

Institution: University of Reading
Unit of Assessment: UOA11 – Computer Science and Informatics
<p>1. Unit context and structure, research and impact strategy</p> <p>Overview</p> <p>The UOA is coincident with a new Department of Computer Science (established August 2016) within the School of Mathematical, Physical and Computational Sciences (SMPCS) and an associated Computer Science Research Division within the University's Environment Research Theme. Led by a Research Division Leader (RDL), our research is organised into three groupings, which collectively represent our applied and interdisciplinary approach to data and computational science: Computational Vision (CV), Data Science and Artificial Intelligence (DSAI), and Advanced Computing for Environmental Science (ACES). CV addresses computational issues of perception and reasoning in relation to image interpretation, at the forefront of international security research. DSAI researches machine learning, data mining, big data analytics devoted to algorithms, and techniques and applications for data-driven knowledge discovery from big data. ACES conducts cutting-edge research in computer science to accelerate environmental science.</p> <p>Position since REF2014</p> <p>Since REF2014 (when Computer Science was a subject group within a wider School of Systems Engineering, submitted under UOA13), the subject group was identified as an area of excellence in its own right and received substantial investment by the University in launching as a new department. The establishment of a new identity, in conjunction with extensive working relationships we have built with local, regional and global business and third sector organisations, has: supported and strengthened our research agenda; led to a significant income and outputs quality profile; and resulted in realisation of significant impact under each research grouping.</p> <p>Research strategy</p> <p>Our vision is to deliver international excellence in applied and interdisciplinary research in data and computational science, based upon an excellent core of fundamental computer science, and to realise significant and far-reaching interdisciplinary impact.</p> <p>As a newly formed Unit, our key aims within the REF period have been to:</p> <ul style="list-style-type: none"> • build up a critical mass of staff • maintain and build on existing strengths while focusing on emerging activities which have considerable impact potential • increase collaborative interdisciplinary activity with the School, wider University and external collaborators • attain high-quality journal publications • target funding sources most suited to delivering aims 1 to 4. <p>We have met (1) through a round of strategic appointments since 2013 (including Assistant, Associate and Full Professors) totalling eight staff. This has grown our Category A FTE count from 6 to 10.4 representing a small but critical mass of academics covering the core areas of Data Science and Computational Science.</p> <p>To meet (2), existing strength in Computational Vision (CV) was validated by generating sustained and significant targeted research income, outputs and impact (see REF3b), while existing and emerging activity in data and computational science was consolidated into two new research groups, namely Data Science and Artificial Intelligence (DSAI) and Advanced Computing for Environmental Science (ACES).</p>

To meet (3), the creation of ACES has increased collaborative interdisciplinary activity, specifically supporting SMPCS and the University's Environment Research Theme in conducting cutting-edge research in computer science to accelerate environmental science. We have also established new relationships with a wide range of companies, third sector and government organisations to maximise the relevance and use of our work.

For (4), we have published 385 papers in international peer-reviewed journals and conference proceedings (314 in journals classified as Computer Science by Scival). Of these 314, 40.5% are in Q1 (by SNIP) Computer Science journals, with three in every five outputs (57%) resulting from international collaborations.

For (5), we have won large collaborative interdisciplinary grants of >£5.5m overall EU research income (with a total of ~£7m, or £95k/year per FTE, from all sources) since 2014 (see Section 3).

Our future strategic goals are to:

- Support new emerging and focused areas of research in data science and machine learning (e.g. interpretability and explainability of AI, scalable and efficient machine learning).
- Strengthen interdisciplinary and applied research both within the University and externally, incorporating, for example, the joint topic of machine learning and data simulation bridging Computer Science, Mathematics and Meteorology, with significant impact potential in areas including medicine and climate science.
- Further strengthen our links with industry and establish other strategic partnerships.
- Embrace and demonstrate a strong commitment to open research to further the usefulness of our work.

Research themes, achievements, and future 5-year research goals

Achievements and strategic plans for each of our research groups are summarised below. Note that staff can be affiliated to more than one grouping.

Computational Vision (CV) (Badii, Di Fatta, Ferryman, Hong, Wei)

This research group exploits synergies between focused areas of computer vision and image analysis and real-world applications, supported by substantial grant awards totalling >£3.3m from the EU since 2014. Contributions from this approach are reinforced through close collaborations with end users and a wide range of stakeholders, from domains covering critical infrastructure protection to border security to remote sensing. Strategic areas of interest and achievements include:

- Two major collaborative EU projects (FASTPASS, PROTECT, one led by Reading with grant value €5m, total €1.97m to Reading) have profiled Reading as a world leader in identity solutions for border security. **Ferryman's** work (as lead on main technological workstream on traveller identification in FastPass) on multimodal biometrics and counter spoofing led to the world's first deployment and evaluation of a harmonised on-the-move biometric identification system in a real operational setting for both cruise ships and land borders (with vehicles). The follow-on PROTECT project (led by **Ferryman**) developed, trialled and evaluated the world's first pervasive border control no-gate crossing point solution and was shortlisted for the Times Higher Education Awards 2020 in the STEM research category. The solution integrates non-stop contactless biometrics on-the-move, exploiting mobile devices, advanced passports and tracking through re-identification, and is applicable to air, sea and land borders and commercialisation and standards development thereof.
- Furthering the biometrics work, **Wei** developed an approach to user authentication based on non-conventional keystroke dynamics. Remaining within the domain of border security, **Ferryman's** work in FastPass and PROTECT, as well as EU EFFISEC (€547k to Reading), led to development of novel video analytics for abnormality detection (e.g. left luggage detection, tailgating), abnormal behaviour detection, and dynamic queue estimation, supporting border guards' monitoring at checkpoints.

