

**Institution: Loughborough University**

**Unit of Assessment: B11**

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

Investment in staff, including appointments on the new Loughborough University London campus, has delivered almost 50% growth in the Unit to 26FTE. Our transformative research has

- reached hundreds of millions of users of digital cameras and displays,
- contributed to the training of *every* radiologist in the NHS,
- contributed significantly to the economy through 34 collaborative R&D projects funded by InnovateUK, EU, and industry.

### 1.1 Research Structure

This Unit comprises 27 (headcount) staff including all staff (23.4FTE) from the Department of Computer Science (CS), with computer science researchers from the Wolfson School of Mechanical, Electrical and Manufacturing Engineering (WS) and the Institute for Digital Technologies (IDT) at Loughborough University London (LUL). LUL, which opened in 2015 on the Queen Elizabeth Olympic Park (QEOP), is the biggest strategic investment in the University's history.

Computer Science is a Department within the School of Science (SSci), which also includes chemistry, maths, maths education and physics. The Institute for Digital Technologies is one of seven Institutes at LUL, which has a multi-disciplinary faculty spanning entrepreneurship, design, media, management, politics, sport and technology. SSci, LUL and WS are 3 of the University's 9 autonomous Schools. Each is led by a Dean with a Senior Management Team (SMT) whose membership includes Associate Deans for Research (ADR) and Enterprise (ADE) and, as appropriate, leads of constituent Departments and Institutes. For example, the Head of Computer Science has vital responsibilities on the SSci SMT representing the interests of the discipline and in facilitating opportunities for cross-disciplinary research within the School. The ADE for SSci is a member of Unit staff, demonstrating how the Unit offers significant leadership at institutional level.

The Unit has three **Research Themes**

- **Vision, AI, Autonomous and Human Centred Systems (VAAH)** addresses both fundamental and applied challenges that arise from real-world applications in AI, deep learning, autonomous and robotic systems, human-machine interaction and computer vision. Examples include significant achievements in bio-inspired learning and robotics supported by EPSRC and DARPA.
- **Networks and Systems (NetSys)** focuses on networking and communication systems research, from the underlying theory to practical creation and operation of networked systems. Examples include modelling of mobile networks and large scale edge computing research funded by DSTL and EPSRC.
- **Theoretical Computer Science (TCS)** investigates fundamental questions in the theory of computing such as algorithms, cryptography, combinatorics on words and formal languages. Recent research highlights include work on word equations and query languages, and deep insights into cryptographic attacks.

Colleagues from LUL and WS work in VAAH (3D video quality assessment metrics and robotics) and TCS (encryption).

**Interdisciplinarity** is critical to the real-world problem-solving nature of many of our activities. The institutional 'CALIBRE' strategic research framework drives interdisciplinary activity across

all Schools. We engage with CALIBRE's programmes, particularly in the Beacons for High Value Manufacturing (embedded intelligence), Transport Technologies (driverless vehicles) and Sport and Exercise. For example, Li has successfully applied deep learning approaches to human motion analysis in football.

## 1.2 Objectives and Research Plans described in REF2014

The implementation of our research plans and objectives plans was informed by feedback from REF2014, guided by a new University strategy (2015) and supported by significant changes to our staff base.

A fundamental element of the University's "Building Excellence" strategy has been to focus on strengths and refreshed priorities. We identified a critical mass of excellent researchers and forward-looking agendas in applied digital imaging and artificial intelligence, in combinatorial aspects of theoretical computer science, and in networks/systems. Building on the leadership of existing staff with a large-scale, strategic investment in new staff - over 60% of Unit staff were appointed since 2014 - we introduced our 3 Themes and have made significant achievements:

- The VAAH Theme has made significant contributions in machine learning, robotics, and computer vision. We developed novel image enhancement and quality assessment algorithms inspired by human visual systems, leading to one ICS in §1.3; In an EPSRC project on autonomy for unmanned vehicles, we developed unique distributed cooperation methods for a team of networked heterogeneous unmanned vehicles and applied the developed approach to solve the challenges in a search and rescue scenario.
- The NetSys Theme has grown significantly since REF2014 and the Unit has strengthened capabilities in Cybersecurity, Cloud Data Centres, Edge Computing and Mobile Networks such as Vehicular ad hoc networks (VANETS). Appointments have also strengthened links between practical and theoretical research. The EPSRC Fruit project produced a large-scale datacentre from Raspberry Pis that is underpinning future work in these areas.
- The TCS Theme has built a very substantial group in formal language theory and combinatorics on words, which, for example, has given fundamental insights into combinatorial properties of monoid morphisms, with applications to long-standing open problems for pattern languages and regular expressions with backreferences. The group was invited to host the 12<sup>th</sup> International Conference on Words in 2019, demonstrating its recognition within the international community.

REF2014 plans to deliver a research centre to support future mobile technologies and video analytics were fulfilled in the form of the School's new interdisciplinary Centre for Sensing and Imaging Science. Some highlights of our extensive research in this field include applications of AI in medical imaging such as a machine learning model for the detection of presence and stage of prostate cancer using a simple blood test, and a unique transfer learning approach using a multi-scale and multi-network ensemble for skin lesion classification.

Our analysis of feedback from REF2014 prompted us to place a stronger focus on theoretical research, positioned in areas that have a clear counterpart in real-world applications. Examples include combinatorial properties of bio-sequences, distributed computing and database theory. This sharpened focus in our fundamental research is illustrated by numerous papers submitted since 2014, such as Mercas' "Pattern Matching with Variables: Efficient Algorithms and Complexity Results" (ACM Transactions on Computation Theory), exploring the tractability of important pattern matching problems, and Freydenberger's "A logic for document spanners" (Theory of Computing Systems), introducing a novel approach that revolutionises our understanding of this information extraction concept.

Our final objective was to improve our ability to react to changes in the funding landscape. The Unit improved communication across the Themes and particularly between the CS Research Coordinator and SSci's ADR. As a consequence, income streams have diversified since

REF2014 to include international funders (e.g., DARPA) complementing UK sources, and research income increased by 172% from 2013/14 to 2019/20.

### 1.3 Enabling and Facilitating the Achievement of Impact

Our REF2014 impact strategy delivered on the following objectives:

- **Bringing staff together to generate impact:** Tailoring training at individual and group level was found to be effective. Staff were advised on which courses to follow and senior staff with impact generation experience provided mentoring.
- **Proactively involving industry in the Unit's research:** The School's Partnership Development Manager (PDM) and the ADE actively supported staff in establishing and nurturing partnerships. This strategy resulted in award of InnovateUK and Newton Scheme funded projects with more than 15 industry partners, e.g. UK SMEs (Surface Intelligence, Statmetrix), large companies (ARM UK) and international industry (Nantong Guangyi Mechanical & Electrical Co., China).
- **Working closely with LU's professional services to facilitate impact generation:** many impact generating projects originate from research funded by bodies such as UKRI or EU. These were supported by the Research Development Team. The PDM co-ordinated support available further along the pathway to impact, from preparing industry-led R&D grant applications to contracts and commercialisation teams support to impact generation via consultancy projects with Public Health England, NHS Trusts of Scotland, Wales and Northern Ireland.
- **Making research services available to external users:** Through Loughborough's EPSRC-funded CDT in Embedded Intelligence (CDT-EI), the Unit received 9 industry-led PhD studentships (£40k each from industry), since 2015. These studentships resource impact generation in the long-term, by supporting underpinning research and initiating ideas and opportunities for InnovateUK / KTP grants (e.g. ARM, Motion Robotics).
- **Actively supporting early-stage impact generation opportunities:** Support available includes funding for commercialisation and impact generation through the University's Enterprise Projects Group (EPG). For example, Li's proof-of-concept project on using AI for Football Match Analytics received £5,000 and subsequently won a Minority Supplier Development UK (MSDUK) Innovation Challenge Award in 2019.

#### 1.3.1 How the Selected Impact Case Studies Relate to our Approach to Achieving Impact

The Unit identified potential REF2021 ICSs in 2016. All were actively monitored, supported and progress recorded on an annual basis within ICS Action Plans. We selected those with the greatest significance and reach.

