Institution: University of Sussex

Unit of Assessment: 11 – Computer Science and Informatics

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

The unit of assessment (UoA) is largely congruent with the Department of Informatics which continues the unique interdisciplinary research of the former School of Cognitive Science (COGS) at Sussex. We contribute to many areas of Informatics and our interdisciplinary work is underpinned by both the different disciplinary backgrounds of researchers within the Department and close collaborations with leading researchers from fields as diverse as Biology, Psychology, Engineering, and Humanities, including Philosophy and Ethics.

The Department is relatively compact with 28 (24.4 FTE) REF category A faculty, 24 RFs and 78 PhD students and it forms roughly half of the School of Engineering and Informatics. Additionally, we are including 3 (2.5 FTE) faculty into the UoA, from the cross-department Creative Technology group, who are affiliated with the Department of Engineering and Design. Members of the Department belong to one of three research groups, aligned to our research strengths:

- The AI research group (12.4 FTE REF faculty) with strengths in applied natural language processing (NLP), machine learning (ML), ethical AI, computational Neuroscience, complexity science, consciousness science and bio-inspired AI and robotic control,
- The Foundations of Software Systems group (FoSS) (5.2 FTE REF faculty) with strengths in code verification, foundations of programming languages and network communications,
- The Creative Technology group (CTG) (9.3 FTE REF faculty) with research strengths in human computer interaction (HCI), digital economy (DE), and technology enhance learning (TEL).

The groups have been evolved from four research groups presented in REF2014 to better align with our research and the continually changing external research landscape. The census data represents only a snapshot of a continuously developing picture and excludes four academics from the CTG who moved to University College London (UCL) in June 2020 and three new arrivals who joined the Department briefly after the census date. During the vast majority of the REF period the Department has seen steady growth in key indicators, which are slightly obscured by the REF-related CTG departures (Fig. 1).
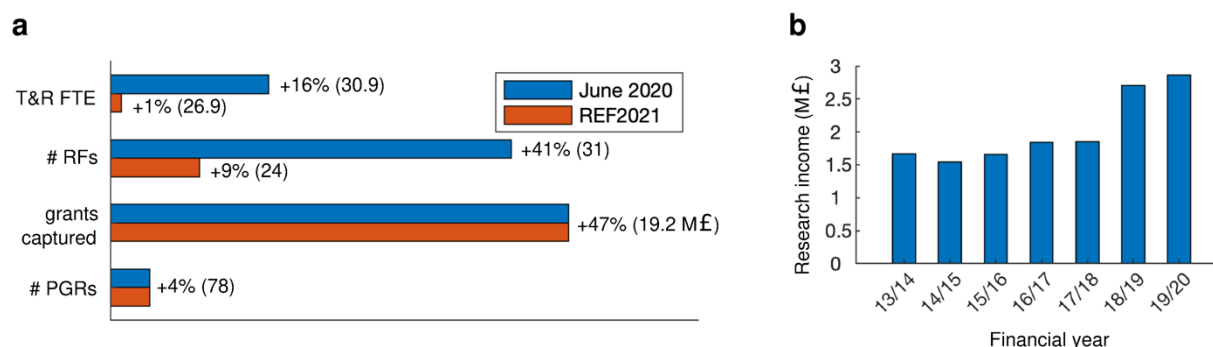

Figure 1: a) Bar chart of % change of key indicators over REF2014, visualising our upwards trajectory before the change in CTG (June 2020). After the departure of a part of CTG, the numbers look misleadingly more comparable to REF2014. The numbers in brackets are total values. b) Total research income per financial year (see REF4b) showing our growth trajectory.

Research strategy

The overarching strategic research aim of the Department is to advance knowledge in Informatics and related subjects by conducting world-leading basic and applied research, as exemplified by the main strategic research goals (SRGs):

SRG1: to contribute to the foundations of computer science and related areas;

SRG2: to develop and apply computational methods in science, industry, and society; and

SRG3: to pursue interdisciplinary research and help to establish computational techniques as core methodologies in other disciplines.

These SRGs have been stable since before REF2014 and reflect our desire to leave room for the academic freedom of individuals. This has enabled exceptional success in attracting original researchers who cannot be confined into narrow research labels. The general SRGs are underpinned by concrete strategies for improving our research environment:

- *We systematically foster interdisciplinary collaboration* and members of the Department direct four interdisciplinary research centres and are involved in several others, as described below.
- *We attract and develop leading researchers*, *train future research leaders* as post-doctoral research fellows and research students and while looking for the most talented, *we strive to improve equality, diversity and inclusion* with respect to gender balance as well as racial diversity and other characteristics. See Section 2.
- *We continuously improve our research environment,* both through strategic investment and by supporting grant capture, which has seen a 47% growth compared to REF2014, see Section 3.
- *We strongly engage with all research stakeholders* as detailed in Section 4.

The strategic direction in these activities is provided by the School Management Team (SMT), most relevant here, the Head of School (HoS), Head of Department (HoD) and Director of Research and Knowledge Exchange (DRKE), and the research committee, which is chaired by the DRKE and consists of research group heads and postdoc representatives.

The three research groups naturally embody our research themes. In the following paragraphs we describe their achievements and strategic aims and relate them to the plans from REF2014 and the SRGs described above.

The AI research group was formed in early 2020 by merging the Data Science group, itself evolved from the CALPS (Cognitive and Language Processing Systems) research group reported in REF2014, with the EASy (Evolutionary and Adaptive Systems) group. The two groups have undergone strengthening and renewal during this REF period. The strategic hiring of Quadrianto (Bayesian approaches to fair and transparent ML) at the beginning of the REF period was complemented by Weeds (NLP) and Simpson (computer vision).

Members of the group, led by Quadrianto, have developed ML algorithms that handle definitions of fairness while also delivering transparency in how they are met (EthicalML, BayesianGDPR projects) [SRG1]. They have also developed the MLS causal ML platform and applied it in India to design evidence based, effective, and acceptable interventions in post-natal care (featured in "AI and the sustainable development goals: the state of play: 2030 vision" by Sadowski and Powell-Tuck) [SRG2]. In collaboration with the Science and Policy Research Unit (SPRU) they also analysed the trade-offs between development, food security, and poverty and applied deep learning techniques to analyse trade-offs in peri-urban agriculture systems in China and India, and so informed urban sustainability policy (British Academy project) [SRG2].

Building on strands of research under development at REF2014, Weir, Weeds and Reffin have made continued advances in compositional distributional semantics, developed state-of-the-art methods for distinguishing ontological relationships based on word usage and developed an

innovative approach to creating larger training data sets [SRG1]. With scholars in the Sussex Humanities Lab, they have developed tools and methodological innovations enabling data-driven analysis of both modern and historical transcripts and records [SRG2]. Arising from a long-standing collaboration with the Demos think tank, Weir and Reffin have also set up CASM Technology LLP through which they conduct impactful research projects with users (over 20 contracts with industry and charities; see also the impact case study led by Weir) [SRG2].

