

**Institution: Oxford Brookes University**

**Unit of Assessment: Unit of assessment: Computer Science and Informatics - 11**

## **1. Unit context and structure, research and impact strategy**

### 1.1 Unit Context and Strategic Goals

Computer science research at Oxford Brookes comprises a dynamic group of researchers whose work combines academic excellence with innovative practice based scholarship providing a pathway to impact. Part of a successful and ambitious modern university, our researchers are at the cutting edge of new developments and have a distinctive profile in artificial intelligence (AI) and software engineering. These developments are being applied in key areas such as healthcare, telecommunications and digital technology for learning. This is strongly reflected in the impact case studies (ICS) submitted for this REF.

The UoA has developed an inclusive research atmosphere with the aim of maximising the number of staff actively engaged in research. Research directly informs teaching, in particular in the areas of artificial intelligence, machine learning, robotics and software engineering.

Over the period 2014-2020, the school has continued the development of our two research centres; the **Dependable Systems Engineering Research Centre (DSERC)** and the **Intelligent Systems Engineering Research Centre (ISERC)** – (see Section 1.2) which foster collaboration and nurture engagement with the public and other institutions, and support the achievement of impact. In addition, we recently established the **Institute for Ethical AI (IEAI)**. This is a virtual centre which works with both of the above research centres and others across the university. All research-active staff work with at least one group within these centres, developing their own research pathways with the support of colleagues who share similar interests. Our regular research seminar series, which disseminates progress to all researchers in the School of Engineering, Computing and Mathematics (**ECM**), as well as regular group meetings, have fostered a rich, interdisciplinary environment in which research flourishes.

Research and impact generated within these centres has been strengthened by staff success in the university's annual Research Excellence Awards competition, as well as Faculty Impact Acceleration funding schemes (see Section 1.4). The school research budget provides scholarships for research students, and targeted funding for distinct activities and events related to each centre. Interdisciplinary research between the research centres and the wider intellectual communities of the faculty and university is advanced through a range of collaborative projects (see Section 1.5).

The number of staff returned has increased from 13 FTE in 2014 to 17.3 FTE in 2020. This FTE value represents 75% of eligible computer science staff. The external research spend has increased from c.£1,000,000 in REF2014 to c.£2,350,000 over the period of REF2021. These figures show that the UoA is growing and improving its research capability.

### 1.2 Research Centres

The work in each Research Centre is formed into groups that address specific areas of research and which are led by an experienced researcher. 11 FTE carry out research within **DSERC** and 6.3 FTE work within **ISERC**.

**DSERC** is led by **Harrison** and the centre comprises three groups. The **Cloud Computing and Cybersecurity (CCC)** group headed by **Zhu** has been working on the key area of software testing. **Zhu and Bayley** have developed a new method for testing AI applications, *Datamorphic Testing: A Method for Testing Intelligent Applications* (Zhu et al, 2019). **Bayley and Zhu** have investigated how to ensure that third-party software services that are dynamically discovered and composed are semantically correct, *Monic Testing of Web Services Based on Algebraic Specifications*, (Bayley et al, 2016). Design patterns provide reusable software solutions and are widely used in software development. **Zhu and Bayley** have been studying how a developer can prove that an application of a pattern is valid, *On The Composability of Design Patterns* (Zhu and Bayley 2015). Security is a newly established area of research being led by new cyber security lecturers **Kamarudin** and **Dehghanniri**, who have expertise in malware and the social impact of cybercrime. Initial work is focussed on a security framework for autonomous vehicles.

**Harrison** leads the **Applied Software Engineering and Data Analytics (ASEDA)** group in **DSERC**. **Harrison's** work on software engineering has applied a paradigm known as 'learning from crowds' to classify software engineering defects with non-expert knowledge, *Learning to classify software defects from crowds: a novel approach* (Harrison et al, 2018). **Martin** and **Harrison** have developed case based reasoning techniques which have been applied to a patient-controlled diabetes management system, *Temporal Case-based Reasoning for Type 1 Diabetes Mellitus Bolus Insulin Decision Support* (Martin et al, 2018). **Aldea** and **Younas** have shown how to use semantic similarity and ontology mapping to automate regulatory compliance management, *Automating the Semantic Mapping between Regulatory Guidelines and Organizational Processes* (Sapkota, Aldea et al, 2016). In the area of data analytics, **Younas** has been investigating the application of NoSQL databases for the analysis of London bus service data, *Testing of Transactional Services in NoSQL Key-Value Databases* (Younas et al, 2018). **Basu** has developed a software tool for selection of cloud services based on quality of service, *Modelling and Simulation of QoS-Aware Service Selection in Cloud Computing* (Basu et al, 2020) and **Younas** has developed a software tool for detecting malware, *CloudIntell: An intelligent malware detection system* (Younas et al, 2018).

**Jabir** leads the third group in **DSERC** which is the **Advanced Reliable Computer Systems (ARCoS)** group. This group has a long history of developing resilient VLSI circuit designs and during this REF period has designed and patented a concurrent error detection and correction system electronic hardware, *A Low-Complexity Multiple Error Correcting Architecture Using Novel Cross Parity Codes Over GF(2<sup>m</sup>)* (Jabir et al, 2015), The main thrust of the work is now on memristor logic designs including resilient cross bar architectures and memristor sensor arrays, *Efficient sensing approaches for high-density memristor sensor array* (Jabir et al, 2018). The group received the best paper award at the IEEE IOLTS'2016 conference for the paper *Novel Memristive Logic Architectures* and the work has resulted in the filing of 8 patents.

