

Institution: Newcastle University
Unit of Assessment: UOA 11 Computing Science and Informatics
<p>1. Unit context and structure, research and impact strategy</p> <p>a. Overview</p> <p>UoA11 at Newcastle University (NU) is based in the School of Computing (Faculty of Science, Agriculture and Engineering) – the current embodiment of over 60 continuous years of computer science and informatics research at NU. The period since 2014 has been characterised by investment and growth in research, focused on areas of strong business, societal or human interest. This is founded on a culture of engagement with the beneficiaries of our research, and an increasingly multi-disciplinary approach in technical, biological, human and social systems.</p> <p>The institutional importance of Computing was highlighted in 2017 when NU invested £58M (out of the total £90+ million investment over the review period) in a new building designed to meet the needs of a growing, ambitious, 21st century School of Computing. The Urban Sciences Building (USB) is now the working home of 45 academics on Teaching & Research contracts, 15 academics on Teaching & Scholarship contracts, 69 Research-only staff, 164 PhD students and over 1300 students on taught programmes. It incorporates almost all teaching and research in Computing and was designed to make research more visible to students at all levels: this was hard to achieve in the former dispersed and “vertical” accommodation. Crucially, relocating to the £350M “Newcastle Helix” site created adjacency with spaces for tech businesses in Newcastle, including IBM Red Hat and AkzoNobel. It also provided a home for the new EPSRC National Innovation Centre for Data (NICD), created as an organisation and location, which has already attracted the Alan Turing Institute (ATI) and Dstl.</p> <p>Compared to REF2014, our return increased from 27.5 FTE (Full Time Equivalent) appointments to 49.8 FTE. Of 48 full-time staff submitted now, 32 are new appointees. As 10 of these new appointees were Early Career Researchers (ECRs), a significant mentoring and support effort has been provided by established staff to sustain our project portfolio and PhD completion rates. The risks associated with rapid growth and relocation of UoA11 were addressed through a comprehensive review of our research group structure. This consolidated model-based research - previously split between two groups - in the <i>Advanced Model-Based Engineering and Reasoning (AMBER)</i> group, and also identified a distinctive new interest in systems engineering research – accelerated by recent appointments – and so created the <i>Networked and Ubiquitous Systems Engineering (NUSE)</i> group in 2019.</p> <p>b. Research and impact strategy</p> <p>UoA11 research and impact strategy is designed and led by a Research Committee with leading members from all groups, as well as school leadership and professional services. Several members of the committee also sit on the School of Computing executive board. Alignment to university strategy and coordination of cross-disciplinary opportunities come via equivalent faculty-level and university-level groups. All these committees have members with a brief for Equality, Diversity and Inclusion (EDI) concerns, and routinely address EDI issues related to research and impact.</p> <p>Our overall vision for research and innovation has remained aligned with that articulated in REF2014 - <i>‘to be a world-leading centre for fundamental and rigorous computing science research that is stimulated, informed and evaluated by application in areas of importance to industry and society’</i> – and our strategic decisions are aligned with the NU’s ‘Vision & Strategy’ launched in 2018. They are based on the pillars of excellence, creativity and impact, and guided by the principles of working together, visible leadership, freedom and opportunity to succeed, and response to current and future challenges.</p> <p>Our strategic approach to research has been to grow both research power (i.e. <i>capacity</i>) and intensity (i.e. <i>resources</i>) sustainably. Investments have been made in areas of research strength that lead to business and societal impacts, and the opportunity for impact is increased</p>

by working in ways that promote collaboration within the unit, across disciplines, and with wider business and society.

Our *approach to growing capacity* has been to build and maintain critical mass through sustainable research group structures that give staff and students a shared research ethos. We have invested in researchers' and groups' development by providing staff, PhD studentships and facilities. Examples include:

- support for Centres for Doctoral Training (CDTs) and Doctoral Training Partnerships (DTPs) to foster the development of research skills in areas of sustained demand, both within and outside academia;
- creation of academic FTEs in areas of research promise that build on our existing strengths (e.g., cyber-physical systems (CPS), interaction design, secure and resilient computing, and Internet of Things (IoT));
- investment in five career research fellowships which predated the institution-wide NU Academic Track (NUAcT) scheme and was guided by our EDI strategy; and
- investment in staff development relevant to research, following the Concordat to Support the Development of Researchers and Vitae Researcher Development Framework.

Our *approach to growing resources* has focused on investments that create opportunities for collaboration, interaction and cross-disciplinary working. Examples include:

- the design of our new home in the USB building;
- investment in the microbiology and DNA/RNA nanotechnology laboratory;
- partnership in the Alan Turing Institute;
- support for our two RCUK Doctoral Training Centres;
- the Newcastle Data initiative; and
- the National Innovation Centre for Data.

Our **strategic approach to impact** aims to integrate impact systematically in all stages of research. The approach is:

- *user-centric* in that it encourages development of deep relationships with key users, e.g., Dialog Semiconductor in UoA11_Workcraft Impact Case Study (ICS);
- *open* by encouraging commitment to open systems, platforms, tool development and standards, e.g., W3C standard for provenance in UoA11_PROV ICS, and where possible, making research data and publications open access;
- *collaborative* using institutional vehicles to foster multidisciplinary research, e.g., Centre for Synthetic Biology and Bioexploitation; and
- *agile* in supporting flexibility to pursue opportunities for impact, e.g., Rodin Tools spinout in UoA11_Railway ICS.

We strive to build up areas of impactful research systematically, e.g., two of our REF2021 ICSs (UoA11_Workcraft and UoA11_Railway) emerged from our long-term engagement in the design of asynchronous hardware (ICS4@REF2014) and validation of safety-critical systems (ICS2@REF2014). We also provide internal funding (~£30K annually) for impact-oriented activities in early stages of development, which supports new interactions with potential user groups and rapid prototyping based on new research concepts. In particular, we used the internal funding to develop our UoA11_PROV ICS. The long-lasting impact that results from this approach is illustrated by our continuation ICS, UoA11_Redhat.

Current position with reference to REF2014

During the review period, we pursued the agenda that we set in REF2014, while responding to technological and research developments such as the growth in scalable data systems. We have achieved a majority of aims and objectives from our REF2014 agenda (some were revised or extended due to the changes in staffing). Also, thanks to an overall growth in staffing, new research areas emerged (e.g., IoT) and existing areas benefited from strategic investment (e.g., CPS). Highlights include:

- We responded to the opportunities created by the tremendous growth in scalable data systems and data science (especially machine learning (ML)) by investing in new posts at all academic levels. This allowed us to lead first the NU Digital Institute, and now Newcastle Data, which focus on transforming NU's research and its social impact through multi-disciplinary research. In 2017, UoA11 led the successful institutional bid to become a partner in the Alan Turing Institute (ATI). We were also awarded £30M to host the National Innovation Centre for Data (NICD) that addresses the acute skill shortage preventing organisations from exploiting the potential of the vast volumes of data now available to them. Close collaboration with UoA10 led to the award of EPSRC CDT in Cloud Computing for Big Data aimed at forming future leaders in data analytics with the rare combination of skills in scalable computing and statistics.
- The area of interaction design and ubiquitous computing involves tackling challenges that must be approached from human-centred perspective. We were a pioneer in the development of Digital Civics aimed at collaborative technologies to support citizens' civic engagement and empowerment in the commissioning, delivery and evaluation of digital services. Our research proceeded within an EPSRC Digital Economy Research Centre and EPSRC CDT in Digital Civics and will now continue in the recently awarded Next Stage Digital Economy Centre: Centre for Digital Citizens.
- In the area of security and computer systems resilience, we have built on our founding membership of the NCSC/EPSC Research Institute in Sociotechnical Cyber Security. We expanded into application areas in CPS and IoT through membership of the EPSRC PETRAS consortium in IoT, the Active Building Centre and collaborations with the national Centre for Energy Systems Integration based in Newcastle. Our researchers received numerous research grants, including two ERC starting grants. Throughout REF2021 period, our work has been supported by the NCSC Academic Centre of Excellence in Cyber Security Research status awarded to NU.
- A significant investment in our computational biology research at the beginning of the REF2021 period resulted in a premier computational biology group positioned within a UK computer science department - the only one to have both a microbiology and nanotechnology wet lab, including an intelligent biofoundry.
- We invested in ECR academic staff in the areas of CPS and the IoT, and maintained close collaboration with industry, which led to the transfer of our foundational results in formal methods and tool development to the areas of power management of integrated circuits and rail safety systems reported in two ICSs.
- We published 1140 journal articles, over 1850 conference and workshop papers, and over 210 book chapters. We also authored and edited over 110 books and contributed to 28 patents.

Strategic goals and plans

Our vision for UoA11 at NU requires a research environment that fosters discovery and impact. Our strategic approach is to equip all staff and students with the skills, resources and freedom to succeed in their current academic research and external (commercial and public) endeavours, as well as to foster new partnerships and collaborations with industry, business, external agencies and other disciplines within NU.

In the next 5 years, we will prioritise support for external collaboration, dissemination and impact. Aiming at further growth of international recognition of our research, we will provide resources and environment for: organisation of leading international conferences; visits by esteemed scientists; and sabbaticals in leading research organisations. We will also encourage and reward engagement in external advisory boards, conference steering and programme committees, and editorial boards. We will support our existing and emerging areas of research excellence and leadership, by including goal-oriented protected time in workload allocation and funding resources.

We will continue to support the engagement of research groups and individual staff and students in multi-disciplinary research related to national and global challenges (e.g., over 15 current impact cases). We will refresh our strategic advisory board with industry, scientific and public

sector representation, with the aim of developing new project streams such as strengthened participation in Knowledge Transfer Partnership (KTP) schemes. We will maintain already strong links with companies that have played significant roles in our ICSs (e.g., Dialog Semiconductor and Red Hat) but will also develop joint research themes with institutional strategic partners including Siemens and Procter & Gamble.

We will lead work to establish two new NU Centres of Research Excellence (NUCoREs) in Autonomous Systems and Cyber Security, and will target the NUAAct scheme with concerted discipline-oriented recruitment campaign. To further encourage diversity in our PhD cohort, we will set up a new funding scheme for the best international students to complement the top-quality UK students recruited via CDTs.

To ensure sustainability, we will grow the research community through extensive recruitment campaigns for new research-active colleagues. This will reduce our student staff ratio, which rose by 30% in the School of Computing over the review period due to highly attractive courses and successful recruitment. Alongside a proactive approach to promotions, we will prioritise senior appointments (staff returned in REF2014 included 40% full-time Professors compared to the current 23%). We are always working on improving our recruitment processes, in terms of how we reach potential colleagues and how we undertake recruitment.

We will maintain a culture of good practice in research following NU's code of practice, which includes promoting integrity and honesty during preparation, and peer review of research outputs. Ethical considerations underpin all our research, e.g., the proposal approval process will carefully review all ethical issues according to NU's policies and procedures.

Group research profiles, achievements and plans

The main driving forces behind our research are groups which set their own research strategy - developed in agreement with and facilitated by the School, ensuring consistency with NU's strategy and values - and provide support for delivery of research outcomes, training of research students and collaboration with industry. There is also a strong ethos of cross-group working, e.g., DERC (EP/M023001/1) involved researchers coming from 3 of our research groups.

Below we highlight research profiles, advances made during the review period, and plans related to the six UoA11 research groups providing an organisational framework for staff on Teaching & Research and Research-only contracts. Staff on Teaching & Scholarship contracts undertake research-related activities - including involvement in research student supervision - within the Educational Practice in Computing (EPiC) group, often in collaboration with or as members of the other groups. We also list returned staff for whom a group was the primary one over the review period, and indicate group (co-)leads.

- **Advanced Model-Based Engineering and Reasoning (AMBER)**

Bogomolov, Fitzgerald, Harrison, Jones, Freitas, Koutny, Khomenko, Pierce, Pietkiewicz-Koutny, Soudjani, Steggle

The AMBER group's research aims to realise the potential of formal models, methods and tools in engineering challenging types of system, particularly those that are concurrent, asynchronous or cyber-physical. A feature of the group, reflected in the range of collaborations and projects, is the extent to which it combines foundational work that extends the capabilities of formalisms with collaborative projects that assess and improve their applicability with user communities in industry.

The group's foundational work covers the semantics and correctness of concurrent, hybrid and probabilistic systems, e.g., developing models of causal relationships capturing simultaneity and mutual exclusion, synthesis methods for globally asynchronous locally synchronous systems, verification for complex biological networks, and formal methods based on modularity, separation logic, and rely-guarantee thinking as well as verification over hybrid and probabilistic temporal specifications.

Work towards industry deployment focuses on providing multi-disciplinary engineering teams with modelling, analytic and simulation support to achieve better performing and more resilient designs, including those that combine semantically diverse design models owned by multiple stakeholders, as in CPS and systems-of-systems. AMBER's strategy is to embed research outputs in sufficiently robust tools to achieve industry evaluation, e.g., the Workcraft tool embodies work on a range of interpreted graph models, and work on co-simulation of multiple diverse CPS models is embedded in the INTO-CPS tool chain.

Responding to the increasingly heterogeneous character of computing systems (and hence models) the group sought to attract new staff to grow capabilities in probabilistic/stochastic and hybrid system models. The group also sought to develop facilities such as the MindSphere Lab created with Siemens as a focus for work with PhD students in CPS. The group sought funding from diverse sources to support its strategy, notably EC FP7 and Horizon 2020 (COMPASS, INTO-CPS, CPSE-Labs and HUBCAP), and direct industry funding (Dialog Semiconductor). The group was also active in helping to set the European research agenda in CPS (projects TAMS4CPS and Road2CPS).

We maintain extensive international academic collaborations, several on a strategic basis, leading to joint publications and projects, notably with Leiden and Aarhus Universities (between them contributing over 40 research outputs since 2014). We also maintained collaboration with industry, including Siemens (MindSphere), analysing systems interdependencies using a digital twin (Centre for Digital Built Britain), Digital Twins for Resilient Geo-Infrastructure, DECIDe for Rail Systems and Safety Board, and Royston Company on new AI techniques in maritime context.