The members of the former EASy group have continued from strength to strength following the directions planned in REF2014. Led by Seth, members of the Sackler Centre for Consciousness Science (SCCS) have performed world leading research on consciousness and, in line with REF2014 strategy, have extended it into clinical applications [SRG2] while also continuing strong theoretical strands [SRG1,3]. This effort was augmented by the strategic hiring of Buckley (predictive coding and its application in understanding biology and building better robots), Roseboom (advanced experimental design, statistical analysis, and psychophysics) and Barrett (complex systems analysis).

Other members of the group have expanded the work in insect olfaction (Nowotny, project grants from HFSP, Leverhulme) and bio-inspired robotic control and visual navigation (Nowotny/Philippides, Green Brain project, Brains on Board program grant) [SRG3] which involved a new strategic collaboration with Sheffield and led to the substantial additional "activeAI" project (Philippides), which augments collaborations with leading insect navigation researchers in Australia (Barron - Macquarie, Nordström - Flinders, van Swinderen – University of Queensland). This research is underpinned by strong leadership in GPU acceleration for spiking neural network simulations (GeNN) and relates to work in the EUR1Billion Human Brain Project (Nowotny) [SRG1,3]. Additionally, the research in the group has made great strides in applying complexity theory to medical applications and computer network reliability, leading to contracts with industry (Moogsoft, Aviva) and a strong collaboration with the FoSS group (Berthouze, Parisis) [SRG2].

In the future, the AI group will continue to work to its strengths in applied NLP, Bayesian approaches to ML and ethical AI, the understanding of consciousness, bio-inspired solutions to robotics and AI, underpinned by our unique expertise in GPU accelerated simulations, and expanding our research into applications of complexity theory and (bio-inspired) AI. These aims align with the UK Industrial Strategy (autonomous systems, AI, healthy nation).

The FoSS group develops theoretical models and applies them to software systems, with particular strengths in verification and networking. As outlined in the REF2014 strategy, the group has continued work on pervasive computing but with the appointment of Parisis the focus has shifted to reliable network protocols and network analysis tools in co-operation with industry partners Moogsoft (KTP) and OnApp. A novel and more appropriate model for Internet traffic volume has been defined during this REF period that can help service level agreement provisioning; and new protocols for data centres (MMPTCP) and opportunistic, information-centric networks using fountain coding have been developed [SRG1-2]. In the future, analysis will be enhanced by interdisciplinary work with data scientists (and the AI group), such that network configurations can be informed by ML algorithms [SRG1-3]. On the verification side, a first program logic for homogeneous generative run-time meta-programming has been proposed as well as type-safe implicit functions for message passing computation [SRG1]. Numerous contributions to abstract interpretation, effective verification and test generation for low-level software and reactive programs have been made [SRG1]. An interdisciplinary collaboration with immunologists at Brighton and Sussex Medical School (BSMS) was established to help with the need for automatic management of data processing in cytometry [SRG3].

Future FoSS activities will be centred around networking with an ML influence, reversible computing, distributed programming, (development of tools for the) analysis of the dependency of immune reactions on exact HLA amino acid sequences, and the impact of the univalence axiom in type theory (Homotopy Type Theory) which gives way to many applications for correct software development.

The Creative Technology research group (CTG) was formed by combining the Interactive Systems group with colleagues from the Department of Engineering and Design to form a first cross-department research group. We made a major investment into this area and made the strategic appointments of Subramanian, Martinez Plasencia and Memoli. The part of the group relevant to this UoA is working on acoustic meta-materials, visual representation of knowledge, TEL, graphics and media technology, DE, and multisensory experiences for HCI [SRG1-3].

The research has demonstrated world leadership in the area of acoustic meta-materials, including acoustic levitation, and the research in this area has expanded rapidly with substantive underpinning funding (RAEng chair of emerging technologies, ERC advanced grant, and 3 EPSRC grants, Subramanian; EPSRC fellowship, Memoli) [SRG1,2]. Novel interaction techniques involving mid-air touch, taste and smell stimulation have been developed and applied to HCI (ERC starting grant, ERC Proof of Concept, Obrist). Collaborations with creative industries and content creators resulted in successful exhibitions at Tate Britain (Tate Sensorium), the Science Museum (Multisensory Dark Matter), and the World Economic Forum 2019 (TreeVR) [SRG2].

The TEL theme has grown during this REF period, with research foci including game-based learning techniques for programming, video- and voice-based techniques, and technology support for people with disabilities. This has led to new collaborations with partners from academia and external agencies, producing novel outcomes, including a new methodology for conducting participatory design with children with autism (Good) [SRG2]. Other work strands in the group are addressing voice user interfaces in smart home contexts and the visual representation of knowledge, the latter investigating the nature and use of representational systems from the perspective of cognitive science [SRG1-3].

The graphics and media technology theme has continued its research as planned in REF2014, including work on learning-based content production, digital heritage, real-time graphical simulations and virtual environments, DE, mobile and gaming technologies. Achievements in these areas include new interactive technology at the V&A and other major international museums [SRG2].

With the departure of Subramanian, Obrist, Plasencia and Maggioni, the activity around haptic and olfactory interfaces has moved away from the Department, though core research expertise in acoustics, such as acoustic properties of ultra-silent tyres and perception of noise, remain (Memoli). We are planning to rebuild and strengthen CTG with new hires after the COVID crisis. Other strategic future directions for CTG are continuing research related to TEL, knowledge representation, cross-modal interactions in HCI and HCI design for a variety of applications, from healthcare to DE.

Interdisciplinary Working across Departments and Schools

Interdisciplinary working is a particular strength of the Department. Members of the AI group direct four interdisciplinary research centres: DISCUS (Data Intensive Sciences Centre University of Sussex; co-director Weeds), SCCS (co-director Seth), the Cognitive Sciences Centre (COGS; director Chrisley), and the Centre for Computational Neuroscience and Robotics (CCNR; co-directors Nowotny, Philippides). In DISCUS researchers from Physics, Mathematics and Informatics apply expertise in big data analysis to novel, interdisciplinary problems. The SCCS performs research into measuring consciousness, exploring the nature of conscious experience and applied work on disorders related to disruptions of consciousness. COGS is interested in all aspects of cognitive sciences and the CCNR covers research in computational neuroscience, bio-inspired AI, and autonomous robotics.

The AI group also has several active collaborations with the Sussex Humanities Lab, which explores the role of digital technologies in the Humanities. Many of these collaborations revolve around NLP. Group members also deeply involved in Sussex Neuroscience, a University

Research Programme with over 250 members, enabling world leading research in the Neurosciences.

As a cross-departmental research group, the CTG is quintessentially interdisciplinary and works across Informatics and Design. It also works with collaborators from the Arts (see Tate Sensorium), the Business School and Psychology. Members also benefited from collaborations sponsored by the Sussex Sustainability Research Programme.

The FoSS group is less interdisciplinary but nevertheless has links to Mathematics relating to complexity science and graph theory and links to research users in industry (MoogSoft).