**Crook** (2014-18) and **Ball** (2018-2020) lead **ISERC**. There are four groups which address different types of intelligent systems but which have a common objective to analyse and process data to improve system performance. The **Visual AI Lab (VAIL)** is led by **Cuzzolin** and is world-leading in the field of deep learning for action detection in videos, *Deep learning for detecting multiple space-time action tubes in videos*, (Cuzzolin, 2016), autonomous driving, and AI for healthcare, with a strong momentum in the direction of frontier topics such as AI and neuroscience, human-centric AI and machine, as evidenced by the best detection accuracies to date, and the first system able to localise multiple events in real time, *Online real-time multiple spatiotemporal action localisation and prediction* (Cuzzolin et al 2017).

The **AI and Robotics (AIR)** group is led by **Olde Scheper**. The group carries out research into Social Robotics, Human Robot Interaction, Human Computer Interaction, AI & Machine Learning and Bio-inspired Computing, *Biologically Inspired Rate Control of Chaos* (Olde Scheper, 2017). Collaborations with clinicians and experimentalists have provided the opportunity to investigate applications of AI, Human Computer Interface, and data analysis in health and human robot interactions.

The **Performance Augmentation Lab (PAL)** led by *Wild* was established in 2016 to focus on Augmented Reality and Wearable Technologies. The aim is to embed information directly into experience, developing novel and powerful forms of real-time feedback on performance. *Wild's* expertise in this field resulted in him being appointed as the co-ordinator for work on an international standard on *Augmented Reality Learning Experience Model* (IEEE standard P1589/Draft 3). In 2020, the resources in this group transferred to the Open University following *Wild's* award of a Chair in Technology Enhanced Learning.

The **Communications, Media and Telecommunications (CMT)** research group led by **Ball** and including **Ou** and **Sengul** has focussed on intelligent mobile wireless systems, including communication between vehicles and infrastructure, *Multiple Interface Scheduling System for Heterogeneous Wireless Vehicular Network*, (Ball, 2017), improving the performance of radio access networks, *Dynamic Resource Scheduling in Mobile Edge Cloud with Cloud Radio Access Network* (Ou 2018) and the optimisation of parameters for cellular radio, *Self-optimization of coverage and capacity based on a fuzzy neural network with cooperative reinforcement learning* (Sengul 2014). This group was closed in 2019 as the staff moved to new areas of research in the **VAIL** and **CCC** groups.

The **Institute for Ethical Artificial Intelligence (IEAI)** forms part of Oxford Brookes' response to the UK Industrial Strategy. It was established by the co-director **Crook** and formally launched in February 2020. The **IEAI** was founded and is being led by staff being returned to UoA11; it is, however, a university-wide initiative that involves staff from across many disciplines, including social science, business, health and life sciences. The mission of the **IEAI** is to promote the ethical development and deployment of AI technologies, with a particular focus on trustworthy AI solutions for business and society. The Institute is creating a number of new income streams with the aim of becoming financially sustainable. External funding of c.£1,250,000 was won by the institute from the Research England Development Fund. Initially the institute has been working in specific business sectors (HR and Law), to establish pay-for-membership consortiums.

### 1.3 Research and Impact Strategy

The overarching objective for the unit during the assessment period has been to deliver the highest possible outcomes in research and impact in the areas represented by our two research centres. The key objectives identified in REF2014 have been substantially delivered due to the strategy and support structures identified below. These objectives were as follows:

- Develop a research community with the capability of addressing increasingly complex global challenges.
- Make strategic new appointments to strengthen research capacity
- Increase external funding

The objective to develop a research community capable of addressing global challenges has been achieved through the close coordination of the group activities, in particular in the areas of AI technologies and software testing, case based reasoning, data analytics and performance

augmented learning. This has enabled our teams to successfully lead and partner on several major Horizon 2020 projects. These projects are related to the global themes of healthcare (**Martin**, PEPPER project and **Cuzzolin**, SARAS project) and advanced teaching and learning (**Wild**, WEKIT and ARLEM). The expertise in AI technology and big data has also enabled **Cuzzolin** and **Younas** to actively participate in the university's new Research, Innovation and Knowledge Exchange (RIKE) networks (see IES and Section 1.5). In addition, the expertise in AI, for example **Rolf** and **Cuzzolin** (AI algorithms) and **Zhu** (AI testing), has contributed to the establishment of the new IEAI by **Crook**. These areas of expertise have also generated impact and this is reflected in the Impact Case Studies (ICS) on Human Performance Augmentation and Artificial Intelligence for Saliency Detection and Action Recognition (see Section 1.4).

While the core research staff that were returned in REF2014 have all been retained, we have fulfilled the objective to make new strategic appointments to strengthen our research capability. **Rolf** joined in 2016 and has made a significant contribution to successful bids for funding through KTPs with Blenheim Palace and the law firm Moorcroft. **Rast** joined in early 2020 and is an expert with many years of research experience in AI. He is now leading the teaching on our AI programmes and is actively involved in applying his knowledge of AI and computer vision to research into autonomous vehicles, which is a major cross-ECM project; **Pillai** (2016-2018), **Dehghanniri** and **Kamarudin** were appointed to support our new UG and PGT programmes on computer science for cybersecurity, which has been certified by the National Cyber Security Centre and their roles also include the establishment of a new research area in cybersecurity. **Rast**, **Dehghanniri** and **Kamarudin** have been returned as an Early Career Researchers (ECR).

