Institution: University of Nottingham

Unit of Assessment: 11 – Computer Science and Informatics

1. Unit context and structure, research and impact strategy

1.1. Context and Strategy

Computer Science at Nottingham continues to pursue and maximise the impact of its highly successful strategy of grounding its research in real-world challenges and settings. Our strength in advancing core computer science, combined with flexible structures that allow timely response to new challenges and an ability to connect knowledge and methods both across computer science and between the computational and other disciplines enables deep collaborations with diverse research users. Our research naturally remains strongly user-focused, interdisciplinary and impactful.

Following intense strategic expansion in the previous REF period, the School has worked to maximise flexibility and effectiveness before again increasing both capability and capacity. Over the current period our commitment to and success in delivering our research strategy - supported by significant investments in both people and facilities - have been marked by:

- Extension of our core capability through the establishment of a new Cyber Security (CybSec) group (following recruitment of Furnell, He, and Muller) and new appointments in visualisation (Laramee) and robotics (Kucuckyilmaz, Turner). The existing Horizon Digital Economy Institute, Intelligent Modelling and Analysis Group, Computer Vision Laboratory, Functional Programming Laboratory, Mixed Reality Laboratory and Computational Optimisation and Learning Group have also been strengthened by new appointments.
- Restructuring of and relaxation of the boundaries between the School's research groups to produce an increased number of more responsive smaller, often overlapping, units.
- Increased interdisciplinary activity through the establishment of the Smart Products Beacon of Excellence [REF5a-2.1b] within the School (led by Benford) and active involvement in the University's Future Food (Pridmore, Pound) and Precision Imaging (Valstar, French, Pound, Chen) Beacons (all arising from a £22.5M investment by the University) and the Mental Health and Technology Theme of the £23.6M NIHR Biomedical Research Centre (Valstar, Garibaldi, Perez).
- Renewed funding for the Horizon Digital Economy Institute (£4.1M, Koleva, McAuley) and Centre for Doctoral Training (£5.8M, Benford) for an unprecedented 3rd iteration.
- Strengthened links with established industries (e.g. Unilever, Microlise, Syngenta, NATS(Services) Ltd, BBC) and successful establishment of the spin-out company BlueSkeye AI with £235K investment from Angels and the University (Valstar).
- Influence on Government policy through McAuley and Rodden's work on the 'Age-Appropriate Design Code' introduced by the Information Commissioner's Office and Rodden's appointment as Chief Scientific Advisor to the Department for Digital, Culture, Media and Sport (DCMS).

The School currently numbers 50 Category A academic staff (46.2 FTE, of which 21% are female), 47 post-doctoral researchers and 76 PhD students with further support from the experience of 24 technical, managerial and professional employees. Our funding portfolio has matured, with average income increasing from £3.9M p.a. in 2014 to £4.7M p.a. from a broader range of funding sources. The School is now in receipt of awards from six of the seven UK Research Councils, Innovate UK, the Royal Society and EU. Our international standing has also

led to direct funding by the US Air Force Office of Scientific Research (Altenkirch) and US Dept of Energy (Pridmore).

The School has directly received £33M in research income. The rich interdisciplinary nature of our research, however, means that School staff are often instrumental in obtaining funding for projects spanning the University; the total value of these awards to UoN within the REF period is £70.9M, a significant increase on the £52M reported in 2014.

As recognised in our REF 2014 strategic aims, our vision of Computer Science as "computing in the world" requires the School to *continually strengthen and extend its core research base*, *reach out to new industrial and academic partners* and *broaden its international scope*. In addition, *flexible structures* are required which both maintain depth of research in key areas of computer science while supporting *intra- and inter-disciplinary collaboration*. Throughout the current REF period the School has successfully achieved these goals; and it will maintain this approach.

1.2. Flexible Structures

The School's research structures are designed to allow those working in distinct areas of computer science the autonomy needed to pursue the most promising lines of enquiry while encouraging and supporting intra-disciplinary collaboration. Our strategy has been to i) recognise areas of significant activity within the previous group structure and ii) soften boundaries between groups to encourage greater collaboration. Our model is of a larger network of more interconnected, often smaller units, with staff operating across that network to best advance their research and address emerging opportunities.

In the REF period the School has recognised the Agents Laboratory as performing high-quality research in a distinct area; Alechina and Logan were previously members of the Foundations of Programming group, now Functional Programming lab. The Lab for Uncertainty in Data and Decision Making (LUCID) has emerged from Intelligent Modelling and Analysis (IMA) and Computational Optimisation and Learning (COL, previously Automatic Scheduling and Planning) to sit between and foster collaboration between those continuing groups. Renewed funding for the Horizon Digital Economy Institute has ensured its continued existence, while the creation in 2020 of a Cyber Security group further extends core capabilities.

The School now recognises nine groups:
- Agents Laboratory
- Computational Optimisation and Learning (COL)
- Computer Vision Laboratory (CVL)
- Cyber Security (CybSec)
- Functional Programming (FP)
- Lab for Uncertainty in Data and Decision Making (LUCID)
- Intelligent Modelling and Analysis (IMA)
- Mixed Reality Laboratory (MRL)
- Horizon Digital Economy Research Institute (Horizon)

These are discipline-based and located in distinct areas of the Computer Science building, allowing senior staff to support the development of early career researchers and students and encouraging co-working between staff with shared research interests. Each group is primarily responsible for the development and pursuit of its research agenda, operating in the context of the University's research initiatives and structures; this independence is facilitated by devolved budgets over which the groups have full autonomy. While each staff member is assigned to one group for administrative purposes, group membership is informal and flexible. Many colleagues

identify with and contribute to multiple groups, providing transfer of ideas and knowledge across the School and allowing us to respond effectively to emerging challenges and opportunities.

Cross-group strategy and processes are co-ordinated by the School's Director of Research (Pridmore) who convenes a quarterly Research Strategy Group (RSG). RSG is a broad forum discussing both long-term strategy and operational matters and includes representatives of each group and School Research Administration Team. The Director of Research serves on the School Operations Team alongside the Head of School (Garibaldi), Director of Teaching (Landa Silva) and Director of Operations (Palmer), ensuring effective communication between research groups and School Management.

1.3. Strengthening Core Research

Throughout the REF period the School's core research has been driven and strengthened by the creation, activities and achievements of its research groups.

Agents Laboratory (Logan, Alechina (until 2019)). Research in the Agents Lab spans the specification, design and implementation of agent-based systems, including logics for agents, agent programming and verification, and the application of agents in simulation and virtual environments. The Lab is internationally leading in the verification of autonomous systems that operate under resource constraints, and in the synthesis of provably correct multi-agent programs. Since 2014 the group has produced 9 PhDs and published 23 papers in top-ranked (Microsoft Academic) international AI conferences (IJCAI, AAAI, AAMAS, ECAI) and 7 papers in leading journals (AIJ, TCS, JAIR, JCSS). With financial support from the School, Agents Lab instigated the Intention Progression Competition, an international initiative to advance research in agent decision making (the paper proposing the competition won Best Paper at AAMAS 2017). The Lab has received funding for work on the verification of multi-agent systems and has strong links with colleagues in the Faculty of Engineering, collaborating on manufacturing-focussed grants with a total value of £7.2M.