Impact Strategy

Excellence and impact are at the heart of every research activity in the Department. With support and oversight from the research committee, the DRKE, HoS and HoD are in charge of implementing our impact strategy, establishing goals and policies, and ensuring appropriate support. During the REF period we have created the new role of Academic Lead for Impact (currently Berthouze), who assists with realising and documenting impact opportunities. This work is recognised in the workload model and we generally recognise impact work in promotion considerations.

Our strategy for achieving research impact is inclusive, supporting research impacts in all potential forms. For instance, during the REF period, our work has achieved changes in public perception through outreach and public engagement; and as economic impact through spin-out companies, contract research for industrial partners, and a large number of consultancies for local industry and government. Our impact case studies were selected as particularly striking examples of impacts from this wide portfolio based on a systematic selection procedure including independent reviews and several steps of long- and shortlisting:

- The "Inspiring new understanding and engagement with the Science of Consciousness" (Seth) case study demonstrates significant impacts with worldwide reach in changing public perception and understanding of consciousness.
- "Improving efficiency and effectiveness in patient identification for clinical trials" (Beloff) is an excellent example of economic impact with industrial partners.
- "Enabling better informed government, public and private sector decision-making around social media content and public safety" (Weir) showcases our far-reaching and significant impacts in policy- and decision making in public bodies as well as industry and wider society.

We recognise three main factors as being necessary for supporting impactful research: (1) establishing and nurturing relationships with non-academic beneficiaries; (2) securing resources for activities that facilitate the realisation of impacts; (3) training, supporting and rewarding staff who carry out impact-related activities.

We use a number of methods to *establish relationships with non-academic beneficiaries* with the objective of achieving impact. For instance, we have extensive educational collaborations, mostly in the form of student placements, which allow supervising academics to form deeper relationships with companies and their staff. Members of the Department also engage with industry/academia networking events. For instance, Light has worked with Digital Catapults in both London and Brighton and Nowotny, Obrist, Philippides and Subramanian have presented at the Fuse Box coffee mornings, a networking event organised by the Digital Catapult in Brighton. Nowotny participated in the driverless car roundtable at the British Science Festival 2017 and was a delegate to the Huxley Summit.

Another form of engagement is the use of one-on-one meetings with industry. The University has a directory of research expertise and our faculty is listed with appropriate keywords. We regularly receive queries from interested industrial partners and organize personal meetings to

explore shared interests. Examples during this REF period have included Intel, Southern Water and Huawei, and, for example, the meetings with Intel and Huawei have directly led to contract research.

Having identified and developed relationships with potential non-academic beneficiaries, we *secure resources to support the development of impact*. We use a range of mechanisms, short to long term, depending on how far the research is from application. These include: Innovate UK research projects, UK Research Council and EU projects (see section 3), consultancies, user-funded contracts, Knowledge Transfer Partnerships, spin-outs and numerous outreach activities (see Section 4), as well as internally funded pump-priming, e.g. using a budget allocation from the Higher Education Innovation Fund (HEIF) to fund activities for creating seeds of new impact (Obrist) or strengthening existing areas of strong impacts (Weir, Beloff, Wakeman).

The final element of our approach is to *train, support, and reward academic staff for achieving impact*. Implementing University policy, we recognise the value of consultancies in supporting impact; and so, for consultancy activity facilitated and recorded by the University, members of staff have the option of taking 85% of the fee as salary or using it to support their research. Excellent performance in achieving impact is recognised through promotion and salary bonuses; for example, during the REF period, two promotions were strongly supported by evidence in the area of impact (Wakeman, Memoli).

Our impact strategy has been very successful with a sharp increase in measurable impacts since REF2014 as described in our impact case studies and in Sections 3 and 4.

Open Science

The Department is engaging strongly in the Open Access/ Open Science agenda against the known financial pressures and legal resistance from publishers. 90% of our submitted outputs, and 63% of all our outputs in the REF period (73% of outputs 2016 and later) are open access, either gold, green, or hybrid solutions (source: Scopus). Nowotny helped setting up SURE, the figshare based Sussex open data repository, and members of the Department (Philippides, Husbands) were the first to deposit datasets in it. Several of our researchers are developing software packages as part of their research activities. These are published under Open Source licences as standard, unless there are IP implications; see Section 4 for details.

Members of the Department working in relevant areas are also keenly aware of practices for reproducible science. Indeed, Nowotny has even published on the issue of correct validation in machine learning (DOI: 10.3389/frobt.2014.00005).

Ethics and Professional Standards

Research ethics and adherence to professional standards are second nature to the Department. This starts from how we educate our students, with stringent ethical approval processes for final year or MSc projects and continues throughout all our research activities. Implementing University policy, all research involving animals is subject to a full ethically review and we support the three R's (Replacement, Refinement & Reduction of animal experimentation), typically by minimizing animal sacrifice through substituting computational methods.

At a different front of ethical challenges, our researchers are all trained and follow best practice for data protection, including bespoke GDPR training. Researchers in the most vulnerable research topics around the use of Twitter data and related areas, have regular meetings to discuss ethical concerns.

Going beyond "just" adopting best practice in data protection and ethical research, the ethics and fairness in AI are also active research topics at the Department (Quadrianto).

2. People

Employment Strategy

The Department's employment strategy is designed to strengthen and develop the research groups described above, in order to build on and complement existing strengths. New appointments are made with a particular focus on cross-disciplinary working, matching the interdisciplinary ethos of Sussex and the Department.

Implementing our strategic aims described above, we have hired emerging leaders from leading institutions (e.g. Quadrianto – Cambridge, Buckley – RIKEN, Memoli – Imperial, Schrammel - Oxford) and industry (Simpson - Anthropics Technology, previously UCL), who thrive in our vibrant and supportive research environment, build substantial research teams and attract research funding, for instance Quadrianto: ERC starting grant & grants from the Surgo Foundation, Buckley: BBSRC new investigator grant, Memoli: EPSRC Innovation Fellowship, while Schrammel is currently partially seconded to diffblue, a very successful spin-out company he co-founded. All of the submitted REF faculty are on permanent contracts.

The departures of Subramanian, Obrist, Plasencia, Maggioni and 7 PDRFs, while regrettable, are another clear indication of the success of our strategy. The group came together at the Department during the REF period and have now grown to leaders in their field, forming a world leading research group at UCL.

Equality, Diversity, and Inclusion

Equality, Diversity, and Inclusion (EDI) are at the core of all we do, but most particularly in our approach to people in the Department. We are improving equality and diversity because it is the right thing to do, but also because it improves our research environment. The University procedures for advertising and appointing to posts have equality built in, as do the promotion and staff-development procedures. In addition, every member of staff with responsibilities for recruitment receive mandatory equality and diversity and unconscious bias training. We follow best practices in our advertising and portrayal of the Department, including gender neutral language and diverse visual materials.

We have made progress in some areas while others remain challenging. During the REF period, 13 permanent staff were appointed of which 3 (23%) were women, coincidentally the exact same fraction as women in the REF faculty. While this compares well against the worldwide average for tenure track faculty in Computer Science (15% female, Way et al.), we strive for further improvements. On the positive side, women thrive in the Department - from 17 promotions during the REF period, 5 were of women (30%) and one out of three impact case studies is led by a woman (Beloff).

