

Institution: University of Bath

Unit of Assessment: 11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

The Unit of Assessment (UoA) provides a vibrant, inclusive, supportive and effective environment for a broad range of computer science research. Highlights during this REF period include:

Recruitment of excellent staff in areas of strategic importance, with 38% growth in the staff base and establishment of critical mass in Machine Learning and Artificial Intelligence since 2014;

Capture of significant funding to support research, totalling over £25M in awards, including a recently established UKRI Artificial Intelligence CDT, a further CDT in Digital Entertainment, and an EPSRC/UKRI Digital Economy Centre;

Investment in physical and technical infrastructure, worth over £8M, providing a newly refurbished building housing the UoA, new research labs, dedicated high performance computation servers, and a new off-site space for engagement with industry; and

A collegiate and supportive environment that nurtures, recognizes and rewards the effort of our staff to deliver high quality research with impact.

Structure

For this exercise, the Unit of Assessment coincides with the Department of Computer Science; note that at previous exercises this UoA has returned staff from other departments at the University.

The UoA is structured in four groups:

- Artificial Intelligence (AI): classical and statistical approaches to the creation, application and evaluation of intelligent machines and their integration into larger systems and society;
- Human-Computer Interaction (HCI): theoretical, empirical and practical aspects of the design, development and evaluation of interactive systems to support activities of individuals and groups;
- Mathematical Foundations: using mathematics to understand programs, programming languages, systems and their components, and developing systems to do mathematics;
- Visual Computing: automatic interpretation of photographs and videos and recombination with graphic elements, with applications in graphics, films, games and the entertainment and education industries.

We lead several funded research centres that enhance the cross-disciplinary and industry-facing focus of work in the UoA:

- CAMERA, the Centre for the Analysis of Motion, Entertainment Research and Applications: an EPSRC-funded Digital Economy Research Centre, hosting work combining visual computing with health and sports science research, funded in 2015, renewed in 2020;
- ART-AI, the UKRI Centre for Doctoral Training in Accountable, Responsible and Transparent AI, funded in 2019;
- CDE, the EPSRC Centre for Doctoral Training in Digital Entertainment, founded in 2009 and re-funded in 2014.

Organisation

Research in the UoA is overseen by the Department of Computer Science Research Committee, chaired by the Director of Research, who sits on the Department Executive. Each group is represented by a group lead, appointed by the Head of Department. Current group leads are all mid-career (Senior Lecturer or Reader) level. Impact is overseen by an Impact Director. Research infrastructure development is managed by the Computing Liaison Committee, including our technical team; the academic chair of this Committee sits on Executive.

Objectives and strategy

The development strategy indicated in REF2014 focused on the establishment of expertise in Machine Learning, with the goal of delivering a coherent spectrum of research strength drawing together all our groups and reflecting a significant refocusing of our research direction, consistent with our achievements and strengths but looking towards future applications in both fundamental research and impact delivery. Particular synergies between AI, HCI and Visual Computing were envisaged. These goals have been achieved. We have built on preexisting strengths in Computer Vision to recruit new staff in Machine Learning; we have grown the department by 38%. This growth, guided by a proactive approach to equality, diversity and inclusion, has increased the diversity of our academic staff as detailed in Section 2 below. Sustainability is underpinned by income from strong MSc provision and buoyant undergraduate recruitment.

Synergies between AI, Visual Computing and HCI are already coming to fruition, within the University (where they are key in nurturing interdisciplinarity) and more widely, including internationally. We have established two interdisciplinary research centres: *REVEAL*, the Real and Virtual Environments Augmentation Labs centre, directed by Lutteroth, which hosts collaboration between staff in the Departments of Computer Science and Psychology and the Department for Health; and *MAD*, the Centre for Mathematics and Algorithms for Data, co-directed by Campbell, supporting collaborations with staff from Mathematical Sciences. The ART-AI CDT further expands this interdisciplinarity and international reach, with partners in institutions in 10 countries. Submitted outputs include collaborations with researchers at prestigious institutions across Europe (e.g. Paris 7, Max Planck Institute, TU Darmstadt, TU Munich) and worldwide (e.g. Berkeley, Stanford, MIT, Princeton, Tsinghua, Auckland, IIT Hyderabad).

UoA Research GroupsArtificial Intelligence (Chen, De Vos, Golbabaee, Haines, Isupova, Li, Padget, Şimşek)

The AI group has expanded significantly since REF2014 (from 2.3 to 8 FTE, with further recruitment in progress), substantially increasing the capacity and breadth of AI research in the Unit. From a primary focus on AI ethics, multi-agent systems, knowledge representation, and reasoning, the staff additions to the group, mostly Early Career Researchers (ECRs), work in machine learning and its intersection with fields such as robotics and natural language processing. Our expertise in AI ethics and our increased research capacity underpinned Bath's successful bid for the UKRI Doctoral Training Centre for Accountable, Responsible, and Transparent AI (ART-AI). The group is currently working towards enabling the establishment of the research identities of its ECRs as well as developing strength and collaborations around areas such as Bayesian machine learning (Haines, Chen, Isupova), reinforcement learning (Simsek, Li, Namboodiri), and knowledge representation and reasoning (Padget, de Vos), with questions around AI ethics, transparency, responsibility, and accountability deeply embedded in all research.

Human-Computer Interaction (Alexander, Fraser, Jones, Lutteroth, O'Neill, Payne, Watts)

The HCI group's research includes innovation in the areas of immersive, virtual and augmented reality technology; mobile, wearable and ubiquitous computing; fabrication of functional devices;

and social computing. The group broadly studies the relationship between people and new interfaces and technologies in order to generate theory for the field and positive user experiences for the real world. Much of the work of Jones, Lutteroth, O'Neill and Watts is directed towards digital healthcare monitoring, interventions and assistive tools, such as gaze-based interactions and the use of VR in Exergaming and patient rehabilitation. Alexander and Fraser bring a hardware-directed focus, including work on fabrication, wearable devices for gesture detection, tangible interfaces, and shape-changing displays. A strong indicator of the international excellence of the HCI group at Bath is its consistent presence at the largest and most prestigious international conference, the *ACM Conference on Human Factors in Computing Systems (CHI)*. The group stands amongst the top 40 institutions worldwide by number of publications at CHI, each year from 2017-2020. Fraser holds an EPSRC Fellowship and Alexander holds an ERC Starting Grant.

