Institution: University of Exeter

| Unit of Assessment: UoA11 Computer Science |

1. Unit context and structure, research and impact strategy

<u>Overview</u>
UoA11 is a vibrant research unit with a clear upward growth trajectory, having tripled in size since REF2014 to a headcount of 30 (27.9 FTE). A strong recruitment-drive over the census period has built on our areas of strength (Machine Learning, Evolutionary Computing and High-Performance Computing) and added new groups in Cybersecurity and Urban and Environmental Data Science. These research areas, together with interdisciplinary initiatives in the University and beyond, tackle some of the most compelling questions that our society faces around the development and application of AI to address challenges in transportation, urban living and the environment, the transformative capability of 5G systems, the rise of social networks mediated by technology and methods to keep our systems and data secure.

<u>Current Unit Structure</u>
The unit currently consists of 30 staff (current positions: P=Professor, AP=Associate Prof., SL=Senior Lecturer, L=Lecturer) across the research groups described below:

- **Machine Learning and Computer Vision:** Everson (P), Arribas (AP), Christmas (SL), Danon (SL), Ruan (SL), Costa (L), Dutta (L), Livi (L), Rowlands (née Shirazi) (L), Wahlstrom (L)
- **Evolutionary Computing and Optimisation:** Fieldsend (P), Keedwell (P), Li (SL), Moraglio (SL), Vaughan (SL), Alyahya (L), Chugh (L)
- **High Performance Computing & Networking:** Min (P), Wu (SL), Hu (SL), Luo (SL)
- **Cybersecurity;** Brucker (P), Marmsoler (L)
- **Urban and Environmental Data Science:** Menezes (P), Williams (AP), Arthur (L), Barbosa (L), Botta (L), Di Clemente (L), Oliveira (L).

Leadership and Decision Making
The unit is led by Head of Department (HoD) Professor Ronaldo Menezes, supported by Directors of Research (DoR) (Keedwell), Education (DoE, Wakeling – Education Only Contract),

Figure 1 - Research organogram

Impact (DoI, Christmas) and Global Development (DoGD, Oliveira). Computer Science sits within the College of Engineering Mathematics and Physical Sciences, led by a Pro-Vice Chancellor. The Discipline Executive Committee (membership above) leads decision making at the departmental level and reports to the College Executive Group through the HoD. The DoR attends three-weekly, College-level Research and Impact Committee meetings chaired by the College Associate Dean for Research (ADR). This provides a forum for the sharing of information and best practice among departments. The ADR reports to the institutional-level Research and Impact Executive Group chaired by the Deputy-Vice-Chancellor for Research. The DoR is supported by the Academic Leads for each research group and the Directors of Postgraduate Research and Impact. This structure is summarised in Figure 1.

<u>Vision</u>
Our strategic goal is to become a global leader in applied computer science research, particularly in the development of novel Data Science, AI and advanced analytics methods for

application to complex social, urban, environmental, health, economic, and technological challenges. The growth in this REF cycle focused on broadening our research base resulting in a 180% increase in FTE and two new research groups. We now aim to achieve further growth to 35-40 FTE in the medium term, a size commensurate with the top-10 UoAs for Computer Science, with a focus on adding further depth to our current research profile. This growth will enable us to tackle interdisciplinary challenges at the boundary between machine learning and optimisation (e.g., hyper-heuristics), human-in-the-loop and explainable AI systems, software-defined networking in 5 and 6G networks, the changing patterns of human mobility, reduction of inequalities, and the development of data science methods to address climate change and environmental sustainability. The rigorous exploration of new methods in these areas will underpin the development of high performance, sustainable and explainable systems and will increase our understanding of the interactions between humans and their environment.   These areas strongly align with institutional, national and international goals (e.g., the University's Declaration of a Climate Emergency, UN Sustainable Development Goals) and represent some of the most challenging computational research areas of our times.

We will accomplish the above through consistent and targeted growth throughout the next REF cycle, consolidating our current research groups adding depth to the broad portfolio that we have achieved in this REF cycle. The current profile of our UoA puts us in a strong position for targeted growth in the areas of Artificial Intelligence, Urban Systems, and Environmental Data Science. To achieve this, we will recruit staff to complement current research, leading to new 'spin out' groups from the current set once they achieve critical mass (e.g., Computer Vision from Machine Learning, Urban Analytics from the Urban and Environmental Group). This will allow us to take advantage of the many new strategic development opportunities (see Strategic Developments since 2014, below), and to create a larger-scale, vibrant research community, co-located in the newly refurbished building on the Streatham Campus that is now the dedicated home for Computer Science at Exeter.

Progress Against REF2014 Strategy
We have achieved our aim from 2014 to build new capability in **HPC and Scientific Computing**, predominantly through the creation of the HPC and Networking group under the leadership of Min. It consists of 4 core staff and 2 affiliates, 4 postdoctoral researchers and a growing number of PhD researchers, many of whom are industrially funded. With colleagues in Mathematics and the GW4 group of Universities, we (Fieldsend) received funding for Isambard, a novel architecture 10,000 core ARM-based HPC system based at the Met Office (https://gw4.ac.uk/isambard/), the first of its kind in the UK. This Tier 2 service has fostered collaborations with Mathematics (Wingate, Akman) on the development of new parallel-in-time codes for weather and climate modelling and models for systems biology. A University-level HPC governance group, led by Everson, has been established and oversees the procurement and management of the University supercomputer, *Isca* and the new research computing service (http://www.exeter.ac.uk/researchcomputing/). More recently, Everson has overseen the creation and recruitment of a Research Software Engineering group, part of a £975K University investment to provide support to researchers in the development of effective and efficient codes on the increasing array of architectures available to them.

We further aimed to build new capability in **bioinformatics and systems biology**, leveraging the University's £52M investment in the Living Systems Institute (see 1.3 & 4.16 Institutional Level Environment Statement (ILES)) and building on collaborations between Computer Science, Mathematics, Biology and the Medical School; this aim has also been met. The strategy has generated fruitful collaborations between computer scientists and mathematicians in the field of computational biology through EPSRC-funded research and joint publications (Fieldsend and Akman); work with the College of Medicine and Health (CMH) to explore AI in genomics (Keedwell); and COVID-19 research funded by the AFR (Keedwell) and MRC (Danon). Computer Science staff have also collaborated with colleagues in Biosciences and the CMH in pilot projects with the EPSRC Centre for Predictive Modelling in Healthcare (Keedwell, Fieldsend, Everson), resulting in interdisciplinary publications and research funding.   Keedwell

is also a panel member of the MRC Skills Development Fellowship Host Leadership team to evaluate projects that develop the computational skills of early-career biomedical researchers.