Sussex is a member of the Athena SWAN Charter for the advancement and promotion of the careers of underrepresented groups in STEM subjects; the School of Engineering and Informatics holds an Athena SWAN Bronze award, which was successfully renewed during the REF period. This was enabled by a standing Athena SWAN committee for EDI monitoring, which was recently complemented by an EDI committee for the development and implementation of EDI policies. During the REF period, the University became a Stonewall Diversity Champions member. The Department implements the University's supportive policies, including above-standard maternity/paternity leave arrangements and "flexible working by default".

Outputs for the REF submission were selected in an equitable, data driven manner. All outputs were reviewed by at least one independent external expert and the final selection was performed by a REF panel consisting of the HoS, DRKE, impact lead and heads of research groups, all of whom have received mandatory EDI training. The final selection was audited with respect to EDI by the SMT.

Staff development

Staff development occurs at a formal Departmental level and more informally within the research groups. All staff have an annual appraisal, which is used to identify research goals and strategies aimed at career development. Goals and targets are set to reflect each individual's career trajectory, with an overall aim of achieving and maintaining research of significant international influence. The University's Staff Development Unit supports this activity and provides a comprehensive programme of courses for enhancing research and professional skills which are fully compliant with The Concordat to Support the Development of Researchers. The University's Research and Enterprise Division also runs regular training courses, which are often led by external specialists. The Department normally operates a sabbatical scheme for all academics with the aim of allowing for one term sabbatical leave each seven terms, though currently paused due to COVID.

Early career researchers are supported by the same mechanisms and in addition are assigned a senior academic as a personal mentor. All new permanent staff have reduced teaching loads, no substantive administrative roles, and research equipment set-up funds. They also receive funding for a first PhD student in addition to any other start-up funds. To help sustain and further encourage strong engagement in research, the management of funded research projects and PhD students is factored into our workload allocation model.

Collaborative and peer support
Staff development at all levels is greatly enhanced by a supportive and collaborative culture within the research groups, enabling the exchange of ideas and best practice. This culture allows privileged access to research resources, as well as the extensive national and international networks of senior members of the Department (see Section 4). The success of this approach is evidenced by the fact that during the REF period more than 95% of staff had co-authored research outputs within the Department, 94% nationally, and 90% internationally.

Developing income capture skills
The Department runs a rigorous internal review process for all external grant applications. This allows less-experienced staff to rapidly develop grant-writing skills under the guidance of senior colleagues. Annual School research away-days enhance the research environment and provide support to staff through targeted activities. Each away-day has a different focus, with topics ranging from identifying funding opportunities, to writing successful grant applications and maximising the impact of outputs.

Members of the Department have benefited greatly from university-wide initiatives aimed at research pump-priming (14 successful applications for the Sussex Research Development Fund). In addition, the Department has a conference travel fund and discretionary periods of sabbatical leave can be granted to develop new collaborations and grant proposals.

Evidence of the success of our approach to career development can be seen in the career paths of staff who joined as early career researchers (Buckley, Howland, Memoli, Obrist, Quadrianto) at the beginning of the REF period and have since had multiple external grant successes and have been promoted (Obrist to Professor, Quadrianto to Reader, Buckley and Howland to Senior Lecturer). This compares to a total of 11 promotions in the REF period, three to Senior Lecturer (Buckley, Howland, Quadrianto), three to Reader (Obrist, Parisis, Quadrianto), and five to Professor (Berthouze, Good, Obrist, Philippides, Wakeman).

Applications for personal research fellowships are actively supported as part of our staff development strategy and many of our staff have been successful recipients of fellowships (see section 3).

International outlook
The Department's strong international reputation is reflected in the volume of international movement of staff (incoming and outgoing) and the high number of visiting scholars from

overseas, all of which enrich the research environment and build lasting international collaborations. More than 35% of our faculty originate from countries outside the UK, 10 (32%) currently have non-UK nationalities. At any one time, we typically have 10 visiting scholars from around the globe. 73% of our current PGR students come from outside the UK and they have 18 different nationalities.

Postgraduate Research Students

The Department greatly values its post-graduate research students who, as in most science disciplines, play an essential role in realising research projects and contribute strongly to our outputs. PGR training is guided by the University's 'Principles to Govern Doctoral Studies', supported by the Sussex Doctoral School and complemented by local support in the Department. We have slightly grown the number of PGRs in the Department from 75 reported in REF2014 to 78 currently, and this means there are 2.8 students per FTE REF faculty. Some of these will be co-supervised by faculty from other units as will faculty in the Department co-supervise students at other Departments across Sussex. Student financial support comes from EPSRC DTA, a Leverhulme DSP (Seth), Sussex Neuroscience, the Department, and individual research grants (e.g. Leverhulme projects). We also have a good number of self-financed students.

Research training of doctoral students occurs at three main levels: (1) Specific training related to students' research within each research group, drawing upon the on-going research activity of typically two supervisors and intensively supported by research fellows and experienced fellow students. Students have at least one formal supervision meeting per month (usually many more), which the student minutes. (2) Participation in the Doctoral School's provision of transferable and professional skills training, based on individual assessments, is expected of all candidates. (3) The Department runs its own two-term research-training module for first-years which focuses on skills at a level designed specifically to bridge the gap between the necessary specificity of (1) and the generality of (2).

PGRs undergo a stringent annual review process with a PhD committee to monitor and support their progression. The arrangements for doctoral studies are overseen by the Director of Doctoral Studies and the University's Student Life Centre provides co-ordinated access to a full range of study, personal and financial support services.

3. Income, infrastructure, and facilities

Funding Sources

Research in the Department is funded from diverse sources, ranging from traditional research funders, such as UKRI and the European Union Framework Programmes, over charities, such as The Leverhulme Trust and the Human Frontiers Science Program, to industrial partners and philanthropic donations. Fig. 2 gives a breakdown of the funding secured over the REF period detailed by funder type. Academics from the Department have secured more than £19M in research funding, in 98 research projects, including large and/or prestigious fellowships (Subramanian RAE chair in emerging technologies £1.3M, Seth, Wellcome Trust Public Engagement Fellowship £167K, Nowotny RAE Advanced Research Fellowship £45K), personal grants (Obrist ERC starting grant £1M, Quadrianto ERC Starting Grant £1.2M, Subramanian ERC Advanced Grant £1.9M) and a program grant (Nowotny/Philippides EPSRC program grant £1.6M to Sussex (£4.8M total)) as well as co-leading a £1.1M EPSRC Network Plus (Light) and a PGR training centre (Seth, Leverhulme DSP, £1.1M).

Another source of income is consultancies, of which faculty undertook more than 25 during the REF period (Weir, Reffin, Weeds). Industrial funding came also as contract research from partners including Intel, Moogsoft, NVIDIA, Huawei, OCULUS VR, and Jaguar Land Rover (see

Section 4). This evidences a vibrant research environment in which projects and consultancies of any scale can be achieved and are welcomed.