Mathematical Foundations (Bradford, Davenport, Guglielmi, Heijltjes, Laird, McCusker, Powell, Vorobjov)

The Mathematical Foundations (MathFound) research group has a dual focus on Logic and Semantics (Guglielmi, Heijltjes, Laird, McCusker, Powell) and on Computer Algebra (Bradford, Davenport, Vorobjov). The group prizes highly original and creative research and promotes the ongoing UoA focus on excellence in fundamentals. The Logic and Semantics team are well known for the Deep Inference project of Guglielmi, a broad and highly successful re-imagining of the entire field of structural proof theory, and for work in proof nets (Heijltjes), denotational semantics (McCusker, Laird) and applied proof theory (Powell). An emerging theme across Logic and Semantics is the use of graphical reasoning techniques (proof nets, string diagrams.) Work is regularly published in the top conferences in the field (LICS, CSL). In Computer Algebra, a focus is the technique of Cylindrical Algebraic Decomposition, which can be used to tackle quantifier elimination problems and satisfiability modulo theories, with many applications in verification. Bath research has been incorporated in the Maple computer algebra tool, one of the internationally most respected general-purpose computer algebra systems.

Visual Computing (Campbell, Cosker, Hall, Namboodiri, Richardt, Yang)

The visual computing group conducts research at the intersection of Computer Vision and Computer Graphics, with overlapping interest in Machine Learning and Human-Computer Interaction. The group's high-quality research is regularly published in top venues, including 10 papers in the flagship ACM Transactions on Graphics in this assessment period as well as over 20 papers in leading vision conferences CVPR, ECCV and ICCV. Illustrative achievements include Campbell and Li's Roto++ accelerated rotoscoping tool (SIGGRAPH 2018); Cosker and Richardt's advances in unsupervised image-to-image translation (NeurIPS 2018); and Namboodiri's work on speech-to-lip generation (CVPR 2020). Cosker is the director of the CAMERA centre; Hall directs the Centre for Digital Entertainment; Cosker and Campbell received Royal Society Industry Fellowships and Richardt holds a UKRI Innovation Fellowship.

This growth and focus within the UoA supports our broad strategic aims:

- to conduct rigorous research in the theory and practice of computing, leading to the advancement of knowledge, encompassing both deeper understanding and more effective application of theories and techniques in computing;
- to train and develop researchers in computing to ensure the continued advancement of knowledge;
- to disseminate the results of our research to stakeholders worldwide, including academia, industry and government, and to engage with them to deliver impact and develop insight.

Strategic development over the next five years will assist the UoA in delivering on these aims. Our significant growth has developed a cohort of early career academics centred around AI and Machine Learning but spanning across all our research groups. The excellent work that this cohort are contributing to this REF demonstrates the potential for an exciting new generation at Bath. Our future strategy is to nurture a new departmental culture and identity from the shift of focus brought by this cohort. We are excited to enable our ECRs to establish themselves both individually and as contributors to the cohesive spectrum of work we do. As we embrace these developments we will take steps to enhance our long-term aspirations, our multi-institutional and multinational activities, and the impact of our research in tackling major societal challenges, as follows.

- **Refining Research Culture.** We have put in place a series of cohort-building and peer mentoring schemes to enhance the culture we encourage in our ECRs: focus on research that matters, prizing quality over quantity, leading to academic, societal and economic impact. Our development activities provide an opportunity for mid-career and senior faculty to mentor and lead. We emphasise long-term character, exemplified by existing foundational activities such as Deep Inference, and sustained application through our larger centres such as CAMERA.
- **Growing International Focus.** Increasing emphasis on longer, larger collaborative projects requires a more outward facing attitude within and beyond the UK, leading and participating in teams between institutions where appropriate. It is a timely moment to consolidate links to partners in North America, Europe, and emerging new regions of strength in Computer Science. To support this goal, we will significantly enhance our international outreach, by championing enhanced provision of sabbaticals, visitor programmes and involvement in major conference organisation. A step change in our social media presence will be enabled by employing a new designer, embedded in our research team, to create online materials communicating our work and to prototype ways of visualising and communicating research ideas as they develop. This will target this work to online tech communities, instructables, industrial forums and showcases.
- **Joining Up Impact.** To ensure our impact network can accommodate larger scale planning and thinking, we will invest in making industrial opportunities greater than the sum of the parts across our portfolio. Our successful network includes numerous CDT partners, large-scale industrial work through centres such as CAMERA, student-facing activities such as prominent industrial placements at Bath, our significant alumni community, and the SetSquared spinout incubator and wider entrepreneurship networks. The Impact Director's role will be extended to take overall responsibility for all these activities, supported by a new impact committee with dedicated budget. We will continue to build infrastructure to support broader cross-disciplinary teams, with a second materials-focused hspace currently under construction to enhance collaboration between computer science and engineering partners.

Approach to Impact: Activities, Case Studies and Future Opportunities

The approach to delivery of impact in the Unit centres around an increasing culture of co-creation of research and impacts in partnership with industry and third sector organisations. We recognize the **enabling nature** of computer science work, and during the REF period have been increasingly creating the conditions for our refocused research growth and excellence to have impact by:

- **developing close, long-term relationships with research users**, exemplified in the Impact Case Studies on **Design and Evaluation of Digital Technologies** and on **Artificial Intelligence & Ethics**. Our staff and research students (notably our CDE EngD students) undertake secondments and placements with industry partners; staff from the Unit have been continuously on secondments throughout the assessment period, building on a long history of such relationships with Vodafone, DSTL, Foundry, DNEG, HP Labs and others; research student placements are detailed

below. As an example, Campbell's Royal Society Industrial Fellowship delivered a Rotoscoping tool (Roto++), developed with partner The Foundry, that has been made freely available for non-commercial use in post-production.

