REF2021

Institution: Nottingham Trent University (NTU)

Unit of Assessment: B11 - Computer Science and Informatics

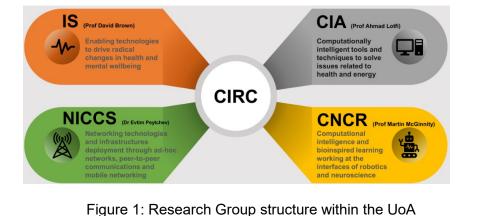**1. Unit context and structure, research and impact strategy**

The Computer Science and Informatics Unit of Assessment (UoA) at NTU is a highly interdisciplinary UoA that delivers theoretically grounded and determinedly impactful research that enables us to bring multiple computer science approaches to bear on issues of societal concern. Our research coalesces under the theme of 'Enabling Digital Technology' and extends to the following areas: health and wellbeing; physical rehabilitation; care of the elderly; education through personalised learning systems; and intelligent transportation systems. Our collaborations involve industrial partners across 18 countries, sharing our vision of bringing together advanced technologies and digital systems to create smart innovative services and intelligent business models for our end-user communities.

Building on the strengths documented in RAE2001/2008 and REF2014, we have created a vital and sustainable research environment with significant levels of growth. Notable achievements for this UoA include:

- grant income spend has increased to £3.06M in REF2021 from £1.26M in REF2014;
- PhD completions have more than doubled to 34 in REF2021 compared to 14 in REF2014; and
- 414 outputs have been published with 84.8% in Q1 journals by SNIP and 62% with international co-authorship (Scopus/SciVal, 2014-2020).

1.1 The UoA's research structures

Professor David **Brown** is the Director of the UoA's Computing and Informatics Research Centre (CIRC), which is based within NTU's School of Science and Technology (SST). Alongside **Brown** are Dr Colin **Wilmott** as Research Coordinator and Deputy Director and Professor Ahmad **Lotfi** as Head of the Department of Computer Science. Research leadership is provided by the Centre's Research Advisory Group, which is responsible for developing and implementing our research strategy. CIRC comprises 14 research academics, 2 independent research fellows, 35 post-doctoral and PhD researchers across four Research Groups: Interactive Systems (IS); Computational Neuroscience and Cognitive Robotics (CNCR); Computational Intelligence and Applications (CIA); and, Network Infrastructures, Computing and Cyber Security (NICCS). Each Research Group is led by two senior researchers (e.g., a professor and an associate professor) to ensure expertise and sustainability. Since 2014, NTU has invested in an Associate Dean for Research (ADR) in every academic school who mentors group leads. As a member of both the University Research Committee and the University Leadership Team, this role links the UoA directly to the strategic decision making of the University. SST provides a Postgraduate Researcher Tutor who supports PhD student recruitment, selection, and training, as well as supervisor training. CIRC also engages with NTU's five strategic research themes (see REF5a) which bring together researchers from across disciplines to address key societal challenges as outlined in Section 1.3 on interdisciplinarity.

Figure 1: Research Group structure within the UoA

1.2 Research and Impact strategy

1.2.1 Achievement of REF2014 research strategy
The UoA reviewed its research objectives at the start of this REF period before embarking on an ambitious strategy to realise our Enabling Digital Technology vision. Highlight metrics include:

- £3.06M in grant income spend, representing a 155% increase over REF 2014;
- 34 PhD completions, representing a 143% growth;
- 414 scholarly outputs co-authored by UoA members, with 84.8% in Q1 journals by SNIP and the majority having at least one international co-author (Scopus/SciVal 2014-2020); and
- 15 keynote speeches, 4 visiting professorships, participation on 20 journal editorial boards, 5 conference prizes, hosting of 6 international conferences and membership of 16 research funding panels.

Our strategy was to enhance the quality of colleagues' contributions in world class facilities, thus growing our portfolio of grant income from high-quality sources. Strategic investments in people, buildings and equipment, and utilisation of enlarged key University teams (Section 3.2), including Research Operations (RO) and Research and Strategic Partnership Development (RSPD), have driven a step-change in the UoA's research environment since REF2014. In REF2014 (REF5), we undertook:

1. *To address societal needs with ubiquitous computing research, increase user engagement, diversify our funding portfolio, and grow our research base*

This REF period has seen the formation of CIRC where our Enabling Digital Technology vision has focused on applying computational research to areas of societal concern (Sections 1.2.2 and 1.2.3).This has inspired a virtuous circle from innovation through to implementation, user engagement and impact, leading directly to high levels of grant capture from prestigious sources.

Table 1: Data on income and PhD completions

	REF2014	**2014-2021**
Grant Income Spend	£1.2M	£3.06M
PhD Completions	14	34

2. *To conduct interdisciplinary research and partnerships*

Investments in state-of the-art, interdisciplinary research facilities have pioneered new research areas and facilitated interdisciplinary research. These include: the £11M Interdisciplinary Science and Technology (ISTeC) facility for integrating computational techniques with cognate disciplines for applications to the real-world; and the £0.5M SmartNTU House facility (Section 3.3). Examples of consequent interdisciplinary research encompass CNCR's *SiElegans* project and NICCS's *REMOURBAN* project involving 21 partners (Section 3.1). More recent investments, such as with Medical Technology Innovation Facility (MTIF) and Smart Wireless Innovation Facility (SWIFt) continue this trend of interdisciplinary research into the next REF cycle (Section 3.3).

3. *To recruit and nurture excellent research staff and students*

Investment has strengthened senior leadership in CIRC with new professors and associate professors. Given sector challenges in recruitment, the development of early career researchers has been supported through two appointments under the SST Early Career Independent Research Fellowship (IRF) Scheme and through four academic associates who conduct PhD studies alongside a part-time teaching position (Section 2).