- A further four major collaborative EU projects (VideoSense, led by Reading, overall value €5.28m, £1.12m to Reading; P5 (Privacy Preserving Perimeter Protection Project); ARENA; IPATCH, total €1.48m to Reading) led to:
- establishment of framework for personalisable context-aware privacy filtering/masking of video-audio (**Badii**)
- development of TRL7 open and flexible architecture for multimodal sensing and analysis (robust object detection, tracking, classification and especially semantic activity characterisation and unified action recognition enabling abnormality discovery and threat detection) for both real-time ground-based fixed and on-board mobile asset (critical infrastructure) protection (**Ferryman**).
- The research extended to development of universal privacy protection measures applicable to both visible and thermal imagery, with anticipated impact on wide deployment of automated video surveillance solutions (**Ferryman**).
- **Wei's** work broadened our research into the application of computer vision to remote sensing (in collaboration with the University of Indonesia), and image registration for 3D surface reconstruction (in collaboration with Tianjin University). **Ferryman's** research into development of algorithms for analysing full waveform airborne LiDAR for characterising vegetation has made a significant contribution to automatic determination of tree/vegetation structure, quantity, and growth. Furthermore, extracted information can be used both for rural scene classification and canopy height profiling with release of an open-source toolkit. In the long term, there is likely to be impact in environmental planning as well as in understanding the dynamics of the global carbon cycles.
- **Wei's** work on image fusion, in collaboration with Wang (Tianjin University), contributed to China's 2019 historic robot moon landing through 3D reconstruction of the moon's surface from satellite imagery. **Hong's** work on subspace clustering is widely applicable to real-world data (e.g. faces and handwritten digits images).
- **Ferryman's** leading role in benchmarking, specifically scenario-led benchmarking on tracking and surveillance (PETS), has led to worldwide impact (including industrial application) in development of video surveillance systems, especially for crowded scenes and for applications (e.g. critical infrastructure protection). Further related work includes development of a novel method for performance diagnosis of video trackers, with anticipated impact on improving robustness of surveillance systems.

Our five-year goals for CV are to expand research, deployment and practitioner-led validation of our research. This includes: novel approaches to identification, addressing the whole identity lifecycle (e.g. new €736k EU project D4fly integrating biometrics on-the-move and alternative technologies to identifying people); multimodal, multisensory surveillance (e.g. EU FOLDOUT €458k) on through-foliage sensing and alarming in harsh environments for (border) security; enhancing impact; and pursuing new large collaborative grants. We will develop strategic partnerships with industry, working via the University's Knowledge Transfer Centre and Innovate UK, to: (1) widen our funding base; (2) explore opportunities for further development and knowledge transfer of identity and surveillance solutions; and (3) strengthen promotion of our work in security research.

Advanced Computing for Environmental Sciences (ACES) (Kunkel, Lawrence, Maynard)
The [ACES group](#) provides a nexus for developing and exploiting advanced computer science techniques for deployment in real applications of multidisciplinary environmental science; leveraging the world-class meteorology and mathematics research within SMPCS and close collaborations with the UK Met Office and the European Centre for Medium-Range Weather Forecasts (ECMWF).

Close collaborators include staff from the [Institute for Environmental Analytics](#) (IEA), the Computational Modelling Services unit of the [National Centre for Atmospheric Science](#) (NCAS), and both the [Centre for Environmental Data Analysis](#) (CEDA) and the [Scientific Computing Department of the UKRI Science and Technology Facilities Council](#) (STFC).

Strategic areas of interest and achievements include:

- Storage systems and input/output performance: Work in this area is led by **Kunkel** and includes analysing HPC storage system performance, his leadership role in establishing the [IO500](#) which describes supercomputing storage system performance, and new methods of choosing storage compression technologies. Funding includes an Advanced Storage Management (ASM) technology transfer grant to **Kunkel** from the European Commission. Further, **Lawrence** has a leadership role within the European Centre of Excellence in Weather and Climate Computing (ESiWACE) for storage and workflow solutions for exascale computing.
- Energy and Performance: Some of the first published detailed analyses of methods for energy savings from systems scheduling (**Kunkel**) and applications (**Kunkel**), with measurements and plans for understanding power consumption in climate science (**Lawrence**).
- Metadata systems and computing infrastructure: The development of metadata schema for describing numerical simulation workflows with application (**Lawrence**). Architecture and implementation of the Earth System Grid Federation in support of climate model intercomparison (**Lawrence**). **Lawrence's** role in the development of cloud computing for JASMIN and establishing global climate computing infrastructure. Architecting and building systems for delivering open data for the European Space Agency.
- Next generation systems and programmability: Early thinking on use of quantum-based circuits. **Maynard's** development of mixed precision arithmetic high-performance numerical solvers now operationally in use at the Met Office, with multigrid solvers for the next generation models. Work on extreme scaling of weather and climate simulations codes. A leadership role in exposing exascale-coding issues.

Our five-year goals for ACES: Motivated by ever-growing challenges around extreme scale simulation, our goals are to continue to focus on computer science problems relevant to cutting-edge weather and climate simulation as well as more general applicability to exascale simulation workflows (especially for data handling). Existing partnerships with national (Met Office, NCAS) and international organisations (Argonne National Laboratory (ANL), ECMWF, German Climate Computing Centre (DKRZ), National Center for Atmospheric Research (NCAR), Oak Ridge National Laboratory (ORNL), Sandia National Laboratories) will be strengthened, alongside new and existing relationships with the storage industry (DDN, KOVE, Seagate). We will also build on the relationship with UK NVIDIA AI Technical Centre, in partnership with the University of Edinburgh and the STFC Hartree Centre, to exploit ML and AI techniques in environmental science.

ACES will continue to focus on delivering impact via research and development that can be directly applied in environmental science software and computing infrastructure (e.g. to support scalable performant weather and climate models, the Met Office supercomputing and analysis systems, the JASMIN supercomputer, European supercomputing systems and the global Earth System Grid Federation), as well targeting industrial partnerships.

Data Science and Artificial Intelligence (DSAI) (Badii, Di Fatta, Lester, Liang, Nicosia, Ojha, Stahl, Thorne)

[DSAI](#) focuses on research activities on algorithms for data mining and machine learning, as well as systems and applications for multidisciplinary data-driven knowledge discovery. The activities are supported by a significant and diverse grant portfolio (primarily from the Australian Research Council, BBSRC, EU, Innovate UK, NERC).