- **providing access** to our research, its products, and our expertise. Perhaps the highlight here during the REF period is the ready access to our visual computing research provided via the CAMERA studio's outward-facing activity, detailed below and exemplified in the **Facial Performance Capture and Animation** Impact Case Study. O'Neill's work with the cultural heritage sector has included co-production of interactive museum installations (National Trust, Ruhrmuseum) and running workshops to educate curators in the use and value of digital interactions based on the Unit's research, while new gaze tracking methods (Lutteroth; actigaze) are enabling users to control electronic devices using their eyes;
- **collaborating** broadly with researchers in other disciplines. Advances in computer science can lead to impact via incorporation in research led by other disciplines. As detailed briefly above and in more detail in section 4, our UoA collaborates with every Faculty and School at the University of Bath as well as extensively worldwide. Impact-related activities in this area have included motion capture work in rehabilitation (including with amputees) with our Department for Health, and with the UK Skeleton Bob team, with colleagues in Sports & Exercise Science.
- **engendering future collaboration** through public engagement activity, including local, national and international events and collaborations with the creative industries and arts sectors.
- **enhancing the regional digital economy**. More recently, the Unit's influential role in the digital economy (spearheaded by the CAMERA Centre) has been deployed increasingly in the regional context. CAMERA has expanded its facilities into the Bottle Yard Studios in Bristol through a European Structural Infrastructure Fund (ESIF) award, supporting the creative industries sector in the region in collaboration with Bath Spa University, Radium Audio Ltd and Bristol Old Vic Theatre School. The Unit is also a partner in the Bristol and Bath Creative R&D Cluster, a £6.8M regional academic-industrial collaboration established in 2018. The UoA and its strong digital-focused research is key in a number of strategic regional research opportunities being pursued by the University, including the I-START initiative to be located in a new development close to Bath City Centre.

This culture is underpinned by a number of formal, funded activities:

- The *Centre for Digital Entertainment* (CDE) is an EPSRC Centre for Doctoral Training, founded in 2009 and re-funded in 2014 in collaboration with the University of Bournemouth. Since 2014 the Centre has received £4.6M in EPSRC funding plus investments from industry partners of £700k, and University investment of nine four-year doctoral studentships. Research engineers studying for an EngD in the CDE are placed with industry partners for up to three years. The portfolio or thesis that they submit must demonstrate the impact of their research. Such work underpins a number of impact-generating activities from the Unit, including: O'Neill's work with Research Engineer and later PDRA De Angeli on digital cultural heritage noted above; Bath research jointly patented with Disney (US2014267306); and a collaboration with CDE partner DNEG, where underpinning Bath research was taken forward by a CDE alumnus and delivered effects that were incorporated into high grossing films including *Ant Man* and *Tenet*;
- The CDE's activities are further amplified by the Marie Skłodowska-Curie action *Fellows with Industrial Research Enhancement* (FIRE) programme which provided £800k funding to support 10 research fellows pursuing doctoral degrees who again have industrial research engagement embedded in their programme of study. We note that our long-standing culture of extended engagement with industry partners at

the PGR and staff levels is complemented by similarly active placement programmes for UG and PGT students, amplifying the reach and range of our partnerships;

- The CAMERA Centre supports development activity to deploy the results of research in industrial applications and engagement with industry to launch further development projects e.g. via InnovateUK funding applications. CAMERA works alongside ImmerseUK, the UK's immersive technology network, to run workshops promoting the co-creation approach to research and impact with a range of partners. CAMERA is funded to provide consultation and access to technology and expertise free of charge to local SMEs. The ICS on Facial Performance Capture and Animation derives directly from work within CAMERA.

The impact culture in the Unit is supported by the academic role of Impact Director, established during the REF period. The Impact Director has responsibility for nurturing impactful research to delivery and for the documentation of impact. Impact is a standing item on staff and research meetings within the Unit. The Impact Director holds a dedicated budget, devolved from the departmental operating budget, to support activity that promises to lead to delivery, or documentation, of impact. Funds were used, for example, to support interaction between academics and museums and between the Unit and standards committees (Bryson; AI & Ethics ICS).

University-level support is also provided for the delivery and documentation of impact. The Research and Innovation Services (RIS), our research development and support department, has worked closely with all the impact case study authors to elucidate the impact, as well as supporting the project bids (CAMERA, InnovateUK bids, Royal Society Industry Fellowships, etc) that underpin our impactful work. We have accessed the EPSRC-funded Impact Acceleration Account to conduct work taking our research towards impact; in the case of Campbell's work with The Foundry this led directly to his Royal Society Industry Fellowship. RIS also provides advice and guidance on appropriate protection of Intellectual Property rights, particularly valuable when academics work in partnership with industry.

Approach to Interdisciplinary Research

The subject of Computer Science is inherently interdisciplinary. This is reflected in the backgrounds of our academic staff which range across mathematics, engineering and psychology as well as Computer Science. We see no barrier to interdisciplinary work and as a result are leaders of several large cross-disciplinary efforts:

- The CAMERA research centre involves members of the Departments of Computer Science and Psychology and the Department for Health
- REVEAL, the Real and Virtual Environments Augmentation Labs centre, is a Faculty of Science Research Centre for interdisciplinary work on VR and AR led by our staff. Its members include staff from Health, Psychology, Physics, and Engineering
- MAD, the Centre for Mathematics and Algorithms for Data, is a Faculty of Science Research Centre for fundamental and applied work aligned to data science, again led by our staff and bringing together Computer Scientists and Mathematicians.
- Our doctoral training centres in Digital Entertainment (CDE) and Artificial Intelligence (ART-AI) are designed to be interdisciplinary; ART-AI's leaders are drawn from Engineering, Education and Social and Policy Sciences as well as Computer Science.
- The Institute for Mathematical Innovation (IMI) is one of the University's flagship Institutes, an outward-facing entity which uses the power of mathematics to address challenges in other areas of activity. We participate in and lead IMI activity: Simsek served as Deputy Director of the IMI; Bryson and Davenport led an IMI thematic semester on AI Ethics; and Chen enjoys a funded IMI secondment,

- The Bristol and Bath Creative Industries cluster is an AHRC funded collaboration between Bath, Bath Spa, Bristol and UWE involving the Computer Science department plus Psychology and AHRC disciplines across the institutions.