Strategic Developments Since 2014
Through a dedicated, flexible approach to management, the unit has been able to make the most of the following new opportunities to build capacity and engage in interdisciplinary research underpinned by University, national and European investment:

- The creation of the University's **Institute for Data Science and Artificial Intelligence (IDSAI,** see 1.3 & 4.18 ILES**)**. This interdisciplinary institute has a large core representation from the unit (Everson – Director, Barbosa, Botta, Costa, Danon, Di Clemente, Fieldsend, Keedwell, Livi, Luo, Menezes, Moraglio, Oliveira, Williams) and academic membership from across all University Colleges and campuses. It has provided access to new seed-corn funding streams (e.g., IDSAI research awards and Exeter-Turing pilot grants) and is a catalyst for interdisciplinary research across departments. IDSAI was founded in 2018 to develop innovative approaches to the use of data science and artificial intelligence in modern society and has rapidly grown to over 80 affiliated members of academic staff, and a wider membership of over 300 research staff. The Institute is the focus for the University's membership of the Alan Turing Institute (ATI), hosting 25 Turing Fellows and enabling in excess of £3.4M of research income from Turing. IDSAI has instigated interdisciplinary MSc programmes, such as Data Science, Data Science with Artificial Intelligence, and Data Science for Health.

- The creation of the **Environmental Futures and Big Data Impact Lab (Impact Lab)** (£1.3M to the unit, see 1.11 ILES). This ERDF-funded initiative aims to stimulate impactful research and innovation through support from a team of industrial research fellows to enable local (Devon-registered) SMEs to leverage their data using research and knowledge transfer from the University, primarily from this UoA, supplemented by expertise and data from the Met Office. Researchers in the unit (Christmas, Costa, Everson, Keedwell) contribute their expertise to the planning and strategic direction of these projects, providing an excellent pathway to realising impact for the region. This activity has created 12 new businesses, developed 10 new-to-market products and assisted the development of 10 new-to-firm products. It has also created 12 new jobs, has laid the foundations for follow-on Innovate UK funding worth over £2.5M to local business, and has supported product developments that have formed the basis of £1M+ funding cycles. For example, Everson and Costa's work with Applegate began in the Impact Lab and has led to the development of a COVID-19 PPE supply hub. This facilitated the delivery of over 100 million items of PPE to businesses during the first lockdown and won a Tech South West 'Hero Award' in 2020.

- Work on climate change and the environment has been identified as a strategic priority for the University and its regional collaborators through longstanding research collaborations with the Met Office. Computer Science has made a significant contribution to this through the award of the **UKRI CDT in Environmental Intelligence (EI)** in 2018. This £5.3M investment will train 50 PhD students over 8 years in the computational and data science methods required to allow informed decision-making by stakeholders for sustainable futures. An interdisciplinary CDT, it spans Mathematics, Management, Geography, Psychology, Philosophy and Medicine, with significant Computer Science involvement (Arribas, Everson, Williams (co-Director)). It benefits from strong industry involvement from partners AWS, Deepmind, IBM, Microsoft, ONS, Ordnance Survey, UKHO, the ATI, WHO, the Met Office and Exeter City Futures.

- Computer Science will also have significant involvement in the new, flagship, **Joint Centre for Excellence in Environmental Intelligence (JCEEI),** see 1.7 ILES, which cements Exeter's pivotal strategic partnership with the Met Office through a pool of 20 new and repurposed research appointments drawn from both the Met Office and University.

- **Membership of the Alan Turing Institute (ATI).** Exeter was invited to join the ATI, the national institute for data science and AI, in 2018. Six members of the unit have been awarded Turing Fellowships (see Section 4) and Everson is the Turing University Lead. Through the

Turing Institute we have engaged in new machine learning and data science projects and co-lead the "Data Science for Sustainable Development: Environment, Climate, and Health" project (Arribas, Everson) with Mathematics and the Medical School. Our membership has been instrumental in developing a new Operational Alliance between the ATI and the Met Office. On behalf of Turing, in a partnership with Alzheimer's Research UK, Everson leads the analytics hub of the Early Detection of Neurodegenerative Disease initiative (EDoN). We have also benefited from participation in new interdisciplinary communities across the Turing network and have forged new connections with industry and the third sector. Collaboration with the Turing Research Engineering Group has been important in establishing the University's centralised Research Software Engineering group. Finally, Turing membership has been critical for attracting new staff and many of our recent appointments have indicated their interest in Exeter due to our membership of the ATI.

- Participation in large national schemes including the **£20M Institute of Coding.** Although primarily an education initiative, Exeter has secured research funding for machine learning and networks research into visualising the changing jobs landscape; and for research into effective pedagogical methods for delivering Computer Science skills to non-Computer Science students. This venture is enhanced by the building of the **South West Institute for Technology**, located adjacent to the Computer Science building on Streatham campus, as part of a large national effort to provide the technical skills required by employers**.**

Our involvement in the initiatives described above, strengthens our ability to engage in internationally excellent, interdisciplinary research, linked with the national Computer Science research and policy landscape, and demonstrates the growing influence of Exeter computer scientists. Through the above, it is clear that Computer Science at Exeter is embedded in the fabric of the South West, collaborating with local organisations (e.g., industry, catapults and LEPs) and delivering research, impact, skills development and education opportunities for people within the region. Our work often reflects the region's unique economy, geography and demographics by:

- Working with businesses that rely on the natural environment, through the EI CDT and UKRI-funded research with local water companies (Keedwell, Everson).
- Developing novel processing of photogrammetry images to bring new insight into local historical artefacts (Christmas).
- Working with local SMEs to increase the sustainability of buildings and transportation systems across the region (Everson, Fieldsend and Keedwell).
- Helping to develop the local economy through impactful research and knowledge exchange with local SMEs and startups (Impact Lab).

Strategy Beyond 2021
We aim to build on recent successes to increase our world-leading research in 5G/6G and cybersecurity; and to become a global centre of excellence in the development of data science and AI methods to address environmental and urban issues, underpinned by high quality infrastructure and world-class computing facilities. To accomplish this, we will continue to grow to create critical mass with commensurate increases in research indicators such as PGR students and research income. Further hires will strengthen our existing research groups and enable us to 'spin-out' groups in our areas of strength aligned with national strategic priorities in **Computer Vision, Urban Analytics and Environmental Data Science**; we also plan to expand capacity in the critical issue of detection of misinformation and disinformation, and further our **AI** portfolio towards human-AI systems. We aim to establish a new research group in **Software Engineering,** which will enable us to create new interdisciplinary partnerships with the AI (e.g., in search-based software engineering) and cybersecurity (e.g., in engineering safe and secure software systems, software testing) groups.
We will continue to extend our research support and management structures to accommodate these new groups and provide support for new staff and early career researchers. Each new group will have an academic lead to support all aspects of the research process including grant

writing and management, publication and impact activities, and to provide guidance on career progression through our performance development review process.