AMBER's focus on the "pipeline" from foundations to industry practice has been vindicated through several advances including:

- Work on asynchronous circuit design implemented in Workcraft was adopted by Dialog Semiconductor (exclusive supplier of power management integrated circuits for the Apple iPhone, iPad, and Watch), providing the basis of UoA_Workcraft ICS. Dialog funded 2 PhDs and 2 US patents, and David Lloyd, a Senior Member of Technical Staff at Dialog, became a Visiting Professor of Practice in the School of Computing to provide close and regular contact with AMBER.
- The recently established spinout ScubaTx resulting from collaborative efforts with NU's medical researchers and Newcastle Hospitals NHS Foundation Trust leverages AMBER's expertise in verified software design to commercialise persufflation - a proven but unexploited organ preservation technique.
- Work on CPS, including probabilistic and stochastic aspects, e.g., simulation of big bleed trauma emergencies with Royal London Hospital, NIDUS (dialysis machine capable of infant dialysis) achieving CE marking and commercialisation with Newcastle's Royal Victoria Infirmary (RVI), and EMV2 security analysis of EMV contactless credit and debit cards.

Over the next 5 years, the group plans to develop its international profile in formal model-based methods for asynchronous and cyber-physical systems. It will continue to focus on foundational work that has impact through tools and methods, using this to attract and retain expertise in stochastic and hybrid systems modelling and verification. It will focus on novel technologies for design of asynchronous circuits and development of well-founded tool chains for the engineering of digital twins for CPS. Application foci under active development include methodologies and tools for supporting criminal investigations based on causality, and on the opportunities created by the rise of model-based engineering in infrastructure and the built environment.

- **Interdisciplinary Computing and Complex BioSystems (ICOS)**
Bacardit, Bauer, Goni-Moreno, Fellermann, Kaiser, Krasnogor, Lord, Taylor, Wang, Wipat, Zuliani

ICOS is the premier computational biology group within a UK Computer Science department and the only one to have both a microbiology and nanotechnology wet labs, including an intelligent biofoundry. Our mission is to carry out ground breaking research at the interface of computing science and complex biological systems, creating the next generation of algorithms that provide innovative solutions to problems arising in natural complex systems (e.g., Biology, Chemistry, and Physics) as well as synthetic ones (e.g., Biological/Software Engineering and Healthcare). ICOS substantially expanded during the review period, reaching a steady state of 50-60 members coming from a range of disciplines (e.g., Computing Science, Engineering, Physics, Chemistry, Biology, and Social Sciences) and including approx. 25 RAs and 25 PhDs.

In the review period, the growth and high-quality output of ICOS were enabled by substantial external funding, including £7.5M (£4.7M from EPSRC, £1.5M from NU, and £1.3M from industry) EPSRC Programme Grant with an additional £2M funding from NU for microbiology and DNA/RNA nanotechnology laboratory as well as various Innovate UK KTPs, H2020 projects and a RAEng Chair in Emerging Technologies for Krasnogor (one of only two such awards in NU).

ICOS regularly collaborates with other NU schools, e.g., the above Programme Grant involves six different groups and all three of NU's Faculties. In addition to state-of-the-art synthetic biology, ICOS members conduct internationally leading research on neuroinformatics, e.g., in 2020 Kaiser published in MIT Press a foundational book on brain connectomics.

ICOS is part of a strong network of leading international collaborating institutions including universities, companies and research laboratories, including BBN, Boston University, Utah University, Kobe University, NUS, Procter & Gamble, Prozomix, GSK, CERN, ECLT, Weizmann Institute, Tel Aviv University, Granada University, Centro Nacional de Biotechnologia, SRC, Huawei, Sixfold Bio, Nanoverly, CPI, and PROIMI. The excellence of ICOS environment has helped to generate outputs in high quality and highly interdisciplinary areas that range from stem cells and tissue engineering to computer-driven neurological interventions, synthetic biology, and DNA/RNA nanotechnology.

ICOS strategic goal in the next 5 years is to cement further a worldwide technological lead in computer-aided biology and computer-aided nanotechnology with the key objective of accelerating translation and spinouts for the science produced by the group. The starting point for achieving this is very strong, building on Krasnogor's 10 year RAEng Chair and Taylor's 5 year UKRI Future Leaders Fellowship. Moreover, Krasnogor established a software-as-a-service venture, Workli, which enables seamless teamwork via user-friendly collaboration pipelines. This unique experience enabled mentoring and advising ICOS' RAs and PhD students (e.g., Ding, Kozyra, and Sanassy) who then participated in incubators and accelerators programmes such as ICURE, SETsquared, Health Innovation, and Entrepreneur First. They established their own companies, e.g., Kozyra (Nanovrey, nano-bio-tech), Ding (X-Wow! making digital pathology available in third world countries), and Sanassy (Vochlea Music, AI for the creative industries). ICOS will build on this experience and with the help of NU's business development unit convert its internationally leading research outputs into commercial opportunities.

- **Networked and Ubiquitous Systems Engineering (NUSE)**
Davison, Morgan, Puthal, Solaiman, Ranjan, Ushaw

The group, newly created in 2019, is building a global reputation for leading research in distributed systems, working on emergent paradigms including IoT and Game Engineering. Contributions to distributed system security and dependability include the development of a novel hybrid smart contract (on and off-blockchain, in collaboration with Cambridge University) architecture for monitoring and enforcing contracted interactions in distributed applications such as IoT. The group's work with the global video games industry includes carrying out over 15 industry-based projects a year on commercial games that have generated £5B revenue. The group builds on a foundation of excellent research (e.g., the 2020 Stanford University

bibliometric study in distributed computing positioned Ranjan as a highly cited author, at #6 in 2019 when 46% of his journal articles were co-authored with NUSE members).

Working with NU's Urban Observatory co-located in the USB (which shows how improvements in the research environment have facilitated new highly productive collaborations), the group made significant advancements in open source technologies (IoTsim-Edge, IoTsim-Stream, BigDataSDNSim, and IoTsim-Osmosis) enabling the creation, simulation and testing of scalable computing environments as well as supporting the rapid development of IoT and Big Data analytics applications. IoTsim-X technologies leverage CloudSim (invented by Ranjan who continues to maintain its code base) as the baseline simulation framework and one of the world's most adopted Cloud Computing simulators (with nearly 3000 citations a key publication on CloudSim is the fifth most cited (Scopus, top 0.007%) of 78,864 papers published in Distributed Systems between 1960 and 2020).

Successful collaboration with NU's Schools of Engineering and Business resulted in four major UKRI research grants with combined funding over £6M that build on the group's advances in developing analytical methods and software systems for processing the "big data" generated by IoT infrastructures that address societal challenges (e.g., flooding, landslide, air quality, and GDPR compliance). For example, IEEE TPDS selected our paper on remote sensing applications in Digital Earth as the 'Spotlight Paper'. Also, our collaborative G-Hadoop paper was selected as 'high quality research paper' by Future Generation Computing Systems to celebrate the Chinese Computer Science research landscape in 2012-2017. G-Hadoop successfully integrated, managed, and processed 2.36PB of remote sensing data across 8 satellite data centres. G-Hadoop holds the current world record for remote sensing "big data" management and processing.

NUSE has collaborated with medical professionals on diagnosis of eye disorders (Health Innovation Challenge Fund). Working with NU's Biomedical Engineering, we pioneered the use of artificial intelligence combined with image analysis to demonstrate how robotic prosthetic limbs can grab and hold items without human control. Recent collaborations with NU's Civil Engineering applies our real-time simulation expertise to aid in managing water security in developing nations while utilising gamification to spread knowledge and know-how across partner organisations (UKRI GCRF Water Security and Sustainable Development Hub).