Many exemplars of the extensive range of collaborative and interdisciplinary work arising from these and other efforts are detailed in Section 4.

Open research environment

The Unit benefits from a strong cultural commitment to open research, including open access to publications and open data. This is supported from the highest level in the University. The University of Bath Library was one of the first to establish a permanent data management service. This mature service supports Computer Science researchers in the planning, curation, preservation, and publication of research data, software and data access statements. Our expectations on researchers are aligned with the Concordat on Open Research Data and the FAIR principles and set out in our internationally recognised Research Data Policy. To implement this, we provide managed data storage to all research projects. These measures have allowed us to publish experimental data as supplementary material to papers e.g. in HCI. We also take advantage of external services such as GitHub to make source code available, enabling reproducibility of our work. Within the unit, local code and data repositories are maintained for sharing across our research community. Our Doctoral Skills training provision includes courses on research data handling, analysis and management. Information Security Awareness training is also provided by the University and is mandatory for all staff.

The Library's Open Access Team supports researchers in ensuring their research can be made available via open access. The University's Open Access Publications Deposit Mandate, published in 2011 and updated in 2017, requires full versions of all outputs to be made available via our institutional research repository. The Director of Research receives monthly reports on the open access status of publications; compliance in computer science is typically close to 100%.

Research Integrity

Integrity and a proactive approach to research ethics are fundamental to our research culture. The unit has been a national leader in promotion of the consideration of ethical issues around Artificial Intelligence, including our establishment of the ART-AI Doctoral Training Centre. We embed ethics and integrity throughout our work: there is mandatory research integrity training for all staff and research students, and formal documentation of ethical considerations is required for all research projects, including work undertaken by taught students. Scrutiny of these documents is the responsibility of the Department Ethics Committee, with escalation available through the University Ethics committee structures. The Departmental Research Ethics Officer reports to the Research Committee and leads discussion on ethics and integrity at the Departmental Staff meeting.

2. People

Staff Development Strategy

Mentoring and training

Our recruitment and growth strategy rests on attracting and developing ECRs to become the research leaders of the future. New recruits are supported with a bespoke package of funding on arrival. Faculty-funded PhD studentships are also made available. New academic staff are supported throughout a three-year probationary period. Workload is reduced in the first two years and time allocated to a centrally provided development and training course introducing key aspects of teaching, research development and career management, leading to FHEA status. Successful completion is a formal requirement for all probationers. Mentoring is offered to all

staff. Probationary staff have a mentor from the senior staff of the department, nominated by the Head of Department and typically chosen to have related research expertise. Allocation of mentors outside probation is handled by a Mentor Coordinator who works with staff to identify an appropriate mentor for their needs. This has been especially popular with postdoctoral research staff wishing to take an academic career to the next level.

An innovation within this unit is our *Early Career Lunches*, a monthly cohort-building exercise for our early career staff, where issues related to career development are discussed. The sessions are organised and run by the ECRs themselves, with funding from the department; senior staff attend by invitation to provide insight.

Staff appraisal is via "Career Conversations", a novel approach centering on the individual academic and their career horizons rather than the traditional annual performance lifecycle. Career conversations focus on strengths and development rather than performance management (handled separately where needed). Senior staff receive dedicated training to conduct these coaching-like conversations.

The University offers a broad range of development and training opportunities for all staff; the UoA funds training where the University offering does not cover needs, e.g. for our in-house technical support team. Staff have taken advantage of almost 400 sessions of training during the assessment period, including Project Management, Effective Meetings, Funding Opportunities for Women, and Mental Health and Wellbeing. Within the Unit, annual awaydays provide opportunities for cohort-building and sharing of best practice, including sessions dedicated to development of collaborative research projects.

In 2015 the Faculty of Science introduced a series of development programmes for PDRAs, aimed at assisting them to obtain Fellowships or Lectureships. Access to these programmes was competitive across the Faculty. We proposed four candidates, all successful. All have gone on to permanent academic positions: Jones is a member of this UoA; the others hold Lectureships in Management at Bath and in Computer Science at Coventry and Middlesex. For more senior staff, the University's *Academic Leaders Programme* recruits 12 staff per year across the University and develops strategic leadership skills over a series of workshops; Cosker, De Vos and McCusker have all taken advantage of this training; De Vos also participated in the Advance HE Aurora programme to develop female academic leaders.

Staffing and recruitment

This REF period has seen considerable change in our staffing profile. Of the 24 staff returned in 2014, four retired (H. Johnson, P. Johnson, Power, Willis), two left the UK to take academic posts overseas, and one moved to a commercial position (Brown, to Google). Three staff entered in this UoA in 2014 were not members of the Department of Computer Science and will be returned in other UoAs in this exercise. We have recruited very successfully: new staff are Alexander, Campbell, Chen, Fraser, Golbabaee, Haines, Isupova, Jones, Kim (now at UNIST, S. Korea), Li, Lutteroth, Namboodiri, Powell, Richardt, Simsek, and Yang. This represents net growth of five FTE staff in the UoA since 2014, and an increase of eight staff in the Department of Computer Science, growing from 21 to 29 staff: **38% growth in the Department**. Our new staff increase the diversity of the UoA, coming from China (3), Iran, Turkey, Germany (2), S. Korea, India, New Zealand and Russia as well as the UK (5). All our category A staff are on long-term, open-ended contracts.