Our objective to increase external funding has been very successful and overall the external funding has increased by 235% as described in Section 3.1.

Moving forward into the next five years, we will sustain and further develop our rich research and impact culture. Our main aims are as follows:

- To enhance pathways to impact by identifying opportunities for impact at an early stage and fostering them through to a successful outcome.
- Further develop inter-disciplinary research across the School, between Faculties with other universities and with industry.
- Increase the number of applications for external funding to sustain and expand the research in line with the university strategy as described in the IES.
- To increase our flourishing community of postgraduate researchers through the continuation of faculty-funded PhD bursaries and by seeking external or collaborative funding.
- To enhance the careers of early researchers through the university's continuing commitment to supporting research and impact as integral parts of academic duties.

#### 1.4 Impact Support and Development

Support for impact is delivered through the Faculty Impact Lead (Gupta), underpinned by the university's Research Impact Steering Group and Research Impact Officers. Together the impact team offers dedicated sessions on planning, delivering and recording impact activity, working in partnership with the university's Research and Business Development Office. Within the school, the research centre leads, in collaboration with the group leaders, monitor research work and identify and support activities that can enhance impact. Additional support is provided through mentoring by the unit's 'Impact Champions' whose work forms the basis of our submitted ICSs.

A regular programme of faculty and departmental events explores the opportunities and benefits of impact and is open to colleagues at all career stages. Impact is firmly embedded into the annual Personal Research Planning (PRP) process in which all research staff participate and impact is considered in workload allocations as well as applications for promotion.

Under the umbrella of the above support schemes, projects are monitored and supported to maximise impact. The university Impact Tracker database is used to record evidence of impact as it occurs during a project. Examples include the work by **Olde Scheper**, **Aldea** and **Martin** on the application of 'Rate Control of Chaos' analysis for identifying medical conditions. Trials have been carried out in a hospital in Mexico and the work was awarded Impact Acceleration funding from the Faculty which allowed the team to organise a focus group of medical and technical stakeholders to disseminate the findings of the research.

The work on predictive personalised decision support for diabetes management by **Martin** and **Harrison** was also identified as having potential for impact (more details provided in Section 4.2). The Faculty awarded Impact Acceleration funding to this project which enabled a video to be produced to increase the dissemination of the work. Project videos have received well over 7500 views between them: ([tinyurl.com/pepperh2018](https://tinyurl.com/pepperh2018) and [tinyurl.com/pepper2020](https://tinyurl.com/pepper2020)). Trials of the monitor have now been completed and have shown that the system could be extremely beneficial to people managing diabetes.

Through the Horizon 2020 WEKIT project, *Wild* has developed a technology platform using augmented reality for producing 3D augmented reality training content enabled by smart wearables. The project validated the methodology and technology in pilot test-beds in aviation, space engineering and medicine. *Wild* was awarded Impact Acceleration funding by the Faculty to deliver training on the use of performance augmented learning to local schools and colleges to broaden the awareness of the opportunities offered by this technology. Important impact resulting from this work is the first standard on performance augmented learning produced by the IEEE sub-committee chaired by *Wild* (see Section 4.1).

**Cuzzolin** has developed an international reputation for his group's work on computer vision and action recognition. The impact from this work is starting to emerge and is likely to grow significantly over the next few years. Earlier work under *Torr* (now UoO) on saliency detection was further developed by Huawei and deployed on their mobile phones for processing images for their 'selfie' feature. More recently **Cuzzolin** has been working with Huawei and his consultancy has led to the development of action recognition algorithms that have been selected for deployment in the next generation of Huawei mobile phones. In addition, **Cuzzolin** has a successful KTP with Createc whose business includes the development of a tool for analysing football players. **Cuzzolin's** action recognition technology is able to monitor players' behaviour on football pitches, such as how they land from a jump and how they kick a ball, which will have impact in terms of player performance and analysing causes of injury. This KTP work has facilitated connections with three Premier League clubs and funding for development has been received from one of these clubs.

The work of *Wild* (Human Performance Augmentation) and **Cuzzolin** (Artificial Intelligence for saliency detection and action recognition) were selected for the ICS for REF2021.

There are promising indications that all the above projects will produce significant impact over the next REF period and they will continue to be monitored and supported together with emerging new projects. The procedure for identifying key areas of research and monitoring the progress towards

impact has been very effective in terms of keeping impact as one of the strategic targets for the research. It is therefore planned to continue this approach into the next REF period.

### 1.5 Interdisciplinary Research

Research staff are supported in engaging with researchers from other disciplines. Over the last few years there have been a number of very successful collaborations, with publications expected in due course. Examples include:

**Olde Scheper** (Computing with UoA3) was awarded a faculty funded PhD student scholarship as a result of a faculty initiative to develop interdisciplinary collaboration. This collaboration is with Dawes (UoA3, Faculty of Health & Life Sciences [HLS]) and Dr Karl Morten, Nuffield Department of Women's and Reproductive Health, Oxford University [UoO] and studies Criticality Gait Analysis. Dawes' group is providing data for the analysis and joint publications are planned in future. **Aldea** and **Olde Scheper** (Computing with UoA3) were awarded a Newton Institutional Link grant for the CARDIGAN (Criticality Analysis of Diabetic Gait in Children) project. This is a multidisciplinary project in collaboration with Dawes (UoA3, HLS) and a children's hospital in Mexico (Obesity Clinic, Hospital Infantil de Mexico Federico Guzman). **Martin** (Computing and Medicine) was awarded Global Challenges Research Fund (GCRF) funding from Innovate UK for the project AbleDoc (Avatar-Based Learning for Diabetes Optimal Control) project. This project is in collaboration with Cognitant and Hospital Universitario San Ignacio (Colombia). A joint publication between the collaborators is in preparation. **Olde Scheper** (Computing and Engineering) received a university central fund award to work on applying rate control of chaos to the control of petrol engines.