NUSE will continue to pioneer the fundamental resource and data management principles for orchestrating cross disciplinary (e.g., smart cities, healthcare, and industry4.0) IoT application workflows. The group will investigate new theoretical models to address performance modelling, workload modelling, and data fusion in the context of orchestrating IoT workflows in a hybrid environment with both cloud and edge data centres. We plan to strengthen collaboration with the NHS on blockchain storage technologies for managing personal healthcare data generated by IoT technologies such as wearables. We will continue repurposing projects developed in collaboration with the video games industry into other settings, employing our recently developed streamed gaming platform to effect global-scale interactive simulations. With industry partners and NU's School of Engineering, we will seek to create highly precise simulations for river erosion, autonomous flight navigation, and carbon-neutral landscape.

- **Open Lab (OL)**

Bowen, Clarke, Crivellaro, Durrant, Guan, Kharrufa, Kirk, Smeddinck, Vlachokyriakos

Open Lab is an Interaction Design and Collaborative Technologies research group with specific expertise in Human-Centred Design and Ubiquitous Computing. The group has a world leading reputation for pioneering and developing the subfield of Human-Computer Interaction (HCI) known as Digital Civics. This area develops digital technologies to support citizen engagement and community empowerment, in pursuit of education, health and wellbeing, social care and public participation in democratic processes. The strength of our research output is attested to by consistently significant output at ACM CHI (the most prestigious dissemination venue for HCI research).

OL pursues development of theory, methods and technologies, is highly interdisciplinary (both within the group and externally) and works with a broad community of partners (over 30 on the latest funded project). The partners span government authorities, NGOs, charities (local and international), educational organisations, health and social care services (including NHS X/Digital), media companies (BBC R&D) and industry (Microsoft, Google, Mozilla), alongside a broad network of international academics.

Since 2014 OL has been supported (as lead) by a £16.6M portfolio of UKRI-funding, including CDT in Digital Civics, Digital Economy Research Centre (DERC), the Not Equal Network+, and EPSRC Next Stage Digital Economy Centre - the Centre for Digital Citizens (CDC) valued at over £8M. The CDC will fund a programme of Innovation Fellowships for post-docs to support digital social innovation research using novel participation platforms and data-driven technologies with a network of partners and the urban, rural and coastal communities of the North East (and internationally).

An exemplar of our interdisciplinary internal collaborations includes working with MoveLab (NU Institute of Cellular Medicine) to collaborate with Oxford University for the UK Biobank Study. OL and MoveLab expertise was employed to develop wrist-worn accelerometers used as part of the largest ever population assessment of physical activity (100,000+ participants).

Recent extensive collaborations include the International Federation of the Red Cross/Crescent Societies (IFRC) that involved OL developing techniques to drive consultations with more than 3000 members of the organisation's youth volunteer-base, directly informing and feeding into the IFRC's Strategy 2030. This was launched in Geneva and further disseminated at that event through a bespoke installation of a VR Escape Room experience (311 delegates in 27 national teams used it). In 2020 we also built a bespoke web platform for IFRC to host their first global Climate Conference to host over 10,000 international delegates to the virtual conference.

In the next 5 years, the new CDC will pioneer processes of digital social innovation for social and environmental sustainability and will act as a catalyst for further research development. To achieve this the group will continue to explore design futures and the development of collaborative digital platforms using new algorithmic, data-driven and AI technologies to support future living and new models of participatory education, health and social care, and local democracy. OL will also pursue further challenges in developing digital support for Sustainable Development Goals in international contexts and pushing the digital civics agenda towards an environmentally focused Sustainable Digital Society agenda. Further to the digital healthcare interests, OL will also continue behavioural informatics work to develop new ML techniques for activity recognition in pursuit of digitally enabled healthcare interventions, in particular, using wearable sensor platforms.

- **Scalable Computing (SC)**

Ezhilchelvan, Fernstad, Forshaw, Holliman, McGough, Missier, Mitrani, Thomas, Watson

The group is internationally renowned for tackling research challenges in High Performance Systems, Data Science, and ML. During the REF2021 period we focused on growing in key areas of Data Science and AI, including data systems performance, data provenance, data analytics, data visualization and ML. This included designing and building specialist facilities to support our visualization research and innovation.

Through its leadership, the group has developed a “virtuous circle” that productively links research to teaching and engagement in data science resulting in over £100M in external funding for NU in the past decade. The importance of the group's work to NU-wide research resulted in the creation of “Newcastle Data (Watson)” to co-ordinate, support, grow and promote data science across the institution.

The group's reputation in scalable data analytics led to NU being invited to apply to become a partner in the Alan Turing Institute (ATI) in 2018. This has provided new funding and opportunities, including PhD internships, and collaborations with world-leading researchers spread across The Turing's partners. For example, SC (Holliman) leads the Turing visualization interest group #VizTIG and (McGough) the TIG developing best practice for collecting cyber security data. SC also has active links to research teams in the USA, Australia, Italy, Switzerland and Sweden, often supported by overseas research funding.

Over the review period, SC built strong collaborations with NU's School of Mathematics, Statistics and Physics. Key to this was the CDT in Cloud Computing for Big Data, which is now supported through investment from NU and our industrial partners, especially Red Hat (IBM). The CDT creates future leaders with the rare dual competencies in the statistics and computing required to drive forward scalable data analytics. It has successfully brought together a diverse range of students, many of whom have had placements at companies as far away as California (Twitter) and Australia (Woodside). We recently established an expanding portfolio of spin-off MSc programmes (OfS funded) in Data Science to fill the long-term research and innovation pipeline with a diverse set of high-achieving students.

The group's work is also driven by collaborations with those who apply our research outputs to transform their own data-rich research fields. We use these applications to challenge our methods, inspire new approaches, and provide a means to evaluate their utility. Healthcare and Urban Analytics, with recent expansion into security and defence, have been particularly productive areas, and our tools now underpin large research projects. A spin-off of this activity is the RSE (Research Software Engineering) team as a NU facility (engaged in 32 NU research projects in 2020). The establishment of a Turing DstI Applied Research Centre (ARC) at Newcastle is one further outcome of the collaborative approach developed during the REF2021 period.

Many of our projects involve industry and over the past 6 years NU has set up major initiatives to engage at scale with companies that lack their own data analytics skills. Among these, NICD provides a route for SC to have a major impact on tens of public and private sector organisations each year through collaborative projects. The new Catalyst building - a melting pot of academics, students and industry working on data driven innovation - provides spaces designed by the group for interaction with industry (e.g., IBM Red Hat) and includes state-of-the-art visualisation facilities, e.g., the Team Decision Theatre.

Our research plans are focused on designing new methods for large-scale data analytics such as a novel visualization method - Missingness Glyph - for analysing and exploring missing values in data, generating impact by transferring the knowledge this generates to industry through NICD, and producing the future Data Science leaders through the CDT and MSc programmes. We will also develop a key new strength in image informatics through the appointment of a joint chair with the Faculty of Medical Sciences.