11 of the staff recruited in the assessment period are in Machine Learning or Visual Computing, implementing our strategy of developing strength in these areas and their interface; a further four are in HCI, again consistent with strategy. Two were recruited at Senior Lecturer level and two at Professor; the remainder were appointed as Lecturer. Our commitment to development of ECRs has led five of these to achieve promotion to Senior Lecturer or Reader in this period. Our strategy has resulted in a more balanced demographic with a range of levels of seniority in all areas. Our quickly-progressing early-career staff influence the running of the Unit: three of the research group leads and the Computing Liaison Committee Chair are among the recent recruits (Campbell, Jones, Richardt, Simsek) and sit on the Department Research Committee and Executive. Further evidence of the quality of our recruitment is that four of the new recruits hold

prestigious individual research awards (EPSRC Fellowship, UKRI Innovation Fellowship, ERC Starting Grant, Royal Society Industry Fellowship).

Research leave

The University's sabbatical scheme supports leave of one semester per 3.5 years' service for staff out of the probationary period. Sabbaticals are awarded on a competitive basis: applicants must demonstrate the value that research leave will bring, for example in developing collaborations, delivering impact, or deepening research. All applications from the UoA have been successful: Bryson - Princeton; McCusker - Paris VI; Guglielmi - Paris VII (12 months), Lutteroth – Auckland; Willis – a number of locations in China and Australia. For opportunities which did not fit this scheme, we have made local arrangements to facilitate extended research visits by reducing teaching and administrative commitments: Laird held a visiting Professor position at Marseille, Davenport a Fulbright Fellowship to NYU.

Industry/academic exchange

Secondment to industry is common in the Unit, from research student level up. Our EngD research student cohorts spend significant time embedded with their industrial partners. Formal relationships include P. Johnson's long-term 0.4FTE secondment to the Defence Science and Technology Laboratory, Campbell's Royal Society Industry Fellowship which places him with Foundry, a world-leading supplier of software tools to the Post-Production and Creative Industries, and Cosker's RS Industry Fellowship placing him at DNEG, an internationally acclaimed post-production company that has won four academy awards.

Recognition and reward

The University operates a flexible workload model which recognizes the effort required to conduct research and deliver impact. We provide full buy-out for all funded projects, and allocated time for non-funded research and impact work including underlying scholarship and bid development. Our approach to promotion is inclusive and based on transparent criteria. Explicit research- and impact-related criteria reward impact, research recognition, public engagement activity, and major grant capture. The department's promotion committee actively encourages and develops applications. All staff who have indicated interest in promotion have been supported to develop their applications and all but one application in the period have succeeded. Within the Unit, we actively publicize and recognize success in research outputs and funding bids: staff are publicly congratulated via news bulletins and announcements at staff meetings. The Faculty and University take time to congratulate winners of significant research funding at Faculty Research Committee, at Senate, and via the website. We also recognize the value of preliminary efforts to establish new activity, and make use of departmental funds to seed research projects or investigation of possible avenues for impact.

Research Students

Recruitment

Our body of research students is growing, with a mean of 11.45 graduations per annum in this REF period, compared to 9 per annum in the previous exercise. Recruitment of research students is a robust process with at least two staff members involved in all decisions, and all offers derived from interviews by a panel of at least two academic staff trained in diversity and unconscious bias. The process is overseen by the University's Doctoral College. All our advertisements include a statement of our commitment to diversity and particularly encourage female applicants as part of our work towards gender balance. We encourage a diverse range of applications by engaging early with promising candidates and assisting them in preparing their applications, rather than expecting a polished research proposal. Our efforts in respect of gender equality have been successful: our PGR cohort is now 35% female, on a continual rising trend from 23% in 2013/14; this should be contrasted with the UK-wide undergraduate figure of 17%.

In our EngD cohort, 17% has a disclosed disability (vs UK population of adult of working age 19%).

Studentships from major funding bodies

Significant studentship funding has been a feature of this UoA for over a decade. Since 2009 we have hosted the EPSRC *Centre for Digital Entertainment* doctoral training centre, in collaboration with the University of Bournemouth. In 2019 we won £7M funding for the UKRI *Centre for Doctoral Training in Accountable, Responsible and Transparent AI (ART-AI)*, directed by O'Neill. We also hold £800k of funding from EU H2020 for the Marie Skłodowska-Curie action *Fellows with Industrial Research Enhancement*; research fellows funded under this scheme pursue PhDs in the Computer Science department. In addition to these major awards we hold EPSRC Doctoral Training Partnership studentships.

Monitoring

Postgraduate research student progress is monitored via 6-monthly reporting which engages the student, their supervisory team and the PGR director of studies, with scrutiny and support/intervention from the University-level Doctoral College where required. Formal milestones include PhD status confirmation at 12 months, to that ensure students have engaged actively with an appropriate research project and are on course for timely completion. This also requires the completion of our Academic Integrity Training and Test. Support for disabled students is coordinated with the University's Disability Services who help to produce bespoke Disability access plans for each student in conjunction with supervisors and DoS. A feature of our EngD programme is the placement of students in industry. Students on placement receive pastoral visits to ensure the success of their placement.

Skills support for PGR students

The University implements the Vitae Researcher Development Framework, supporting PhD students in areas including research governance, public engagement and impact. We provide a wide range of skills training for PGR students, and encourage and monitor the uptake of training via the regular monitoring reports, with an expectation that all students take 10 days' training per annum. Areas covered include management of time and career, teaching, communicating research, academic writing, and public engagement. Our Masters level *Entrepreneurship* module is available for all PGR students and compulsory for EngD students on the HCI route.

In the visual computing area, students receive practical training on imaging and motion capture and analysis from the CAMERA team, including training on popular industry tools. CAMERA also has a student technician team who are being trained to perform motion capture and will work on commercial and research projects.

The embedding of EngD students in industry allows them to develop relevant skills while conducting their research. Evidence shows that they become highly valuable: one third of EngD graduates gain employment with their host companies.