Computational Optimisation and Learning (Atkin, De Maere, John (new, until 2020), Karapetyan (new), Landa Silva, Neri (new), Ozcan, Parkes, Qu, Triguero(new)). COL (the natural evolution of the previous ASAP group) is at the cutting edge of new methodologies and techniques for optimisation and learning. COL's research is driven by a strong multi-disciplinary approach to tackling real-world optimisation and data science problems across various sectors including transport, energy, food production, logistics, healthcare, manufacturing, aerospace, communications, finance and built environment. Core research covers mathematical optimisation, evolutionary algorithms, swarm optimisation, hyper-heuristics, learning classifiers, big-data learning algorithms, feature selection, neural P systems and membrane computing. Impact is realised through the group's many successful collaborations with industry. During the REF period, COL has produced 37 PhDs and published 142 papers in leading journals (IEEE TEC, IEEE TFS, EJOR, COR and others). COL's work has contributed two ICSs [REF3 *Improving Operations at London Heathrow and Geneva Airports* and *Improving Homecare Quality*]. The high-impact, multi-disciplinary nature of COL's work is evidenced by their success in obtaining Innovate UK and EU funding; during this REF period the group has been awarded 6 KTPs, 2 R&D Collaborative projects and 1 EU Horizon 2020 project.

Computer Vision Laboratory (French, Pound, Pridmore, Torres Torres, Tzimiropoulos (new, until 2019), Valstar). CVL performs basic and applied research in image manipulation, analysis and computer vision. The group develops novel and efficient techniques for the extraction of quantitative descriptions of viewed objects from a variety of images and image sequences, and translates those techniques into high quality software tools addressing real world problems. This REF period has seen CVL supervise 43 PhDs, publish 8 papers in the top 3 computer vision

conference (CVPR, ICCV, ECCV – Microsoft Academic) and 6 in top 5 Computer Vision journals (IEEE PAMI, IEEE IP, IJCV – Microsoft Academic). CVL's application-focussed work is also internationally recognised. The group has expertise in visual affective computing and face analysis, conducting world-leading research on topics including apparent emotion recognition, face tracking, and the automatic assessment of mental health based on expressive behaviour. Valstar (internationally the second-highest cited person in the field of social signal processing) is Deputy Director of the Biomedical Research Centre's Mental Health & Technology theme, a 5-year interdisciplinary research programme on objective mental health assessment. This led to spin-out in 2019 of BlueSkeye AI. CVL is at the forefront of image-based plant phenotyping research in the UK and Europe, evidenced by its key role in the ESFRI roadmap project EMPHASIS, in which they are partnered by BBSRC and BEIS. Pridmore received £300K from the US Dept of Energy (ARPA-e) to support work in this area and is Director of the UK's national plant phenotyping network, PhenomUK.

Cyber Security (Furnell (new), He (new), Muller (new), McAuley, Wagner, Pound, Twycross, Radenkovic). CybSec was formed in 2020 following appointment of Prof Steven Furnell but draws together members of pre-existing groups with an interest in security. CybSec is a centre of interdisciplinary cyber security research and education, securing the digital environment through combined advances in formal and human-centric cyber security research. The unpinning aim of the group's research is ensuring security that is effective for those who need it, recognising who cybersecurity is actually for – namely the individuals, organisations and wider society that want to use and trust the technology – and enabling protection that works in a manner that they can relate to. CybSec's core activities sit at the intersection of security technology and those that use it. The group's focus is upon delivering the theoretic security properties in practice, removing technical obstacles and achieving effective and usable approaches, alongside human-centric solutions that empower people to be the strongest link.

Functional Programming Lab (Altenkirch, Capretta, Hutton, Kraus (new), Nilsson). FP's aim is to develop simple but powerful techniques for writing and reasoning about programs, by recognising and exploiting their underlying mathematical structure. Since 2014 FP received £1.75M of external funding, graduated 15 PhDs, and developed fundamental new results in type theory, category theory, functional programming, reactive programming and corecursive structures. Altenkirch's work on dependent types was internationally recognised by the award of $700 from the US Air Force Office of Science and Technology. Kraus recently joined the group as an associate professor, supported by a £550K Royal Society University Research Fellowship. Members played a leading role in the international community, serving on the editorial boards of the Journal of Functional Programming, Fundamenta Informaticae and ACM ICPS, program chair of the TLCA, MPC and FARM conferences, chair of the Haskell committee, member of the EU-TYPES cost action and co-founders of the Midlands Graduate School.

Intelligent Modelling and Analysis (Chen (new), Garibaldi, Greensmith, Qiu, Siebers, Turner (new), Twycross, Wagner, Zhou(new)). IMA's work on complex data analysis, knowledge representation, machine learning, decision support algorithms and modelling of human decision making have impacted biomedical informatics, security, energy management and digital economy. The group played a leading role in developing computational algorithms for the Nottingham Molecular Pathology Node, one of the six national MRC/EPSRC pathology nodes launched in 2014 which aimed to establish multidisciplinary centres of innovative molecular diagnostic test discovery and development bringing together the research base, pathology/genetic NHS services and industry. IMA also contributes decision support algorithms, medical modelling and data analysis to the Nottingham Biomedical Research Centre. IMA's multidisciplinary research has been instrumental in creating novel models of synthetic biology within the University's Synthetic Biology Research, a £14.M centre funded by BBSRC/EPSRC in 2014. IMA has strong links to the Advanced Data Analysis Centre (now Digital Research

Service), which has been established as a permanent unit within UoN during the REF period and links IMA research outputs to real-world applications.

Laboratory for Uncertainty in Data and Decision Making (Wagner, Garibaldi, Figueredo, John (new, until 2020)). Alongside colleagues from COL, members of IMA established LUCID in 2016 to encourage agile collaboration between staff and students working on uncertainty in data and decision making. Building on a rapidly growing network of national and international collaborators, including at ANU (Australia), CMU (USA), UNavarra (Spain), and Uni.lu (Luxembourg), LUCID has addressed research challenges around uncertainty-in-data in areas from data-driven environmental management and smart (consumer-led) manufacturing to cyber security. It has attracted ~£1.7M direct funding and ~£24M as stakeholder in hub and centre grants from a diverse set of research funders including EPSRC, NERC, Unilever, JP Morgan, DSTL and the NCSC. Most recently, LUCID launched DECSYS, a novel survey platform for sourcing uncertain information directly from people, with direct support from the NCSC. DECSYS has already been used in cyber security and marketing research and the underpinning science is being explored for a new generation of consumer engagement with leading manufacturers including Unilever, Nestlé and PepsiCo.

Mixed Reality Laboratory (Benford, Chamberlain, Crabtree, Fischer, Flintham, Greenhalgh, Koleva, Kucuckyilmaz (new), Laramee (new), Milic-Frayling (new), Marshall, Reeves, Rodden, Tennent, Wilson). The lab creates and studies interactive technologies and experiences that interleave the digital and the physical to enhance everyday life. Research themes have included human interaction with agent collectives; establishing trust in personal data; and brain and body control of interactive systems. Cultural and creative applications have remained a major focus, with collaborations with artists producing performances that have been directly experienced by 40000 people in 40 venues across seven countries [REF3 ICS: *Innovating Cultural Products*]. Work on Internet of Things has led to burgeoning research on smart products including a research framework agreement with Unilever, while digital technology and mental health is emerging as a key research area, in collaboration with the University's Institute of Mental Health. Notable achievements during this period include: 3 Best Papers, a Best Arts Paper and 6 Honorable Mentions at the CHI conference; 9 papers in ACM Transactions on CHI; an EPSRC Platform Grant; two EPSRC Programme Grants; two EPSRC Fellowships; a Leverhulme Fellowship; a Nottingham NRF Fellowship; and Rodden being elected an ACM Fellow, seconded to be deputy CEO of EPSRC, and Chief Scientific Advisor to DCMS. The lab celebrated its 20th anniversary in 2019 by staging a major retrospective exhibition at the CHI conference and hosting the first Halfway to the Future symposium.