Strategic areas of interest and achievements include:

Data mining and big data analytics:

- Application of highly innovative data stream classification (**Stahl**) for 1) performance bottlenecks and fault detection (EPSRC Fast Generalised Rule Induction, £98k, with partner BT) and 2) real-time smart home intrusion detection (EU CHIST-ERA COCOON, €120k to Reading). A KTP project with Exonar Ltd. (**Di Fatta, Stahl**) for a document classification platform to help large organisations to identify, monitor and protect from

leakage very large and distributed sets of confidential documents within private networks. A KTP project with Churchill Controls Ltd. (**Stahl**) on data management and analytics support for the next generation of telemetry equipment for the water industry; a KTP project with One Sight Solutions (**Stahl**) resulting in development of an innovative dashboard system to support storage and analysis of building lifetime data for the intelligent building control sector. Research collaboration with KNIME (Switzerland) (**Di Fatta**) on algorithms for advanced and guided data science.

Applications for data-driven knowledge discovery:

- Significant industrial engagement via KTP (**Hong, Ojha**) with Optimal Monitoring Ltd. on development of a world-leading automated anomaly detection platform for energy management (EMMA AI) led to the winning of the prestigious 2019 Wright Commission award.
- An EPSRC project (**Hong**) for online monitoring of nuclear power plants based on new approaches to improve the prediction of critical faults in nuclear reactors, in collaboration with the University of Portsmouth.

Systems for data-driven social computing:

- Project led by Reading, EU SciCafe 2.0 (**Badii**, €339k to Reading): the creation and curation of the European Observatory for Crowd-Sourcing, a portable virtual platform and observatory for crowd-sourcing and extending wiki-based and other media and knowledge bases with an invitational and customisable interface, to engage both offline/online communities and support them in joint deliberation to resolve real problems/dilemmas faced by society.
- Development of next-generation system for 2nd screen services in a social media context, whereby valuable business intelligence is captured, analysed and used to push relevant content directly to consumers (EU SAM, **Badii**, €343k to Reading).
- Development of an innovative digital toolkit (**Liang**) to enhance communication of scientific health claims (EU EIT FOOD Health Claims Unpacked).
- Improvement of workplace-based assessment and feedback through learning analytics and e-portfolio (EU WATCHME, **Badii**, €428k to Reading).
- Novel adaptation of techniques originally applied to genomics to enable privacy-preserving speech processing in the cloud (with Intelligent Voice Ltd., UKRI, **Badii**, £110k to Reading).

Machine learning and optimisation algorithms:

- Innovative research work on multi-objective optimisation (**Nicosia**) showing that (1) different real-world transport networks (airplanes, trains, buses) can all be characterised in terms of Pareto Optimality, (2) worldwide ethanol production could potentially be doubled, and (3) higher efficiency solar cells can be realised.
- Novel method for modelling metabolic fluxes (with open source software), and research on gene regulatory network inference, enabling new biological insights (**Thorne**).
- Other research work on nonlinear dimensionality reduction for image analysis with potentially important applications in several domains such as pharmaceutical drug design and border access control (**Hong**).

Our five-year goals for DSAI are to: (1) develop a focused area of research in data science and machine learning, specifically in interpretability and explainability of AI and in scalable and efficient machine learning; (2) strengthen interdisciplinary and applied research including, for example, in the joint topic of machine learning and data simulation; (3) apply our expertise in advanced data analytics to new application domains, e.g. coordination of EU-wide IOT blockchain-enabled security framework for next generation critical cyber-physical systems for the finance sector (CRITICAL-CHAINS, **Badii, Di Fatta**, overall grant value €5m, €696k for Reading); and to consolidate and build up existing activity, e.g. EIT Food work with follow-on funding (Horizon2020) (**Liang**).

Research integrity: open and reproducible research

Adopting the University's proactive approach to open research (as the first UK university to adopt an institutional statement on open research, see IES, Section 2), we develop tools and

standards to support manipulating, sharing, and archiving data (e.g. [CEDA](#) with Meteorology), and to generate [open data portals](#) and reproducible numerical simulation (e.g. [CMIP6](#)) leading to standards and requirements which have become de-facto (e.g. [cfconventions](#), [es-doc](#)). We produce open-source software and platforms (e.g. [Generalised Rules Induction](#), [LinkSmart](#), [KNIME certification](#) in Data Science) and benchmarking methodology, software and datasets (e.g. [IOR](#), [IO500](#)). Released in 2017, [IO500](#) now follows a regular bi-annual release cycle at two premier HPC conferences with 3000+ and 14,000+ attendees and gained significant attention from the HPC community and vendors in the storage area. We organised four PETS benchmarking workshops between 2014 and 2017, continuing leadership of this world-leading activity since 2000, and we developed the [MediaEval](#) benchmark for multimedia evaluation. Open Access APC charges are included as part of other direct eligible costs in grant proposals wherever possible.

Research integrity: ethical, professional and legal obligations and standards

The SMPCS Ethics Committee reviews all relevant research projects, with those requiring further scrutiny reviewed at University level. We lead by example, generating informed consent processes for our EU projects involving (sensitive) personal data which now act as a reference for other (external) EU projects. Our annual Professional Development Review process incorporates a strong professional standards aspect which reinforces issues of research integrity and provides an opportunity for consideration of training needs. Our staff are made aware of the values set out in the University Code of Good Practice in Research and responsibilities under the Concordat to Support Research Integrity through this process.

Supporting interdisciplinary research

As described in the Institutional Environment Statement (IES, Section 1), the University's research activity is structured around four interdisciplinary research themes. Computer Science is one of nine Research Divisions that make up the Environment Theme, and we have close working links in particular with the three Divisions in Meteorology.

Interdisciplinarity is core to our research vision and is a central ethos of our research culture. We have strategically focused on developing interdisciplinary work with the wider SMPCS by appointing **Lawrence** and **Maynard**, who have world-leading expertise in climate science. This has resulted in new knowledge (including in exploiting AI/ML in both data exploitation and simulation, cloud and exascale computing) and opportunities being brought into the Unit which can also be used to tackle industrial applications.