**Martin** (Computing and Health/Medicine) is the PI for the Horizon 2020 project PEPPER in which the project partners are: Imperial College London, University de Girona, Girona Biomedical Research Institute – Hospital Dr Josep Trueta, RomSoft SRL and Cellnovo Ltd. The project uses case-based reasoning as the basis of the diabetes management system. A publication from this collaboration has been returned, *A Modular Safety System for an Insulin Dose Recommender: a Feasibility Study*; more details are given in section 4.2. **Martin** (Computing and Health/Medicine) was awarded GCRF funding from the Royal Academy of Medical Sciences for the project COORDINATES: (Cloud-Based Tool for diabetes management and research in Colombia). The project partners are Hospital Universitario San Ignacio (Colombia), Universidad Antonio Narino, Imperial College. The project explored the feasibility of a cloud-based platform for diabetes management.

**Wild** (Computing with Arts) has explored the application of augmented reality with a number of different disciplines including most notably design sciences (Schools of Art, Built Environment and Architecture) and HLS (Medical sciences, Nursing, Psychology, Sports).

Interdisciplinary research is also carried out through the university's new RIKE networks (see IES). **Cuzzolin** is contributing his expertise in AI to the Health Ageing & Care network. **Younas** is a co-lead of the Refugees and Migration network, where he is applying his knowledge of big data to the information analysed by this network. **Crook** has established the **IEAI**, which is addressing AI in a business context (Computing with HR/Law); see also Section 1.2.

### 1.6 Open research environment and ethics

This UoA has gone beyond the requirements: almost all outputs over the period have been made open access (OA) on Oxford Brookes' institutional repository RADAR through either the Green or Gold routes to OA. The UoA encourages all researchers to make their work available through

publically accessible websites. Over the last 6 years the research work which forms the basis of the ICS has been carried out by **Cuzzolin's** Visual AI lab and **Wild's** Performance Augmentation Lab. Each of these labs has its own website for sharing information: <https://cms.brookes.ac.uk/staff/FabioCuzzolin/> and <https://pal.cct.brookes.ac.uk/> respectively.

The two largest projects in the UoA also both have a website describing the progress of the research work. Information on the PEPPER project, managed by the project PI **Martin**, can be accessed at (<http://www.pepper.eu.com/>). Information on the Horizon 2020 project SARAS, for which **Cuzzolin** is a co-partner, is publically available through the project website (<https://saras-project.eu/>).

Staff make open datasets for non-confidential data generated in research projects. For example, **Ball** has made the data generated in tests carried out in Guildford, UK to measure roadside parking spaces with a mobile sensing system available as an Open Dataset (DOI: <https://doi.org/10.24384/dkha-9n48>) and the dataset for **Harrison's** paper, *Learning to classify software defects from crowd* has been published and will allow other researchers to develop medical diagnostic decision-making tools.

The research integrity of the unit is overseen by the University's Research Ethics Committee whose membership brings cross-faculty researchers (staff and students) together members external to the University. The faculty has a dedicated Ethics Officer responsible for reviewing projects and liaising with appropriate university committees. Good practice concerning data protection, privacy, and the involvement of human participants is shared among staff through a Research Committee where applications for ethical approval are shared and discussed.

## 2. People

### 2.1 Staffing Strategy, Support and Development

The unit's research activities are overseen by a Research Lead (RL, **Ball**) who has overall responsibility for strategy and management, working closely with the Postgraduate Tutor (PGRT, **Olde Scheper**) and the Research Centre Leaders to ensure effective liaison with the postgraduate community. **Ball** and **Olde Scheper** represent the staff on the Faculty RKE Committee, chaired by the Associate Dean (AD) RKE. All researchers complete a Personal Research Plan (PRP) every May, in consultation with the RL. This enables staff to identify research goals in keeping with their career stage and the unit's strategic priorities and to identify how their research impact could be enhanced. PRPs are considered by the RL, Head of Department and Faculty ADRKE, and feedback is provided to guide each researcher. The amount of time allocated to staff for research is determined in accordance with the university's workload planning framework. At every stage, EDI issues are taken flexibly into account.

The UoA provides support for ECRs by providing a mentor (e.g. **Olde Scheper** for **Kamarudin** and **Dehghanniri**, and **Rolf** and **Cuzzolin** for **Rast**) for both teaching and research. The researchers are also encouraged to work with teams within the Research Centres. ECRs are also guided through the 'Your First Three Years' scheme as described in the IES. This provides training and guidance for early career researchers to establish a research career. ECRs are also allocated time to develop their research as part of the workload planning process coordinated by the Head of School.

There are a range of opportunities for both ECR and mid-career researchers to bid for internal funding to support their research. Examples of the schemes that have been available and where they have been used over the period 2014-2020 are shown below.