> *4.   To increase our national and international profile for research excellence*
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> Our external collaboration evidences our increased profile with nearly three quarters of our outputs having external collaborators. Staff in CIRC are now involved in a range of high-profile activities beyond NTU, from H2020 grant panel memberships to visiting professorships and delivering international summer schools in quantum computing (Section 4).
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> *5.   To improve our external standing in research strength and quality*
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> CIRC staff have maintained a record of publication in high-quality journals and the highest profile academic conferences, including IEEE Transactions on Fuzzy Systems, IEEE Internet of Things Journal, and IEEE Transactions on Systems, Man and Cybernetics.
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> **1.2.2 Achievement of REF2014 impact strategy**
> In REF2014 (REF3a), we aimed to: target wider engagement with end user communities; influence government via our Research Centres, conferences, KTNs and equivalent networks; embed the value and importance of impact into the foundations of our work; and engage in consultancy and partnerships. These aims have been achieved across a range of initiatives set out below.
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> We have developed impact with a range of end-user communities across all our research activities (Section 4.2). This is exemplified by service users from Nottinghamshire MIND being central to **Brown**'s EPSRC project to enable improved perceptions of mental wellbeing by networked smart textile objects. **Brown** also engaged stakeholders across Europe, through two H2020 funded projects (No One Left Behind and MaTHiSiS), to improve the inclusion of students with learning disabilities through accessible and adaptive learning technologies (REF3). As a consequence, he has influenced government through giving oral evidence to the House of Commons Education Select Committee in 2019 on the future of AI in the classroom (Section 4.3). We have developed new end-user engagement through the award of three Innovate UK projects; of particular note is **Kanjo**'s eNurture Project (TangToys) in partnership with the Nottingham Schools' Trust and the Ann Craft Trust.
>
> In recognising the value and importance of impact, we have developed an extensive network of partnerships within financial services, transportation, energy and education sectors with which we have facilitated sustained knowledge transfer through explorations of new products and services. Examples include **Kanjo**'s match-funded studentship with The Manufacturing Technology Centre (Section 2.2.1), **Peytchev**'s *REMOURBAN* project involving 21 partners, including local authorities and companies, and **Wilmott**'s quantum computing work with UK-based banking institutions (Section 4.4).
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> Through our commitment to developing and strengthening partnerships with industry, we have secured £0.8M competitive D2N2 Local Enterprise Partnership (LEP) Local Growth Fund co-funding to support the establishment of NTU's new £1.6M Smart Wireless Innovation Facility (SWIFt, Section 3.3). This will enable senior academics from CIRC to work ever more closely with local businesses on the development and implementation of innovative 5G technology.
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> **1.2.3 Enabling, facilitating, and achieving impact**
> Building on the REF2014 strategy, CIRC has generated a range of sustainable mechanisms to help incubate the best impact of our research at all stages. We have targeted resources, including funds, studentships and sabbaticals, towards prioritising projects with planned impact routes. This has included: practice-sharing workshops with RAND Europe; a 'Fast Track Impact' workshop by Prof Mark Reed; IP exploitation training by NTU's Knowledge Exchange team; and, funding for collaborative travel for all CIRC staff.
>
> Examples of where investment has enabled impact include:

- The realisation of the impact of **Peytchev**'s 'Connected and Autonomous Vehicles i-Motors' project with Control F1 was underpinned by a six-month research assistant (RA). This CIRC-funded RA provided critical stability of skills and expertise for impact development. The i-Motors project enabled a communication framework capable of improving autonomous vehicles' awareness of surrounding traffic. It was described as '*instrumental for development and economic impact*' (Dale Reed, Control F1) and has since generated £5M of economic impacts for Control F1 (see our Mobile Networking Case Study);
- The realisation of the impact of **Brown**'s co-creation project with Fujitsu and the subsequent co-development of the mobile app to improve the mental wellbeing of workers with autism, called 'My-State', was supported by a one-year RA. It was also underpinned by a formal strategic partnership between NTU and Fujitsu (see our Inclusive AI Learning Systems Case Study);
- Two NTU-funded RAs underpinned **Lotfi**'s research to assist regional companies to explore the use of emerging technologies within their business environment products. JustChecking Ltd deployed the group's expertise in activity recognition and machine-learning for future product lines. Alcuris Ltd made use of our insight into activity recognition and abnormality detection for their elderly monitoring product 'memo'; and
- Funding from the 'Enabling Innovation' project, jointly funded by European Regional Development Fund (ERDF) through the LEP and NTU, allowed CIRC to work on product and process innovation within SMEs in the D2N2 area. We supported over 150 local SMEs and companies, such as Digital Affinity, through design workshops, prototype building, and continuing support.

1.2.4 Future research and impact objectives
Our future strategy synergises further our approach to research and impact and will continue our Enabling Digital Technology vision:

1. *Exploit our interdisciplinary strength to explore 'Smart Technologies' for future living and working spaces*.
   The University's new £1.6M Smart Wireless Innovation Facility (SWIFt, Section 3.3) will allow CIRC, especially our CIA and NICCS groups, to introduce innovative technology onto the Clifton campus, allowing us to explore 'Smart Places' for the future. The £280K *5G Connected Forest* project, newly-awarded to **Kanjo,** will explore the potential for 5G applications to preserve forests and their environment. Similarly, our NICCS Research Group will work towards a smart cloud-based activity recognition system as a service for real-time monitoring and recognition. Our SmartNTU House facility will also provide a living lab facility to explore further research in improving people's lives through the application of smart technologies.

2. *Address grand societal challenges, such as human health and an ageing society, through digital technologies, such as AI and data science*.
   In terms of health and AI, our IS Research Group will explore the relationship between interaction and wellbeing of students with learning disabilities using tangible interfaces. For example, a €449K Erasmus+ project newly awarded to **Brown** will develop an AI tool to predict engagement and 'Meltdown' events in individuals with autism. Our CIA Research Group will pursue further algorithms for human activity recognition in multi-occupant environments using new sensors, such as Infrared Thermal Sensor Array, alongside the application of entropy measures in activity recognition.