Research Management

Research Integrity and Open Access: 100% of Computer Science staff are ORCID-registered and researchers are expected to uphold the institutional principles of the Research Integrity Concordat (see 2.8 ILES) of honesty, rigour, transparency and open communication, care and respect, and accountability in their work. Colleagues are supported in this by the department's academic lead and mentoring initiatives, the ethics committee and the DoR. New guidelines and information are disseminated through the regular staff meetings and annual research awaydays. Researchers are encouraged to publish their work as open access and non-compliant publications are identified and remedied quickly through staff consultation. Staff are signposted to University resources to cover article processing charges and in 2019, 10 such requests were made, up from 3 in the previous year. Support is provided centrally through the library, who proactively manage journal copyright requirements and deposits to our institutional repository, ORE. In 2019, the department exceeded 10,000 publication downloads through ORE and in the first six months of 2020, regularly exceeded 1,000 downloads per month. Open access principles are therefore embedded in the department as 'business as usual' and our work is clearly in demand through this channel.

Impact: Researchers are encouraged to consider the potential impact from their research throughout the development of a project, from conception of an idea to the final stages of project delivery and beyond. This is facilitated through close collaboration with our Innovation, Impact and Business (IIB) service at the University, which provides support for all aspects of impact generation and business engagement. Staff are encouraged to engage industrial and other non-academic partners in funding applications as a matter of course, ensuring that even fundamental research has a route through to impactful application. The success of this approach is evidenced through the award of 8 KTPs, 2 Innovate UK grants and 15 industrially-funded studentships and consultancy projects during the census period totalling £943,000 of industrial funding into the unit (see Section 4).

Impact case studies were developed throughout the census period in partnership with IIB and the DoI, starting with a wide pool of potential studies and eventually focussing on the 3 strongest cases. The nominated 3 have arisen through distinct routes: from UKRI-funded research, Innovate UK funded research and from an industrial partnership, illustrating the diversity embedded in the selection process and in our mechanisms for generating impactful research.

Interdisciplinarity: Computer Science has a strong history of collaboration with other disciplines, supported through activities at the departmental, College and University level, including the strategic developments described above. Researchers are encouraged to pursue interdisciplinary collaborations through the promotion of opportunities via e-mail, staff meetings and awaydays. The DoGD encourages multidisciplinary initiatives with international partners as part of the development of strategic partnerships (e.g., in China, Brazil, India - formalised through MoUs), in line with the institutional Global Strategy. The University's College structure encourages interdisciplinarity as shown through particularly strong relationships with the Centre for Water Systems (Engineering) through the EPSRC WISE CDT (http://wisecdt.org.uk/) (Keedwell, Everson) and Computational Fluid Dynamics groups (Everson, Fieldsend); and with Mathematics colleagues in Systems Biology (Fieldsend) and Environmental Science (Everson). Figure 2 demonstrates the breadth of these collaborations across 14 separate University disciplines.
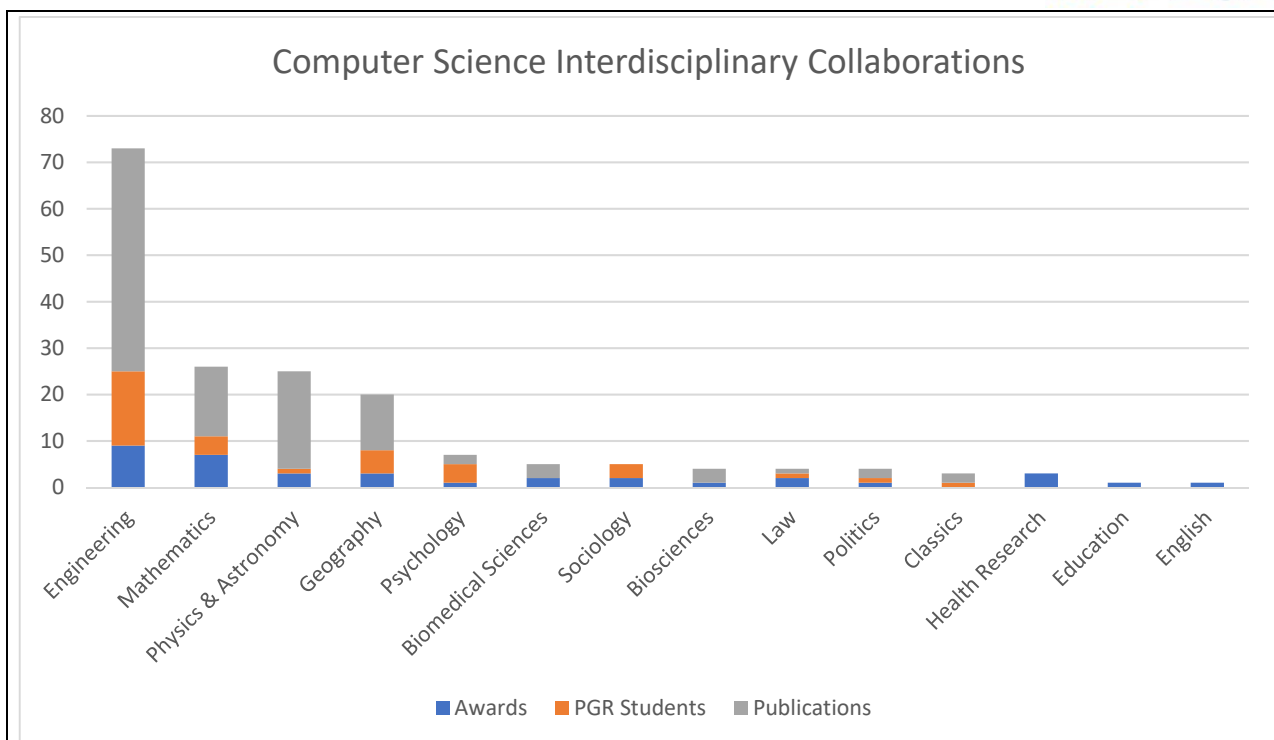
Computer Science Interdisciplinary Collaborations

Figure 2 - Collaborations by research awards, PGRs co-supervision and publication co-authorship

Research Events: Research activities at the departmental level are underpinned by a weekly seminar series, fortnightly staff meetings, termly department meetings and an annual research awayday.