- University 'Next 10 Awards' - **Cuzzolin** received this award from the university in 2014 which provided a scholarship for a PhD student with a value of £60,000. The resultant project produced excellent work on action recognition which has been a key factor in stimulating the growth of Cuzzolin's research activities over the last 5 years.
- Central Research Funds (CRF) – **Bayley** and **Zhu** received an award of £20,000 to work on Cloud computing and Big Data which has led to further work on cloud-based software.
- CRF Research Excellence awards - **Ball** received an award of £20,000 to complete research publications resulting from a PhD project on heterogeneous wireless communications and mobile sensing.
- CRF 150<sup>th</sup> Anniversary studentship awards - **Olde Scheper** was awarded £60,000 for a PhD studentship on 'Criticality control of insulin release'. **Martin** received an award of £60,000 for a studentship to work on case based reasoning.
- Faculty funded PhD studentships – **Olde Scheper** was awarded a PhD studentship on Criticality Gait Analysis (£90,000) and **Zhu and Bayley** were awarded a £90,000 studentship on AI Software testing.
- School awarded PhD studentships – These are used to stimulate new areas of research and particularly for ECRs. **Bayley**, **Kamarudin** and **Dehghanniri** were awarded £60,000 for a PhD studentship on cybersecurity, **Cuzzolin** and **Bradley** were awarded a £90,000 PhD studentship on autonomous technologies, **Rolf** was awarded a £60,000 studentship on deep reinforcement learning based on temporal goals.
- HEIF funding - **Olde Scheper** was successful in applying for £185,000 to work on bio-inspired rate control of chaos. This project has resulted in a patent being granted in the EU, US and Japan.

Faculty funding is also available to support staff in realising impact as described in Section 1.4. In addition, a budget of £20,000 is made available to the research centres for research expenses such as travel to collaborators and conference attendance, which all staff can apply for. This provides an opportunity for staff to present their work and facilitates networking.

The recruitment of new staff is described in Section 1.3. There have been three academic staff promotions over the last 6 years. **Crook** was promoted to Professor in recognition of his leadership role within the university; **Cuzzolin** has been promoted from Reader to Professor in recognition of his outstanding research, including world leading work on action recognition; **Younas** was promoted from Senior Lecturer to Reader in recognition of his contribution to teaching and his research on data analytics, web and cloud-based systems and services and his collaborations with co-workers around the world.

Succession planning is facilitated through the structure of the Research Centres and their constituent groups. When staff have established an area of research, a new group can be formed e.g. **Cuzzolin** - **VAIL**, **Wild** - **PAL**. When a group leader is promoted, a member of the group is able to progress to group leader e.g. **Olde Scheper** – **AIR**, taking over from **Crook**.

Over the assessment period, the UoA has had 10 PDRAs funded by the Horizon 2020 project SARAS, the Horizon 2020 PEPPER project and the Leverhulme Trust projects on Machine Theory of Mind and Self-Repairable Memristive Gas Sensor Arrays. There has been one Research Fellows (RF) funded by the Faculty (2019). Of the 11 post-doctoral positions, 2 are women reflecting the national percentage of women in computer science, and 6 are from a BAME background. We are making a concerted and co-ordinated effort to address the gender and ethnicity balance through our involvement in the Athena Swan and Race Equality charters. The Faculty to which UoA11 belongs has Athena Swan Bronze, which will be submitted for renewal in 2021.

RFs and PDRAs play an important role in the UoA research; they bring experience from previous posts and play a key role in the successful delivery of the projects. For example, **Cirstea**, employed under the Leverhulme Trust project on Machine Theory of Mind, came with a very strong background in reinforcement learning and inverse reinforcement learning that made him a very valuable addition to the team. **Skarga-Bandurova** is working on the EU funded SARAS project; she is an experienced researcher who was head of department in her previous university and has greatly helped with the management of the project. Within the UoA, PDRAs and RFs contribute to seminars, which are given on a bi-weekly basis throughout each semester and to research group discussions. They are also given the opportunity to do some teaching, which can be beneficial to the development of their academic careers. Of the PDRAs that have reached the end of their contracts, one has moved to be a PDRA at UoO, one has joined Trip Advisor as a Senior Software Engineer and one has taken a software position in the USA.

## 2.2 Links with Industry

Several good connections with industry have been established through KTP projects. **Cuzzolin** (Metavision, Createc), **Ball** and **Ou** (Clearview Traffic), **Rolf** and **Olde Scheper** (National Heritage, Blenheim Estate), **Crook** and **Rolf** (Moorcrofts LLP). In addition to KTPs, **Ball** worked on a project with Ethos Valuable Outcomes and **Cuzzolin** has been awarded funding from Huawei for consultancy (0.2 FTE) and support for a RF and a PhD Studentship. Additional links with industry have been established through the School's Industry Advisory Board. Members represent a cross section of the computer science industry and provide guidance and advice on both teaching and research.

The support within the university for establishing links with industry is described in Section 3.2.

Through our contacts with industry we have received equipment to support our research. **Wild** received samples of HoloLens from for his work on AR and **Cuzzolin** received a hardware grant of £650 from NVIDIA for a Titan GPU card to support his work on action recognition.

## 2.3 Research Students (PGR)

The university has a strong doctoral student culture and this is coordinated at the School level by the Post Graduate Research Tutor (PGRT, **Olde Scheper**). We are focussed on creating opportunities for our PhD students to develop the necessary experience to equip themselves for future academic or technical careers. All PGR students are given the opportunity to provide teaching support through lectures, tutorials and laboratory work. The majority of research projects involve the use of software tools for simulation and analysis which are commonly used in industry, so students gain skills which are highly valued by employers.