Future research funding

Our research environment is well-secured for the future, as we are particularly well aligned to elements of the Industrial strategy and the UKRI delivery plans 2019. For instance, EPSRC will "invest in calls on natural language processing and software engineering, which are essential to adoption of artificial intelligence (AI) technologies [...]" (EPSRC delivery plan p3). Our work on NLP in the AI group feeds directly into this. Further, EPSRC wants to "explore [...] opportunities to research the 'body-technology interface' (EPSRC delivery plan p4), which directly relates to the work in the Creative Technology group. More generally, much of the work we do in the AI group feeds into the Data Science and AI Grand Challenge and the work of the FoSS group into the theme of resilient nation. In addition to these strategic opportunities, we have also already secured substantial funding for the coming years: £2.9M (2020-21), £1.8M (2021-22), £1M (2022-23), including another Leverhulme DSP for 7 years led by Nowotny and Philippides with Graham in the Life Sciences, £1.4M.

Research grant capture is supported by a team of research development officers working centrally in the University, from which we have a dedicated officer at the School level. Once grants have been received and accepted, they are handed over to the post-award team who support academics in all aspects of running the grant and reporting on it.
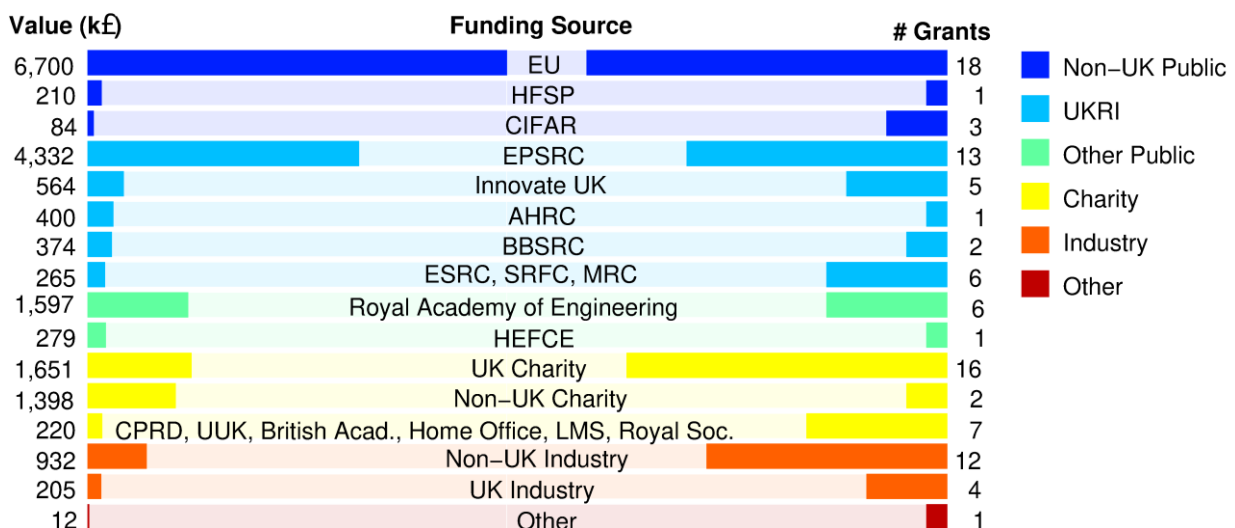

Figure 2: Research grants captured within the REF period, a total value of £19,221,793 in 98 grants.

Research equipment and facilities

The AI group has three large general computing labs with specialist hardware and software (including space for the four research centres they (co-)run – DISCUS, CCNR, COGS and SCCS – see Section 1b above), two labs with specialist robotics equipment, including motion capture for flying robots and a large 3D gantry robot for "simulated flight", and a dedicated shielded EEG/TMS laboratory, which uses 64-channel waveguard caps (ANT Neuro) and a VISOR2 neuro navigation system, allowing precise TMS targeting of brain regions based on individual structural MRIs. Further facilities include a state-of-the-art virtual reality laboratory, equipped not only with standard VR but also augmented and substitutional reality environments. The AI group also makes extensive use of (and partly funds) neurophysiological facilities in Life Sciences, the University's fMRI facilities (Siemens 3T and AVANTO 1.5T scanners with MRI-compatible EEG, near-infrared spectroscopy (NIRS), and eye-tracking devices and a wide range of MRI compatible physiological measurement devices including pulse oximetry, and respiratory and cardiovascular monitoring), and EEG facilities in Psychology.

FoSS has a group of flexible computing and computer network research labs.

The CTG combines several research lab spaces and interlinks with the product design facilities of the Department of Engineering and Design. The Multimedia Technology Lab brings to the group two TV studios with up-to-date multimedia editing facilities, high end A/V recording and post-production equipment enabling the exploration of novel video based and distant learning approaches. The Representational Systems Lab has dedicated facilities for behavioural research on the reading of tactile displays, writing and drawing, and eye-movement recording.

The product design team has further established a design studio for physical computing and material explorations that includes the latest textile fabrication equipment and 3D printers.

All groups make use of the University's HPC cluster and data centre, parts of which were purchased by the Department.

Investment in research infrastructure

Since 2014, the Department has made substantial investments in research infrastructure. In the last REF period, the Department had consolidated into one main building (Chichester I Building on the Falmer Campus of University of Sussex) with some additional spaces elsewhere. During this REF period the Chichester I building was completely refurbished (£11M, of which 50% was invested centrally by the University) including network updates and completely refurbished computing labs. This also included the creation of a flexible research and teaching space – the Future Technologies Lab, opened in 2017 by Jo Johnson, the Universities minister at the time. In late 2019, Sussex also became a partner in the Tier 2 JADE2 supercomputing facility in a consortium led from Oxford (Nowotny is Sussex co-I) and members of the AI group have access to the Jülich supercomputer centre through collaborative compute time proposals.

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

Academic collaboration

All academics in the Department have at least one collaboration, typically many more and at scales from local (within groups, within Department, School) to global (e.g. Human Brain Project with 120+ partner universities, HFSP global collaboration, ActiveAI grant with Australia). These collaborations are enabled and supported centrally by an excellent research development office, a contracts team to support collaboration agreements and other contractual arrangements, and a post-award research finance team. All teams have extensive knowledge and experience of collaborations, both academic and industrial.