- **Secure and Resilient Systems (SRS)**

Coopamootoo, Dong, Gross, Mace, Maxion, Mehrnezhad, Morisset, Randell, Romanovsky, van Moorsel

The group is recognised internationally for its research contributions to creating modern information systems, networks and infrastructures that are dependable and secure. The group extensively collaborates with psychologists, engineers, mathematicians, industry partners, standardisation bodies, and users of systems. In the review period, to inform and lead novel work on evidence-based methods in Cyber Security research, the group brought expertise in from CMU (Maxion).

NU became a NCSC Academic Centre of Excellence in Cyber Security Research in 2012 and has maintained this status throughout REF2021 period. The centre provides a strong interdisciplinary research environment for the group, including researchers in engineering,

business, medical and social sciences and law. The group publishes routinely in the main venues for Cyber Security and Resilience, including ACM CCS, IEEE TDSC, and USENIX Security, and has achieved a number of important funding successes detailed below. The group also has been awarded two ERC grants (Hao and Gross), dealing with the important challenges of online voting without central authorities and security assurance of evolving network topologies.

An important strand of research achievements is in human factors of Cyber Security, including both qualitative and quantitative elements. UoA11 was a founding member of the NCSC/EPSC Research Institute for Sociotechnical Cyber Security (RISC). The group continues to be active in RISCs, including through a role in the advisory board. Important milestones include the establishment of the SCENE design framework for behavioural nudges in Cyber Security, the developments in keystroke dynamics, and analysing and improving evidence-based methods.

A second important set of achievements is in security and privacy of IoT, where the group established NU as a full member of PETRAS. The work in smart systems, and particularly in smart buildings (also supported by the Active Building project), leverages NU's Urban Observatory and the ability to experiment in the USB.

A third strand that has seen important progress is that of artificial intelligence, be it in terms of understanding resilience and security of AI approaches, or the use of AI for improved security or privacy. In particular, the group hosts one of only two EPSC Cloud Crime Centres in the UK, which is an interdisciplinary centre exploring the use of ML in Cyber Security, e.g., aimed at highly accurate remote inferring of PINs entered on mobile devices. It also is the home of the interdisciplinary EPSC FinTrust project, which has established important outputs in the foundations of trusted automated services in collaboration with Atom Bank.

To support data-driven research, the group has established a secure data vault in the University's data centre, funded through NCSC. The group also has a fully outfitted cyber incident room for ethical hacking experimentation and user studies.

The other strand of SRS research was concerned with system dependability, fault tolerance, safety, software architectures, exception handling, error recovery, system verification for safety, system structuring, and verification of fault tolerance and safety. A key support in this area was provided by the EPSC STRATA platform grant on Layers for Structuring Trustworthy Ambient Systems. Recently, SRS led several projects on formal verification of railway safety supported by industry. The focus of this work was to develop scalable and usable industry-strength techniques for fully automated verification of signalling and interlocking.

The group plans to develop and lead a NUCoRE which brings together and promotes security and resilience interests across NU. Staffing plans include further diversification (e.g., with respect to race and culture) aiming to further strengthen and emphasise the research threads of human factors, privacy and security of IoT and smart systems, and security/resilience of AI-based systems.

2. People

a. Staffing strategy and staff development

Our staffing strategy aims to create and maintain sustainable research groups while giving researchers freedom to pursue new challenges (both speculatively and across disciplinary boundaries). We also aim to reinforce areas of special economic and societal importance. For example, we expanded the expertise in cloud computing and data analytics with the appointments of Forshaw and McGough, created capability in scientific visualization by appointing Fernstad and Holliman, and established a critical mass in CPS by appointing Bogomolov, Pierce and Soudjani. Our future staffing will make the most of the opportunities for collaboration and growth afforded by the new facilities in USB and NICD. We will also leverage investment from other units and our involvement in NUCoREs to further multi-disciplinary

research, exemplified by the chair of image informatics established jointly with Faculty of Medical Sciences.

The vitality of our research environment can be appreciated through several national and international senior academic appointments: Andras (Keele University), Balaam (KTH), Comber (KTH), Hallinan (Macquarie University), Hao (Warwick University), Montague (Northumbria University), Olivier (Monash University), and Ploetz (Georgia Tech).

To bring fresh research ideas and practices to the unit, we consistently recruited from as wide a pool of talent as possible. Among the returned full-time staff, 65% are originally international, and of those appointed during the review period, over 60% fall into this category. The international dimension of our approach to staffing is further reflected by the range of Visiting Scholars, e.g., Joseph Davis (University of Sydney), Ian Hayes (University of Queensland), Jetty Kleijn (Leiden University), and Federica Mandreoli (University of Modena).

The unit is advised on strategic industry challenges by Visiting Professors of Practice: Nick Booth (CHC), Mark Little (Red Hat), David Lloyd (Dialog Semiconductors), Tom McCutcheon (Dstl), Phil Tetlow (IBM), and Jim Webber (NEO4J).

Staff development

The overarching principle guiding staff development is to give each researchers “freedom and opportunity to succeed”. NU’s Organisational Development Team manages and co-ordinates staff development processes, delivering training aimed at all career stages. During the review period, over 170 of our academics and researchers attended over 200 training workshops and events, including career-related (78), PI-related (65), research-related (47), EDI-related (18), and leadership-related (18). Additional support for research staff development is provided by a Career Pathways Framework Programme, which explicitly outlines the range of career pathways available, and assists in planning development activities to support their future career aspirations.

Newly appointed staff undertake a comprehensive induction. During the first two years of employment, ECRs and new lecturers in particular have their workload carefully shaped to ensure that they have the opportunity to establish themselves as successful researchers. A group-based mentoring scheme for new research staff at all levels aims to advise, integrate and build networks. This has been important in the generation of external fellowships (e.g., EPSRC UKRI Innovation Fellowship for Bauer and UKRI Future Leader Fellowship for Taylor). We provide all new academics with additional research allocation in the workload model, funding (personal allocation for initiatives, travel, and equipment, e.g., Forshaw received funds for a 6-month sabbatical at ETH), mentoring, and a first research studentship. The probation process typically lasts two years and was successfully completed by over 90% appointees (and by 100% female appointees) during the review period.

All new staff members are introduced to Library facilities, including support for open access publishing, research data management, understanding copyright, and creating researcher profiles on a variety of platforms to aid research dissemination, discovery and openness. All new lecturers (unless they hold an equivalent qualification) undertake the Newcastle Educational Practice Scheme (NEPS), which covers research, teaching and management. Also, new academic staff receive individual support from the Research Funding Development Manager who guides new staff through their “first grant” applications, and who ensures staff benefit from internal peer review of research proposals. More experienced staff benefit, e.g., from a six-month Principal Investigator Development Programme (attended by, e.g., Mace and Pierce) covering the roles and responsibilities of PIs, including project, people and team management. Senior staff are supported in developing into leadership roles, e.g., Fitzgerald, Krasnogor, and Lord benefited from the Top Management and Academic Leaders Programmes. The AURORA Development Programme, attended by Heels and Mehrnezhad, provides leadership training for those who identify as female. Access to careers advice, training and development is aligned to

the Concordat to Support the Development of Researchers and Vitae Researcher Development Framework.