All PGR students are members of the Graduate College which is a student community coordinated by the university's graduate office. Within the Faculty, the UoA fosters close and supportive links between staff and PGR students, which are further developed through the faculty's programme of events. All students are involved in the Faculty's Doctoral Training Programme, which provides a programme of professional development and careers training. The supervision team are available to provide technical guidance and advice on the direction of research; all students produce an annual report and have an annual appraisal organised by the PGRT who monitors the overall progress of the project and the training to ensure progress is appropriate for a timely completion. All postgraduate research students have an opportunity to present their research work at the Faculty Research Festival which is held in May each year and is co-ordinated by a team of students.

Over the period 2014-2020 there have been 18 PhD completions, which compares to 14 over the previous REF period 2009-2014.

We are very proud of the record of the career progression of our PGR students. We believe that the research environment has played a significant role in this success due to the quality of the technical training as well as the mentoring provided for all students. Students that have completed their PhD with supervisors in **ISERC** have been employed with Samsung Research Centre in the USA and as PDRAs at Stanford University, ETH Zurich and UoO. Students that have completed their PhD in **DSERC**, now have roles as Head of Microcontroller Series Development Group at Continental AG Automotive Industries group in Germany, Senior Software Engineer at Trip Advisor, Data Analyst at Deductive and Senior Analogue Verification Engineer at Infineon Technologies; this alumnus also now serves as a member of the School's Industry Advisory Board.

PGR students have also been recipients of awards as a result of their research excellence; a student with **Olde Scheper, Martin** and **Aldea** received the best poster award at Womencourage 2019 for her work on diabetes management. In **VAIL**, a student supervised by **Cuzzolin** won the reading group prize at the 2015 International Computer Vision Summer School (ICVSS) and a team of students secured 2nd place in both the 2016 and 2017 Computer Vision and Pattern Recognition (CVPR) activity detection challenges.

#### 2.4 Equality and Diversity

Advancing equality of opportunity for all researchers, and a concern for equality and diversity, is embedded into our University systems and structures as detailed in our Code of Practice, and the IES (Section 3).

Of the 23 (by headcount) eligible staff in UoA11, 18 have significant responsibility for research (SRR) (17.3 FTE). Of the 17.3 FTE with SRR, 17% are women reflecting the current proportion of women in computer science nationally (15%); 75% of eligible women have SRR. In addition, 23% are from a BAME background; this compares to the national average for engineering and technology of 23%. Our EIA showed no significant difference in those with SRR by any of protected characteristics including gender and ethnicity. Equally, there were no differences in the selection of outputs by gender, ethnicity or other protected characteristics. As stated in Section 2.1, we are making a determined effort to address the gender and ethnicity balance through our involvement in Athena Swan (Faculty Bronze) and the Race Equality Charters (Institutional application planned for 2021).

We are endeavouring to attract more women into computer science through summer computing workshops run by **Aldea, Kamal** and **Martin**, who introduce the subject to women students in a friendly environment. The events include programming and the design of wearable technologies.

Of the 18 PhD completions, 18% were women; this compares to the national average of 17%. In addition, 76% of these PGR students were from BAME backgrounds, which is significantly above the UK average (27%). Six of the PhD students were funded by university scholarships. We are pleased to report that, of the current cohort of 13 PGR students, 46% are women, which is showing a positive trajectory in terms of gender equality and we hope that this will encourage more women into computer science research in the future as more role models graduate.

### **3. Income, infrastructure and facilities**

#### 3.1 Income

One of the strategies for the UoA over the period 2014-2020 was to 'increase external funding' (Section 1.3). The unit has had notable success over this period with over 50% of the staff submitting bids for external funding. A process of internal peer review of funding proposals has been introduced to improve the quality of the proposals and to share good practice.

The total external funding spend over the current REF period was c.£2,350,000, which compares to c.£1,000,000 over the previous REF period.

The major sources of external funding are as follows, noting that a number of the recent awards will realise research spend over the next REF period.

#### Awards in ISERC:

- **Cuzzolin:** Horizon 2020 project SARAS (Smart Autonomous Robotic Assistant Surgeon) €596,073. More details of this project are given in Section 4.1.
- Knowledge Transfer Partnerships (KTP) with Meta Vision LTD (£143,000) and Createc (£190,000) – see Section 2.2
- A three-year research agreement on complex activity recognition from videos with Huawei Technologies Canada (£278,000)
- A Leverhulme Trust award £273,000 for research on Machine Theory of Mind.
- **Cuzzolin** is also a Lead Team member and advisor for the recent £1,257,000 Research England UEZ-funded Oxford Brookes Artificial Intelligence & Data Analysis Incubator (AIDA), which is led by **Crook** and is co-funded by Oxford Brookes for an additional £654,000.
- **Wild** received EU funding for projects directed at the application of augmented reality and performance augmented learning:
  - Wearable Experience for Knowledge Intensive Training (WEKIT), (c.€280,000)
  - Textile & Clothing Business Labs (TCBL), (c.€401,000)
  - Learning Analytics for Augmented Reality (LAAR), (c.€58,000)
  - Augmented Reality for Formal European University Education (AR- FOR-EU), (€78,800)
  - Augmented Reality Interactive Educational System (ARETE), (€342,000)