A new interdisciplinary area of advanced computer science applied to medicine was realised through establishment in 2017 of a Joint Academic Board between the University and Royal Berkshire NHS Foundation Trust (RBFT), leading to a new strand of research for us and a successful funding bid by **Liang** (see Section 4). Further, we focused on, and were highly successful in, targeting multi-year EU research funding, which is inherently interdisciplinary (see Sections 3, 4).

Impact strategy and development

During the assessment period we have implemented a range of initiatives to embed engagement and impact at all levels of our research and to maximise impact opportunities. The majority of our research proposals have been co-created with industry and other stakeholders (hard-wiring impact into the research process), and staff and PhD students have been provided with increased resources, tools and training to develop impact opportunities. Impact is incorporated into staff performance targets (e.g. probation, personal development review, work-load models and promotion processes) and is an important consideration in recruitment of new academic staff. Staff are encouraged to submit projects to the University's annual Research Engagement and Impact Awards, which recognises and celebrates best practice in this area.

We have strengthened our link to user communities by expanding membership of our Industrial Advisory Board, organising events involving practitioners, and maintaining active links with partners and beneficiaries following project completion (e.g. continued engagement with the

Home Office in the wake of EU PROTECT led to EU D4fly and ultimately continued and new impact).

Impact leadership has been strengthened through the appointment of an academic Impact Lead within the Unit, supported by an Impact Development Manager for the Environment Theme (based in Research and Enterprise Services, RES). The strong institutional support and seed-funding available, from the University's impact support programme (BOISP, see IES, Section 2.3) brought c.£30k to the Unit and is reflected in our submitted impact case studies, which demonstrate our focus on interdisciplinary research answering to real user needs and are based on strong evidence-based narratives. Beyond our impact case studies, Section 4 highlights examples of our many short-term and ongoing impacts within the REF period.

Going forwards, a vital goal will be to build on existing strong industrial engagements and to forge new relationships, particularly within the Thames Valley tech sector via the University-led Thames Valley AI Hub (see Section 4). Further, we will benefit with increased working relationships with the Reading-based IEA and ECMWF that provide a meaningful link between science and the translation of environmental data into societal impact.

2. People

Staffing strategy and staff development

We strive to create a diverse and inclusive community and environment that attracts, supports, develops and rewards excellent computer science researchers in their careers and in working to our research goals, with equality and diversity at the forefront.

In this assessment period, we have built up our staff from 6.0 FTE to 10.4 FTE, with a focus on recruiting ECRs, developed existing staff toward senior positions, and increased our research capacity by recruiting dedicated teaching staff (to reduce researchers' workloads). This has given us a solid foundation for the coming period to tackle our research goals.

Recruitment and development of staff are crucial aspects of our vision and key to our future success in achieving our research and impact goals. We determine areas for recruitment with reference to research as well as teaching needs. Practices and policies across our UOA adhere to our values and culture of promoting equality, diversity, inclusion and wellbeing for all of our students and staff, mirroring those of the wider University. Selection processes and panels are formed with diverse staff who receive training in D&I, unconscious bias and responsible use of metrics, with all our staff having completed mandatory D&I training within the last three years.

All Category A eligible staff are being returned to the REF. Among our staff, we have a BAME representation of 25% UK and 50% non-UK nationals. 27% of our staff are female, which is above the sector average of 14 to 21%, according to HESA data. Our grade profile is now 36% Lecturer, 27% Associate Professor and 37% at Professorial level, reflecting a combination of our own as well as University support towards recruitment of ECRs and internal staff promotion.

Building a critical mass

Our recruitment has resulted in eight new academic T&R appointments (five Assistant, two Associate and one full Professor), increasing our FTE count by ~75% (from 6.0 to 10.4 FTE). The strategic dual/joint appointments of **Lawrence** and **Maynard**, together with the appointment of **Kunkel**, led to the setting up of the ACES group to conduct cutting-edge computer science research to accelerate environmental science. The appointment of ECRs **Lester**, **Liang**, **Ojha**, **Thorne**, in addition to existing staff **Badii**, **Di Fatta**, **Stahl**, has built up the expertise and remit of DSAI. Our third research group (CV) has remained unchanged in staffing and retained its successful focus on computational vision applied to physical security and remote sensing. The strategic appointments of **Nicosia** and **Thorne** enhanced our interdisciplinary capacity in AI, applied to synthetic biology, bioengineering and bioinformatics. We additionally recruited two Teaching Fellows, reducing the teaching load for Category A staff to enhance our research capacity.

Career development support

We work to sustain and develop an inclusive environment that enables and supports researchers to thrive and prepares them for future careers. All academic staff have an annual Performance and Development Review (PDR) with their line manager, providing an opportunity to discuss and reflect on achievements, career plans and support or training needs. PDRs also enable the Head of Department, RDL and Research Dean to identify common needs or challenges and work towards ways to address them.

As well as internal funding opportunities, all staff have access to a wide range of training and development opportunities run by People Development, including personal development, communications skills, publishing, open research and grant applications. Research staff receive specialised guidance on developing research independence from RES, including a dedicated Research Development Manager who supports all Computer Science funding applications. Within the UOA, we offer further, tailored support, primarily led by the RDL. Support and training for RDLs is achieved through multiple processes such as regular Community of Practice meetings within the Environment Theme and via the Research Deans' office.

Research excellence and engagement has contributed to the promotion of three members of staff: two to Professor (**Di Fatta, Ferryman**); one to Associate Professor (**Stahl**). The School holds Personal Titles meetings each year to proactively identify candidates for promotion and to provide mentoring where appropriate to strengthen cases, including for self-nominations.