Horizon Digital Economy Research Institute (Koleva, McAuley, Benford, Crabtree, Fischer, Flintham, Perez, Radenkovic, Reeves, Rodden, Valstar, Wagner). The UKRI funded Horizon Digital Economy Research Institute centred at the University of Nottingham brings together an interdisciplinary team with expertise from a wide variety of backgrounds including computer science, engineering, mathematics, psychology, sociology, business, social science and the arts. Horizon focusses on the collection and understanding of personal data to address the user-centred design and development of data-driven products, which are more personalised, adaptive and trusted and as a result, deliver greater value to consumers, producers and society. Horizon was established in 2009 and its EPSRC funding renewed in 2015 and 2020, providing £20.7M in total. It is an active member of the national network of Digital Economy Centres. Horizon has strong links with external organisations including those working in the areas of healthcare, art, communications, finance and creative media. Horizon's body of research and the impact this is having on how users and policy makers engage with technology is the subject of an impact case study [REF3 ICS: *Protecting the Rights of Young People*].

1.4. Working across Disciplines

The University of Nottingham's commitment to maximising the transformative value of research led to a £22.5M investment in 6 Transdisciplinary Beacons of Excellence [REF5a-2.1b] during the REF period. Each Beacon addresses a global challenge and is directed at UN Sustainable Development Goals. Computer Science is closely involved with 3 Beacons: *Smart Products* (intelligent products, production and consumer experiences), *Future Food* (feeding the world in the context of climate change) and *Precision Imaging* (precision medicine).

Smart Products (centred on the School and led by Benford) articulates a new research vision around the future of products. This brings together views from manufacturing and consumption into a whole-life perspective and combines technologies concerned with physical artefacts from Engineering with those focused on digital media from Computer Science and Arts and Humanities. Smart Products is supported by two new appointments (Kucuckyilmaz, Turner) in Computer Science, and investment of £632K (£212K by EPSRC and £420K by the University) in a new Cobot Maker Space, a facility dedicated to human-robot interaction and collaboration where researchers, industry partners (especially SMEs) and the public can engage with Interactive Robotics and AI.

Smart Products has awards totalling £21M, including £17.9M directly linked to the Beacon (30 awards). A significant proportion are strategic awards to multidisciplinary groups of researchers at UoN, working alongside collaborators at other Universities. This includes the EPSRC-funded Horizon CDT (£5.8M) and Horizon Digital Economy Research Centre (£4.1M) - both proposals had the Smart Products vision at their core – and the recently announced Trustworthy Autonomous Systems Hub (£2.2M).

Computer Science involvement in Future Food centres on plant phenotyping technologies, specifically the computer vision techniques underpinning image-based phenotyping. Pridmore serves on the Leadership Team of the Beacon, and Pound transitioned to an Assistant Professorship in Computer Science in 2020 following successful completion of his Nottingham Research Fellowship, associated with Future Food. Beacon investment has provided some £2M in cross-university support for phenotyping equipment and development resources, including state of the art laser ablation tomography, fluorescence and structured light imaging equipment and a dedicated Maker Space supporting development of hardware solutions. Within the REF period CVL has won 10 research awards targeting computer vision problems in plant phenotyping with a total value of £2.2M. Nottingham now leads both the UK national plant phenotyping network and UK involvement in the ESFRI EMPHASIS project, highlighted in BBSRC's 2019 Delivery Plan.

School staff contribute to and benefit from interactions with the University's world-leading MRI and precision medicine community. Valstar's work on computer vision and healthcare, and French, Pound and Chen's on bioimage analysis contribute to the Precision Imaging Beacon. Valstar, Perez Vallejos' and Garibaldi's involvement in the University's Biomedical Research Centre (BRC) has contributed to Nottingham becoming a recognised centre of excellence for objective assessment of mental health conditions and led to collaboration with the University of Auckland on digital mental health interventions (Greenhalgh).

In addition to these established and recognised research units, interdisciplinary projects are common within the School including:
- Greensmith's (IMA) completion of an EPSRC-funded discipline hopping grant working with immunologists in Nottingham's School of Medicine.

- Ozcan's partnership in two Marie Curie ITN awards led by Nottingham's Faculty of Engineering and co-investigator role in an EPSRC CDT in Sustainable Chemistry led by Nottingham's School of Chemistry.
- Twycross' involvement in the Nottingham Synthetic Biology Research Centre and work with School of Life Sciences.
- MRL's multiple collaborations with the Dept. of Music (including Greenhalgh's 'Losing her voice' opera project) and portfolio of four AHRC grants totalling over £1M.

1.5. Impact and Knowledge Exchange

Impact and knowledge exchange is guided by the University's Knowledge Exchange Strategic Delivery Plan, Research Vision and Impact Strategy, with local support and processes in place at school level.

The School takes a proactive approach to impact, with investigator-led impact reviews of each grant being prompted by administrative staff at regular intervals. Investigators have access to a Faculty-funded Impact Officer who works with academics and researchers to develop, document and evidence impact, and a senior academic has time dedicated to supporting impact. Horizon employs a dedicated Knowledge Exchange and Impact Officer who works across the portfolio of Horizon projects to identify, accelerate and publicise impacts generated by the institute and a Transformation Manager with expert knowledge of the funding environment and who facilitates industrial links. These colleagues work with academic staff to identify opportunities for impact acceleration and translation through engagement with bodies such as Nottingham's Institute for Policy and Engagement, the IP Commercialisation Team and by supporting applications to Impact Acceleration Account (IAA) funding. In the REF period the School has won 13 EPSRC IAAs, one BBSRC IAA and an MRC Confidence in Concept with a total value of £184K.

In addition to the four impact case studies in REF3 - *Improving Operations at London Heathrow and Geneva Airports Through Modelling and Optimisation* (Atkin), *Improving Homecare Quality in the UK Through Optimised Workforce Planning* (Landa Silva), *Innovating Cultural Products for the Creative Industries* (Benford), *Protecting the Rights of Young People Within the Digital Space* (McAuley, Perez) - impact achieved in the current period includes:
- integration of the School's research into government policy through Rodden's role as Chief Scientific Advisor to DCMS.
- contribution of research expertise to UK government policy supporting the UK's digital competition market (McAuley).
- adoption by the Western Australian Government of the uncertain data-driven environmental management and policy design methodology developed in collaboration with LUCID and highlighted in the 20-year management plan for the Toolibin wetland, a Ramsar-certified wetland of international importance.
- successful spin-out of BlueSkeye AI with £235K venture capital (Valstar). Blue Skeye has met its OEM targets each year, now employs 7 staff (2 further posts advertised) and has contracts worth £360K in its development pipeline.
- embedding of high dynamic range imaging research at Nottingham into photo editing software, providing the foundation of the internationally renowned photo editing application, FOTOR (Qiu).
- adoption of novel deep machine learning applications by Syngenta, a leading international agritech company (French, Pridmore, Pound).
- development (with the BBC) of 'Databox', a platform allowing individuals to securely manage their own personal data (McAuley, Crabtree).
- commercial impact on the BBC through understanding of people's engagment with Internet of Things devices in the Living Room of the Future (Crabtree).

- release of a machine learning-based software tool for neurofibre segmentation, now in use by >100 groups worldwide (Chen).
- educational and commercial impact from the best-selling book Programming in Haskell (Hutton), which includes many aspects of the author's research, sold 34,000 copies worldwide and has been adopted by >100 University courses and online professional courses with >100,000 participants.