#### Awards in DSERC:

- **Martin** is the PI for the H2020 collaborative research project 'PEPPER' (Patient Empowerment through Predictive PERSONALISED decision support) (2016-2020). The project has total funding of c.€3,500,000 with €643,000 for OBU. More details of this work are given in Section 4.2.
- **Martin** was also part of a GCRF Royal Academy of Medical Sciences grant of £59,700 (£12,000 to OBU) (2019 – 2020) for the project COORDINATES: (Cloud-Based Tool for diabetes management and research in Colombia). More details in Section 4.2.
- **Aldea** and **Olde Scheper** were awarded a Newton Institutional Link grant (£97,281 for OBU) for the CARDIGAN (Criticality Analysis of Diabetic Gait in Children) project. More details in Section 4.2.
- **Martin** has been awarded GCRF Innovate UK funding of £10,000 (total project £59,600) for a 6 month pilot study (2020) to study the acceptance of immersive technology as an educational tool for patients with diabetes. More details in Section 4.2.
- **Jabir** was awarded a Leverhulme Trust Research Project Grant: "MONITOR: A Self-Repairable Memristive Gas Sensor Array" (£234,000) See section 4.1 for more details.
- There have also been 5 KTPs with industry partners as described in Section 2.2

### 3.2 Infrastructure and Facilities

**Organisational infrastructure:** Research in this UoA is coordinated by the RL (**Ball**) and the Research Centre Leads (**Harrison** and **Ball**) supported by the Group Leaders. A PGRT (**Olde Scheper**) manages the PhD students.

The UoA is supported by the Faculty Research Support Office. This provides support for academic staff in the Faculty of Technology, Design and Environment to undertake high quality, high impact

research and knowledge exchange activities. It also supports the Faculty in the development and delivery of the strategies which lead to these activities. It consists of a Research Manager who provides a link between each UoA and the ADRKE, two Grants officers and a Research Administrator who provide information about available funding opportunities and support in the bidding process. The Research Support office supports the research programmes through regular RKE Committee meetings, an Ethics approval panel and a Grants approval panel. The Research Office also coordinates a mentoring scheme. The university Research and Business Development Office (RBDO) has an IP & Commercialisation Manager who works closely with all our researchers to identify and develop ideas to maximise patent and commercial opportunities.

The RBDO support a KTP Manager who establishes links between companies and research teams and supports the preparation of KTP proposals.

**Operational infrastructure:** Brookes IT Services maintain the university computer infrastructure. It also hosts workstations used for AI simulation in a secure, air-conditioned server room with uninterruptible power supplies for high reliability operation. ECM has an IT Technical Coordinator who supports the computing infrastructure for both teaching courses and research. The Estates and Facilities are managed centrally within the university but the School has a Technical Support Service Manager who coordinates facilities for the School and liaises with the central team. He also manages the technical support staff. The university library has a librarian dedicated to the School who maintains access to the key resources including publication databases.

**Facilities:** Each Centre has a dedicated laboratory for the research students. These laboratories were relocated into refurbished accommodation at the start of 2018 as part of a campus re-organisation. As the number of researchers in **Cuzzolin's** group has increased since 2018, a second laboratory was made available for **ISERC**. These dedicated laboratories provide an environment where students working with similar skill sets can interact and share their experiences. The staff that are associated with each Centre have offices close by the laboratories which encourages a close working relationship between all the researchers in each centre and maximises the opportunities for sharing information and expertise.

A new fabrication laboratory was established in 2018 to support courses and research which require hardware build and software integration. Two networking labs were set up in 2018 to support teaching and research into cyber security.

An eight GPU workstation (£34,000) was funded by the School in 2019 to support the work on action recognition including the work on the ICS for Artificial Intelligence for Saliency Detection and Action Recognition.

A dedicated laboratory was set up in 2019 for experimentation with Augmented Reality. This has cameras and AR headsets for testing AR algorithms. This infrastructure supported the ICS on Human Performance Augmentation.

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

##### 4.1. Collaboration

Collaboration with other groups and institutions both nationally and internationally has been one of the key factors in influencing the generation of impact from our research.

In **ISERC**, **Cuzzolin's VAIL** has been a partner in the H2020 project SARAS (Smart Autonomous Robotic Assistant Surgeon). This project partners are University of Verona, University of Ferrara, University of Catalonia, University of Dundee, Università degli Studi di Modena e Reggio Emilia, Ospedale San Raffaele, Medineering, Austrian Center for Medical Innovation and Technology. SARAS aims at developing the next-generation of surgical robotic systems that will allow a single surgeon to execute Robotic Minimally Invasive Surgery (R-MIS) without the need of an expert assistant surgeon. The design approach in this project will have significant impact for hospitals as it is to produce a cost effective solution being developed in this project will have a tremendous impact for hospitals as it will allow more hospitals to access this technology and reduce their operating costs. (<https://saras-project.eu/>). We expect that impact from this work will be realised in the next REF period.

**Cuzzolin's** international reputation in action recognition has led to his collaboration with Huawei's research lab in Vancouver. Action recognition algorithms developed under **Cuzzolin's** guidance have been selected for use in Huawei's mobile phones as described in Section 1.4. For this reason we have selected this work as one of the ICS for this UoA – see section 1.4.

**Cuzzolin** is also collaborating with Cambridge University on the Leverhulme Trust project 'Machine Theory of Mind'. This project combines the action recognition skills in Cuzzolin's group and the clinical neuropsychology knowledge of Sahakian (Cambridge) to investigate the next generation of action recognition techniques.

In the **PAL**, over the period 2014-2020, *Wild* has been working on five collaborative European projects listed in Section 3.1. These projects include over 20 partnering organisations in countries across Europe. *Wild's* work on **PAL** and his contribution to the IEEE specification for Augmented Reality Learning Experience Models (ARLEM, IEEE standard association working group p1589) could not have been achieved without this broad collaboration.