Many of the collaborations are with academics from world leading Universities. In total there were 52 collaborations within the groups of the Department, 13 between groups, 60 with other groups at Sussex, 116 national and 131 international collaborations. This is also reflected in the co-authorship of our outputs (Fig. 3). Of these collaborations 168 were interdisciplinary.
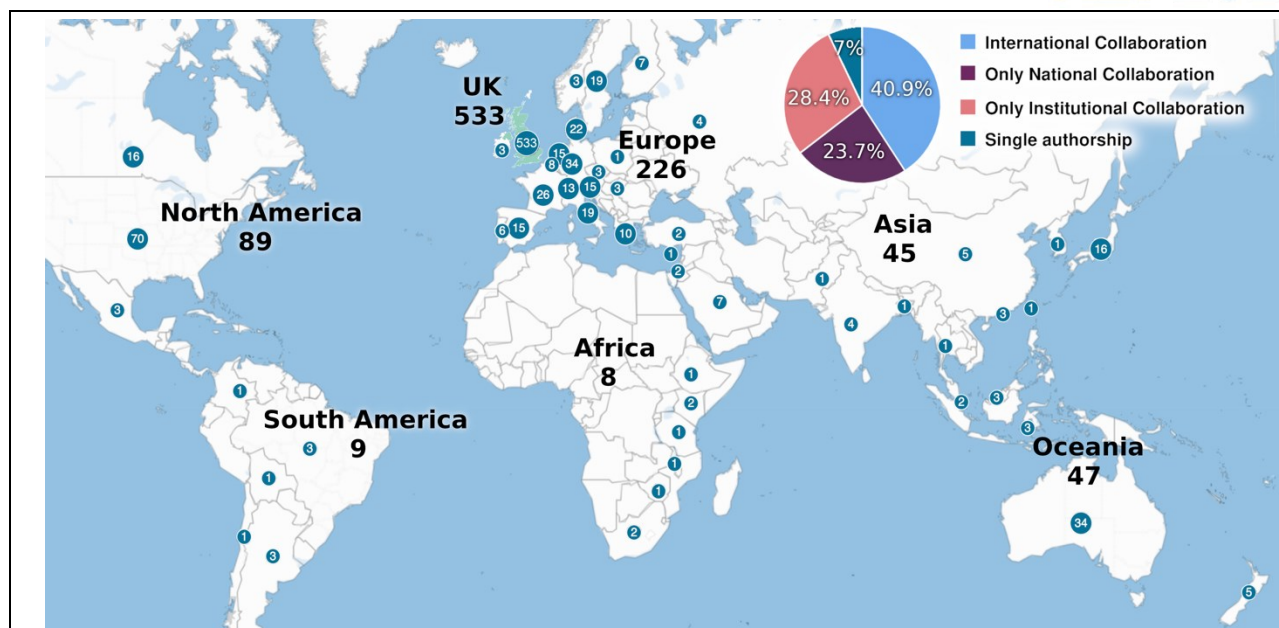
Figure 3: Map of collaborations worldwide in terms of the number of co-authored publications during the REF period that involve an author of each country (continent). Inset pie chart: percentage of outputs in terms of collaboration reach (source: SciVal).

A few salient examples of our collaborations:

In the AI group, besides the major Green Brain, Brains on Board and activeAI collaborations already mentioned, Nowotny also worked on the Odor Objects project (HFSP), with University of Konstanz, Arizona State, and University of Tokyo, and is a partner of the Human Brain Project (EU FET Flagship with > 120 partner universities). Husbands/Philippides collaborate internationally with leading robotics labs, such as Floreano, EPFL, and Bongard, University of Vermont. Berthouze is working with Farmer, UCL (6 co-authored publications) and internationally with Simon, Eötvös Lorand University (5 co-authored publications). Buckley is collaborating with Toyoizumi, RIKEN and Seth with numerous groups, including Friston, Fountas at UCL; Nikiforou, Shanahan at Deepmind, Mediano, Cambridge and more than 11 other groups worldwide. Furthermore, Quadrianto is working with Ghahramani, Cambridge but also with partners in Austria, Germany, Russia and Australia. Weir is working with many colleagues within Sussex but also with Bollegala, Liverpool and Conway, Dublin. Weeds is working with Clark, Cambridge; Grefenstette, Oxford; Sadrzadeh, UCL; and Lapata, Edinburgh.

In FoSS, Mackie is working with Yildirim, Erzurum Teknik Üniversitesi, Turkey and Parisis with Crowcroft, Clegg, and Pavlou, Cambridge, Queen Mary University of London (QMUL), and UCL (4 co-authored publications). Berger is working with Yoshida, ICL, Clark, UCL, and Tratt, Urban at Kings College. Reus is working with Altenkirch, Nottingham.

In the Creative Technology group, Cheng is working with Jamnik, Cambridge (supported by EPSRC, three co-authored publications) and Fetais and Khan, Qatar University (funded by QNRF) and Howland with Harley, University of Brighton (funded by EPSRC, 4 co-authored publications). Obrist was working with Velasco, BI Norwegian Business School (many joint publications). Subramanian was working, amongst others, with Drinkwater, Roudaut at Bristol, Fraser at Bath and internationally with Irani, Manitoba University (Canada), Hornbaek, Copenhagen, Ramani, Purdue and Lotte at Inria Bordeaux. Newbury is working locally with White, Watten, and Holroyd (11 co-authored publications, one of which has led to a commercial product on the app store). Beloff is working with White (shared research grant, more than 10 co-supervised PhD students; 2 PhD scholarships were jointly funded by the Department and AMEX) and White is also working with Nee, University of Portsmouth (MiPP and eMove grant). Good is working in a large network of collaborations (25 nationally and 18 internationally),

including Parsons, Southampton and Brosnan at Bath (8 shared papers); Manches and Robertson, Edinburgh (2 papers); and Mademtzi, formerly at Yale, Bossavit, Dublin, and Pares, Barcelona.

Wider collaboration and engagement with stakeholders

Members of the Department engage regularly and actively with the wider community of research stakeholders in a variety of forms. This includes:

Consultancy and Advice
Members of the Department are involved with many partners in more or less formal consultancy arrangements. Weir and Reffin run numerous consultancies through the CASM spin-out and through University of Sussex consultancy services, Husbands has worked with the BBC to advise on the accuracy of content on the history of AI, and with the Science Museum to advise on their blockbuster 'Robots' exhibition. He has also advised Future Visual on the potential role of ML in their business. White has worked with Kord of Synertial UK, providing advice relating to Innovate UK grants.

Contract research for industrial partners
Members of the Department worked with a number of national and international industrial partners in projects financed by the partner. For instance, Husbands, Philippides and Buckley worked with Intel (2 projects), Nowotny with Huawei, Howland with Hive (Centrica Connected Home), Obrist with Disney Research, Berthouze and Parisis with Moogsoft (also InnovateUK KTP and multiple funded PhD studentships) and Berthouze with Aviva, Beloff has worked with Clinical Practice Research Datalink and DATALINE Software Ltd. (leading to more than 4 publications and an impact case study), and White with American Express (2 part-funded PhD students).

Engagement with end-users
We strongly engage with end-users of innovations that are based on our research and with organisations representing them. For instance, Howland has a long-standing engagement with the Research Institute for Disabled Consumers (2 related research grants and 4 related publications) and Cheng is working with Hodges and Fife of the Educational testing service, Princeton (1 joint publication, 3 data-sets).

Shared research interests
Other engagements are based on less formal collaborations with researchers in non-academic entities that are valuable due to the mutual exchange of expertise and other research synergies. These collaborations include work of Husbands with Fernando of Deep Mind, Mackie with Siafakis and Hassan at tapSW, Obrist with Keller and Gatti at Oculus VR/Facebook and Carter at ultraleap (funded PhD studentship), Parisis with Chesterfield at OnApp and Chown at JISC, Quadrianto with Vetrov at Samsung AI Centre Moscow, and Weir with Miller and Bartlett of Demos Think Tank/CASM (more than 10 consultancy projects) and with Ginnis of IPSOS-MORI (2 projects). Seth is working with Kanai of ARAYA Brain Imaging, Tokyo, Subramanian has continued his longstanding collaborations with Long and Carter at ultraleap and with Seah and Kildal at Nokia Research, and Berger is working with Evans of DeepMind.