3. *Develop innovative and intelligent technologies for future medical devices and industrial practice.*
   CIRC, through IS, CIA and CNCR Research Groups, is a collaborative partner in NTU's LEP co-funded £23M new Medical Technology Innovation Facility, MTIF, that will specialise in healthcare-related commercial product development (Section 3.3). Furthermore, our Research Groups have expertise in cognitive and assistive robotics which will be explored for human-robot co-working scenarios in industrial digitalisation.

4. *Recruit and support excellent researchers, embedding diversity, inclusion, and innovation in our ways of working.*
   CIRC aims to build on our successes since 2014, enhancing sustainability and increasing research capacity. Our objective is to recruit and support the highest quality staff aligned to our Research Groups and further develop EDI policies and practices. We will also continue our drive to attract high-quality research awards and exploit new investments in research facilities (SWIFt and MTIF, Section 3.3). We are also committed to recruiting excellent and diverse PhD students and enabling their full research potential.

1.3 Approach to Interdisciplinary Research

The structure of CIRC was designed deliberately to cultivate interdisciplinary and multidisciplinary research within the UoA and across SST and NTU. This is further achieved by:

- Our shared research infrastructure (Section 3.3) supports excellent research with impact across all areas.
- CIRC groups coordinate weekly meetings where all members meet alongside our departmental seminar sessions allowing for frequent interactions and enabling cross-disciplinary work.
- CIRC encourages multi-disciplinary collaborations across NTU, which have led to joint publications including: **Brown** with Pockley and others in UoA A03; **Shahtahmassebi** with Liang in UoA B12; and **Kanjo** with Kuss in UoA A04.
- CIRC staff are involved in NTU's five strategic research themes (REF5a), in particular with the Medical Technologies and Advanced Materials theme through work with the John van Geest Cancer Research Centre and with Liang on Global Heritage: Science, Management and Development. The latter has now been selected as NTU's first Research Peak (REF5a), with £500k pa of investment to further development, it exemplifies NTU's excellence in research and societal impact; CIRC is involved through **Pourabdollah's** work on digital humanities.
- To encourage cross-disciplinary discussions, SST's Annual Research (STAR) conference brings together speakers from across all the STEM disciplines.

1.4 Strategy for an open research environment

NTU's Publication Policy mandates the deposit of full text journal articles in our institutional repository; this enables the sharing of research outputs and underlying data. A centrally-managed open access fund was established in 2014 to increase our ability to provide immediate open access to outputs via the gold route; within the UoA, funding of some £40k has supported publications since 2014.

1.5 Supporting a culture of research integrity

Matters relating to research integrity, including research ethics, are overseen centrally (REF5a) and managed locally. The University Research Committee, chaired by the Deputy Vice-Chancellor – Research and Enterprise, and reporting to Academic Board, is responsible for the development and monitoring of research integrity policies and procedures. The Research Integrity Committee provides support and advice to Research Centres, including CIRC. Robust systems are in place to ensure research projects requiring ethical enquiry are thoroughly scrutinised.

2. People

2.1 Staffing strategy and staff development

CIRC has an inclusive staffing strategy focused on strategic recruitment and supportive retention. The UoA has targeted growth through strong research teams, with senior appointments and internal promotions providing credible leadership and succession planning. Key external appointments have been made at senior levels including 2 new professors (**McGinnity**, **Sanei**) and 2 new associate professors (**Cang**, **He**). Through the SST Early Career

IRF Scheme (Section 2.1.3), launched in January 2016, we have appointed two individuals on ascending research trajectories and provided them with time to get their research portfolio established whilst building their teaching experience.

2.1.1 Staffing and Recruitment policy

Staff retention. CIRC has actively facilitated existing researchers fulfilling their potential. As already mentioned, the UoA has also recently piloted a doctoral fellow scheme (academic associate), which has seen four new part-time lectureship/research associate posts leading to a PhD award.

External recruitment. Recruitment has focused on the establishment of new robotics research in addition to significant investments in our three existing Research Groups. CIRC has attracted and promoted two internationally leading professors in robotic systems research, ambient assistive technologies (**McGinnity**) and networking technologies (**Sanei**). The UoA has benefitted from the SST IRF Scheme that supports increasing research capacity whilst providing areas of research strength with succession planning. Two high achieving researchers (**Shen** and **Zhong**) with outstanding potential were appointed in 2019 to 5-year positions with tenure track routes to lectureships (Section 2.1.3).

In making new appointments, we ensure that each of our four Research Groups enjoy a mixture of staff seniorities to allow for succession planning, mentoring and exchanges of ideas. Each Centre has benefitted from new appointments and promotions as set out below:

- The CIA Research Group has benefitted from a promotion to professor for group lead (**Lotfi**), the external appointment of two associate professor posts (**Cang** and **He**) and the external appointment of a senior lecturer (**Pourabdollah**). The group has also received additional investment in an IRF (**Zhong**) in assistive robotics who is being supported to progress to permanent status.
- The NICCS Research Group's strengths have been complemented by the recruitment at professorial level of an expert (**Sanei**) in signal processing with application to analysis of brain signals and images (particularly brain-computer interfacing). Additionally, the group has benefitted from an internal promotion to associate professor (**Peytchev**), and the recruitment of two senior lecturers (**Sculthorpe** and **Kaiwartya**).
- The CNCR Research Group was established in 2014 with the external appointment of a professor (**McGinnity**) in robotics research. It has been strengthened further by an external appointment at senior lecturer level (**Ferreira**) and the appointment of the UoA's second IRF (**Shen**).
- The IS Research Group has been strengthened by an internal promotion to associate professor (**Kanjo**) and through the recruitment of a senior lecturer (**Mahmud**) with expertise in machine-learning that has led to the further development of the group around its commitment to user-centred approaches of enabling technologies.