We employ relatively small numbers of postdoctoral researchers, mostly on a fixed-term basis linked with funded projects, who therefore have a more fluid career progression. Training for PDRAs, provided by professional services teams, includes sessions on open research and research data management, research communications and University finance processes. We proactively seek ways to provide greater security of employment for PDRAs, including: (i) ensuring fixed-term contracts run for as long as possible, especially on renewal, ideally several years for multi-year grants; (ii) providing bridging facilities, and (iii) maintaining an SMPCS list of research staff who are nearing the end of their contracts so that opportunities for re-employment can be maximised. PDRAs are entitled to the same enhancement opportunities as lecturing staff and are supported to engage in small amounts of teaching to gain experience and enhance employability. Several internal funding schemes are also open to PDRAs (including seed-funding awards, travel and undergraduate research placements). During the assessment period our PDRAs have used such awards to devise and lead on interdisciplinary events (e.g. 2018 workshop on Behaviour Analysis of Ageing People at Home, co-organised with researchers in Psychology).

We follow University policies and procedures to provide support for personal circumstances, including flexible or part-time working, maternity/parental/adoption leave, ill-health or caring responsibilities. A dedicated SMPCS website includes case studies of the benefits this can deliver for individuals and teams, drawn from our community. Circumstances can be raised as part of PDR discussions and are also considered in the promotion process.

All permanent staff have a Staff Development Account which receives an annual fixed sum from School funds and variable income relating to research grant awards and consultancies. The account can be used for equipment purchases, travel, conference attendance and payments to research staff. In addition, all academic research staff can apply for a sabbatical period (typically 6-12 months), which is considered depending on how the proposed research project fits with our research strategy as well as staff development objectives. Two have been awarded since 2014 (**Hong** for six months for a collaboration with Imperial College London; **Badii** for 12 months for a collaboration with the University of Notre Dame).

Enhancing our stability is that fact that all staff in this submission are on permanent contracts. Leadership roles are generally cycled every three to five years, providing career development

opportunities and fresh perspectives. Thus, processes that support succession planning are well embedded within Computer Science driving a strong culture of leadership ambition and achievement.

Early-career researchers: supporting excellence and ambition

Early-career members of academic staff (**Kunkel, Lester, Liang, Ojha, Thorne**) were each assigned a mentor to provide individual support, independent of their line manager. We have worked to improve mentoring (e.g. on grant applications), adopting the wider SMPCS process. Our ECRs attend training workshops organised by RES, which include opportunities to network with researchers from other Divisions and Themes. University policy provides ECRs with a 3-year probation period, and expectations and specific probation targets are discussed and agreed with the Head of Department to ensure they can establish themselves as independent researchers. ECRs are afforded a reduced teaching/administration load during probation to help build research momentum, as well as start-up funds (~£3k) and/or a fully funded PhD student. The success of these measures is demonstrated by the prominence of contributions by ECRs in winning DTP studentships and KTPs. **Ojha** won one studentship jointly with Professor Carrassi in Meteorology – a collaboration between machine learning and data assimilation to infer, estimate and characterise model errors. The second is joint with **Wei** – on smart LED lighting for eco and assisted living (with Kosnic Lighting Ltd.), providing expertise in AI and machine learning and enabling access to electronic and sensor systems expertise. ECRs have also been successful in winning EU funding (**Liang**: EIT FOOD).

Supporting and rewarding staff

SMPCS runs an annual Rewarding Excellence process for all staff, which enables accelerated progression (via additional spinal point increment(s) or in Grade). In addition, the University has arrangements to reward staff via lump sum awards considered twice-yearly, with decisions made at School level, or Celebrating Success awards, to recognise and reward staff for a job well done or for the demonstration of positive professional behaviours. Over the assessment period, five of our full-time staff (two female and three male) have been awarded contribution points.

Knowledge exchange with industry, public and third sector bodies

We promote and support enterprise activities via (1) the Knowledge Transfer Centre, with a dedicated Business Relationship Manager for the Environment Theme, (2) the Thames Valley AI Hub and (3) user-focused collaborative projects such as PROTECT, see Section 4. Individual academics also engage with industry, e.g. **Kunkel** has run a series of collaborative workshops covering storage technologies and developed a new collaboration with NVIDIA. Our strategic appointments have facilitated two-way knowledge exchange e.g. **Maynard**'s dual position with the Met Office has enabled research students and staff to be introduced to new ways of developing applications with domain specific languages, and **Lawrence** and **Maynard** have together developed collaborations around next-generation application development. **Lawrence**'s partnership with STFC has resulted in new ways of using cloud computing in environmental science.

Promoting diversity and inclusion



We are committed to Diversity and Inclusion (D&I) and are proud of the Athena SWAN Silver Award received by SMPCS. An Equality and Diversity committee is led by a dedicated Director of Wellbeing, Inclusion, Diversity & Equality (WIDE) and is embedded into the School's management structure. Staff at all research levels (including PDRA) are represented on the committee. All staff receive D&I training and our key staff have received unconscious and implicit bias training. During the assessment period we have improved professional skills

development by incorporating D&I training into PGR skills modules.

A strong culture of flexible working has developed, particularly following constraints imposed by COVID-19, as well as for students with disabilities, including tailored provision of computing equipment for remote use. We proactively support wellbeing through Stress Management Workshops, a regular WIDE newsletter, trained Wellbeing Peer Support staff volunteers, and SMPCS Wellbeing webpage. All PGR supervisors have access to a Graduate Briefing guide on how to support student wellbeing. There is also a blog for students led by an external wellbeing consultant, as well as Graduate School drop-in sessions. We actively promote accessibility and inclusivity of research degrees, and we ensure female staff representation at Open Days to provide role models for all prospective students. Overall, we strive to cultivate an open, interactive and friendly working environment.

E&D with respect to REF submission

In line with the University's Code of Practice, while output quality is the main selection criterion, diversity across a range of characteristics (gender, ethnicity, career stage) was taken into account in the selection of outputs. Notably, 37.5% of submitted outputs are from women (1.5 times the 25% proportion of women in the return), 29% are authored by Assistant Professors, 17% from Associate Professors, and 54% from Professors. Furthermore, almost one third are from ECRs. The University's interim Equality Impact Assessment carried out a main panel level (2020) and bias analysis of the final pool (2021) identified no statistically significant differences for protected characteristics in our selection.