Before applying for grants, all academics are supported by a Research and Funding Facilitator, who provides training on writing grant proposals through a group-based Proposal Club and directs researchers to relevant funding calls. Researchers submitting proposals are supported by designated experienced colleagues who advise on proposals and help to prepare for interviews, e.g., by running mock panels. Evidence of the success of these measures is provided by the research projects awarded to staff in highly competitive open calls, e.g., Krasnogor's RAEng Chair, Gross' ERC Starter Grant, Hao's ERC Proof of Concept Grant, Bauer's EPSRC UKRI Innovation Fellowship, and Taylor's UKRI Future Leadership Fellowship.

All staff benefit from an annual appraisal with their line manager as part of the Performance Development Review (PDR) process aimed at reviewing the past performance, agreeing current objectives/priorities, discussing difficulties and identifying training needs. The PDR process also identifies promotion opportunities. During the review period, 4 colleagues progressed to professorship, 7 to readership, 9 to senior lectureship, and 7 to lectureship. The overall success rate for all promotions was 60% (71% for female colleagues).

We are committed to supporting the development of staff returning from extended leave. For example, Mehrnezhad received funding to organise the SSR'19 conference, and we help researchers returning from maternity leave by underwriting their contracts for six months.

In 2020, following consultation with all staff and being guided by the 2018 Athena Forum report on workload allocation models, we re-designed the workload model to better help staff in advancing their careers, addressing work-life priorities, and balancing research demands with educational, administrative and community service demands. This now provides a full profile of contributions to teaching, research, management, and engagement activities with time-equivalent tariffs alongside an individual's employment position and any special circumstances. The individual and group profiles help in allocating and balancing workloads as well as enacting strategic plans. Supported by the new workload model, we will develop a group-centred sabbatical scheme, aimed at doubling the current 10% rate of research sabbaticals and focussing on mid-career researchers engaged in impact-oriented activities.

b. PGR students

An integral part of the advancement and dissemination of our research vision and culture has been an exceptional cohort of PhDs. Being the only Computer Science unit in England running two centres awarded in the 2013 EPSRC CDT exercise, during the review period we graduated 157 successful PhDs (124.88 FTE) achieving 44% growth with three year average increased from 19 in 2015 to 27.3 in 2019 (in terms of FTE, 47% growth with three year average 14.4 in 2015 to 21.9 in 2019). On average, our PhD graduates received 20% of their training from other NU units, evidencing our commitment to interdisciplinary research. Extensive interactions with other Schools across all three NU Faculties have helped us to redefine the boundaries of a Computer Science PhD and the success of our approach to PhD training is exemplified by the fact that the CDT in Cloud Computing continues with new recruitment being sponsored by our industry partners, many of whom also provide internships, e.g., Brown (Nvidia), Lee (Activision), Whinham (Coconut Lizard), Matthews (Jumping Rivers), and Georgopoulos (Ansys).

Our long-term strategy has been to grow the PhD cohort sustainably, and fully integrate PhDs into the life of the unit. We achieve this by treating them as regular members of research groups during the time they receive a balanced training and supervision programme. For example, to ensure that PhDs are fully embedded into our research community - and following an approach piloted in Open Lab - in designing the USB we created workspaces close to and mixed with the staff of their research groups. Initial evidence of the success of the approach is seen in the recent prizes and awards won by our PhD students that was not the case previously, e.g., 10th SPEC Kaivalya Dixit Distinguished Dissertation Award (Alharby and Cooper), ACM SIGCHI Distinguished Dissertation Award (Elsden), Young Digital Leaders 100 Award (Talhouk), and

Pathologist Trailblazers Powerlist 2019 (Ding). The vitality of our PhD environment is further evidenced by graduating co-founders and CTOs of start-ups (e.g., Sanassy and Kozyra), and new faculty (e.g., Davison, Germanos, Kirkham, Nicholson, Wang, and Zeng).

All PhD students are encouraged to take an active role in suggesting and promoting improvements to the research student experience with the PGR Student Staff Committee. They are also invited to participate in the annual Postgraduate Research Experience Survey (PRES), organised by the HEA. In the 2019 survey with 44.9% response rate, 90.7% of UoA11 respondents were satisfied with their experience of research degree programme, 94.6% felt better prepared for their future careers, and 93.3% were satisfied with their working environment.

Monitoring and management

We provide a high level of support during the period of registration on a PhD programme, as set out in a work agreement between the students and supervisors. Every student is allocated at least 2 academic supervisors, who work with the student to produce an initial research proposal within the first 3 months and then supervise their research. ECRs initially co-supervise with more experienced colleagues.

Following NU's Code of Practice for Research Degree Programmes, supervisory teams formally monitor PhD progress through annual reports. The University provides generic research skills training and monitors the number of courses attended. Training credits are awarded for completion of these training modules, and a minimum score is needed before students can proceed to further years of study. An independent Progression Panel, comprising 2 academic staff, assesses the student's reports and oral/poster presentations, and Dean of Postgraduate Studies reviews recommendations externally. Progress is monitored and recorded through an online system. Students are able to raise academic or pastoral issues at any time with their supervisory team, or independent members of the school PhD team, or outside the School to Faculty.

Recruitment

We have been proactive in growing our PhD cohort while maintaining quality, despite changes to funding regimes. Individual research students are recruited through application in response to advertised studentships or, for self-funded students, direct application. To widen access, we offer a four-year Integrated PhD programme with specialist MSc-level training and research preparation before commencing the PhD. EDI plays a significant role in PGR recruitment, as discussed in Section 2.c below.

To help recruit the best PhD students, we provided a £1.2K annual top-up (or as stipend for an additional writing up period) to all PhD scholarships funded in accordance with HEFCE guidelines, and matching funds for partial scholarships. In addition, each new PhD student receives at least £1K p.a. as research support fund, facilitating travel, publication and additional resources. To provide initial support for new staff (in particular ECRs), we directly funded 5 full studentships in the review period. We increasingly seek CASE awards (5 during the review period), and industry scholarships (e.g., funded by Dialog Semiconductors, Red Hat, Datalytx, Nonover, and Siemens). Also, we were awarded 9 scholarships as part of the AHRC Creative Exchange Knowledge Exchange hub in digital public space.

Training and supervision

NU's policy is to provide at least 10 formal supervisory meetings a year although in practice the norm is many more. Academic and research staff working on related topics within the research group provide additional support.

NU offers a comprehensive programme of over 30 skills training courses for research students, based on the Vitae Researcher Development Framework, and including research skills and techniques, communication skills, networking and team working, and career management. PhD students take part in NU's Research Student Development Programme in which they broaden skills by taking 120 credits of relevant taught modules run by specialist teams. For example, NU's Library provides a blend of face-to-face and online opportunities, e.g., two online modules

for Finding Information and Managing Information developed in October 2019 (completed by 30 PhDs). Also, the Writing Development Centre offers guidance to PhDs on developing their writing style, reading strategies and approaches to learning as they make the transition from a taught environment to independent research, including the “Write Here, Write Now” writers’ group. The PRES in 2015, 2017 and 2019 found that over 90% of UoA11 PhD students are satisfied with library facilities (physical and online).

c. Supporting and promoting equality, diversity and inclusion (EDI)

EDI is fully embedded into the operation of the School of Computing. An EDI committee – with membership covering all academic career stages and major operating committees - reports to the School of Computing’s Executive Board and the Faculty EDI Board as standing items, ensuring consistency with the NU’s Equality Strategy. The committee comprises diverse membership and is co-chaired by two members of academic staff with experience of both research and teaching: one of them (identifying as female) is teaching-focused, and the other (identifying as male) is research-focused.