In the Dependable Systems Engineering Research Centre (DSERC), **Jabir's** Leverhulme Trust funded project on Self-Repairable Memristive Gas Sensor Array is in collaboration with the University of Rome. This project is investigating gas and chemical sensing properties of memristors and the collaboration combines the circuit design knowledge of Jabir with the fabrication facilities in Rome.

Additional (interdisciplinary) collaborative projects are described in Section 1.5.

Our KTP projects are an important part of our collaboration with industry and these are described in Section 2.2.

#### 4.2 Contribution to the Economy and Society

The vitality and diversity of our research culture is demonstrated by the wide range of colleagues involved in developing impactful relationships with research users outside of academia.

Our healthcare related projects will have a significant impact on the general public in the coming years. For example, **Martin's** project PEPPER (see also Sections 1.5 and 3.1). This system provides a personalised decision support system using case-based reasoning combined with predictive computer modelling to enable patients with Type 1 diabetes to safely self-manage their condition. The project results and feedback from the trials indicate that the system has the potential to improve health outcomes for people with insulin-dependent diabetes. The long-term impact of

PEPPER is to contribute to the evolution of diabetes technology to increase the participation of the patient in the care process which could lead to a reduction in global healthcare costs.

**Martin's** project, Abledoc, shows how immersive technology can be used as an educational tool for patients with diabetes. **Martin's** project, COORDINATES is working with a hospital in Colombia to develop a Cloud-Based Tool for diabetes management. **Aldea** and **Olde Scheper's** project, CARDIGAN (Criticality Analysis of Diabetic Gait in Children) project is working with a children's hospital in Mexico (Obesity clinic, Hospital Infantil de Mexico Federico Guzman). It uses rate of chaos for gait analysis and the tests indicate that clinical intervention can be effective for improving the health of obese children. (See Sections 1.5 and 3.1 for additional information on these projects).

**Olde Scheper** and **Crook** have been champions for outreach to the local community. Over 50 presentations have been given to schools, churches, University of the 3<sup>rd</sup> Age and interviews on radio and TV. For example, **Olde Scheper** and **Hughes** gave a presentation on robotics to St Andrew's Church of England Primary School (January 2018) and **Crook** gave a talk on 'Robots vs Humans' to Magdalen College School and a talk on 'Robots of good character' to the University of the 3<sup>rd</sup> Age at OBU (23<sup>rd</sup> November 2015). Crook has also given several interviews on robotics on radio and TV such as 'Realistic humanoid robots and computer graphics', BBC World News, Global programme, 6th November 2014 and 'Comments on Autonomous moral vehicles', BBC Radio Oxford Radio 9th February 2018. **Olde Scheper** has given an interview on 'Artificial Intelligence' on BBC Radio Oxford (27 August 2017).

#### 4.3 Contribution to the research base

Staff contribute strongly to the process of research dissemination through their journal editorship e.g. **Harrison** is Editor-in-Chief of the Software Quality Journal and **Cuzzolin** is on the Editorial Board for IEEE Transactions on Fuzzy Systems. Staff also serve as conference chairs and on programme committees e.g. **Zhu** is a co-founder of the IEEE international Conferences on Artificial Intelligence Test (AI Test) and a general chair of its first edition held in San Francisco in April 2019, **Harrison** has served on the programme committee for the International Conference on Software Engineering (ICSE), **Younas** has served as Program Chair at the IEEE International Conference on Big Data Computing Service & Applications, California, USA, 2019, **Cuzzolin** was Program Chair of the 3<sup>rd</sup> International Conference on the Theory of Belief Functions (BELIEF 2014) and is a member of the Board of Directors of the Belief Functions and Applications Society (BFAS), which organises the BELIEF series of conferences.

Staff undertake reviews for a wide range of journals including: IEEE Transactions On Systems Man and Cybernetics Systems, Neurocomputing, IET Wireless Sensors Systems, IEEE Access, Information and Software Technology, Journal of Concurrency and Computation: Practice and Experience.

Staff are regular contributors at conferences, and have frequently been invited as keynote speakers e.g. **Wild** gave keynote presentations for European Space Programmes (2019) at ESA in Noordwijk, **Younas** gave an invited talk at IEEE International Conference on Big Data Computing Service & Applications, Bamberg, Germany, 2018, **Jabir** presented invited special sessions at the IEEE International Symposium on On-Line Testing and Robust System Design (IOLTS' 2019), **Cuzzolin** gave a keynote speech at several conferences including the International Conference on Computer Science and its Applications (CSA, 2016).

**Sustainability of the discipline:** Staff in this UoA make a contribution to the sustainability of the discipline through the development of new areas of research; **Cuzzolin** is a leading researcher in action recognition and belief functions, **Zhu**, **Harrison** and **Bayley** are developing the new techniques for software testing of AI, **Jabir's** work on circuit designs incorporating memristor technology provides opportunities for new and improved reliable system solutions and **Crook** has established the **Institute for Ethical AI**.

Staff also contribute to the research community through the peer review process; **Cuzzolin** is a member of the European Research Council, **Younas**, **Harrison** and **Cuzzolin** are Members of the of the Associate College of reviewers for EPSRC and **Crook** is an Expert Evaluator of EU proposals, a Reviewer of EU funded projects and a panel member for the UKRI Future Leader's scheme.