Students are encouraged and enabled to develop organisational skills by running events for the benefit of one another and the department. This includes specialist reading groups and seminar series, and larger events such as the annual PGR student conference in Computer Science. This typically includes events centred on preparation for a career, e.g. keynote talks from graduated PGR students on their early career experience. Until 2020 the monthly department-wide seminar was run by and for our PGR students. The Doctoral Training Centres coordinate buddying and mentoring between research students, both to support newly arrived students and to develop the leadership skills of the more established ones.

Equality and Diversity

We are working actively to increase equality and diversity throughout our research environment, recognizing in particular a historic gender imbalance in the subject and our UoA. We have a

departmental Equality, Diversity and Inclusivity committee, who also oversee our Athena SWAN submission and monitoring; we were awarded Athena SWAN Bronze in 2015. The ART-AI CDT has its own ED&I committee. Partner companies of ART-AI demonstrate their commitment to diversity by signing up to the Tech Talent Charter. Our own commitments and initiatives include the following.

In **recruitment** we ensure a gender balance on all recruitment panels and insist that members are trained in recruitment policy and about unconscious bias. Should an all-male shortlist arise from a selection process, this must be justified in writing by the panel. All job advertisements contain wording describing our commitment to equality and encouraging female applicants. We have engaged a professional copy-writing service to make our advertisements more accessible and have positive (anecdotal) evidence from applicants that this is effective. Monitoring of the diversity of our recruitment processes indicates that since January 2019, of the 30 positions in Education and Research filled in the department (including teaching positions and PDRAs) the gender balance is exactly 50-50. We support staff in taking **parental leave** including shared parental leave. Staff are supported throughout their leave with “Keep in touch” days and on return to work by considered management of their workload to ensure a smooth return to work and to active research. We negotiate **bespoke contracts and working arrangements** for staff wishing to work part-time or flexibly, for example enabling remote working (including teaching) for a staff member whose family commitments moved them away from Bath (pre-Covid). To accommodate the needs of staff with childcare or other caring responsibilities, it is our policy that all formal meetings are scheduled within core hours 10am – 3pm. Staff may request particular hours of the day or week to be blocked out of their timetables to accommodate caring responsibilities. We have offered fully-funded short-term childcare to enable researchers with care responsibilities to attend a research workshop held at Bath.

We actively support **staff and research students with disabilities**, including the installation of a bespoke automatic door for a PDRA with reduced mobility and specialized office furniture and IT hardware to accommodate physical needs for several staff; we develop personal evacuation plans for disabled users of our building and provide training on how to approach assistance dogs for all staff.

To address gender and generational barriers to career progression, we promote **role models** including the award of an honorary degree to Gillian Arnold, former chair of BCSWomen and now BCS Vice-president; and run **transparency** events to demystify the University’s promotion and progression routes.

In preparing our REF submission we adopted consistent, transparent and accountable processes, conducted in an inclusive manner in accordance with our institutional values and policies, including Equality and Diversity policies and the University’s Code of Practice. Staff involved in the output selection process undertook appropriate training including a full day session on reviewing outputs for REF. Our process assessed outputs on research quality only. We note that inclusion of an individual’s outputs in the REF submission plays no role in the University’s probation and promotion processes.

We encourage a collegiate environment via social events including weekly staff coffee and cake, a corresponding event for PGR students, and an annual (secular) Christmas event.

3. Income, infrastructure and facilities

The UoA has benefitted from significant infrastructure investment and increased research income in this assessment period. Since 2014 the Department of Computer Science has occupied an **entirely refurbished building** in the centre of the University campus. Total University investment in this building was £21M. The building houses individual offices for all academics, shared office space for PGR students and PDRAs, dedicated labs for Visual Computing and HCI work, the CAMERA studio, and labs for our taught students. The HCI lab includes a high-frequency eye-gaze tracker, panoramic screen, and multi-channel video recording system for remote monitoring and recording of user behaviour. The visual computing

lab offers a full 3D scanning facility and associated analysis hardware. The CAMERA studio is a state of the art specialized motion-capture studio, with its own technical support manager, and equipment valued around £500k. Facilities include marker-based, markerless, and inertial motion capture, force-plates for kinetic measurement, VR/AR equipment, handheld 3D scanners, face/body 3D capture, 4k video recording, and professional creative software. Beyond this building, a further Maker Lab includes fabrication facilities (laser cutting, soldering, PCB etching, 3D printing) enabling the construction of specialist devices for research including HCI and robotics. From Spring 2021 this will be augmented with an additional 110m² lab providing new fabrication capabilities to support research projects that involve hardware development and physical prototyping, with equipment investment of £60k from the University. A significant addition to our physical space from Spring 2020 is the establishment of a **600m² off-campus studio dedicated to engagement with industry** associated with the CAMERA project. This new facility, located in the heart of the Bristol-Bath creative quarter at the Bottle Yard, is supported by £900k from the European Structural and Investment Funds, leveraging a further £900k investment from the University. The studio is fitted with equipment valued at £380k including a state-of-the-art motion capture system and instrumented treadmill.

Our shift towards Machine Learning research has led to an increase in computation-intensive work. To meet demand, we established in 2019 an in-house compute cluster, with 20 GPUs, 14TB of solid-state storage and 24TB of magnetic storage. This facility is available to staff, PGR students and appropriate taught students, and has already supported the computation needs of research projects leading to outputs in Machine Learning and Visual Computing.

Fundamental to our strategy on the use of this infrastructure to support research is an inclusive attitude that invites participation from people at all levels, from Professor to Undergraduate. Lab spaces are not owned by particular groups but are available for all appropriate research use. Opening our labs to UG and PGT project use amplifies the research value of University investment and our success in attracting students. Students have contributed to several outputs in this period, across multiple research groups.