Wider engagement and impacts

Spin-outs and early-stage trading ventures
Members of the Department are involved in a number of spin-out companies that are creating impacts and we actively support this through our impact strategy. This included Obrist co-founding OWidgets, Wakeman founding InCrowd Sports, Subramanian co-founding ultraleap and still working with the company and Schrammel co-founding and being CTO of diffblue, seconded to it part time for a large part of the REF period. Memoli and Subramanian are spinning out Metasonixx, Weir continues to be a partner in CASM (annual turnover over £600K)

and Carroll in iLexIR (£4.7M turnover). This was enhanced with internal support ranging from advice on drafting a business plan, to providing substantial start-up funds for equipment, teaching relief, and hosting and mentoring by the Sussex Innovation Centre (an on-campus business incubator). Members of the Department also received funds from the University of Sussex Enterprise Panel to support work with their spin-out companies: Obrist received £7K for a market analysis regarding OWidgets, Memoli/Subramanian £120K for business planning related to Metasonixx. Wakeman and Maggioni were also recipients of RAEng Enterprise fellowships.

Other emerging impact cases
While we are submitting our three strongest impact case studies as outlined in Section 1, there are at least four additional emerging case studies that we believe can become of similar strength – Peter Schrammel's work with the diffblue spin-out, Ian Wakeman's work that led to the spin-out of InCrowd Sports, and two of Memoli's projects related to ultra-silent tyres (great potential for economic impact) and noise perception in aircraft flight paths (potential for economic/societal impact). Obrist's outreach work in collaboration with the Tate Gallery and Subramanian's continuing work with ultraleap will continue at UCL.

Outreach and public engagement
Members of the department are engaged in a large variety of outreach activities, foremost Seth, who is a Wellcome Public Engagement Fellow and spends 50% of his time on outreach activities with worldwide reach. Seth's 2017 TED talk was viewed by more than 11M people and ranked higher than the Pope's. Besides Seth's worldleading work, described in one of our case studies, many other members of the Department are also actively engaged. Members of the Department are STEM ambassadors (e.g. Berthouze, Howland, Nowotny), Howland is the liaison for a Robogals chapter at Sussex, and others regularly deliver outreach activities to School children (Nowotny, Obrist, Reus), in the majority locally and regionally, but also occasionally internationally (e.g. Reus - Canterbury School of Gran Canaria). Relatedly, we regularly contribute to science outreach events, including the annual Big Bang South East, the annual Brighton Science Festival, the British Science Festival 2017, and the Imperial Science Festival 2019. Other activities include engagements with Museums and exhibitions. For instance, in 2015 Obrist ran the "Tate Sensorium" at the Tate Gallery in London, with more than 3500 visitors.

Faculty are also deeply involved in outreach activities addressing the general public with regular public talks, such as Nerd Nite Brighton (co-organised at Brighton by Howland), Cafe Scientifique Brighton and U3A Lewes.

Members of the Department have appeared in the media, in print, online, radio and TV, most prominently Seth with dozens of public appearances and millions of viewers (see impact case study), but also including Memoli, Obrist, Good, Philippides and Nowotny. In 2017, for instance, Memoli and Obrist demonstrated TastyFloats on ITV Good Morning Britain and Nowotny appeared on Australian National Radio.

Many members of the Department have contributed articles to The Conversation, including Barrett, Light, Reffin, Obrist, Berger, Chrisley and Nowotny.

Software
The Department also achieves strong impacts through our contributions to public software packages accessed by users worldwide. Cheng has published MIDAS-logger, an Android software app for recording interactions with tactile graphics overlaid on a tablet computer screen and MIDAS-analyser, a desktop program for the interactive visualisation and analysis of MIDAS-logger data.

Nowotny has published and continues development of the StdpC dynamic clamp software, the GeNN accelerated spiking neural network simulator and the Brian2GeNN interface between the popular Brian simulator and GeNN. Furhermore Nowotny/Philippides have supervised the

development of the Bob robotics C++ based framework for robotic experimentation and Phlippides has published software for analysing vascular image data relating to diagnosis of diabetes and cancer.

Barnett/ Seth have published and are continuing to develop and support the MVGC Multivariate Granger Causality Toolbox (more than 3500 downloads since inception). Good has developed and released the ASCmeI.T. app for iOS and Android that allows autistic individuals to submit ideas for technologies they would like to see developed and the "African Farmer Game", an educational game simulating the complex decision making involved in smallholder subsistence farming in Africa.

Interdisciplinarity

Interdisciplinary working is second nature to most academics in the Department and 79% of submitted outputs are interdisciplinary. The disciplinary mix of our publications is shown in Fig. 4, demonstrating the striking breadth of our work, which is supported by the interdisciplinary research centres we run and by our numerous collaborations. The large number of engagements makes it difficult to identify a representative set but to give just a handful of further examples, there are long-standing collaborations between the AI group and the Life Sciences, most prominently Philippides with Graham, Buckley with Lagnado and Nowotny with Kemenes, a strong connection to the Digital Humanities (Weeds/ Weir with several academics in Arts and Humanities) and a long-standing collaboration of Berthouze with Kiss in Mathematics. Naturally, the work of SCCS is entirely interdisciplinary, as detailed above.
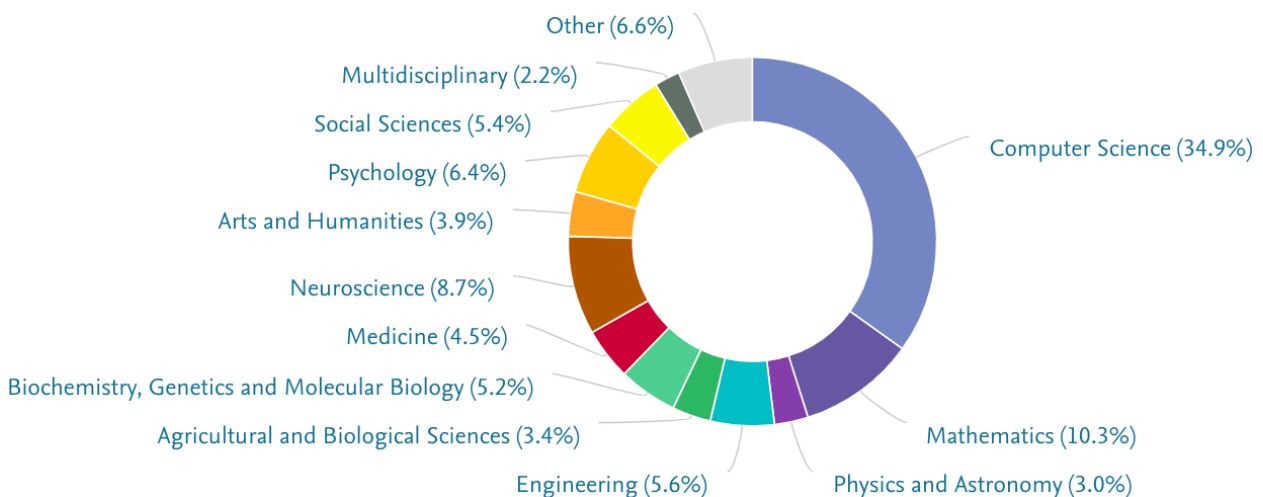

Figure 4: Distribution of the recognised discipline of all research outputs of REF faculty during the REF period (Scival).