This approach to ensuring mentorship and new ideas is underpinned by a programme of international exchanges and visiting researchers, including Professor Muñoz-Organero (Universidad Carlos III de Madrid, Spain) and Professor Jose Maria Sarabia (University of Cantabria, Spain) who contribute to and enrich the research culture (Section 4.1).

2.1.2 Staff Development Strategy

Staff development is coordinated by the Director of the UoA's Computing and Informatics Research Centre (**Brown**) in concert with the Head of the Department of Computer Sciences (**Lotfi**). In line with the UK Concordat to Support the Career Development of Researchers, a range of opportunities are offered, tailored to career stage. Our mentorship programmes provide all staff below professorial level with a senior research mentor (professors or associate professors), who has relevant research experience, to complement support through the Department-run annual appraisal system that encompasses Individual Research Plans to identify short-term goals and longer-term career objectives. Developing funding applications

through individual peer-review and sandpits aids colleagues to transform new ideas into stronger project proposals.

CIRC invests in a portfolio of staff development initiatives that build strategic research capacity in areas aligned to our Enabling Digital Technologies vision, including: staff research sabbaticals; incoming and outgoing international researcher mobility; match-funded PhD studentship scheme (Section 2.2.1); and financial support leading to grant capture (Section 3.2). Sabbatical leave has been provided to allow concentration on research, impact and building collaborations via the UoA's funded study leave programme. Two types of sabbatical have been funded based on research accomplishment and leadership and research career stage. During the period, **Wilmott** and **Shahtahmassebi** have received periods of research leave.

2.1.3 Early Career Researcher Support
ECR support is particularly important to our long-term strategy and the sustainability of the UoA. A wide range of support for ECRs is available, including: the Winning Grant Funding Programme (Section 3.2); new ECRs pairing with a research mentor; and ECRs being prioritised with NTU-funded studentships. They have also benefitted from reduced teaching and administrative loads for ECRs, typically, a reduction of 60% in Year 1, 30% in Year 2 and 10% in Year 3.

An exemplary case of our ECR strategy is the SST IRF programme: five year roles with reduced teaching (initially 50 rising to 100 contact hours/year) and dedicated research support (£10k/year) are intended as 'tenure-track' routes to permanent lectureships.

The UoA benefits from a vibrant community of research assistants and research fellows. Postdoctoral staff are actively supported in their transition to academic or non-academic posts by the School's Staff Development Programme and via the University's appraisal framework, involving regular career development meetings with senior CIRC staff. Staff undertake a bespoke programme, offered through NTU's Researcher Development Gateway, to assist career planning and grant writing. There are also opportunities to gain teaching experience and qualifications.

2.2 Postgraduate Researchers
Postgraduate researchers (PGRs) are an integral part of our research culture. The total number of PhDs completed in the UoA has increased to 34 (4.9 p.a.) in REF2021 from 14 (2.8 p.a.) in REF2014. CIRC has developed a research environment involving academic staff, research fellows, PhD students, Erasmus students and summer interns in discussions that are inclusive with the aim of promoting the sharing and exchange of research ideas with and through the use of computing environments and facilities. CIRC also enjoys a number of cross-institutional supervision collaborations, including **McGinnity**'s supervision of 7 doctoral candidates from Ulster University (Professor Coleman), **Pourabdollah**'s supervision of 2 doctoral candidates with the University of Nottingham (Professor Jon Garibaldi), and **Shahtahmassebi**'s co-supervision of PhD research with University of Plymouth (Peninsula College of Medicine, Mr David Stell).

2.2.1 PhD Funding and Recruitment
CIRC's PhD student cohort: Support for, and the development of, the UoA's expanded postgraduate student community is core to the success of our research environment. Our current cohort of 26 PhD students (31 July 2020) includes 50% Home/EU and 50% international students, the latter from Libya, Nepal, Argentina, Iran, Nigeria and India. Our current PhD cohort includes 7 funded by overseas Governments, 6 that are self-funded, and 2 part-time PhD students who study as academic associates with a concurrent 0.5 FTE 5-year Lectureship, promoting career development. NTU's PhD Studentship Scheme has provided competitive, fully-funded scholarships that cover tuition and stipends to 13 CIRC PhD students since 2014. Collaborative PhD research is promoted via NTU's match-funded scheme (launched 2016) which covers half of tuition fees and stipend, where an external sponsor contributes the other half. An example is **Kanjo**'s project with The Manufacturing Technology Centre (Section 4.2).

Recruitment. Fair and consistent admission is ensured by the School Postgraduate Research Tutors who chair PhD interviews. PhD applicants are required to have a Master's degree (with

Merit) or a first-class or 2:1 BSc Honours degree. EDI data on enrolled PhD students is available at School of Science and Technology level; our gender balance is the same as the sector (HESA) whilst our PhD population is considerably more ethnically diverse than the sector (HESA).

Supervision. Supervisory teams include at least two NTU staff with experience of at least two PhD completions between them. All supervisors attend a two-day training course and are invited to meetings of SST's Supervisors' Forum, which supports best practice in supervision.

Monitoring. Students typically meet their supervisors weekly. Progress is formally monitored via a supervisory panel and independent assessor, with annual monitoring as well as key deliverables around Month 6 (Project Approval) and Month 18 (Transfer from MPhil to PhD).

Training and support. Training opportunities are covered during induction with the SST PGR tutor and postgraduate representative and reviewed as part of annual monitoring. The NTU Doctorate Plus Programme (see REF5a) maps PGR training to the Vitae Researcher Development Framework and the requirements of the UK Research Councils and Quality Assurance Agency.

SST-specific training supplements NTU-wide opportunities such that PGRs can create bespoke packages of activities to support their development. There are workshops on research methods, report writing, project management, research data management, equality and diversity awareness, and additional English classes for researchers with English as a second language. Our PGRs receive an annual research budget of £1K. In Year 1, this is expected to help fund any additional specialist training requirements, equipment, or conference attendance, and in Years 2 and 3, the funds are expected to contribute to conference attendance.