Mean annual **research income in this assessment period is 60% greater than in REF 2014**. Awards supporting research activity total more than £25M in this period. The CAMERA awards are a centerpiece of our current portfolio: CAMERA was inaugurated with a £4M EPSRC award in 2015 and has recently received a further £3.4M EPSRC award and an £880k Horizon 2020 award. Research throughout the department is supported by regular funding from a number of sources including the Royal Society, InnovateUK, AHRC, EU H2020 and ERC as well as EPSRC which is our principal funder, and industrial awards from Axa, Google and DSTL. Our two Centres for Doctoral Training received awards of £11.5M in this period. ART-AI has additional funding from industry partners of £380k with a further £438k pledged; CDE has secured £708k of income from industry partners. Our research awards reflect and benefit from the diversity of the UoA. For instance, the group of investigators on the CAMERA awards exhibits diversity across nationality (UK, China, S. Korea, Europe), career stage (Professor to ECR) and gender.

Support for grant proposals

We offer support for preparation of funding bids at all levels. Information and analysis of funding opportunities is provided by the Director of Research and by the University-wide Research and Innovation Services, including Department-wide awaydays devoted to analysis of the funding landscape, University-level information days about access to particular funders, and online resources. The Research Committee oversees development of grant proposals and assembly of teams to address funding calls. We work closely with investigators, particularly ECRs on first grants, conduct internal peer review to assure and increase the quality of bids, and organise mock panels and interviews to prepare applicants. Successes include Richardt's award of a UKRI Innovation Fellowship early in his career with us. Additional support for industrial funding

bids, including InnovateUK, is available from the CAMERA management team; InnovateUK successes include the *Rheumatoid Arthritis Flare Up Profiler*, a project with the Royal United Hospital, Bath; and the *HMC for Augmented Reality Performance Capture* with the Imaginarium as well as projects reported in our Impact Case Studies. The increased research power arising from our success in attracting funding in this period has led to a marked increase in research outputs including publications in the prestigious SIGGRAPH and CHI conferences, with multiple Best Paper awards.

Organisational infrastructure to support research

The research organisation of the Department of Computer Science is set out above. At Faculty level, the Science Faculty Research Committee comprises an Associate Dean (Research) and the Directors of Research from the departments in the Faculty. It oversees research across Science, including establishing and monitoring the performance of research centres such as *REVEAL* and *MAD*. At University level, Research and Innovation Services offer support for grant management, accessing university funds e.g. studentships, equipment funding, and commercialisation contracts including KTPs.

Technical infrastructure

Over the REF period the UoA has benefited from two dedicated systems support staff entirely devoted to specialist computer science activity, as distinct from commoditised activity such as email and standard software support. They specify, purchase, install and maintain all research equipment, including the local cloud hardware and a diverse range of machines and devices. An additional technical manager supports the CAMERA motion capture studio.

Further support for research is available from the CDE, ART-AI and CAMERA support teams who handle, among other things, the annual Digital Entertainment conference, and support the monthly departmental seminar.

Scholarly infrastructure

The University Library is a central part of the scholarly infrastructure supporting the UoA. It offers 24-hour access to its collection of texts and journals, electronic access including IEEEExplore, the ACM digital library and electronic journal subscriptions, and a wide range of support services. Its work in supporting open access and open research has been described above. We make regular use of its research analytics service, to obtain bibliometric and other quantitative analyses of the research performance and behaviour of our UoA and comparators.

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

Our open and supportive research environment engenders a broad range of research collaborations, engaging with and contributing to the scientific, economic and societal needs of a diverse range of researchers, users, and publics. We routinely seed or revitalise collaborations with in-house research funding. Budget for this is held by the research committee, regularly advertised at departmental staff meetings, and has been sufficient to fund all requests to date.

Collaborations

Our staff engage in a wide range of collaborations, throughout the University, and with partners nationally and internationally. This includes supervision of PhDs at Max Planck, TU Berlin, Cork, Porto, Beijing Jiao Tong University, Tsinghua, and Hong Kong University; hosting extended research visits from University of Hong Kong, CNRS Lyon, Xi'an university, Technische Hochschule Köln, and TU Braunschweig; and made visits to Tsinghua, Aix-Marseille and ongoing transfer arrangements with Cambridge and NII Tokyo.

The change in working arrangements caused by the Covid-19 pandemic led to innovations supporting collaboration. Moving research seminars online enabled broad participation from outside the university; for example, our Mathematical Foundations seminar attracts audience members from France, Italy, Luxembourg, Finland, and Lithuania.

Engagement with business and third sector

We have extensive engagement with partners in industry and the third sector as research collaborators and users. Partnerships range from significant formal relationships with commitment of funds and in-kind benefits, including those associated to our research grants and doctoral training centres, to individual researcher-to-partner collaborations. Exemplars of research detailed in our submitted outputs that was produced in collaboration with or has had direct influence on industry includes Jones's personal informatics work, which has informed the exist.io platform, the main product of Melbourne start-up Hello Code, and Hall's woven fabric model, used by KiSP/Yulio in their VR products for architectural design. We have over 50 industry, public- and third-sector partners engaged in active, funded projects and initiatives. These range from SMEs – e.g. FatPebble, Wonky – and local organisations and companies – e.g. NHS trusts in Bath and Salisbury, Wessex Water – to national and multinational corporations – e.g. BBC, Disney, DNEG, Sony Interactive, Samsung, Shell, PwC, DeepMind, Aardman, Bank of England, National Trust and UNICEF. The CAMERA commercial team also develops industry collaborations and enables the use of the CAMERA studio for them; the number of partners involved in CAMERA work has grown from 8 at the founding of the Centre to 22 at the time of the successful CAMERA 2.0 follow-up bid.

Interdisciplinary research and engagement with research users

Our staff maintain active collaborations with researchers from every Faculty and School in the University and a wide range of industry and third sector partners as co-creators and users of research. We support formal structures for interdisciplinary work, including the *MAD* and *REVEAL* centres; Simsek was deputy director of Bath's Institute for Mathematical Innovation; De Vos is a core member of Bath's Centre for Therapeutic Innovation.