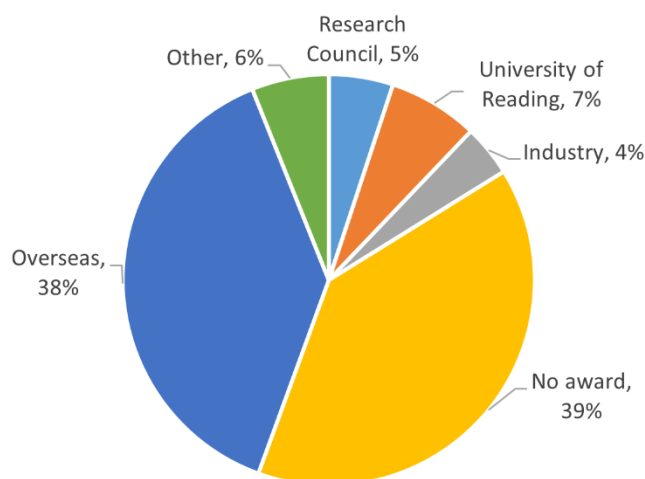
Support for research students

Our vibrant and growing community of PhD students is well integrated in our research groups and activities, supported by our PGR Programme Director and the Graduate School. We offer flexible modes of study (including PhD by distance), and all research-active staff supervise postgraduate researchers and act as assessors for PGR monitoring. 27% of our current PhD cohort are female, 63% are non-UK nationals and 7% have a disability. We have significantly increased the proportion of BAME students from the UK, from 6% in 2013/14 to 64% in 2019/20.

PGR recruitment: With 63% international students in 2019/20, we attract a large number of international students funded by national governments. Furthermore, 37% of the 2019/20 cohort are part-time, demonstrating our commitment to supporting flexible study. There are ~25 funded or self-funded PhD projects proposed each year by our staff and widely advertised.

All applications are facilitated by the Unit's PGR Programme Director and overseen by the Graduate School. For admission it is required that interviews are held with two staff either in person or by video/phone for international students, with further review by the PGR Coordinator. In line with SMPCS policy, we adopt a proactive and inclusive approach to recruitment of students with protected characteristics.

PGR tuition fee source 2014/15 to 2019/20



We have been successful in winning studentships including from EPSRC DTP, NERC DTP and Wilkie Calvert (with TUI, UK). Some of these are jointly supported by industry partners, with contributions in partial fees or staff time, e.g. BT and Kosnic Ltd. International government sponsors include Brazil, Iraq, Libya, Nigeria, Saudi Arabia and Thailand.

PGR monitoring, support mechanisms and skills development: The School PhD handbook provides essential information to new students on general orientation, training, and monitoring and progression. The Graduate School coordinates

postgraduate researcher training with a threshold of achievement required by all PhD students to progress beyond their first year. Bi-annual monitoring of each student is carried out by a Committee of two assessors based on submitted reports to ensure that students are making satisfactory progress and are receiving appropriate levels of supervision and support. Confirmation of PhD registration after a year (or part-time equivalent) is granted only after assessment of a comprehensive transfer report.

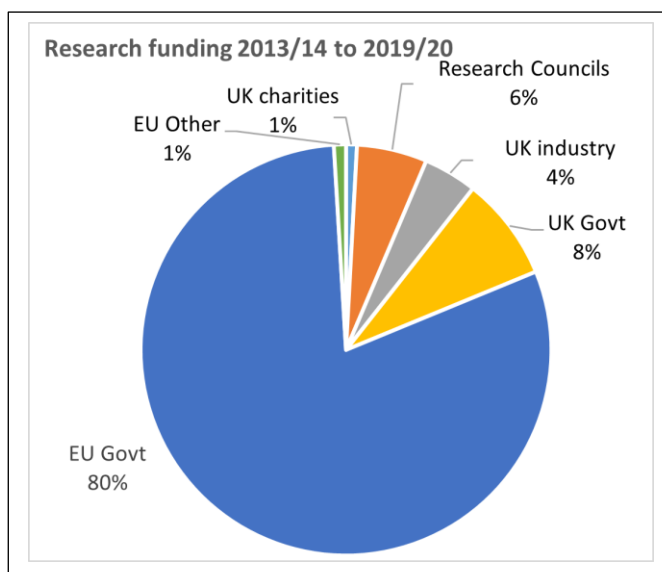
There is an annual welcome event for new PhD students and a PhD workshop. PGRs are strongly encouraged to attend departmental seminars (mainly given by external speakers), as well as to attend at least one international conference during their studies with each student allocated £1000 for travel. Other activities include organised trips (e.g. annual Computer Science visits to Bletchley Park and JASMIN Data Centre at Rutherford Appleton Laboratory), reading groups organised by PhD students, and active participation of PGRs in the Unit's Data Science Club and hackathons. Welfare support is available through Student Services and the student Counselling and Wellbeing Service.

The success of our PGRs is evidenced by the high number of doctoral degrees awarded in the assessment period (45, or the equivalent of 4.36 per FTE, 90% with minor amendments). Between 2014/15 to 2019/20, over a third of our PGRs were self-funded. Following completion, a number have returned to permanent academic positions in their home countries or hold R&D positions.

3. Income, infrastructure and facilities

Research funding portfolio, impact and strategies for income generation

We have achieved research income totalling £6.93m in the assessment period (£95k/FTE per annum). The strategy to pursue larger collaborative grants led to a substantial £5.6m total of awards from the EU. Our engagement with UK industry yielded awards totalling over £1m from KTPs over the same timeframe. We achieved this through new support staff, structures and resources to PIs (time, travel funding, including travel for EU grant applications, reduced workload and internal peer review offered for all grant applications). RES provides support in all aspects of preparing and managing research grants, in particular fellowships and large collaborative grants. For the latter, an EU-team with a dedicated funding manager for the Environment Theme organises sessions and information days on specific funding instruments, an annual EU research opportunities event, and has developed a repository of successful grant applications representing good practice (including some provided by our Unit), all of which have contributed to a high success rate: 25 EU proposals resulted in ten awards (40% funded), including three where the Unit is project coordinator.