Seminars/Lectures
Departmental seminars provide opportunities for researchers to discover the latest research findings from national and international researchers. All staff, postgraduate research students, and undergraduate students are encouraged to attend and to engage with the internal and external networking this provides. Seminars include an additional hour for coffee and discussion with the external speaker to promote networking and new idea incubation. During the COVID period, we have hosted live events on YouTube with leading international researchers on topics such as 'Industry 4.0', and the effect of the pandemic on female researchers. In recent years, we have also hosted a department-wide Christmas Lecture from an inspiring speaker on a topical Computer Science subject, including speakers from DeepMind, the Met Office, and most recently, an historian illuminating the work of Lovelace and Babbage. These events have proven popular with both staff and students, typically attracting over a hundred participants. IDSAI runs a parallel programme of seminars and a Christmas Lecture on data science topics, providing further engagement with researchers from around the University.

Meetings/Awaydays
The fortnightly staff meetings provide an opportunity to disseminate relevant research calls and to discuss operational items. Termly departmental meetings focus on strategic planning and consolidation of material. A termly College meeting disseminates College/University-level research strategies and targets within an interdisciplinary setting and provides an opportunity for researchers from the unit to meet with colleagues from the College and to celebrate collective research successes.

Annual research awaydays provide an opportunity to reflect on progress during the year, to develop future research strategies, and involve workshop presentations on specific topical research items e.g., impact or open access.

Workshops
Where an area of particular need is identified, workshops are arranged to provide additional support on particular topics throughout the year. One such example is our early-career grant writing workshop, which is run in conjunction with Research Services to provide guidance on developing ideas and applying for research funding for the first time. Other workshop series include 'IIB Essentials', a bi-annual event run by the IIB service that covers the development of impactful research through a set of themes: Supporting Research, Commercialisation, Spinouts and Start-ups, Intellectual Property and Commercialisation and Knowledge Transfer Partnerships.

Conferences
Since 2014, the department has hosted national and international conferences including the UK Computational Intelligence Conference in 2015, the 9th EAI International Conference on Big Data Technologies and Applications in 2018, the Environmental Intelligence Summit (170 delegates) in 2019 and the 11th International conference on Complex Networks in 2020 (CompleNet) (online due to COVID-19). The University supports academics in the organisation of conferences through professional services and events team support and the Support and Scholarship (S&S) time described below.

2. People

Strategy
The overarching aim for the department is to grow staff numbers to build research capacity in strategically important areas, encourage impactful activity and provide effective leadership to support world class research. We recognise the importance of aiming for a balanced portfolio of staff, both in terms of research area and seniority, and our recruitment since 2014 reflects that. We have successfully built on our research strengths and through our appointment and promotion strategy, have increased the number of senior staff in the department significantly. This has seen the number of Chairs increase to 6 (from 2 in 2014), APs from 1 to 4 (2 of whom subsequently became Chairs) and SLs from 2 to 5 during this REF cycle. As part of this process, a new, experienced HoD (Menezes) was recruited from the USA. He replaced Everson, who was appointed as Director of the IDSAI and University Turing Lead. Our strategy provides a pipeline for succession planning and future leadership to provide strategic direction to the unit and involves earlier career academics, who are encouraged to take on administrative roles at an appropriate career stage, providing departmental resilience and evidence for personal progression.

Appointments
Appointments are made according to the departmental strategy, which considers existing research strengths of the unit, the wider University and the national and international research landscape. They are made at the appropriate level, appointing at the professorial level where this leadership and vision is required, for example to establish new research groups. Examples of this are Min (HPC & Networking), Menezes (Urban and Environmental Data Science) and Brucker (Cybersecurity). Further appointments at Lecturer or SL (e.g., HPC & Networking - Hu, Luo, Wu; Urban and Environmental Data Science - Barbosa, Botta, Di Clemente, Oliveira; Cybersecurity - Marmsoler) are then used to build capacity and to support the internationally-excellent research of the chairs, in addition to other appointments that strengthen existing research groups.

Staff Promotion and Career Support
The unit supports applications for promotion from staff and encourages all to apply as soon as they are considered to be at the appropriate level. Staff are encouraged to discuss their promotion case initially with their academic lead and subsequently with the head of department. Support is provided through the Exeter Academic scheme (see 3.3 ILES), which provides guidance on expectations for promotion for all career levels and academic job roles. This combination of local departmental support aligned with the University-level process has led to promotions at all levels throughout the department during this REF cycle:

AP->P – 2 (Keedwell, Fieldsend)
SL->AP – 3 (Keedwell, Fieldsend, Williams)
L->SL – 5 (Christmas, Li, Moraglio, Wu, Luo)

General
Staff within a research group are supported by an academic lead (AL), a senior academic within a similar research field, who supports and mentors members of staff in their research and career development. The AL role is an important way in which we democratise leadership roles and provide academics with a strategically important first point of contact for research mentoring. In addition to regular informal meetings, staff review performance annually with their AL through the performance development review process. This encompasses performance across the academic job role, identifies areas to be addressed and opportunities for the year ahead. These meetings, supported by performance metrics (e.g., research funding applications/awards), provide an important stock-check of performance, an opportunity to discuss progression and to develop research strategies for the coming year. In recognition of our increase in size and research diversity, our number of ALs has increased from 2 to 5 in order to provide appropriate and tailored mentorship to our academics. ALs will be allocated to each of the additional research groups described in our future strategic expansion.

Through our workload planning system, staff are allocated 20% S&S time to devote to activities that enhance their research. This is in addition to time allocated to funded research, student supervision, education and administration activities and so provides valuable space for researchers to write funding applications and to contribute to the life of the discipline (see Section 4).

Early Career Academics
On appointment as lecturers, staff undergo an 18-month Academic Professional Programme (see 3.5 ILES), culminating in HEA membership, and receive specific support through 'ramped' teaching loads providing staged relief from education in the first three years. During this period, staff are encouraged to develop their collaborations within and beyond the University with academic and industrial partners and to develop applications for funding, such as for EPSRC First Grant/New Investigator Awards (NIA). To further facilitate this, ECRs are encouraged to engage in training mapped against the Researcher Development Concordat and the HR Excellence in Research charter (see 2.9 & 3.8 ILES). We also provide bespoke Computer Science training, explaining the research funding landscape and best practice in writing effective research proposals. Where an interview features as part of the assessment for a funding scheme, mock panels are convened with senior staff to provide applicants with experience of these challenging events. These initiatives have led to some notable ECR successes including EPSRC NIA awards for Pugeault (now at Glasgow) and Wu, and a prestigious £1M UKRI Future Leaders Fellowship award for Li.

Postdoctoral Researchers
We recognise that postdoctoral researchers (PDR) experience specific challenges in terms of the typically fixed-term contracts on which they are employed. Staff are encouraged to discuss these issues with their supervisors and we support PDRs in applying for appropriate funding (e.g. EPSRC and ERC Postdoctoral Fellowships) through ECR initiatives. Opportunities for training and gaining teaching experience are signposted to researchers through the induction process and supervisory channels. This has led to a significant proportion of our PDRs going on to become early-career academics, e.g., Chugh, Alyahya, Maxwell (Exeter), Walker (Plymouth), Rahat (Plymouth & Swansea), Kheiri (Cardiff & Lancaster).