Throughout their degrees, PGRs also have opportunities to share their research and develop presentation skills, including:

- In our annual SST STAR Research Conference PGRs typically present a poster in their first year and a talk in their second. In 2020, presentations were adapted to an online/virtual setting, incorporating a 3-minute thesis competition.
- The Department of Computer Science runs a weekly seminar series, with a mixture of invited external and internal speakers from Computer Science and related disciplines. PGRs are invited to present their work as a full seminar in their third year.
- CIRC groups coordinate their own research meetings, with informal opportunities for PGR presentations, such as practice talks for conferences.
- In 2019, SST established a biannual joint networking series with University of Nottingham for PGRs to share research ideas and grow sustainable collaborations.
- CIRC has hosted 6 international conferences this REF period which have provided an excellent platform for our PGRs to share their research (Section 4.4).

The success of our PGR strategy can be seen in our high level of on-time thesis submission rates; 89% in 2017/18. The overall satisfaction for PhD students in the School of Science and Technology in PRES 2019 was 84%, 3% higher than the sector as a whole. It is reflected also in PGRs from CIRC winning awards at major conferences, including the recent best paper award at ICACII 2020: XIV. We have appointed a number of our PhD community into postdoctoral positions (**Taheri**, **Sarsfield** and **Ortega**).

2.3 Equality, diversity, and inclusion (EDI)
The University was awarded the bronze Athena Swan charter mark in April 2019 (see REF5a) and targets a silver submission in 2023. Supporting this, our School strategy aims at departmental Athena Swan submissions from 2022; the Deputy Head of the Computer Science Department (Hartley) is leading on the delivery of an action plan towards a departmental Athena Swan submission, which embeds staff and student mentoring, and includes initiatives such as involvement by female members of academic staff in the creation of the "Women in Tech"

network for East Midlands, and encouraging students (of all genders) to volunteer for Code First Girls. Our School Athena Swan champion supports this initiative and coordinates School-level EDI activities, including participation of six School staff in the Advance HE Aurora programme, events for International Women's week, international women in engineering day, Black History month, LGBT History month, the installation of an on-campus nursing room for nursing mothers, and maintenance of an EDI intranet with links to staff networks, policies and resources.

Recruitment across SST has transitioned through gender decoding of recruitment materials and mixed-gender interview panels, to attract a more diverse staff pool. Specific training improves understanding of equality and diversity within the workplace, including unconscious bias training for all staff. Across all academic and research staff in SST in 2019: 32% identified as women; 16% as being Black Asian and Minority Ethnic; and 4% declared a disability. Within CIRC, 19% are women and over 45% of staff in the Department of Computer Science are from a BAME background. CIRC supports NTU's institutional target to increase the representation of women within the professoriate to 35% by 2022. Presently, 50% of our associate professors are female. Furthermore, we encourage a flexible and inclusive approach for staff working from home or remotely. For example, the Support of Academic Returners (SOAR) scheme funds up to £5k following a period of caring-related leave to support career pathway development.

Staff perception of EDI issues is very positive. The 2018 staff survey (run by an external company) collected responses at departmental level. In the Department of Computer Science, of which the majority of UoA staff are members, there was an aggregate average 92% positive response to EDI questions on equality of opportunity, including EDI awareness and the University's approaches to respect and equality of opportunity.

3. Income, infrastructure and facilities

Our target for this REF period was to develop a portfolio of significant new grant income from diverse, high-quality sources. This has been delivered with an income-spend of £3.06M, compared to £1.26M in REF2014, and major grants from prestigious sources, including EPSRC, BBSRC Innovate UK, The Royal Society, EU H2020, EU Erasmus+, and Leverhulme.

3.1 Research income and funding strategy
The CIRC Advisory Group has consistently offered high levels of support to members to ensure that all Centre-supported proposals are as competitive as possible through detailed grant proposal assessments on a one-to-one basis, and multiple iterations of refinement from conceptualisation to submission. We encourage all members to attend annual Research Operations and Research and Strategic Partnership Development grant writing events (Section 3.2) that focus on building a competitive bid, different types of research calls, and specific funders. CIRC has also utilised direct University investment (approx. £80K p.a.) to pump-prime research and grant submissions through 6-month research assistance, sabbatical cover, and short-term research exchanges. We maintain a specific fund with a light-touch and responsive application process so that we can react to immediate funding opportunities. Our *€449K Erasmus+ 'An AI Tool to Predict Engagement and Meltdown Events in Students with Autism'* and *£280K 2020 UK Government (Media, Culture and Sport) '5G Connected Forrest'* projects are recent examples of how our strategy, research structures, support via studentships and internal investment have led to major grant capture.

CIRC's research funding portfolio consists of 11 projects, comprising funding from UK research councils (EPSRC and Innovate UK) and EU research bodies (FP7, Horizon 2020 and Erasmus+). There are significant awards in all Research Groups throughout our scope. For instance:

- Within CNCR, *Si–Elegans* is a £1.2M EU FP7 project investigating performance discrepancies between artificial computational systems and brains.
- Within IS, *No One Left Behind* is a £457K EU Horizon 2020 project involves gaming toolkits that enhance student abilities across all academic subjects, *MaTHiSiS* is a £467K

EU H2020 on multimodal affect recognition for students with learning disabilities, and *An AI Tool to Predict Engagement and 'Meltdown' Events* is a £430K EU Erasmus + project that focuses on helping individuals with autism.

- Within NICCS, *REMOURBAN* is a £300K EU Horizon 2020 multidisciplinary project centred on accelerating smart urban transformations.
- Within CIA, *iCarer* is a £250K EPSRC project offering adaptive platforms to carers support through a range of monitoring activities.