1.6. Broadening International Scope

REF2014 outlined plans for further global outreach. That this is being achieved is evidenced by:
- 48/116 (41.3%) of our returned outputs including international co-authors.
- MRL's two AHRC-funded UK-China creative industry grants focussed on connected museums.
- Qiu's collaboration on FOTOR (China).
- Pridmore and French's £320K BBSRC GCRF project in collaboration with CIAT, Colombia.
- Wagner's work on environmental management tools with the Dept. of Parks and Wildlife and University of Western Australia.

School researchers also collaborate on large scale international research projects including EU projects (worth £3.65M or 9.5% of award income) and projects funded by the US Government through ARPA-e (Pridmore) and the US Air Force Office of Scientific Research (Altenkirch). Our growing presence at and strengthened research links with the University's China and Malaysia campuses are evidenced by collaborations including Qu's work on container transportation scheduling at Ningbo port, the world's 4th largest container port.

1.7. Open Research

We strongly promote a culture of open research [REF5a-2.3], as the delivery of our vision of "computing in the world" turns on users being able to use solutions developed at Nottingham and feed back to research teams. Support staff target reminders about open access and depositing outputs into the institutional repository to academics with new publications and assist in the process. The School hosts sessions on open access publication at academic meetings and away days, provided by specialists from within the University.

We are proactive in the development of open research infrastructures. Wagner has co-developed multiple open-source software frameworks making research outputs accessible to peer researchers within and beyond computer science including Juzzy and JuzzyOnline, each with some 1000 users. In the last 5 years JuzzyOnline was accessed by users from more than 50 and Juzzy by users from over 125 countries. IMA has released a Fuzzy-R toolkit. Valstar has created and released the AVEC, FERA, SEMAINE, and Noxi datasets, which together have been cited 1575 times during the REF period. Pound and French have developed and released a variety of annotated image data sets designed to support development of machine learning solutions to agricultural challenges through the Annotated Crop Image Database (ACID). ACID has recently been adopted as a national resource by PhenomUK. Links to the open access software and data resources produced by the School are maintained on the School website.

1.8. Research Integrity

The School follows the UoN Code of Research Conduct and Research Ethics [REF5a-2.4], ensuring a sustainable culture of research integrity and good practice. The School Research Ethics Committee (seven academics, four researchers, one research student, one non-school representative, one lay member) approves all taught and research projects involving human

participants or personal data in advance (69 projects in 2019/20). All new research and teaching staff and research students attend compulsory research ethics training; research students also complete an online introduction to research integrity. All taught project students receive a lecture on research ethics. The Ethics Committee maintains a web page with details of processes and links to supporting resources, including relevant school and university policies and best practice. The Research Ethics Officers (Greenhalgh, Crabtree) Chair the committee, contribute to University discussion of research ethics and integrity and ensure that the School remains up to date with University requirements and best practice, updating School processes and reporting to the School at least annually.

The School's research also contributes to wider ethical thinking in Computer Science through Horizon's contribution to methods for Responsible Research Innovation (RRI), led by Perez in partnership with RRI researchers at Oxford and De Montfort, and to industry through the release of our Moral-IT deck of ideation cards and through shaping policies such as Online Harms at DCMS.

1.9. Future Plans

In the next period the School's strength in multidisciplinary research will be expanded through investment in capacity around Cyber-physical AI (CYPHAI) and the related areas of Embodied Intelligence and AI in Manufacturing. Following the formation of the Cyber Security Research Group and building on the recent investments in Smart Products, the School will create three further groupings in this broad area:

1. **Cyber-Medical Research [1-2 new staff]**: A Professor in Cyber-Medical Systems will be recruited to integrate the various strands of medical research underway in the School building on our involvement in the NIHR-funded £24M Nottingham Biomedical Research Centre.
2. **Cybernetics (AI Robotics) Research [5 new staff]**: A Professor in Cybernetics / AI will be recruited to lead a new research group in intelligent robotics, with potential for multi-disciplinary interactions with the Faculty of Engineering, and leading the further development of our newly created Cobot Maker Space.
3. **Embodied Intelligence Research [5 new staff]**: A Professor in Embodied Intelligence will be recruited to lead a new research group in Human-AI Hardware/Software Interaction deepening our involvement with the new UKRI programme in Trustworthy Autonomous Systems, where we are one of the three partners in the £12M national hub and a partner in the Governance node.

A total of 12 new academic staff will be recruited across these areas, taking into account the need to strengthen complementarity with existing research groups within the School. These new initiatives will be supported by construction of a new £260K CYPHAI Laboratory in the School of Computer Science and further investment in the Smart Products Cobot Maker Space. The School will also establish a Doctoral Training Programme in Artificial Intelligence, continuing our policy of supporting intra- and interdisciplinary research in key areas of computer science and further strengthening links with industrial and academic partners.

Though the challenges addressed naturally change over time, our successful strategy of engaging world-leading computer science research with real-world problems has remained in place since the previous REF and is expected to underpin the School's activities for the foreseeable future.

2. People

2.1. Staffing Strategy and Staff Development

The School of Computer Science aims to attract, develop and retain high performing talent while fostering a culture focused on diversity, inclusivity, wellbeing and positive engagement across all our groupings and activities.

At the REF2021 census date: 17% (1.8F, 11.2M) of Category A staff were employed at Professorial level,13% (2F, 9.2M) at Associate Professor/Principal Research Fellow level, 27% (6F,16M) at Lecturer/Senior Research Fellow level and the remaining 43% (9.5F, 24M) as Research Fellows. In our UoA, we have 3% (2M) (FTE) early career, 65% (7.8F, 42.4M) of staff are employed on permanent, contracts and 35% (9.5F, 18M) on fixed term contracts.

2.1.1. Recruitment

16 external appointments have been made to strengthen and extend our core research base and support increased intra- and inter-disciplinary collaboration, particularly around Cyber Security and the Smart Products Beacon. Four Professors (Furnell, Gaertner (until 2019), John, Milic-Frayling), three Associate Professors (Kraus, Laramee, Neri) and nine Assistant Professors (Chen, He, Karapetyan, Kucukyilmaz, Muller, Triguero, Turner, Tzimiropoulos, Zhou) have been appointed in the period. 16 staff left, and Professor John passed away in 2020.

A further four Transitional Assistant Professors were appointed through the Horizon Digital Economy Research Institute. All have now moved to permanent Assistant Professorships at the University, two (Reeves, Torres Torres) in Computer Science, one (Perez) in Mathematical Sciences and one (Pinchin) in Engineering. Twycross (2016), Schnadelbach (2018) and Pound (2020) transitioned to Assistant Professorships in Computer Science on completion of Nottingham Research Fellowships [REF5a-3.2]. Marshall and Tennent were promoted from Senior Research Fellow to Assistant Professor.

Progression of post-doctoral staff has been supported by appointments to partial (0.2 FTE) Assistant Professor positions alongside their research posts. Of the four during the REF period, De Maere is now full time Assistant Professor in the School, Coughlan is Lecturer at the Open University, Soria is Senior Lecturer at the University of Westminster and Rennick-Egglestone is Senior Research Fellow at Nottingham's Institute for Mental Health.

Our recruitment processes take input from the whole School community; interview panels (trained in Interview Skills for Chair and Panel Members) comprise diverse academics working across the School. All academic and research staff and PhD students are invited to and encouraged to attend presentations by candidates and given opportunities to feed their opinions into the process. We strictly follow UoN EDI strategies throughout recruitment to ensure candidates are treated solely on the basis of their abilities and potential.