Staff Voice
Staff (including PDRs) have the opportunity to co-develop departmental strategies though education and research awaydays and staff meetings. The leadership team actively encourage staff to challenge norms and contribute their ideas to departmental strategies. Each senior role has a 3-year term, providing opportunities for a range of individuals to contribute to the

development of the department and to enhance their leadership skills. Staff have multiple channels through which to voice any concerns, including staff meetings, performance development reviews, academic lead meetings, the institutional Staff Survey and annual 'Pulse Checks'. In the most recent (2018) Staff Survey, 91% of Computer Science staff reported that they believe that the work they do makes a difference and that they have good relationships with their colleagues, underlining the collegiate culture that we have developed in the department. Early career staff also engage with the ECR Liaison Forums, through which they have formal strategic representation across the University. Issues arising from these channels are discussed and addressed at Executive Group Meetings, with new initiatives disseminated via staff meetings. Issues with harassment or bullying can be raised through an institution-wide network of Dignity and Respect Advisors and Speak Out Guardians (see 3.15 ILES), who work with the Vice-Chancellor's Executive Group to identify trends or themes that arise from these cases.

Equality, Diversity and Inclusion (EDI)
Computer science has become a significantly more diverse department in this REF cycle, both in terms of ethnicity where the percentage of BAME staff has doubled from 24% in 2014/15 to 48% in 2019/20, and background where the proportion of staff from non-UK nations has increased from 35% to 55% over the same period. These figures justify our commitment to embed institutional EDI practices into our recruitment, training and promotion processes, adopting University procedure and best practice wherever appropriate. All staff involved in recruitment undertake recruitment and selection training, including on the avoidance of conscious and unconscious bias against those with protected characteristics.

We align our research assessment processes with DORA (Declaration on Research Assessment), to which Exeter is a signatory (see 2.8 & 3.3 ILES), and outputs were selected for REF2021 through review by expert panel. All staff involved in the selection of outputs for the REF have undergone additional EDI training to ensure no bias is introduced into this process.

In 2020, as the department achieved greater critical mass, we established an Inclusion and Diversity Committee responsible for establishing an EDI strategy for the unit together with the academic leads and is comprised of our Athena Swan Submission Author (Barbosa), Equality and Diversity Officer (Rowlands), Widening Participation Officer (Alyahya), and Ethics Officer (Arthur). They report quarterly to the unit Executive Group.

Gender Balance
Staff gender balance has traditionally been a challenge for the department and our submission was 100% male in REF2014. However, ongoing appointments have addressed this to a degree and we now have 3 female staff (Alyahya, Rowlands, Christmas) representing over 10% of research-active academic FTE. However, the proportion of REF submissions by female staff is lower than expected as two are very recent lecturer appointments (2020). Christmas achieved promotion to Senior Lecturer during the census period and now occupies a senior management role as our DoI, providing a role model for more junior female staff. Improved gender balance is evident in other areas of the department including teaching-only staff and in our PGR cohort, where almost 24% of applications and 30% of enrolments are female. However, we are continuing to develop measures to address our gender imbalance and we work with more balanced disciplines (e.g., Mathematics) to exchange ideas and best practice. This work has included two successful applications for Athena Swan Awards, where we became the first departments in the University to receive silver awards in 2016 and have recently been awarded a further bronze. We also engage with the College's Workplace, Inclusivity, Diversity, Equality and Respect (WIDER) committee, which develops strategic direction and monitors progress against EDI goals (Barbosa, Keedwell, Christmas).

Parental Leave
Eligible staff are encouraged to apply for parental leave in line with University procedures (see 3.16 ILES). We are strongly supportive of staff who have parental and caring responsibilities. Staff are permitted to work flexibly and can apply to have specific hours in the week removed from consideration for teaching. A significant number of our staff make use of this, and 3 staff work 0.8 or 0.7 FTE to accommodate childcare responsibilities. These reduced hours are

incorporated in our workload modelling and subsequently into individual workloads through the Executive Committee.

Study Leave
Academic staff are encouraged to apply for study leave (sabbatical) at the ratio of 1 year in every 7 (pro-rata for shorter periods) to expand their research, collaborations and impact. Due to our rapid growth, relatively few members of staff have become eligible for a full year but Fieldsend (2013-2014) and Keedwell (2015 & 2019) have taken a year, and Danon completed 6 months leave in December 2020, in part to assist SAGE on COVID-19 modelling through membership of the Scientific Pandemic Influenza Group on Modelling (SPI-M). Williams has approved leave for 2020-21, currently postponed due to COVID.

Research Students
PGR numbers have increased substantially over the census period, increasing 50-60% year on year from 11 in 2014 to 40.5 in 2018/19, resulting in a PGR/FTE ratio of 2.13. A PGR cohort of this size enables a vibrant research-led culture within the department with students contributing to and benefitting from departmental seminars and meetings and events organised by the department's PGR coordinator.
The supervisor-weighted completion rate for students in Computer Science during the census period was 20.3, with 26 students completing during this time. This might seem low in comparison with our FTE, but is a function of our growth: mean PGR registrations during the census period were 28.2 and mean staff FTE was 15.8, indicating a healthy ratio over the REF cycle.

Recruitment, Support and Facilities
We adopt similar processes, norms and expectations to the recruitment of postgraduate students as to the recruitment of staff. The unit has successfully recruited students using a range of funding sources including College, DTP, CDT and industrial funding, indicating that this growth is sustainable in the long term. For most new appointments, a College-funded PGR student is included in the start-up package. The unit aims to provide an inclusive, stimulating and impactful research environment for our postgraduate students, which includes access to excellent facilities and high-quality supervision. At the University level, students are supported by the Doctoral College, which stimulates and supports a vibrant research and intellectual environment across disciplines for postgraduate and early career researchers and PGR liaison groups provide the students with a voice to express concerns that cannot be resolved at the departmental level.   Students are largely homed in a bespoke refurbished space in the new Computer Science building, close to academic staff, and are provided with funds for equipment, travel and consumables. Skills training is provided through central researcher development network modules and a Masters-level Research Methodology module. Students are encouraged to 'audit' (attend without compulsory assessment) taught modules specific to their studies at the supervisor's discretion.

Assessment
Students are assessed via report and mini-viva by two academics, one external to the supervision team, at 6-months, and then annually throughout their studies to receive external feedback and ensure consistent progress. This provides the student with experience of a viva-like setting, feedback on their progress and ideas to take forward. This external assessment also provides opportunities to raise any concerns regarding supervision and we encourage postgraduates to voice their concerns through this channel, through their supervisor if appropriate and via the PRES (The Postgraduate Research Experience Survey). Arising issues are either addressed locally or elevated to the Executive Group where a departmental-wide response is merited.