3.2 Organisational infrastructure

Since 2014, CIRC has engaged with significantly expanded University teams, including our Research Operations (Pre-Award, REF, Governance and Research Information Management) (RO) and Research and Strategic Partnership Development (RSPD) teams. The RO team provides bespoke advice and guidance to researchers with regard to external research grant applications, including the Winning Grant Funding Programme. This team also ensures compliance with terms of national and international research funders and provides support for research integrity and research ethics policies. The RSPD team provides up-to-date knowledge of funding bodies and supports academics to develop external partnerships, build research consortia, and create high quality research and innovation funding proposals. CIRC engages actively with NTU's Knowledge Exchange Directorate (KED) for commercialisation support where it is well practised in developing close partnerships with businesses to maximise commercial potential. Working closely with KED, we have been able to identify, protect and develop intellectual property assets arising from research with a clear and constant focus on potential applications and markets. Other grant support infrastructure includes the £1.1m NTU investment in 'Worktribe', a holistic research management system that is designed to support the whole project proposal life cycle from proposal development to post-award management and publication. Worktribe has been designed as a series of interconnecting modules: Pre-award; Post-award; Contracts; Output Deposit; Staff Profiles; and Impact Recording.

3.3 Infrastructure and facilities

Infrastructure. We have seen very major investment in state-of the-art, interdisciplinary research facilities, including:

- The Interdisciplinary Science and Technology Facility (ISTeC, £11m including £5m from HEFCE/Research England, 800m^2 research wing, completed 2017) that brings STEM subjects together to support collaboration between different subject areas, outreach activities, and industry engagement. This brings high specification spaces for collaborative and multidisciplinary research within one building, including, for example, our robotics research (CNCR).
- The £0.5M SmartNTU House facility (CIA Research Group) which takes the form of a typical home and is fitted with a wide-ranging collection of smart sensors (see detail below).
- CIRC is a collaborative partner in NTU's Medical Technologies and Innovation Facility (MTIF, £23m including £9.7m from D2N2 Local Growth Fund, 3318m^2 on two sites; completed 2020) which aims to enable early stage research and development in medical technology and medical devices. The Boots Enterprise Zone component supports our CNCR and IS research activities in medical design and research, providing an unprecedented new product development facility in the Midlands for partners. The MTIF building on the NTU Clifton campus enables early-stage innovation and impact-generation activities from our researchers.

The provision of significant and innovative new facilities is continuing into this REF cycle. The University's £1.6M Smart Wireless Innovation Facility (SWIFt), again co-funded by the LEP, will turn Clifton Campus into a smart and sustainable 'living laboratory' for businesses, academics, and policy makers. The project heralds a range of innovations, such as intelligent wayfinding and virtual assistants, smart parking and building controls. SWIFt will also examine the application of 5G and other smart technologies in industry, logistics and agriculture and explore how to create 'Smart Places' for the future.

Lab facilities. All our UoA members are located on the Clifton Campus. Our doctoral community is co-located with research staff and supervisors. Every PhD researcher is allocated a desk and computer workstation. The UoA has dedicated research labs within ISTeC, the Engineering Building, and the SmartNTU house facility. The main facilities include:

- a 75m^2 robot arena that has a VICON tracking system and state-of-the-art humanoid robots engaging human-robot/robot-human object handovers where we utilise a range of high specification robots, including iCUB, Sawyer and Robotniq robots, equipped with robot hands and the best tactile robotic sensors currently available (BioTac sensors from Syntouch). Other sensor systems include an AR10 hand and a DAVIS spiking neuron camera;
- a VR Interaction lab equipped with a range of sensors connected to sensing the affective state of learners (Tobi eye gaze, EEG – Open BCI);
- a 300 core HPC cluster;
- a 400 board FPGA computing cluster based on Altera (Intel) Stratix 5 devices. This system is one of the largest FPGA clusters in the country and each FPGA processing board incorporates an Intel/Altera Stratix 5 FPGA device, and is complemented by a separate embedded CPU processor board, memory, and high-speed interconnect. The overall system was developed with a budget of approximately £1M. Recent purchases of Stratix 10 devices from Terasic maintain the currency of the system;
- a 3Brain multi-electrode array system and a BioBot 3D bioprinter which enhances multidisciplinary computational neuroscience projects; and
- SmartNTU house, which is a living lab facility equipped with a range of ambient sensors including PIR motion sensors, thermal cameras, depth sensors, pressure and presence sensors. The facility is also equipped with assistive robotic platforms including a Pepper robot and several NAO robots. As part of the research facilities available to CIA Research Group, a Baxter robot and UR5 robots are also available for research in the development of transfer learning algorithms.

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

CIRC is inherently interdisciplinary, with members of the UoA having backgrounds in mathematics, physics, engineering, and bioscience. We have worked with more than 30 organisations across 18 countries such that that over 70% of the outputs submitted by this UoA involve co-authors from other institutions, and over 50% of the outputs submitted by this UoA involve international institutions. This has been enabled by: internal funding for research visits/exchanges; match-funded PhDs (Section 2.2.1); supporting conference attendance particularly for ECRs; support for pump-prime projects with strategically important collaborators; and organising series of conferences (Section 4.4) in areas of strength and priority.