Computing was granted an Athena Swan Bronze award in 2014 and 2018. In particular, we received positive feedback for our involvement in running a research associate network across the university to support RA career development. Another commendation was for our Career Research Fellow (CRF) scheme created to improve diversity in our academic career pipeline, and which led to the appointment of 5 female research fellows. The scheme helps researchers establish themselves through a series of targets, with a view to progress to an open-ended academic position within 5 years. Compared to REF2014 where 7% of full-time returned academics were female, we have now returned 17%.

When it comes to staff recruitment, we ensure all our job advertisements use gender-neutral language and candidates for academic posts are expected to demonstrate their understanding of EDI in their applications and during interviews. We aim at a wide dissemination of job advertisements, commitment (signposting) to EDI, reasonable application deadlines, and diverse selection and interview panels. We are also now piloting selection processes that are intended to include a wider range of activities in conjunction with the research groups.

The School of Computing consults staff and students regularly to ensure that their views are considered in decision-making. For example, we organised an anonymous online mechanism for raising concerns, suggestions, and support interaction following the outbreak of Covid-19. This influenced our approach to communications and resulted in developing a communication channel so that parents/carers can share resources and report problems. Another example was in the design of the USB spaces. At all levels from concept to detailed design, staff and students participated in a programme of workshops with the architects, and were regularly updated on construction progress, including site visits. A questionnaire was developed to promote suggestions and allow reporting of issues. This resulted in a building that embodies the School’s inclusive ethos with a wide range of spaces to accommodate diverse work preferences and other needs, e.g., gender-neutral lavatories, and quiet rooms that can be used by breastfeeding mothers, or for reflection or prayer, or by those who have disabilities or chronic illnesses and need quiet time.

Another successful initiative is our CDT recruitment. For example, the CDT in Digital Civics has used inclusive recruitment strategies and attracted an average of 40% female students since it began. The CDT in Cloud Computing implemented initiatives to increase diversity including advertising campaigns targeted at minority groups, providing local industrial placements for those who cannot travel, and embedding flexibility into the taught programme for those with caring responsibilities. As a recognition of our efforts, we were an invited panellist at an EPSRC event on increasing diversity that will help influence external institutions on inclusive recruitment methods, and Watson serves on the RAEng EDI Committee.

Diversity is celebrated throughout the School, with members being recognised at university level for their efforts (e.g., the Tech Women team in Open Lab won a NU EDI award). The School has

an extensive list of EDI actions and celebrates social activities such as LGBT history month and International Women's Day.

3. Income, infrastructure and facilities

During the review period, our research has been enabled and supported by a rich project portfolio. The overall research income from 343 funded projects was ~£35M including:

- 140 Research Councils projects totalling ~£23.6M,
- 49 EU projects totalling ~£5.5M,
- 55 UK Government projects totalling ~£2.5,
- 51 UK charity projects totalling ~£1.6M; and
- 42 UK industry projects totalling ~£1.1M.

On average, 30% of the contribution to these projects came from outside UoA11, evidencing our commitment to collaborative research. All our research groups benefited from project support matching their potential and aspiration: AMBER (£3.6M), ICOS (£10.9M), NUSE (£0.7M), OL (£7.7M), SC (£4.2M), and SRS (£7.9M).

External funding reported above was essential to successful delivery of our research in REF2021 period. For example, both Synthetic Portabolomics (EP/N031962/1) and UNCOVER (EP/K001698/1) led to 7 submitted outputs, SiDE (EP/G066019/1) to 6 outputs, and Modelling Human Brain Development (EP/K026992/1) to 5 outputs.

We adopted a strategy of diversifying our funding streams while maintaining our research council income that remained steady at about 67.5% over the REF2021 period. Because of our increasingly multi-disciplinary research, the range of funders has diversified and the proportion of research income due to EU and UK Government has reduced as the income from other resources has increased (three year average 26.1% in 2015 to 19.2% in 2019), and we have seen substantial growth in charity funding (three year average 2.9% in 2015 to 7.6% in 2019) and industry funding (three year average 2.6% in 2015 to 4.1% in 2019). We have therefore achieved, as planned, a much better balance among the non-RCUK research income streams, creating a robust funding structure for the next 5 years and beyond. Moreover, increasing charity funding reflected our commitment to solving societal problems and challenges, and increasing industry funding reflected our commitment to magnifying the societal impact of our research. A key mechanism aimed at securing support for research is the series of events involving industry and business community organised by the research groups, NICD, and the Director of Business and Engagement.

In the review period we benefited from NU's Research Impact Framework awards in digital economy (£1.7M), synthetic portabolomics (£1.5M), and big data analytics (£0.1M). We also benefitted from significant new investment into strategic infrastructure and facilities, including:

- **USB** (£58M from NU). The building - opened in September 2017 at Newcastle Helix - is the new location for the School of Computing and a flagship development for urban sustainability. It hosts laboratories supporting collaborative research on digital aspects of, e.g., sustainability, transport, and energy. In particular, in MindSphere Laboratory we share with Siemens our research on the IoT, and in Decision Theatre - an interactive 3D facility linked to the Urban Observatory (the largest urban sensing network of its kind in the UK) - we develop advanced data visualisation so that policy makers and other stakeholders can plan and operate cities sustainably.
- **National Innovation Centre for Data** (NICD, £15M from EPSRC and £15M from NU). Located in the Catalyst building - opened in January 2020 at Newcastle Helix - builds on our world-leading expertise in data science and its application developed over the past decade. It is addressing the shortage of data skills in the UK transferring practical data skills developed by us into the workforce of private and public sector organisation. NICD has already attracted global leaders - Red Hat and AkzoNobel - and it will provide major opportunity for generating industry impact following our planned investment in data science. NICD has already engaged approx. 5000 representatives from 400 organisations resulting in 60 workshops and 40 collaborative projects.

- **Microbiology and DNA/RNA Nanotechnology Laboratory** (£2M from NU). It hosts state of the art equipment that includes, in particular, facilities to design and manufacture microfluidic devices, an optimal tweezer, DNA sequencing machines, digitally controlled bioreactors, an acoustic liquid handling robot, and a video rate Atom Force Microscope.
- **The Key Building** (£10M from NU). It provides engagement and research space for data science; in particular, for the growing team in image informatics.

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

During the review period we have deliberately fostered cross-disciplinary collaborations through two mechanisms. One was to increase the share of our research income coming from charity and industry, and the other engagement in Newcastle Data and NUCoREs, such as Data-NUCoRE, leading to collaborations crossing established boundaries. This is evidenced by our submitted research outputs which describe:

- collaborations with other disciplines, such as biology, electronic engineering, social sciences, medicine, and media;
- international collaborations on over 61% outputs;
- collaborations with industry, e.g., GlaxoSmithKline, Merck, Illumina Inc., Dialog Semiconductor, InlecomSystems, Thales E-Security, and Microsoft Research.

Each of our groups maintains meaningful collaborative links and holds joint projects with other NU units, external academic organisations, and industry partners. We pursue new collaborations using flexible individual funds as well as a targeted Impact Fund. Also, research centres such as Newcastle Data provide venues for establishing new contacts.