In addition, students are required to present their work, at least annually, to their research group, a requirement that is supplemented in the unit by a postgraduate research event co-located with research awaydays and/or the College postgraduate conference. These two events provide a

valuable forum for the dissemination and exchange of research ideas and outcomes among PGRs.

An exciting development for the unit was the award of an AI **Centre for Doctoral Training in Environmental Intelligence,** which commenced in September 2019. It promises to provide significant numbers of new postgraduate opportunities in this important research area and will benefit the entire UoA11 PGR cohort through new infrastructure and resources and opportunities for interdisciplinary training and industrial engagement, as well as providing significant numbers of new postgraduate opportunities for our unit.

3. Income, infrastructure and facilities

Income

The unit has attracted significant income from a wide variety of sources, including the Research Councils (predominantly EPSRC and NERC), Innovate UK, EU, charities and industry. Total research income during the census period was **£6.95M**, a greater than five-fold increase over the REF2014 census period (£1.29M). A proportion of this is expected due to increases in average FTE over the two periods (REF2021=15.8, REF2014=8.5). However, staff growth explains only £1.11M of the £5.66M uplift in research income. This significant increase clearly indicates a transformational shift in our ability to attract research funding, particularly for larger bids, and our ability to write high quality, exciting and timely grant proposals. Our strategy has been to empower staff to apply for grants commensurate with their career stage, for example by supporting study leave applications for all those applying for fellowships and larger grants and providing relief from teaching for new starters. These initiatives are underpinned by a departmental-wide six-point approach to achieving high quality grant applications:

1. Promotion of funding opportunities at staff, departmental and College meetings and research awaydays.
2. Strong support in bid development through the academic lead system. The academic lead is involved in the early stages of idea generation and bid preparation and signposts researchers to University services.
3. End-to-end support from Research Services and IIB to provide partner engagement, administrative support, and to ensure that bids are costed appropriately.
4. Departmental workshops and monthly writing clubs, aimed at early career researchers, to enable the sharing of best practice among staff.
5. Implementation of a peer-review process that provides independent feedback from senior academics at key stages in the application process.
6. Leveraging of match funding from the College to increase resources for applications (e.g., an additional research studentship), particularly for early career awards.

This democratised approach has resulted in income spread across the department and at all seniority levels. During the census period, 15 separate staff have worked as investigators on funded research projects spread across 33 different funders including UKRI, EU, Alan Turing Institute, RAEng, Royal Society and a wide range of industrial partners.

Notable awards include (Funded amount to the UoA shown):

ERDF: Environmental Futures and Big Data Impact Lab: £1.35M, Everson
UKRI: Future Leaders Fellowship Scheme: £1.0M, Li
EPSRC: Keedwell: £354K, Fieldsend: £300K, Christmas: £288K
NERC: Everson, Fieldsend, Luo: £459K
Innovate UK: Fieldsend: £262K, Keedwell: £188K, Everson: 2x £111K
US Army Research Office: Menezes: £130K
These awards have been underpinned by a host of smaller awards from other funders as described above.

Strategy
Our strategy is to continue to build on this success and to ensure that the implementation of the initiatives described above continues and is further embedded into departmental culture. Through the expanded AL system, we aim to provide research-area specific support to staff of all levels to develop novel ideas into concrete, high quality proposals. We recognise our interaction with industry as a strength and will continue to develop our relationships with industrial partners and to engage with large-scale schemes such as the Industrial Strategy Challenge Fund.

A further challenge to the research funding landscape is the increase in call-based funding opportunities with short turnaround times. To address this, a pipeline of ideas is maintained to provide a pool of potential proposals that can be adapted for these calls. Furthermore, we remain vigilant to new opportunities through web and e-mail announcements, our memberships of various national and regional forums, and our own funder advisory networks (e.g., EPSRC FAN - Keedwell).

Infrastructure and Facilities

Physical Infrastructure
Computer Science is located in a newly refurbished home on the Streatham Campus, Innovation Centre Phase 1. A strategic decision was taken to move to this building to provide a single home for the department, with the attendant benefits to the research environment from Computer Science researchers being co-located in a single facility.

The building has undergone a £1.1M repurposing that has seen the creation of new offices and open-plan workspaces for 70 academics, PDRs and PhD students within a purpose-built environment. These workspaces are located alongside break-out rooms, kitchen facilities and two undergraduate teaching labs, named Lovelace and Babbage by a department-wide popular vote. These improvements have created a home for Computer Science and have raised capacity to 191 spaces for academics, PDRAs and PhD students, providing room for the department to expand in-line with our growth strategy.

There are further plans for researchers and PGRs from IDSAI to be co-located with the Global Systems Institute (GSI) and Astrophysics, providing opportunities for interdisciplinary research, particularly around the Environmental Intelligence theme.

Computational Resources
Researchers can make use of a variety of resources within the department and at the University and regional level. Locally, a significant volume of work is conducted on workstations purchased as part of research projects. However, larger facilities exist at the research group level with specifications tailored for specific research areas, e.g.:

Everson: 12-machine Xeon CPU Linux Cluster
Fieldsend: Tesla k40 GPU servers
Wu: NVIDIA Titan RTX GPUs workstations (funded by an EPSRC Equipment Award)
Menezes: 22-core Xeon Server, 515Gb of RAM, 80Tb of storage, RTX 2080Ti GPU

Researchers in Computer Science also have access to two local HPC facilities that have attracted over £10M of investment in the census period: ISCA and Isambard, described below.

ISCA
ISCA is a £3M University HPC facility designed to serve advanced computing requirements for all research disciplines, combining a traditional HPC cluster with a virtualised cluster environment. ISCA is available free of charge to all research groups and consists of a range of computer resources within a single machine: the traditional cluster (128 GB nodes) is complemented by two large memory (3 TB) nodes, Xeon Phi accelerator nodes and GPU (Tesla

K80) compute nodes. The non-traditional element of ISCA includes a cluster of higher memory nodes (256 GB), 3 TB nodes, and an Openstack environment for the management of virtualised resources. Academics are encouraged to cost in the use of this facility into research grants to support computational work. The unit (Brucker and Keedwell) has recently received an £85K EPSRC Core Equipment Award for x86 (56-core, 768GB) and IBM POWER9 (2x20-core CPU, 4x V100 GPU) nodes to bolster research in the cybersecurity and AI fields.