We take a flexible approach to working patterns; four staff have taken a reduction in FTE at the University, on a permanent or temporary basis, to take on roles at Samsung (Tzimiropoulos), Yahoo (Zhou), Standard Chartered (Nilsson) and Ernst & Young (Koene). These arrangements allow staff to pursue opportunities with high-profile companies and advance the School's strategy of reaching out to new industrial partners. UoN is actively exploring how policies for flexible working can being used as effectively as possible to support all staff.

2.1.2. Staff Development

Personal development and research career progression of all staff are supported and reviewed at least annually through UoN's Appraisal Development Conversation (ADC) process [REF5a-3.1]. This is overseen by the Head of School and Director of Staff Development (Hutton). Early career academic staff benefit from reduced teaching and administrative loads and the support of a senior academic mentor. They are prioritised in the PhD studentship allocation process and provided with a seed budget to help them establish their research. Research staff are supported in achieving their potential through a system of mentoring including their immediate principal investigator, research group leader and the Director of Staff Development.

In addition to peer mentoring and support schemes operating both formally and informally in the School, staff are supported by a comprehensive programme of professional development training. PhD supervision and review skills training is provided by the PGR Director (Qu), working with the Researcher Academy [REF5a-3.3]; research ethics training is provided by the Research Ethics Officers. The University provides numerous research-focussed training courses including annual sessions on research integrity. Staff in leadership roles have access to training and resources through the Nottingham Leadership and Management Academy, which provides a comprehensive programme of activities for staff (Pridmore 2015, Gaertner 2016) across themes including leading people, financial management, networking and managing change [REF5A-3.5].

Support for the development of research is comprehensive:
- Since 2014 our Study Leave programme provided over 8000 hours of paid study leave to academic staff to support writing of research proposals and papers and the development of international collaboration.
- Financial support for the development, acceleration and dissemination of research is provided through the devolved budgets allocated to each research group. These are based on the number of academic staff and PhD students plus a generous percentage of research income. Groups have full autonomy over this budget.
- Additional funding for conference attendance is made available by the Faculty of Science. Allocation is managed by the School to ensure those who most need the funding are able to access it, taking into account individual circumstances, caring responsibilities, etc.
- The School operates a Grant Academy to which staff can submit, at any time, draft research proposals for review by and discussion with senior colleagues.
- The Director of Staff Development is available to support staff at all stages of the proposal development process including assisting with responding to reviewer comments and adapting unsuccessful ideas for further submission.
- In preparation for REF2021 the Faculty made funding available to support enhancement of impact of both potential impact case studies and research outputs. The application mechanism included an EDI process to ensure gender balance and encourage a positive action balance for staff with protected characteristics.

Exceptional performance and contribution in the School are recognised through nomination by colleagues to the Nottingham Reward Scheme, which provides a framework of financial rewards recognising contributions spanning the full range of activities. The School has facilitated eight awards in the REF period (two to academic, three to research and three to administrative and professional staff).

Through ADC we have facilitated seven promotions to Professor (Altenkirch, Crabtree, Koleva, Landa Silva, Qiu, Valstar, Wagner), seven promotions to Associate Professor (Atkin, Fischer, French, Ozcan, Triguero, Tzimiropoulos, Wilson). In line with principles of responsible metrics, h-

index and other publication metrics are no longer an assessment criterion for promotion. Part-time contracts and periods of absence (e.g. maternity leave) are taken into account and the process concentrates on quality of delivery over quantity. Staff are supported through the promotions process by a School promotions group and assigned mentor. Unsuccessful applicants are given constructive feedback, supporting future applications.

2.2. Research Students

Our PGR community comprises 49.4% Home, 7.9% EU, 42.7% International, 96.6% full-time, 3.4% part-time, 27.7% female, and 13.8% declared a disability. Over the REF period we have graduated 157.49 FTE (46.49 F/101 M) PhDs with an average 4-year submission rate of 51%. 34.4% of our REF outputs include a PhD student author and 10.4% of our PhD students have at least one author credit.

PhD funding is received from UKRI, industry, charities and the Horizon CDT, which was renewed for a £5.8M third iteration in the REF period, bringing its total funding to £14.9M. We provide 6-10 fully-funded PhD studentships each year from our Scholarship budget (£194K in 2020/21). A rigorous application and assessment process involves a diverse panel of academic staff who adhere to UoN EDI strategy to ensure the highest quality students receive priority on funding. The CDT programme admits one intake of students per year to promote the building of collegiate cohorts, providing peer support networks for students. The current CDT award will see five cohorts admitted, totalling 65 students and building on the 109 students supported through the first two funding rounds.

2.2.1. Training

PGR students undertake a structured induction programme (covering research methods, ethics, communication and dissemination, supervision practice and University processes) and have access to academic, career and personal development courses run by the Professional Development Unit and the Researcher Academy [REF5a-3.3]. Students funded by the Horizon CDT complete a four-year programme involving an initial training year in the Centre followed by a three year PhD programme embedded in an academic department, many being based in Computer Science. These initial processes are supported by provision of online PGR study materials. PhD students have opportunities to develop teaching/dissemination skills alongside their research with teaching lab demonstration work, guest lecturing opportunities and voluntary placements to teach at Nottingham's overseas campuses in China and Malaysia, all overseen by an academic mentor.

The School takes an active role in the development of research students per se by its involvement in development programmes. Nottingham is a founder member of the Midlands Graduate School in the Foundations of Computer Science (MGS) and hosted the weeklong programme of courses twice during the REF period. Nottingham is also a founder member of the National Taught Course Centre in Operational Research (NATCOR) and has hosted training for PhD students seven times during the REF period. Both MGS and NATCOR have become self-sufficient since 2014.

2.2.2. Support

PGR progress, experience and well-being are overseen by the PGR Director and Director of Research with support from the Researcher Academy.

During the REF period, the School has enhanced its internal review processes to ensure that students are best prepared to progress between each stage of their PhD and into their viva. Each student undergoes a rigorous end of year review, in addition to their regular, recorded, supervisor

meetings, which confirms their progress and implements actions to address areas of concern. At the end of their third year, each student meets with the Director of Research and PGR Director to discuss the writing, submission and examination process and ensure they understand what is expected of them. A Student Welfare Officer is based in the School to provide advice, guidance and support to students experiencing difficulties of any nature, and we have trained seven mental health First-Aiders. Student Services staff are embedded in the School's administration office to provide further advice and support.

The School holds a PGR Learning Community Forum (LCF) meeting three times per year. This is chaired by the PGR Director and provides a forum for representative PGR students to discuss both academic and non-academic issues. In recent meetings, the LCF has discussed the implementation of further support structures for students in their thesis pending periods, an internal communications tool for PhD students to help build the community and representation of PGR students at Faculty level.

Our PhD graduates have been highly successful in their onward careers in this period, securing academic research positions (e.g. Wang and Song now PDRAs at Cambridge), launching start-up companies (e.g. Userfy, Makers of Imaginary Worlds and callforparticpants.com (acquired by Jisc Beta service)), and securing competitive positions in industry (e.g. Amazon, Samsung AI, Facebook, Microsoft, Airbus, Jaguar Land Rover).

2.3. Equality, Diversity and Inclusion

EDI underpins all activities, following UoN's EDI Strategy and supported by the School's EDI Committee, which includes academic, technical, research and administrative staff together with UG and PGR students. The School has held an Athena Swan Bronze award since 2013, renewed in 2017. Our Athena Swan Self-Assessment Team sits quarterly. Each group within the School community is represented, ensuring that our Athena Swan action plan meets the needs of the diverse community it serves.