Provision and operation of specialist infrastructure and facilities

The Unit retains a dedicated infrastructure coordinator (an academic) who liaises with and interacts closely with the University's Academic Computing Team (ACT) which supports and advises staff and PGRs on IT infrastructure. Additionally, ACES advises the Department and the University with respect to internal HPC resources such as the Reading Academic Computing Cluster Service (RACC), which supports both departmental and wider University research activities. ACES group members also have leading responsibilities in the design, procurement

and deployment of national supercomputers. **Lawrence** was a core member of the procurement team for both ARCHER and ARCHER2 and is the Director and Principal Investigator for the JASMIN supercomputer. **Kunkel** led the I/O benchmarking for Archer2. **Maynard** has a key role in setting requirements for Met Office supercomputing. The ACES engagement with JASMIN provides not only access to one of the world's largest data analysis facilities, CEDA, but also to a cloud environment that the ACES group use as a research testbed.

The Unit provides a small cluster equipped with 15 nodes and various types of hardware (e.g. GPUs, ARM64 processors) and software stacks which facilitate a range of services, for instance, the hosting of virtual machines for research projects, or the evaluation of distributed and parallel algorithms before they are scaled on to national supercomputers. The infrastructure is accessible for research partners worldwide. We host regression test suites for popular software such as IOR (<https://github.com/hpc/ior>) and the IO-500 benchmark which is used by HPC experts worldwide to evaluate storage solutions and in procurements of supercomputers. Moreover, it enables us to integrate and evaluate bleeding-edge hardware and software solutions as part of research projects. A dedicated VR-laboratory provides various types of equipment such as Oculus Rifts and an immersive Cave Automatic Virtual Environment (CAVE). Finally, supported by ACT, we provide a dedicated Wi-Fi network that supports the secure evaluation of IoT devices and research network services.

All services and equipment are available to all research students and staff providing an equal and fair environment to share IT resources. Diversity in the ability and personality of students is accommodated by allowing students to make progress at an individual schedule and by providing various means of accessing the different types of equipment. We acknowledge, in particular, that some students make best progress when working in their own environment which they consider safe and less stressful. Both goals are achieved by allowing students to borrow equipment for research projects and by providing 24/7 access to facilities and the various remote resources (hardware and software), regardless of the local operating system, enabled by central Digital Technologies Services (DTS).

Investments in infrastructure and facilities

With part-funding from research grants, we added a research cluster (£40k) in 2019 for research and teaching to staff and students in Computer Science. We also invested £103k to upgrade equipment across four PC laboratories (including a lab dedicated for MSc students) and created a new AI laboratory. At the start of their studies, each PhD candidate receives a laptop (giving them mobility) and is allocated a desk with a PC in a dedicated lab. All staff receive specialised DSE equipment where needed to enhance wellbeing.

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

Collaborations, networks and partnerships

The Unit is involved in significant interdisciplinary collaboration, both within the University (e.g. with Meteorology and the Institute for Food Nutrition and Health) and with external partners worldwide (collaboration with >100 companies, e.g. BAE Systems, IDEMIA, Veridos). In many cases staff are directly involved in the coordination of large integrated European projects won through our strong leadership and responsiveness to EU priorities (e.g., PROTECT and CRITICAL-CHAINS). Such opportunities are the result of focused networking actions and partnership-building, e.g. Security Mission Information and Innovation Group (SMI2G) and SEREN network.

The extent of collaboration is evidenced in our outputs. In the REF period we have produced 385 international peer-reviewed research publications (with 43% journal articles), including almost one third (31.6%) of our REF2 Computer Science outputs in the top 10% most cited Computer Science publications worldwide, and almost two-thirds (63.2%) in the top 10% Computer Science journals indexed by CiteScore. Our interdisciplinary focus is reflected in the number of submitted outputs (~17% of total). Thirteen international patents have been granted which cite our outputs published in the REF period. The interdisciplinary focus extends to PGR training,

with consistently high numbers of students co-supervised with other disciplines (12.5% of the current cohort). Equally, we have extensive international collaborations with 61% of publications in the assessment period having international co-authors, increasing to 70% for REF2 outputs and corresponding field-weighted citation impact score of 2.19. Our strong industrial partnerships drive us to translate research to software solutions and win awards, e.g. **Hong's** KTP with Optimal Monitoring on use of energy monitoring using machine learning earned the [2019 Wright Commission Award](#) voted by the Retail Energy Forum.

Working with end users: developing impact from our research

We establish industry needs through industry approaches via the KTP (with six KTPs awarded during the assessment period and an Innovate UK KTN prize for innovation excellence) and through our Industrial Advisory Board (members include Eli Lilly, IBM, Microsoft, Nationwide, NVIDIA, Oracle, Sony). As well as building on existing partnerships, a key aim has been to forge new relationships, particularly in the Thames Valley. Achievements include:

- 1) A new data science certification programme developed in partnership with [KNIME](#) which directly benefitted us through sponsorship of €25k software licenses for researchers including Master's and PhD students.
- 2) Launch by [NVIDIA](#) of a new technology centre to advance AI across the UK (in partnership with the Unit, EPCC and Hartree Centre). Our contribution is on deep learning methods to enhance simulation workflows in weather and climate.
- 3) In 2019, we set up the [Thames Valley AI Hub](#) in conjunction with the University's Henley Business School, to connect our large and thriving local AI community and accelerate research take-up. Business support services and funders have signed up and a varied programme of events has brought the community together to facilitate new connections and build collaboration. These events showcase state-of-the-art research developments and create valuable 'collision space'. The Hub, overseen by a steering committee with senior membership from the Local Enterprise Partnership, Microsoft, Oracle and Reading Borough Council, has over 400 Linked-In followers (70% manager or more senior role) and over 100 regularly sign up for events. A direct outcome of the community engagement through the Hub was the award of a Royal Society Industrial Fellowship to **Stahl**.
- 4) The success of the partnership between the Royal Berkshire Hospital and the University is evidenced by an approach by a Hospital partner seeking expertise in AI which led to a collaborative proposal, to develop an AI decision-support system for thyroid nodules diagnosis, being submitted to the EPSRC (**Liang**).
- 5) We have engaged with >30 end users/practitioners in our EU-funded projects (including the UK Home Office, Public Health England, Ministry of the Interior (Finland), Fraport, Milan metro, Foinikas shipping company). This has led to consortia and interdisciplinary funding bids and ongoing engagement with users during project execution.