*Isambard (*https://epsrc.ukri.org/blog/isambardhpc/).
We are members of the GW4 consortium that successfully bid for the £3M EPSRC Tier 2 Computing centre based at the Met Office. This system is made up of over 10,000 64-bit ARM cores representing a novel architecture for research. During the census period, significant use (~301,000 core hours) has been made of this by Computer Science researchers for the optimisation of CFD models. Further funding has recently been granted for Isambard 2 (EP/T022078/1), which will use cutting-edge A64fx processors.

Operational Infrastructure
Computer Science is led by the HoD who chairs an Executive Group consisting of the DoR, DoI, DoE and DoGD. The DoR, (Keedwell) is the primary contact for research-related matters and works with Research Services and IIB to support researchers in grant writing, peer review, grant management, output nomination and impact development. He is responsible for the promotion of research activities within the department and liaises with other related administrative roles such as the Director of Postgraduate Research, the Seminar and Event Organiser and the Academic Leads. The DoR has a budget (typically £5-7.5K annually) to support research, providing the opportunity to pump-prime projects that have yet to be externally funded and to support visits to industrial partners or academic conferences, predominantly for ECRs who have limited access to funding.

As discussed in Section 1, the DoI (Christmas) manages impact activities and cultivates impact case study development, and the DoGD (Oliveira) fosters international connections. Researchers are also supported by dedicated contacts in Research Services (Roberts) to assist with the costings and development of proposals, particularly impact and justification of resources sections, and in IIB (Gonzales) to encourage engagement with industrial partners and to promote industrial funding opportunities.

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

To achieve our goal to become a global leader in applied computer science research a strong set of partners and collaborators from across sectors is necessary. We have already developed a rich ecosystem of applied and interdisciplinary research collaborations (both internal and external), broad industrial engagement and societal impact, and we plan to extend its reach both geographically and into important new sectors. This ecosystem is described in more detail below, along with metrics of esteem such as fellowships, prizes, and our contribution to the research base through grant reviewing activities. These activities are promoted through the 1 day per week of S&S time for academic staff described earlier.

Non-Academic Collaborations

Every member of the unit makes a significant contribution to the research base, economy and society. They achieve impact from their research through collaboration with non-academic partners, co-creation of funding applications, student co-supervision, co-authorship of publications and invited talks, grouped into the following broad thematic areas:

Environment & Sustainability

Core to the Environment and Sustainability theme is our strategic partnership with the Met Office, realised through joint appointments (Arribas), the JCEEI and the Impact Lab (see Section 1). Everson leads the Impact Lab and has played a pivotal role in the projects described, along with Christmas, Costa and Keedwell. To date, the unit has worked with 12 partners in this sector: City Science, RegenFarm, OTA Water, Emtec, Floor Dynamics, Thermancy , Milkalyser, Seiche,

Spatial Quotient (formerly That Figures), Minibems, Applegate and FuturebE. These have led to KTPs for Everson (Applegate) and Christmas (That Figures). Further ongoing work in this theme includes engagement with the Flood Forecasting Centre (Williams, Arthur), Global Hazard Map and TIST (Arthur).

We work closely with the water industry and have gained funding for projects on machine learning with South West Water (1 studentship and 1 KTP, Everson), DC Welsh Water (KTP, Keedwell), United Utilities (studentship, Keedwell) and Hydro International (Fieldsend); and a KTP with Artesia Consulting (Everson), which developed new data science tools for leakage management. We are also involved in UKRI-funded interdisciplinary projects that involve wide industry engagement, such as the HOWS project (Keedwell) investigating interactive evolutionary methods for designing and managing water systems, with Bristol Water, WSP, AECOM, SEAMS and SWW.

Optimisation and machine learning for sustainable planning and development has underpinned our Innovate UK-funded collaborations with City Science (totalling £2M; Everson, Fieldsend & Keedwell) and Hoare Lea (Everson, Fieldsend), and a KTP with BEST Energy Saving (Everson and Christmas).

Technology

We work with telecoms providers including BT, with whom we have 3 funded PhD studentships including an iCASE (Min, Luo, Keedwell), and a further 3 with a large telecoms company held by Min (confidential). Everson has also received 3 funded PhD studentships in partnership with Engineers' Gate on data science in FinTech and Keedwell has an iCASE with Dyson working on AI and privacy.

We have ongoing collaborations with Samsung (Wu), Google (Barbosa), Nokia Bell Labs (Menezes), DeepMind, AWS and Microsoft (Arribas), IBM and IBM Research (Arthur, Everson, Hu, Luo & Williams), Ericsson (Hu), Adarga (Williams), Sony CLS (Di Clemente) GE Healthcare (Li) and Cambridge Mobile Telematics (Wahlstrom). Fujitsu have funded significant periods of consultancy and contract research and have an approved patent with Moraglio.

Defence (esp. Marine)

Partnerships in this sector are a particular focus for Christmas, who works closely with a range of organisations including the MoD, Qinetiq, BMT and BAE Systems. During the census period, she worked with the MoD and BAE Systems as part of an EPSRC Prosperity Partnership. Menezes is funded by the USA Army Research Office (ARO) in the understanding of human mobility patterns. ARO have visited the University and demonstrated interest in continuing funded research with Barbosa, Menezes & Keedwell.

Government/Policy/Charity

Danon works for SPI-M carrying out COVID-19 mathematical modelling for SAGE. He has received funding from Pfizer and serves on their academic advisory panel. Botta has worked on data science projects with the Department for Digital, Culture, Media and Sport, Government office for Science, Cabinet Office and ONS, and Arthur works with the Health and Safety Executive. Barbosa has applied his urban data science tools with the Centers for Disease Control and Prevention (USA) and Di Clemente has worked with the Gates Foundation, the World Bank and UN data pulse on data science projects. Menezes works with UNICEF and hosted one of their research scientists which led to activities in other Colleges.

Spin Outs

Social Sensing: An early-stage spin-out that uses social media to map extreme weather and climate events (Williams & Arthur directors). They are currently working with the Environment Agency Flood Forecasting Centre, where their app is providing flood monitoring and retrospective flood forecast verification services. The company is in talks with other meteorological organisations, such as Global Hazard Mapping unit at the Met Office.

Government agencies (such as DFT) and various companies in the insurance sector have also expressed interest.

