of the only five Strategic Partner Acceleration Awards (Shen and Shang) to further develop our research partnership with Northwestern Polytechnical University (NWPU, which is the leading institution in China for interdisciplinary research on AI with Aerospace and Airspace Science and Engineering). The collaboration between us and the School of Computer Science at NWPU over this REF period has been fruitful: We have jointly produced 22 papers in leading computer science and applied journals (including two published in 2017 that have already attracted 400+ and 130 GS cites, with the former listed by Remote Sensing as the most cited within the first three years since publication in this prestigious journal) and graduated 3 jointly supervised PhDs (including the exceptional graduate, Li mentioned in Section 2). Supported by this award both Universities have now signed an agreement to set up a joint international research centre for AI in Space Data Science and Engineering. This perfectly meets, and will strongly contribute to, our research strategic plan on the development of a sub-unit in this area (see Section 1).

General contributions
Members of the Department actively contribute to the vitality and sustainability of the discipline through a wide range of external roles. For example, over the REF period, amongst the 29 Cat-A staff, thirteen have served as an Associate Editor for 22 leading SCI-indexed international journals (with many more serving as an editorial board member), including: Artificial Intelligence (IF=6.628; Jansen); Engineering Applications of Artificial Intelligence (IF 4.201; Price); IEEE Transactions on Cybernetics (IF=11.097; Shen); IEEE Transactions on Evolutionary Computation (IF=11.169; Jansen); IEEE Transactions on Fuzzy Systems (IF=9.518; Jensen, Shen); Information Sciences (IF=5.910; Li); Journal of Biomedical and Health Informatics (IF=5.223; Zwiggelaar); Neurocomputing (IF=4.438; Han); and Pattern Recognition (IF=7.196; Zwiggelaar). Also, our Cat-A staff have acted as a guest editor for many journals, including:

Applied Soft Computing (IF=5.472; Li); IEEE Transactions on Fuzzy Systems (IF=9.518; Li); Journal of Ambient Intelligence and Humanized Computing (IF=4.594; Li); and Neural Computing and Applications (IF=4.774; Qu).

As such, more than 2/3rds of our Cat-A staff have played a leading editorial role in the academic community, covering staff at all career stages, and different genders and ethnic origins. In addition, our staff have participated in the organisation of well over 80 conferences during the assessment period, including: major international events such as ICIRA, FOGA, FUZZ-IEEE, GECCO, PPSN, WCCI. Since 2011 we are organising and hosting the annual iOSDevUK, a conference on app development for iOS devices with about 200 computer practitioners worldwide in attendance every year. We also host the 20th annual workshop on computational intelligence, this series of workshops have been strongly supported by EU and EPSRC.

Departmental staff actively participate in peer evaluation of grant proposals. Particularly, members of staff sit on funding councils or grant review panels nationally and internationally, e.g., Clare on panel for RAEng Research Fellowships; Price on Irish Higher Education Research Council; Shen on panels for: National Center of Science and Technology Evaluation, Kazakhstan, and Yangtze River Research Professorship Selection, China; and Zwiggelaar on panels for: EPSRC and Health and Care Research Wales. Additionally, Lee, Shen, Wilson and Zwiggelaar served as standing members of EPSRC peer review college, with Jansen and Zarges being associate college members; and Price, Shen and Zwiggelaar are on the EPSRC future leader fellowship peer college. Also, during this assessment period, our Cat-A staff have acted as an external examiner for 66 PhD dissertations, including 28 produced in 14 foreign countries (Australia, Belgium, China, France, Greece, India, Italy, Malaysia, Norway, Pakistan, Singapore, South Africa, Spain, Thailand). Furthermore, staff have undertaken various consultancy duties, including major roles (e.g., as advice board member or scientific adviser to an established company) served by: Akanyeti for AberInnovation; Price for Apple and Certiport; and Shen for Agxio.

Research activities conducted by our staff make substantial contributions to the research base, economy and society (see Section 1 for a brief summary from research impact perspective). We are also proactively engaged in outreach and public engagement activities that contribute to the University's civic mission (see REF5a) and to enhancing public understanding of science, including events such as the National Eisteddfod of Wales Science Village (which attracts approximately 150,000 attendees annually). Reflecting the Department's commitment to EDI issues, a notable emphasis has been on activities that support the vitality and sustainability of computer science research by engaging new audiences, including young people. Over this REF period and prior to the Covid-19 pandemic, we have organised: around 150 public events involving local schools (via school visits, robotics club, and science fairs); and an annual public robotics beach lab show for local community and beyond. We also host monthly regional BCS talks and run Aberystwyth Robotics Week attracting popular attendance by staff, students and people from the wider community. These activities help raise awareness of the development of AI research and the advancement of AI applications, and attract future generations of scientists and engineers.