4.1 Research collaborations, networks, and partnerships
The Computational Intelligence and Applications group enjoys a number of ongoing national and international collaborations. Examples include **Lotfi**'s fruitful collaborations with Prof Mario Muñoz-Organero (Universidad Carlos III de Madrid) on the topic of applied machine learning for wearable and mobile sensor data, and Prof Naoyuki Kubota (Tokyo Metropolitan University) on assistive robotic and community-centric system for elderly care. Members are collaborating with the National Institute of Advanced Industrial Science and Technology in Tokyo, Japan on assistive robotics, and, through **Cang**, we have ongoing links with Chiang Mai University (Thailand) through our involvement in the €3M EU Erasmus Modus '*FUSION*' project. In terms of other international projects, the group enjoys on-going strong links with the Chinese Academy of Science (China) through three other major projects (the €900K H2020-MSCA-RISE '*SMart rObOTs for fire-figHting*', the €310K H2020 '*RABOT - Real-Time Adaptive Networked Control of Rescue Robots*' project, and the £152K Royal Society and National Natural Science Foundation of China funded project entitled '*Adaptive Learning Control of a Cardiovascular Robot using Expert Surgeon Techniques*'). **Pourabdollah** is engaged on a major international collaborative endeavour, '*AI-FML International Academy*', whose aim is to promote the IEEE 1855-2016

standard (Fuzzy Markup Language) through real-world applications, including organising educational activities, workshops and competitions for different audiences. The work of the AI-FML International Academy has led to the establishment of the IEEE CIS Content Curation Subcommittee in collaboration with 7 international institutions, including Tainan, Tokyo Metropolitan, Naples, and Santiago de Compostela. **Jun He** has international collaborations with researchers from Sun Yat-sen University, China (Professor Yuren Zhou) on optimization and evolutionary computation, and the University of Nottingham Malaysia (Dr Siang Yew Chong) on co-evolution systems and computational intelligence. Both collaborations have produced journal outputs in leading journals, including IEEE transactions on Cybernetics, Evolutionary Computation, and Artificial Intelligence.

The Computational Neuroscience and Cognitive Robotics group has engaged in an innovative collaboration with the international *SiElegans* project consortia to deliver an enhanced understanding of retinal ganglion cell visual processing. In particular, **McGinnity** collaborates with the Istituto Italiano di Technologia (Neuroscience), University of Ulster (Intelligent Systems), Vicomtech-IK4 (eHealth and Biomedical Applications), and the National University of Ireland. **Ferreria** has been engaged in two Portuguese National Innovation Agency projects (ANI Portugal 2020) with the University of Coimbre, Portugal: *SEMFIRE* provides for the development of a robotic system designed to reduce the accumulation of combustible material in forests for wildfire prevention, and *CORE* which centres on fundamental robotics research. More locally, the group has ongoing collaborations with researchers from the University of Birmingham on topics including machine-learning and data science.

The Network Infrastructures, Computing and Cyber Security group and **Peytchev** have collaborated with 21 partners across 7 countries in the €25M Horizon2020 *REMOURBAN* project which aims to showcase sustainability and future cities. **Shahtahmassebi** is engaged on 2 multinational projects (DigiLab and Swarm-VIP), and was responsible for the delivery of intensive summer training courses on the R Software Package over the period 2016-2018 (attended by 50 researchers from 7 universities (including Nottingham, Imperial and Bristol) and professionals from the NHS, Boots, PepsiCo and E.ON.

The Interactive Systems group has engaged with an extensive range of academic partners and SMEs. On the group's research in *Digital Game Making* through their EU H2020 No One Left Behind grant, **Brown** collaborated with 7 partners from the game industry and the education sector from 4 European countries - Austria, Germany, Spain and United Kingdom, including Graz University of Technology, Universidad Politécnica de Madrid, Stuttgart Media University, INMARK Europa (ES), and Grupo ZED Pyro Studios (ES). This work has led to internationally co-authored papers in *Sensors* and in *Computers and Education*. The group's research in *Robotics* and through their EU Lifelong Learning Programme grant has engaged 7 partners from third sector, industry and education sectors from 6 European countries, including the Pedagogical University of Crakow Department of Psychology, and Aias Bologna Onlus (IT). This partnership has led to internationally co-authored work in *British Journal of Educational Technology.* The group's *Research in AI approaches to personalisation* through EU H2020 MaTHiSiS engaged 18 partners from 9 EU countries, compromising European leaders in business, technology, research and ethics including University of East London, Maastricht University, and Vrije Universiteit Brussel. The project has led to internationally co-authored work in *British Journal of Educational Technology*. A second strand to the group's *Research in AI approaches to personalisation* has, through EU Erasmus Pathway+, seen partnerships with 7 partners from 5 EU countries, representing education, local authority, third sector and industry, and led to an ICACII 2020 best paper award (International Conference on Affective Computing and Intelligent Interaction 2020) for 'Modelling Engagement with Multimodal Multisensor Data Using the Continuous Performance Test as an Objective Tool to Track Flow'.

During this REF period, members of the UoA were supported in visits to over 50 overseas institutions. CIRC funds have been used for research visits to and from NTU, nationally and internationally: examples include exchanges with Masaryk University, Czech Republic to build an EU consortium, and collaborations with van Binsbergen (Royal Holloway, London), Moses

(Delft University of Technology, the Netherlands), the University of Cantabria, Spain (Professor Jose Maria Sarabia) and the University of Waterloo, Canada (Professor Mu Zhu).

These research exchanges have helped to expand the international collaboration links within the UoA, including *visiting professorships*. Professor Mario Muñoz-Organero (Universidad Carlos III de Madrid) was a visiting professor leading to journal outputs with our CIA group, and Professor Jose Maria Sarabia (University of Cantabria, Spain) who was a visiting professor in 2014, also leading to a number of journal outputs. The UoA supports staff to attend international conferences and staff were also active in organising over 20 international conferences, including 3 international conferences hosted by the UoA (see Section 4.3).