We present examples of interdisciplinary work and engagement not detailed elsewhere. In **healthcare**: Cosker and Campbell work with the NHS to develop an AI system to profile Rheumatoid Arthritis; Campbell is developing computer vision and ML techniques for arthritis and malaria detection; Jones works on personal informatics for healthcare, with NHS collaborators from the Royal United Hospital; Lutteroth and Watts pursue multiple projects using Virtual Reality techniques for healthcare interventions, including "exergaming" to encourage patient engagement with therapeutic exercise regimens and VR interventions to support patients recovering from brain injury, with collaborators from the NHS and associated charities (Designability, Brain Injury Rehabilitation Trust). In **sport**: the CAMERA team works with British Athletics, British Skeleton and the Lawn Tennis Association on analysis of elite sports performance using computer vision and motion capture. In the **performing arts and culture**: CAMERA has delivered workshops with Bristol Old Vic Theatre School training actors in using motion capture; Watts works with Jean Abreu Dance Company on the place of robots in dance production; O'Neill pursues collaboration with the National Trust on interaction design for cultural heritage, developing interactive installations bringing cultural heritage to life. In **finance**: Simsek's Machine Learning work, drawing on and contributes to cognitive science, developed psychological heuristics for portfolio decisions and methods for financial crisis prediction in collaboration with the Bank of England and European Central Bank. In the **environment**: Padgett works on air quality monitoring with staff from Architecture and Civil Engineering, and via the EPSRC *Enliten* project, with Psychology and Engineering on the effect of interventions on energy-related social behaviour; Isupova works on detection of environmental factors from satellite imagery, including identification of elephants, prediction of crop yield, and detection of seismic faults, with zoologists and earth scientists at the University of Oxford; and Chen uses machine learning approaches to produce seismograms and detect microseismic events in collaboration with Shell and researchers at Cambridge. We note that these examples of

collaborative activity include staff spanning the full range of career stage, nationality and gender, working with partners from diverse sectors.

Our staff pursue **public engagement** activity, with diverse local, national and international audiences. Exemplars include Richardt's public talks at Bath's Pint of Science events, at the Bath Royal Literary and Scientific Institution 2019 and Royal Photographic Society 2018; Cosker's presentations at the Royal Society summer science exhibition 2016, Times Science Festival Cheltenham 2015 and Bath Science Festival 2016; Isupova at British Science Week 2015. Davenport and Bryson led a Thematic Semester on Artificial Intelligence Ethics in Feb-May 2018, culminating in a public debate with over 100 people, mostly external to the University, and before/after polling indicated a significant shift in attitudes. Haines used his data science expertise to analyse the UK government's approach to A-level grading for the Covid-19 affected 2020 cohort; his analysis led to appearances on BBC News, in the Financial Times, and as a panelist on Turkish television. His original tweet on the topic was viewed over 25,000 times.

Responsiveness to National Priorities and Initiatives

The UK's Industrial Strategy placed Artificial Intelligence at the centre of UK development. We responded to this by assembling the team and successful bid for the ART-AI Centre for Doctoral Training, as well as a successful UKRI Innovation Fellowship (Richardt). Our pedagogical expertise, including research in computer science pedagogy, underpinned our leadership of the consortium that runs the national £40M *Institute of Coding*, headquartered in Bath and engaging members of the UoA, notably Davenport on 0.5FTE.

Indicators of influence

Our staff serve on and chair assessment **panels** for the major funders including EPSRC, AHRC, ESRC, EU and in the EPSRC peer-review college. At least ten of our staff hold editorial positions on journals including Human-Computer Interaction, Journal of Experimental Psychology, Computer Graphics Forum, Frontiers in Virtual Reality, Mathematical Structures in Computer Science, IEEE Computer Graphics and Applications, and IEEE Pervasive Computing. We routinely contribute to and lead **international conference and workshop organisation** with programme committee and chair activity in over 50 events including SIGGRAPH, CVMP, CHI, BMVC, AAAI, CVPR, IJCAI, AAMAS, ISSAC; our staff led two Dagstuhl seminars; De Vos is treasurer for the Association of Logic Programming. Powell organises the international online Proof Theory seminar.

We influence **policy making** via work with the Office for AI, The Department of Culture, Media and Sport, the Cabinet Office, All-Party Parliamentary Group meetings on AI, the Office for National Statistics, British and IEEE Standards organisations; we influence **funders** via the Royal Society Science, Industry and Translation (SIT) Committee, EPSRC HCI Roundtable, the EU ITN Scientific Evaluation Group, EPSRC Digital Economy Centre Directors group, AHRC Creative Cluster Executive Committee, RS Industry Fellows College.

Fellowships

Several of our staff hold prestigious individual fellowships and awards, including: Richardt's UKRI Innovation Fellowship; Fraser's EPSRC Established Career Fellowship; Alexander's ERC Starting Grant; Campbell and Cosker's Royal Society Industry Fellowships; Lutteroth's Association of Commonwealth Universities Information Technology Fellowship; Davenport's Fulbright Cyber Security Scholarship.

Prizes and invitations

Research in every group in our department has won awards in this assessment period. Highlights include two Best Papers and three Honourable Mentions at CHI in 2020 and 2019 (Alexander, Fraser, Lutteroth, Payne); an IEEE LICS Test of Time Award in 2018 (McCusker);

Best Paper at NeurIPS 2018 Workshop on Machine Learning for the Developing World (Isupova); Best Short Paper at CVMP 2018 (Richardt). Lutteroth's Actigaze technology won the New Zealand HealthTech Award 2016 and 2020 Best Assistive Technology Developers award at the APAC Business Awards

Our researchers are regularly invited to speak at local, national and international research and industry events. Examples include Fraser at the EPSRC Connection Nation Showcase 2015, De Vos at the ICLP Women in Logic Programming 2020, Chen at the Society of Petroleum Engineers Abu Dhabi International Petroleum Exhibition & Conference 2017, Namboodiri at Samsung's Technology and Advanced Research (STAR) Labs, US, Cosker at Facebook Reality Labs in 2020, and Powell at Logic Colloquium 2019.