Wider influence, contributions, and recognition

Members of the Department are fully engaged in the academic community and are recognised for their expertise, and profuse contributions. More than half of faculty at the Department are engaged in substantial editorial roles, serving in total more than 49 roles. For instance, Seth is Editor-in-Chief of the Journal Neuroscience of Consciousness, Berthouze an editor of PLoS One and has 4 other editorial roles, and Husbands was associate editor of Artificial Intelligence 2013-17 and is associate editor of Frontiers in Robotics and AI, while serving on 7 distinct editorial boards. Nowotny is associate editor of two Frontiers journals, and Philippides of Adaptive Behavior, Frontiers in Neurorobotics, and is serving on 3 editorial boards. Obrist is associate editor at ACM ToCHI, and has 2 other associate editor roles, Quadrianto is associate editor of IEEE Transactions on Pattern Analysis and Machine Intelligence and has 2 other editorial roles, while Weeds, Wood and White serve on 1, 3 and 4 editorial boards, respectively.

Organization of scientific conferences

Besides journal editorships and other editorial roles, the esteem for members of the Department and their engagement with the scientific community is evidenced by 36 roles as conference chairs. For instance, Light was program chair on PDC 2018, Obrist was program chair of NordiCHI 2018 and TVX 2014, Associate Chair of ACM CHI 2013-2015, 2017 and had 6 other associate chair roles. Nowotny was program chair of CNS 2017-2020 and a director of OCNS 2014-2016 while Subramanian was general chair of ACM ISS 2017. Howland and Good hold chairing roles at the ACM Conference on Interaction Design and Children, Husbands was co-chair for an IEEE CEC special session evolutionary robotics 2016, 2018, Mackie was PC Co-chair for TERMGRAPH 2018 and steering committee chair for "Developments in Computational Models" and "Linearity" workshops. Quadrianto was area chair of NIPS 2015, NIPS 2017, NeurIPS 2018, and NeurIPS 2019, and Senior Area Chair of AAAI 2020 and Reus was Conference chair of the British Logic Colloquium 2017.

In addition, members of the Department have served in more than 64 program committee roles during the REF period.

Grants committees

The Department is highly engaged with funders, and members of the Department have served on grant panels and committees. For instance, Nowotny and Good are members of the UKRI Future Leadership Fellows review college and Nowotny served and Wakeman has chaired EPSRC interview panels. Weeds is member of the EPSRC ICT prioritization panel and has reviewed for the Alan Turing Institute (fellowship awards) and Berthouze regularly serves on EU grant panels.

Fellowships and honorary appointments

Members of the Department have held 10 competitively won personal fellowship grants, see prominent examples above. Members of the Department also hold a large variety of other fellowships and honorary appointments evidencing the esteem for their academic standing and their strong engagement in the scientific community. For instance, Berthouze is honorary Professor at UCL, Buckley a visiting researcher at Kyoto University, Obrist was visiting professor at MIT and was visiting associate professor at Stanford University in 2017 and at the Royal College of Art 2019/20. Philippides was a visiting researcher at Uppsala University and Quadrianto is an Adjunct Senior Lecturer at the University of New South Wales (UNSW), Mentor at the School of AI, and an Academic Supervisor at the Higher School of Economics, National Research University, Russia. Subramanian was a visiting professor at Stanford University and at MIT.

Boden was appointed to the Advisory Committee of the APPG (All-Party Parliamentary Group) on Artificial Intelligence in 2017.

Prizes

Another strong indicator of the esteem in which our academics are held are prizes they received during the REF period. Boden received the Allen Newell 2017 Award from the ACM/AAAI and a Lifetime Achievement Award from the International Society for Artificial Life in 2016. An annual "Margaret Boden Lecture" has been established in her honour at the University of Cambridge's Leverhulme Centre for the Future of Intelligence. Mackie received the Most Influential paper 10-year award 2014 of the International Symposium on Principles and Practice of Declarative Programming. Obrist was selected to be an inaugural member of the ACM future of computing academy (2017) and was invited to attend the 50th Anniversary of the Alan Turing Award Ceremony in San Francisco, selected Young Scientist 2017 to attend WEF (2017), invited to the World Economic Forum (WEF) Annual Meeting of the New Champions 2017 in Dalian, People's Republic of China and re-invited 2018 in Tianjin, People's Republic of China. Nowotny was

nominated for the "best research project of the year" award of IChemE in 2015 and Good received two honourable mentions/ best paper awards in 2017.

Keynotes

High esteem for our academics and their work is also evidenced by 39 keynote invitations during the REF period. To give some illustrative examples, Obrist gave the Opening Keynote at ACM Multimedia 2018 in South Korea, and three other keynotes. Cheng was invited to give 2 keynotes in 2018 and Philippides gave a Keynote at Parallel Problem Solving from Nature 2017 and at the Kongsberg Systems Engineering conference 2019.

Weeds was a keynote speaker at the Workshop on Vector Spaces for Discourse and Dialogue at IWCS 2019, Gothenburg. Seth gave a keynote at VMWorld 2018, Las Vegas, NV (5000 participants) and 7 other keynotes during the REF period and Boden gave a prestigious Turing Lecture.

External examination & advisory roles

Our academics are active in examiner and advisory roles of many kinds with local and global reach. Howland is external examiner for two BSc (Hons) programs at the University of Central Lancashire. Newbury was external examiner for three BSc courses and an MSc program at Oxford Brookes, and for an MSc at Bath. Nowotny was examiner for two MSc programs at Sheffield, and Philippides for a BSc at Keele. Weir was examiner for the Data Science MScs at Sheffield, White for an MSc at Brunel, and Subramanian an MSc in HCI at City University of London. Seth was examiner for the Brain and Cognition RPA, Amsterdam, the Psychology Dept, Hong Kong University, and the Department of Psychology, University of Ghent. Good was external examiner for "My Digital Life" and "Technologies in Practice" at the Open University and Husbands is an advisor on all senior promotions for the AI Department, University of Malaya.

Over the REF period members of the Department have also been external examiners for more than 50 PhD students in the UK and more than 40 students internationally.

Learned societies

As a final indicator of esteem and embedding of our faculty in the scientific community, most members of the Department are members of multiple learned societies and professional organisations. For instance, members of staff are members of the HEA and the BCS, Nowotny is a member of the UK Neuroinformatics network, OCNS and Society for Neuroscience. Obrist was Senior ACM Member, with three separate roles in ACM SIGCHI and Philippides is member of the International Society for Neuroethology and Applied Vision Association.