The school fosters an environment of inclusivity through leadership, education and celebration of diversity adjoined to key national events including annual Ada Lovelace day, celebrating women in STEM, celebration of pioneers in computer science from the LGBTQ+ community and delivery of on campus events (e.g. film nights) during Black History month.

During REF2021 preparations, the University supported employees to voluntarily declare relevant personal circumstances and their impact on REF outputs [REF5a-3.7], while maintaining confidentiality. All staff involved in REF preparations completed a training course covering EDI legislation and principles governing REF conduct, protected characteristics, unconscious bias, and management strategies for positive outcomes. All researchers were asked to nominate as many outputs as they thought eligible for inclusion for REF2021 to our annual internal review process, and all were encouraged to put forward impact case studies (ICSs). Our strategy is to submit the very best outputs and ICSs regardless of other criteria.

2.4 Concordat Implementation

The University of Nottingham is a signatory, through Universities UK, of the Concordat to Support the Development of Researchers and holds an HR Excellence in Research award from the EC. Local implementation of the Nottingham Concordat Plan [REF5a-3.2] is ensured through the inclusion in the School management team of the roles of Director of Research and Director of Staff Development, who are directly tasked with supporting the career development of the School's researchers. The ADC process is applied uniformly to research and academic staff,

researchers are invited to School Staff Meetings and PhD and research staff make up 1/3 of the EDI committee.

Data Protection training is compulsory for all University staff, and refresher training was mandated on the introduction of GDPR legislation, with completion monitored via personalised links. All work conducted using personal data undergoes ethical approval. As a member of the UK Research Integrity Office (UKRIO), the University has access to training provision of UKRIO on research integrity and organised research integrity workshops for academic staff and research students from 2017. Responsible Research and Innovation training is provided by the Institute of Science and Society at the University, one of the foremost interdisciplinary centres for research excellence in the field of science and technology studies.

3. Income, Infrastructure and facilities

3.1. Research Income

In the REF period research income to the School totalled £33M, an average of £4.7M p.a., up from £3.9M p.a. in 2014. Staff have been investigators on grants resulting in £70.9M of income to the University, up from £52M in 2014. We receive funding from a wide range of sources including EPSRC, BBSRC, MRC, NERC, AHRC, InnovateUK, European Commission, US Govt., charitable bodies and industry.

The School leads or contributes substantially to key strategic projects, including:
- the EPSRC-funded Horizon Digital Economy Research Institute, which received a £4.1M renewal in 2020, bringing its total funding to £20.7M.
- Nottingham's £14.2M EPSRC/BBSRC Synthetic Biology Research Centre.
- the £23.6M NIHR-funded Biomedical Research Centre led by UoN and Nottingham University Hospitals Trust.

Other notable awards are:
- UnBias: Emancipating Users Against Algorithmic Biases for a Trusted Digital Economy (£1.3M, EPSRC); followed by ReEntrust (£218K, EPSRC) [REF3 ICS: *Protecting the Rights of Young People*].
- Living with Digital Ubiquity (£1.2M EPSRC Platform Grant to MRL).
- Defence against Dark Artefacts (£1.1M, EPSRC).
- SAGE (€2M European Commission, coordinated by Nottingham).
- Leveraging the Multi-Stakeholder Nature of Cyber Security (£770K, EPSRC).
- Health Data Research UK (£724K, UKRI, Wellcome).

3.1.1. PhD Training

PhD funding centres upon the twice-renewed (total £14.9M) EPSRC-funded Horizon CDT; Nottingham remains the only institution with both a Digital Economy Research Hub and CDT. The renewed CDT will also benefit from over £4.7M in cash and in-kind contributions from industry and academic partners, demonstrating external commitment to its work.

In addition, Ozcan is partner in two Marie Curie ITN awards led by Nottingham – No2Noise (€809K) and OptiMACS (€1.3M) - supporting PhDs across engineering and computer science.

3.1.2. Enabling the Wider Community

In line with our goal of extending intra- and inter-disciplinary collaboration, the School actively seeks funding for transdisciplinary networking:

- John (COL) was co-investigator on the £1.4M EPSRC NetworkPlus Digitally Enhanced Advanced Services (DEAS). DEAS focusses on how digital products and services are used, cascading over £600K to researchers spanning business, computer science and human factors to stimulate engagement in a coordinated programme of research pilots.
- Pridmore (CVL) holds a £528K UKRI Technology Touching Life grant to establish a national network promoting a holistic approach to plant phenotyping. This includes £225K to be distributed to multidisciplinary pump priming projects. Together with £600K funding from the H2020 EPPN2020 and ESFRI EMPHASIS-PREP projects, this award is intended to lead to the creation the UK node of the distributed research infrastructure EMPHASIS.
- Wagner (LUCID) was awarded £400K by EPSRC to fund 15 residencies at the Digital Catapult.

3.1.3. Supporting Impact

The School has secured impact support grants totalling >£200K, including:
- Valstar (CVL) secured EPSRC IAA grant to optimise face recognition technology, leading to the spin-out Blueskeye AI.
- Flintham (MRL) won EPSRC IAA funding for a 6-month collaboration with the National Videogame Arcade on Internet of Things, securing an ongoing partnership between UoN and the British Games Institute.
- Ramchurn and Patel (PhD students, MRL) won EPSRC Digital Economy Telling Tales of Engagement awards to promote the impact of their research [REF3 ICS: *Innovating Cultural Products*].
- Crabtree (MRL) completed the Impact Leaders Programme with the BBC (2015).

3.1.4. Industry partnerships

During the REF period we have participated in four major European projects with industry: MAGELLAN (€477K), GIFT (€ 598K), OPTIMISED (€291K), SelSus (€75K). Innovate UK funding has included Value Enhancement for Data from Assets and Transactions (£359K total) awarded jointly with Microlise and MyHouse (£79K total) awarded jointly with Legendary Games. We have been awarded 9 KTPs with Krow, E.On, EventMAP, PXTech, Intechnica, 121 Systems, Optrack, JP Morgan and Gleeds to a total value of £1.85M. We have received direct industry funding from Google, Adobe, Unilever, NATS, Ford and Syngenta. Our total direct industry funding is £3.532M (9.2% of award income). This is complemented by funding from government agencies including GCHQ (£222K) and DSTL (£95K).

The Horizon CDT benefits from a total of £4.7M industrial funding, working with >50 industry partners including ARM, BBC, Captial One, Digital Catapult, DSTL, Experian, Ipsos-MORI, Ordnance Survey and Unilever.

3.1.5. Fellowships

Staff have held a number of prestigious fellowships during the REF period including awards from the Royal Society (Kraus £550K), Leverhulme (Marshall, £142K), EPSRC (Established Fellowship, Crabtree, £1.13M, Early Career Fellowship, Reeves, £458K) and three Nottingham Research Fellowships [REF5a-3.2] (Schnadelbach, Twycross, Pound).

3.2 Infrastructure and Facilities

The School is located in a purpose-designed building on the University's Jubilee Campus, providing a large, flexible space readily adaptable to our evolving research needs. Research

groups are allocated specific areas of the building, ensuring staff and PhDs are co-located and allowing groups to manage and adapt their space. MRL, for example, has a large open, configurable space equivalent to 8 large offices plus corridor space which allows the creation and study of large facilities [REF3 ICS: *Innovating Cultural Products*]. CVL has a dedicated laboratory used to develop robot systems and a 'virtual' human which can recognise e.g. facial expression, gaze and tone of voice.