Wider societal contributions: creating impact locally, nationally and internationally

Our wider research activity has attained significant societal impact beyond the examples detailed in our impact case studies. Short-term impact is exemplified by:

- **Badii's** Innovate UK work on Privacy-Preserving Speech Processing (PPSP)-in-Cloud (with industry partner Intelligent Voice), which has enabled the company to enhance their speech transcription product, create multiple revenue streams and have [patents granted](#) within the REF period.
- **Ojha's** KTP with Optimal Monitoring Ltd. on EMMA AI led to development of the world's most advanced energy monitoring system, a 6-month pilot at 48 locations in the BetFred estate, which in turn identified energy savings of £140k p.a., with subsequent full rollout.

The Unit has further achieved continuing impacts, for example Badii's research on development of security and context management in middleware for networked embedded systems in HYDRA led to the [LinkSmart®](#) open source IoT platform and resulting [improved energy management and control](#) in existing (even historical) buildings, and creation of interactive [energy awareness apps for the general public](#). The digital toolkit developed by Liang to enhance communication of scientific health claims ([EIT FOOD](#)) has ~900 international public users.

Outreach and public engagement

We are committed to communicating and engaging with public audiences, including media work, supported by the University's Press Office (e.g. **Ferryman**: [BBC News](#), ~500,000 views, Sky News), and other engagement opportunities (e.g. the European Commission's [Science is Wonderful 2019](#); multiple public talks, e.g. to [IET-EC3](#) and [Thames Valley AI meet-ups](#) (**Ojha**, **Di Fatta**) and a BCS Women public lecture on An Introduction to Data Mining and Predictive Analytics (**Stahl**). **Ferryman** has taken part in two Civil Service World briefings on [biometrics in practice](#) and [borders of the future](#). We have produced videos for a range of our projects (including [EFFISEC](#), [FASTPASS](#), [PROTECT](#), [ARENA](#) and [IPATCH](#)) to enhance public understanding of our work. **Di Fatta** led a discussion on Artificial Intelligence, Machine Learning and Data Science at the Henley Business School's [World of Work Conference](#) for business leaders.

Leadership and contribution to the research base

Our contributions to the discipline and research base are evidenced by a range of high-profile activities, including:

- Invited talks: ~20 keynote and plenary presentations (e.g. IDCS2014, ESA BiDS2014, IJCB2017, IEEE Cluster 2018, CAIP2019) and >80 further invited talks in international meetings, conferences, seminar series and with industry.
- Conferences, workshops and other events: Staff have had leading roles in >70 international events including ~10 Conference Chairs/Co-Chairs, e.g. IEEE ICDM, IDCS. Panels: e.g. CPDP2015, SRE2018, CSW18, Festival of Identity 2020, AVSS2019 (**Ferryman**); MultiCore 9 (**Maynard**).
- Awards and prizes: e.g. Leptoukh Lecture for significant contributions to informatics, computational, or data sciences (Leptoukh, 2014); Best paper 9th IDCS2016 (**Di Fatta**); Best papers at AI2016 and ICONIP2019 (**Hong**).

Advisory and steering boards: ~5 of our academics, including:

- **Lawrence**: Chair CEDA/JASMIN governance board; Scientific Advisory Board for Barcelona Supercomputer Centre since 2017; Chair of Advisory Panel for Computational and Information Systems Laboratory (CISL) at US National Centre for Atmospheric Research from 2019.
- **Kunkel**: Founder of HPC-Certification Forum and Virtual Institute of IO ([vi4io.org](#)), Founder and steering board of IO500 benchmark ([io500.org](#)).

Editorial boards/roles

- Board members for e.g. Neurocomputing, Scientific Data
- Editor of IEEE Trans. Syst. Man & Cyb (**Nicosia**); Guest editors of: Sensors J.; Expert Systems J.; Expert Update J. (BCS SGAI); J. of Network and Computer Applications; J. Systems Science; European Network for Earth System Modelling (ENES).

Membership of research council or other national/international committees, including:

- **Badii, Di Fatta**: EPSRC College Members
- **Ferryman**: EC ERNCIP committee, NPCC CCTV committee
- **Lawrence**: EPSRC infrastructure SAT; Chair NERC HPC Strategy Committee; Deputy Chair NERC Information Strategy Group (2008-2017); Member WMO's WGCM Information Panel (2014-2019); Member of the NetCDF/Climate-Forecast Conventions Governance committee (2015-present)
- **Kunkel**: committee member BCS Open Source Specialist Group
- **Stahl, Di Fatta**: BCS Specialist Group for Artificial Intelligence (SGAI) committee.

Refereeing of external academic publications/research proposals/institutions:

- For ~40 journals (e.g. IEEE TPDS, Future Generation Computer Systems, IEEE Big Data, Sensors) and ~20 conferences (e.g. ICCV, ECCV, CVPR, ACCV, BMVC, IJCB, AVSS) by twelve staff
- For proposals: e.g. EPSRC, BBSRC, MRC, Norwegian Research Council, European Commission, Natural Sciences and Engineering Research Council of Canada, Department of Energy (US)
- For institutions: e.g. Karlsruhe Institute of Technology (KIT, Germany), Totalforsvarets Forskningsinstitut (FOI, Sweden), German Climate Computing Centre.

Contribution to standardisation / benchmarking activities (e.g. [ISO/IEC JTC 1/SC 37](#) (see REF3b), [cfconventions](#), [IO500](#), [CADDementia Grand Challenge](#)).