CAFlood is a commercial venture arising from EPSRC-funded research in the simulation of flooding using cellular automata (Keedwell), that has generated licencing and contract research revenues of ~£65K to date and is the subject of an impact case study. It has been employed by local and national government agencies, councils, insurance companies and the water sector internationally to model and simulate various flood scenarios. It has underpinned a £3M+ Torbay flooding infrastructure award, Thames Water's £247M maintenance programme, influenced national flood risk policies (NaFRA2) and has been applied to flood protection systems safeguarding millions of people globally (e.g., Taipei City's early flood warning system).
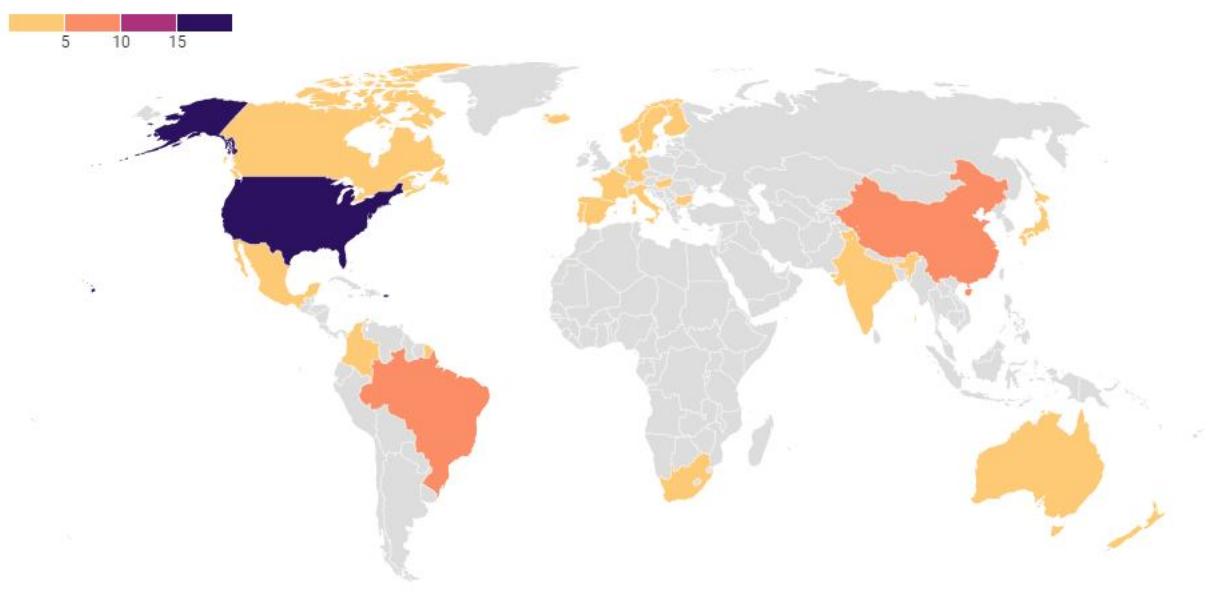
Societal Impact

During the COVID-19 pandemic, we have responded quickly to address needs in the local and national community. Danon received funding to predict the spread of COVID-19 in the UK and evaluate the impact of quarantine restrictions, helping to inform local and national government response. Everson and Costa developed the award-winning COVID-19 supply hub described in Section 1, and Keedwell received funding to develop clinical scorecards for COVID-19 patients incorporating viral load measures. Our academics were also involved in broad cross-institutional initiatives to model the pandemic through RAMP (Royal Society) and DeCOVID (ATI).

Further societal impacts have been achieved through CAFlood (Keedwell), which informed national flood risk policies; the Impact Lab (Everson, Christmas, Costa, Keedwell), which led to the creation of 12 new local jobs and businesses; and collaborative work with DCWW (Keedwell) applying machine learning to sewer maintenance strategies, reducing sewer blockages by 31%, household flooding incidents by 16% and operational costs by £2M and thereby reducing impact and costs for 3M customers (also an impact case study).

International Research Collaborations

The unit has strong research collaborations across the globe, developed and promoted through the DoGD who encourages unit participation in institution-level initiatives (e.g., strategic relationships with Universities of Queensland and Fudan) and the development of unit-level global collaborations, of which there are 77 across 6 continents, as shown in Figure 3. These include visiting professorships, co-development of funding applications, research project collaboration and co-authorship of publications, among others.

Figure 3 - International collaborations by country

Academic Esteem and Contribution to the Life of the Discipline

UoA11 staff have received significant recognition both nationally and internationally as evidenced by the range of fellowships and prizes awarded below and have been invited to review applications for a wide range of funders. They have also contributed over 90 times as conference, programme and workshop chairs and 50 times as journal editors, associate editors and guest editors across conferences and journals in the cybersecurity, networking, HPC, AI, ML and urban systems fields during the census period. These activities are encouraged as a method of contributing to the life of the discipline and for personal development, supported by the 20% S&S allocation.

Fellowships

Arribas, Danon, Everson, Williams, *Pugeault, Roussos* were appointed Alan Turing Institute Fellows in 2018, consolidating our links with this important national institute.   Dutta and Di Clemente received Marie-Curie (2017-2019) and Newton International (2017) fellowships respectively during the early stages of their careers, increasing their research potential and widening their networks. Livi was appointed as a Canada Research Chair in 2019, a scheme that aims to "*attract and retain some of the world's most accomplished and promising minds.*" Also in 2019, Li was appointed as a UKRI Future Leader Fellow which aims to *"develop the next wave of world-class research and innovation leaders in academia and business."*

Prizes

Research excellence has been recognised by a variety of prizes awarded during the census period. Hu and Williams have won best paper prizes at IUCC14, IEEE SOSE16 and ICWSM 2016 and Keedwell won 2nd best student paper at CCWI 2016. Staff have also been recognised by their professional bodies with Brucker awarded Senior Member status of the ACM in 2015 and Min receiving an Award for Excellence from the IEEE TCSC in 2017. Evidence of excellence in impact is evidenced by Arribas' - UK IT Industry RITA Award "Best Innovation in Technology" 2017 / Runner up Best Innovation in Civil Service 2016 and Luo's 2018 Scottish Knowledge Transfer Award from the Scottish Funding Council.

Grant Reviewing Activity and Membership of Selection Panels

Membership of grant review and selection panels are an important measure of esteem and allow us to make a significant contribution to the life of the discipline. Botta (2016-) and Brucker (2015-) are members of the EU ERC/Horizon 2020 review committee and Brucker (2017-), Everson, Keedwell (2013-) and Min (2006-) are members of the EPSRC Review College, whilst Hu and Wu are members of the EPSRC Associate College. We have also contributed to ad-hoc reviewing of UKRI AI Acceleration and FLF schemes, EPSRC, BBSRC, MRC, Marsden Fund, Marie Skłodowska-Curie, Royal Society, and Leverhulme Trust reviews through Everson, Danon, Keedwell, Min and Moraglio. Internationally, staff have conducted reviews for REPRISE (Italy- Di Clemente), NFST (Chile – Menezes), NRF (South Africa – Keedwell, Fieldsend), FFG (Austria), SNSF (Switzerland) and ANR Doctoral Contracts (France) (Keedwell).

Conclusion

Collectively, these sections describe a young and vibrant department, engaged in impactful research connected with the wider international community and making significant contributions to the life of the computer science discipline across the globe.