Computer Science provides nine meeting and collaborative working spaces, bookable by staff and students and including projectors and video-conferencing. Since 2014 we have invested £15K in facilities for these rooms and committed a further £30K in collaborative working equipment, ensuring that staff and students have access to the latest technology.

The School has invested heavily in internal network infrastructure during the REF period, including the renewal of high specification servers running research tasks and creation of an in-house high-performance computing facility for staff and student work. Our in-house technical and IT service comprises three highly qualified technicians who support research in the School through close liaison with research staff.

Specialist research equipment is provided within both the School and the wider University. Smart Products' dedicated Cobot Maker Space includes a cobot room equipped with human-friendly robots allowing up to four human-robot collaboration studies to run simultaneously while gathering data from sensors including thermal cameras, brain scanners and gaze trackers. Creation of this space is made possible by a £632K EPSRC and University investment, while the School's devolved budgets have allowed CVL to construct a cluster of nine multi-GPU enabled servers with associated network storage and scheduling software. This facility is designed to support work in deep machine learning and has facilitated development of novel and highly successful convolutional neural network architectures. CVL is a partner UoN's unique Hounsfield Facility, which provides state-of-the-art imaging facilities supporting their work in plant phenotyping.

The University has invested substantially in High Performance Computing, launching a new HPC service (Augusta) in 2018 (REF5a-4.1(d)). The service now provides 4,720 cores, 31TB RAM, 8 GPUs and 750TB of storage. A charging model for use ensures long-term sustainability and the School is provided with an annual budget of £30K (equivalent to 2,000,000 core hours) for HPC activity not funded by other sources, ensuring that the service is widely available. The University is also a member of the HPC Midlands Plus consortium which allows users at the Universities of Aston, Birmingham, Leicester, Loughborough, Nottingham, Queen Mary and Warwick to access further high performance facilities across the region.

UoN facilitates cloud computing solutions through Microsoft Azure, Amazon Web Services and Google Cloud Platform. This reduces waiting times and allows staff and students to complete tasks requiring more cores than are available on site. These services are managed by the University's Digital Research Services department; each Faculty has a dedicated representative assisting in their use and handling requests for new or extended services. Secure, GDPR-compliant data storage facilities are also available. Research projects with significant data storage needs can access the University's Central Performance facility, which offers up to 5TB free with a subsequent nominal cost per terabyte.

A comprehensive range of central services support the development of proposals, project finances, business engagement, IT and infrastructure support, digital research support and technology transfer and commercialisation. The School supplements this with a Director of Operations, a Research and Operations manager (a post created during this REF period), a Research Administration Manager, Research Officers and Operations Administrators.

The Advanced Data Analysis Centre (ADAC) was founded in 2012 to further increase the impact of the School's research on data manipulation and analysis. It remained part of the School until 2018 when, supported by £300K from the University's Strategic Research Board and renamed the Digital Research Service REF5a-4.1(d), it became independent of the School structure while maintaining its presence in Computer Science. ADAC/DRS's mission is to provide both a service to Nottingham scientists needing access to data analysis and a conduit for the transfer of new techniques to other disciplines. DRS now employs 23 staff, up from six in 2014.

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

Our strategy of grounding core computer science in real-world challenges and settings has led to collaborations with a wide range of commercial, public and third-sector partners, as evidenced by the diversity of our four ICSs [REF3]. Supported by the University's Technology Transfer Team, our research has had demonstrable impact in a diverse range of sectors including Government and policy, healthcare and medicine, logistics, food and agriculture, aerospace, creative industries, retail, energy, finance, biomedical and manufacturing.

4.1. Partnership on Research Grants

COL continues its unique relationship with NATS, refining the take-off time prediction system which has been operational at Heathrow since 2012 and developing and implementing a new departure management system which is further reducing delays and improving recovery from delay incidents [REF3 ICS: *Improving Operations at London Heathrow and Geneva Airports*]. EU projects have allowed the School to engage with research users in developing and testing research solutions in real-world environments, companies the School has collaborated with on EU projects include Laing O'Rourke, Dassault Systemes, Alstom Transport, SimPlan and Smarter Grid Solutions.

4.2. KTPs and Industry-funded Research

During the REF period the School has held 9 KTP awards with a total value of £1.85M. These have embedded the School's research into the industrial practice of Krow, E.On, EventMAP, PXTech, Intechnica, 121 Systems, Optrack, JP Morgan and Gleeds. IMA have continued their relationship with the National Cyber Security Centre, part of GCHQ, and have received two instances of funding; to support a programme of software development and to facilitate an international workshop around handing uncertainty in data and decision-making hosted in Nottingham. The School has received direct research funding from Huawei, Google, Adobe, Syngenta, Diamond Light Source, Meograph, Microsoft Research, NATS and Unilever during this REF period, to a total value of £3.53M (9.2% of award income).

4.3. Spin-outs and Start-ups

Blue Skeye AI (Valstar) was successfully spun out, with £235K venture capital. Blue Skeye has met its OEM targets each year, now employs 7 staff (2 further posts advertised) and has contracts worth £360K in its development pipeline.

Three further start-ups are linked to the School's research: Studio Go Go (Walker, previously Senior Research Fellow, MRL), Makers of Imaginary Worlds (Patel, PhD, MRL), and Userfy (Sam Howard PhD student in Human Computer Interaction).

4.4. PhD Training

Collaboration with industry is a vital element of the Nottingham PhD experience, and embedded in the Horizon CDT. Each Horizon CDT student undertakes an internship (e.g. with Ordnance Survey, DSTL, Experian, Nottingham Contemporary). Diamond Light Source, The Roslin Institute and Microsoft Research are each funding a PhD student and Unilever are supporting an EPSRC iCase studentship.

4.5. Engaging Citizens

The public are the ultimate beneficiaries of our research and much of the School's work engages with the public at some point. Collaborations with artists and cultural institutions have toured galleries, festivals and museums in 22 cities around the world, have been directly experienced by 40,000 people and indirectly by thousands more online and have received media coverage on BBC Radio 4's Saturday Review, BBC News Click, BBC1 East News, ITV East Anglia News [REF3 ICS: *Innovating Cultural Products*].

MRL was commissioned to produce four Artcode pieces to be displayed in the Royal Marsden Hospital's Teenage Cancer Trust Unit, building on work from the EPSRC-funded grant 'Living with Interactive Decorative Patterns'. This work has also been applied in the 'Ice Age to Digital Age' strand of the Nenescape project to celebrate, protect and conserve the natural and built environments of the River Nene Regional Park.

CDT student Ramchurn's brain-controlled film, The Moment, has been featured on BBC Click and has toured film festivals in the UK and across Europe.

Our research on airport scheduling [REF3 ICS: *Improving Operations at London Heathrow and Geneva Airports*] has been featured on BBC4's *The Secret Rules of Modern Living: Algorithms*. MRL work on a project with the School of Law, Corrupt Kitchen, which raises awareness of food hygiene and safety and explores workplace attitudes towards corruption using virtual reality was featured on BBC East Midlands Today. Corrupt Kitchen was also demonstrated at an event held by Just Eat where several hundred food industry professionals had the opportunity to try the VR experience.

Tzimiropoulos' work on 3D face modelling from a single image received national media coverage including BBC TV interviews and articles in e.g. Mail Online. An online demonstration generated >1.5M 3D faces from images uploaded by the public, and 3D prints generated by the method have been exhibited in art galleries.