We actively pursue opportunities to engage business directly with research outcomes. For example, we have been partners in two Innovation Actions (CPSELabs and HUBCAP) which offered equity-free funds (in the case of HUBCAP, €3M) for model-based design tools providers and new users in the CPS arena. This is a vehicle for promoting research outputs in the forms of the methods and tools that we have contributed to or developed. In addition, as a digital innovation hub we offer businesses access to a network of research expertise in institutes across Europe

Computing education

We contribute to the sustainability of the discipline at several levels:

- We are a leading partner in national and regional initiatives to support Computer Science as a new school subject, running outreach events for 1000+ primary and secondary school pupils each year, and holding an annual conference attended by 120+ teachers. Our strong links to local schools inform computing education research in EPiC and Open Lab, and we regularly (pre-Covid) hosted visits, workshops and even “science fairs” from schools, bringing pupils into a research-rich environment in the USB.
- We redesigned the UG curriculum deployed in 2019 to increase focus on research, professional practice, and impact. For example, we designed and introduced a portfolio-oriented curriculum using problem based learning; in Stage 1 students deal with large data sets deriving from our bio-research project; a module worth 25% of Stage 2 introduces activities designed by our research groups; and most student capstone projects in Stage 3 are organised by the research groups.
- 13 specialist MSc programmes closely match the research agenda of our groups, e.g., new programmes in Data Science and in Smart Systems Engineering. All these programmes involve significant project work conducted alongside one of the research groups.
- We have been committed to the successful development of the Institute of Coding set up to tackle the UK’s digital skills gap (supported by £1M from NU), and the already approved Degree Apprenticeship programme, creating programmes in Data Science and Cyber Security that are delivered by research-active staff.

Local collaborations

Now, over 20 projects in our portfolio involve collaboration with other NU units. Exemplars include work on asynchronous circuits and integrated energy systems with School of Engineering, educational technology with School of Education, Communication, and Languages, synthetic portabolumics with Faculty of Medical Sciences, and ethics of AI with the Business School. Also, NICD have recently won £1.6M from North of Tyne to transfer data skills to local industry.

National and international collaborations

Our international academic research collaborations have included: Aabo Akademi, Aarhus University, AIST, Australian National University, Bonn University, Chinese Academy of Sciences, Chinese University of Geosciences, CMU, Concordia University, CSIRO, ENS Cachan, ETH Zurich, Georgia Tech, Leiden University, Luxembourg University, McMaster University, MIT, NICTA, Sao Paulo University, TU Wien, Twente University, University of Augsburg, University of Illinois Urbana-Champaign, University of Melbourne, University of Messina, University of Nantes, University of New South Wales, University of Queensland, University of Sydney, and Wuhan University.

Our national and international industry partners have included: Atom Bank, Bang & Olufsen, Bosch, Google, Hewlett Packard, Komatsu, Mozilla Foundation, Microsoft Research, SAP, Siemens, Swiss Precision Diagnostics, W3C, and over 30 other companies.

Collaborations with research users

Following our approach to research that is inspired by potential impact, we prioritise engagement with research users both to guide our research, and to translate its outcomes into industry. We have established several designated centres to provide informative outlets for our research, and to support events and venues for external interaction. In 2017 the UoA was awarded £30M to create NICD which focusses on enabling organisations to extract value from their data. This is done through programmes of events, training and joint projects (e.g., 76 “discovery workshops”, 24 active and 20 completed data skills projects, and £15.3M in 6 successful research proposals supported by NICD). NICD builds on the success of the Cloud Innovation Centre (2014-17) which had 2000+ attendees at its events and has assisted 200+ companies. UoA11 is also heavily involved in the £40M National Innovation Centre for Ageing (NICA), which has a major theme in healthcare analytics. Both Innovation Centres will share the £50M Catalyst building that has been designed for the purpose (including a high-quality visualization suite).

Responding to national and international priorities

Our research staff and students actively responded to the challenges caused by Covid-19, e.g., by applying ML to predict respiratory failure in patients, and by applying 3D printing expertise to make more effectively components for splash guard visors which resulted in winning a Dynamites 2020 Award. Other examples include developing advanced solutions for combating zika and dengue epidemics, and methods to work with Syrian refugees in Lebanon to design technologies for food security and community resilience.

Exemplars of leadership of the UoA within the academic community

EPSRC College members. Full: Ezhilchelvan, Fitzgerald, Harrison, Koutny, Krasnogor, Morisset, Romanovsky, Shrivastava, van Moorsel, Watson, Wright; associate: Bacardit, Gross, Holliman, Kaiser, Kirk, Lord, McGough, Missier, Ranjan, Soudjani, Wipat, Zuliani

UKCRC members. Fitzgerald, Jones, Kaiser, Randell, Romanovsky, Shrivastava, Watson

Fellowships and adjunct/visiting professorships. Fellow ACM (Jones, Randell); Fellow RAEng (Jones, Watson); Fellow FME (Jones); University Minho Braga (Harrison); Seoul National University (Kaiser); McMaster University, Nicolaus Copernicus University, Xidian University (Koutny); Weizmann Institute (Krasnogor); NII Tokyo (Romanovsky); University Balearic Islands (Thomas); University of Sydney (Watson); ANU, University NSW, Julius Fellow CSIRO, China University Geosciences (Ranjan)

Steering committees. FME chair, Theoretical Aspects Computing (Fitzgerald); Engineering ICS chair (Harrison); Petri Nets chair (Koutny); ECLT chair, Nature Inspired Cooperative Strategies for Optimization (Krasnogor); DILS, TAPP (Missier); ERCIM SERENE (Romanovsky); UK e-Science All Hands Foundation chair (Watson); NSV, NSR (Bogomolov); BS Institute Fundamental Principles of Automotive Cyber Security (van Moorsel), Epilepsy Foundation (Taylor)

Editorial boards of journals and research monograph series. Applied Logic (Fitzgerald); Formal Aspects Computing (Jones); ACM CR (Kaiser); Human Computer Studies (Kirk); editor-in-chief Transactions Petri Nets, EATCS Monographs TCS & Texts TCS, Natural Computing, Scientific Annals CS (Koutny); Natural Computing (Krasnogor); department-editor IEEE SP (van Moorsel); Annals History Computing (Randell); Systems Architecture (Romanovsky); BioIT (Wipat); IEEE TBD/CEM, Communication Systems (Puthal); Networks & Computer Applications, Software Practice & Experience (Morgan); senior-editor Data Information Quality (Missier); PLOS Computational Biology (Taylor); IEEE TCC/TC, ACM CS/TIoT (Ranjan); ACM SIGBED (Bogomolov)

Awards and other forms of international recognition. Jim Gray Award (Watson); BPA QUEST'18 (Bogomolov); Spotlight Paper IEEE TPDS (5 in total) (Ranjan); CHI'14-18 (1-2 UK and 4-7 worldwide); Microsoft Academic Top Authors in Cloud Computing, Big Data, QoS, Resource Management, and Services Computing (Ranjan); Scopus SciVal 3rd in Cloud Computing, Clouds, Distributed Computer Systems (Ranjan, 2010-2019); one of most influential papers in 30 years of ISSRE (van Moorsel)