4.2 Collaborative creation of research impact

Our Enabling Digital Technology vision has involved extensive engagement with research users from diverse sectors including financial services, transportation, energy, healthcare, education and security with whom we have facilitated sustained knowledge transfer through explorations of new products and services. Specific examples include:

- Our IS group (**Brown**) has developed AI-based algorithms which can infer users' affective states (Horizon 2020 MaTHiSiS and Erasmus Pathway+ projects) that have been adopted by Fujitsu.
- The EPSRC 'An Internet of Soft Things' (**Brown**) project investigated how networked smart textile objects could improve perceptions of mental wellbeing in partnership with service users from Nottinghamshire MIND.
- Our NICCS group (**Peytchev**) is part of the €25M Horizon2020 REMOURBAN project (REF3 case study), which is a large-scale, international collaborative venture involving hundreds of research users across three lighthouse cities (Valladolid in Spain, Nottingham in United Kingdom and Tepebasi/Eskisehir in Turkey).
- **Wilmott** has engaged with UK-based banking institutions on quantum computing and associated security implications such as Deutsche Bank UK (Andrew Wray COO), Deutsche Bank Labs, Palo Alto (Aleksandr Oysgelt, Director for Technology and Innovation), and Santander UK (Ceri Godwin CIO). **Wilmott**'s 'Quantum Readiness Programme' which assesses robustness levels of current banking security against quantum technology, is due to be delivered at Refinitiv's three Gravitate Global Summits (NY, Singapore, London in 2021/2).
- Our collaborations with research users extend to engaging the public as the ultimate users of our research. We hold annual conferences at NTU to engage teaching staff and Special Educational Needs Coordinators from the Nottingham Schools' Trust to involve them in research on enabling technologies that support education.
- Our match-funded PhD programme (Section 2.2.1) also prioritises collaboration, industrial sponsorship, and networking opportunities. Partners include The Manufacturing Technology Centre that is part of the High Value Manufacturing Catapult, supported by Innovate UK.

4.3 Contributions to the economy and society

Our *REMOURBAN* project in sustainable energy solutions improves the quality of life for residents and smart energy usage initiatives have reduced energy costs. The energy monitoring systems developed through REMOURBAN have impacted on the supply chain for SMEs involved in the production of sustainable energy products, leading to the development of more cost-efficient methods of housing retrofit, thus increasing the size of the potential market for these products. Further, this increased quality of life and reduced fuel poverty for over 460 households in a deprived area.

Interactions with research users through our collaborative projects have led to economic and societal impacts. Specific examples are reflected in our UKRI eNurture Project (TangToys) in partnership with the Nottingham Schools' Trust and the Ann Craft Trust. TangToys examines how the digital world is changing the way young people with learning disabilities interact with family, school and peers and what these changes mean for their mental health.

Our IS research in multimodal affect recognition has informed UK policy debates. In May 2018, the House of Commons Education Select Committee launched its inquiry into the Fourth Industrial Revolution. Based on his published research, **Brown** gave oral evidence to the Committee in January 2019. Brown's appearance in front of the Committee led to an invitation from David Davis MP to meet in Westminster to discuss how his research would enable changes in the role of the teachers in the classroom and help to increase the effectiveness of education.

Other contributions to society delivered by the UoA include: our work on improving the accessibility of Digital Game Making for students with disabilities involving 6 key European partners; and our AI research to create personalised learning pathways for students with learning disabilities and autism (EU H2020 MaTHiSiS and Erasmus+ Pathway+) involving 18 international partners from industry and academia including the aerospace and gaming sectors, education, local authorities, and disability charities. The MaTHiSiS project focused on the real issue of teachers not having enough capacity to attend to individual learning needs. Our engagement detection algorithms addressed this issue and have been adopted by Nottingham City Council's Educational Psychology Service in its wider toolkit developed to support children with social, emotional and mental health needs across 66 schools.

4.4 Contributions to the research base
Our members have delivered 15 keynotes at international conferences and have chaired 21 conferences, secured 4 visiting professorships, acted on 20 journal editorial boards, and assisted 16 research funders through peer reviews. Over the REF period, our UoA hosted 6 international conferences: iTAG 2014-2016 which was attended by 100 participants each year; the 18th UK Workshop on Computational Intelligence (UKCI 2018) which was attended by 108 participants and led to the publication of 32 peer reviewed research papers as part of the Workshop's edited book (Advances in Computational Intelligence Systems: 18th UKCI, Nottingham UK 2018, Advances in Intelligent Systems and Computing, 840 Cham, Switzerland: Springer); and Recent Advances in Industrial Digitalisation, Robotics and Automation (Smart Industry) Workshop 2019 comprising 13 keynote lectures. Recently, CIA group members with researchers from Tokyo Metropolitan University have co-hosted the international conference on community-centric systems.

In terms of peer review three of our staff are current members of the EPSRC peer review college; one is on the ESRC review college; four sit on the European Science Foundation peer review college; and a further three sit on other international peer review colleges (including, EURAMET and Marie Curie Fellowships). We are active in journal editing with eight staff holding 23 editorships, including Brain Informatics; Soft Computing; IET Intelligent Transport System; EURASIP Journal of Computational Intelligence and Neuroscience; IEEE Signal Processing Magazine. Eight staff have organised or chaired 21 conferences. **Sanei** had several visiting professorships during the REF cycle (Imperial College London since 2016, King's College London 2016–2018, University of Surrey 2016-2018 and Shahid Beheshti University, Iran since 2014. A further five staff have delivered 15 keynote lectures.

CIRC members have secured best paper awards. For example, **Brown** at JAT 2014 and ICACII 2020: XIV, **Cang** at 10th Int. Conf. Software Knowledge Information Management and Applications Chengdu China 2016, and **Mahmud** at ICEEICT2014 and IEEEHealthCom2018. Other recognition awards include **Peytchev**'s Best Reviewer award at EURASIP 2014, Diploma of Honour from the Romanian Biomedical Engineering Council and EPSRC (Recognition of Major Contribution) award in 2018.

In addition to contributions to academic publishing as members of editorial boards, CIRC members have acted as *guest editors on 8 Special Issues* including: Brain Informatics (Machine Learning Techniques for Neuroscience Big Data); Cognitive Computation (Advances in Brain-Inspired Cognitive Systems) 2016; and Virtual Reality (Virtual Reality for Therapy, Psychological Interventions, and Physical and Cognitive Rehabilitation).