The School's *Computerphile* YouTube channel hosts bespoke videos presenting our research and its context to the general public. Computerphile benefitted from funding from Microsoft Research and John Warnock (co-founder of Adobe) during the REF period and received its YouTube 'Golden Button' for 1 million subscribers in 2018. *Computerphile* now has 1.72M million subscribers and has received over 136 million video views. YouTube also commissioned the Computerphile team to produce a set of bespoke videos in the area of data analysis.

4.6. Widening Participation in Computer Science.

The School is an active part of the academic community in Nottingham and works with local schools and other institutions to engage communities which may not traditionally have identified with Computer Science. Examples include:
- Nottingham's first girls-only CoderDoJo, organised in conjunction with Thomson Reuters and attended by 40 girls aged 7 to 17 (2017, repeated in 2019).

- A CodeFirst:Girls course for 30 female Nottingham students in other disciplines including law, chemistry and economics, teaching them how to code, with female researchers and PhD students delivering the course content.
- Ada Lovelace Day events in 2018 and 2019 engaging some 100 female year 12 and 13 students from local schools including Nottingham Girls' High School and Nottingham University of Science and Technology. These students attended talks by women occupying high profile computing roles in industry and academia including academic and research staff at UoN.
- An annual Sutton Trust Summer School, hosting 25 students jointly with Engineering and Mathematical Sciences. Places on Sutton Trust Summer Schools are prioritised for students who are high academic achievers and from underprivileged backgrounds.
- Partnership on the £500K Institute of Coding-funded programme, TechUp Women, which upskilled 100 women from BAME and underrepresented communities in the North and Midlands in the digital sector through online training and a residential course at UoN.
- Exhibitions at the Nottingham Festival of Science and Curiosity in 2018 and 2019.
- Organisation of Inspire Women in Technology Nottingham in 2018.
- Delivery, with B3 Media, of TalentLab, which trained 40+ young BAME artists in digital technologies and provided indirect support to a further 500 through spinout projects [REF3 ICS: *Innovating Cultural Products*].

4.7. Academic Collaboration and Leadership

The School has engaged in extensive academic collaborations during the REF period to strengthen its core activities and develop new research areas. These include:
- Agents Laboratory's joint publications with Cornell (United States), Bozen-Bolzano (Italy), Utrecht (Netherlands), Rio Grande do Sul (Brazil), RMIT (Australia).
- COL's relationship with Queen's University Belfast produced a spin-out company, EventMAP, in the previous REF period. In this period EventMAP partnered with the School on a KTP project. Other international collaborations include Granada (Spain), Maringá (Brazil), Leuven (Belgium) and Virginia (United States). Ozcan was awarded Royal Society-Newton International Exchanges funding to collaborate with the University of KwaZulu-Natal in South Africa.
- CVL research collaborations include two ARPA-e projects with UHV Technologies and Penn State University (both US). CVL collaborated with Rothamsted Research on an MRC-funded Technology Touching Life network and with Augsburg University (Germany), University of Twente (Netherlands) and Paris Telecom (France) on the Horizon 2020 grant ARIA-VALUSPA, which it coordinated.
- Horizon's collaborations include two EPSRC Digital Economy Research hub grants with the University of Cambridge, Nottingham Trent University, the University of Oxford, the University of Exeter and more than 50 partners across the transport, communications, entertainment and policy-making sectors. Horizon collaborates with the Universities of Oxford and Edinburgh on UnBias and ReEnTrust, two EPSRC-funded Trust, Identity, Privacy and Security grants. Research findings from Unbias and ReEnTrust were instrumental in driving UK policy change for online protection of young people [REF3 ICS: *Protecting the Rights of Young People*].
- IMA collaborations include those built as part of the Marie Curie IAPP Action AIDPATH which included hospitals in Italy and Lithuania and universities in Italy and Romania. Wagner spent 9 months as Visiting Professor at Michigan Technical University and holds a collaborative EPSRC grant with Carnegie Mellon University.
- MRL's international collaborations include the EU-funded GIFT project, led from Copenhagen, which is enabling people to experience art and culture from home as an immediate solution to COVID-19 restrictions. MRL staff were investigators on the

EPSRC-funded project 'Scaling the Rural Enterprise', which included research institutions in India and South Africa.

4.8. Esteem and Research Leadership

Our success in research leadership is evidenced by editing major journals, chairing key conferences, major strategic advisory activities, invitations to present prestigious keynotes and best paper awards. Selected examples include:

Journal editors-in-chief. IEEE Transactions on Fuzzy Systems, 2017-date (Garibaldi), Information and Computer Security, 2007-date (Furnell), Plant Methods, 2016-2019 (Pridmore).

Associate Editors. International Journal of Human-Computer Studies, 2015-date (Wilson), Journal of Simulation, 2014-date (Siebers), Computational Intelligence Magazine, 2016-date (Qu), Image and Vision Computing, 2014-date (Tzimiropoulos), IEEE Transactions on Fuzzy Systems, 2014-date (Wagner), Plant Phenomics, 2019-date (Pridmore).

Editorial board members. Memetic Computing, 2009-date (Landa Silva), Neural Computing and Applications, 2013-date (Landa Silva), Journal of Functional Programming (2014-date) (Hutton), BMC Source Code for Biology and Medicine, 2006-date (Garibaldi), Fundamenta Informaticae (Altenkirch), ACM Transactions on CHI (Benford).

Guest Editors. ACM Transactions on Computer-Human Interaction special issue, 2013 (Crabtree), Functional Plant Biology, 2015 (French), Mixed Reality Interfaces in Multimodal Technologies and Interaction, 2019 (Koleva), IEEE Access, 2018 (Triguero).

Senior and Strategic Advisory Roles. Members of staff have engaged in managerial and advisory roles at external institutions including key funders and government departments. Rodden was elected a Fellow of the Royal Academy of Engineering in 2018, ACM Fellow in 2015 and seconded to the role of Deputy CEO at EPSRC from 2016 to 2019. Since 2019, Rodden has been Chief Scientific Advisor to the Department of Culture, Media and Sport. McAuley is advising the Investigatory Powers Commissioner's Office and serves on HM Treasury's Digital competition expert panel. Furnell is a Member of DCMS Cyber Resilience Expert Advisory Group (2020-date), a Steering Group member for the Cyber Security Body of Knowledge (2020-21), Member of the UK Cyber Security Council Formation Project (2019-21), Chair of Technical Committee 11 of IFIP, and a Board member of the Chartered Institute of Information Security. Since 2018 Crabtree is a member of the EPSRC Strategic Advisory Network. Benford and Rodden are members of the CHI academy. In 2015, Hutton was recognised as a Distinguished Scientist by ACM. Valstar sits on the board of the Association for the Advancement of Affective Computing (AAAC) as Treasurer. Milic-Frayling is Chair of the Programme Technology and Research Workgroup, part of UNESCO's Platform to Enhance the Sustainability of the Information Society Transglobally (PERSIST) and Chair of ACM Women Europe.

Best-paper awards and other prizes. KI 2018 – Best student paper (2018); ACM CHI Conference on Human Factors in Computing Systems – Best paper (2020, 2018, 2014), Honourable mention (2020, 2019, 2016, 2015); Designing Interactive Systems – Honourable mention (2018); Autonomous Agents and Multi-Agent Systems – Best paper (2017); International Symposium on Algorithms and Computation – Best paper (2014); Ackermann Award (European Association for Computer Science Logic Outstanding Dissertation for Logic in Computer Science) (2016), L'Oréal-UNESCO For Women in Science UK & Ireland Rising Talent Programme (2020).