The **Computer Aided Safety-Engineering ICS** originated from underpinning research funded by EPSRC (2005-12) and EU (2005-10). Supported by the University's commercialisation team and funded by the local government, venture capitalists and LU (total investment £1.3M) we formed the spin-out HAZID Technologies in 2002. Chung was awarded a 6-month study leave (Gatsby Fellowship) in 2002 to focus on HAZID as its founding Technical Director. The outcomes of the EU VIRTUALIS project further supported this ICS through collaboration with BP and Igloo Vision in 2014-15, funded by BP.

The **Image Enhancement ICS** originated from underpinning research conducted within two industry funded PhD studentships, one EPSRC Engineering Doctorate studentship and research conducted by three KTP projects and one InnovateUK project. All projects were in collaboration with the SME Apical (since purchased by ARM), who benefitted from the Unit's pro-active strategy to facilitate impact generation from research. The Unit's PDM coordinated support for the submission of all InnovateUK grants. The success of the partnership with Apical was also recognised by the LU Enterprise Awards for Knowledge Transfer in both 2013 and 2014.

The **PERFORMS ICS** originated from an extensive programme of consultancy projects (£4.66M since 2000) with NHS / Public Health England, with support from the contracts, consultancy and partnership development teams. All staff of the PERFORMS team were provided with impact related training. PERFORMS received a prestigious Loughborough University Enterprise Award in 2010 and was shortlisted for a further award in 2015.

#### 1.4 Research and Impact Objectives and Plans for the Next Five Years

The Unit will now capitalise on the newly-created, focused structure and staff base. Our future strategy has the following three research and impact priorities:

##### a) Growing research to tackle emerging challenges

**VAAH** will tackle real world challenges in AI, robotics and computer vision, aligning with the Industrial Strategy. Research will be prioritised in robotics for service applications and challenging environments, trustworthy AI (Cosma, Meng), cognition, human-machine cooperative autonomy (Meng, Soltoggio, Lock, Chen), embedded and distributed intelligence (Edirisinghe, Fatima), vision-based scene understanding and human behaviour analysis (Li, Schaefer, Fang, Cai). Building on our recent developments in learning mechanisms inspired by infants (Meng), lifelong learning (Soltoggio) and brain inspired embedded neural networks (Edirisinghe, EPSRC, £965k, 2020-23), the Theme will address emerging challenges in psychologically and biologically inspired learning, adaptation and self-organisation theories and mechanisms in autonomous systems.

**NetSys** now has a strong track record in core internet, network edge computing and vehicular networks. Future research will cover the spectrum from modelling (Nagal, Guan) and simulation to testbed implementations (Adnane, Phillips, Tso). These areas include low-latency computation using edge computing techniques and data plane programmability building an army of highly composable network service functions that can flow data to computation; trust management and the human factors of security for future smart cities' applications and connected vehicles; performance modelling and evaluation, optimisation and prediction in non-continuous, heterogenous networks and systems. The Theme intends to build its network of industrial and international contacts including, Cisco, DSTL ("Internet of Battlespace Things (IoBT) Services", DSTL/QinetiQ, £347k, from Jan 2021), MoD, Rolls Royce, and ATOS.

**TCS** has a strong track record in formal language theory and combinatorics on words (Day, Freydenberger, Mercas, Reidenbach). The Theme will tackle fundamental open problems that primarily arise in application-driven models of formal languages that currently impede the practical use of these models. Future research will include new models of query languages (EPSRC, "Foundations of the Finite Model Theory of Concatenation", £397k, 2021-23) and algorithms for biosequences, as well as topics where expertise is currently emerging and major progress is expected, e.g., tractable classes of word equations. Cryptography is another strong area of expertise in TCS (Adnane, Rahulamathavan, Salagean) where emerging problems in that field will be addressed, e.g., cryptographic attacks, privacy-preservation mechanisms.

Loughborough's Vehicle Safety Research Centre is academic lead for the Smart Mobility Living Lab (SMLL, £19M InnovateUK funded, led by TRL) which is partly located on QEOP and which unites CS and IDT. SMLL provides an excellent platform to support our future research on AI, computer vision, networks, and encryption for driverless vehicles.

##### b) Increasing international visibility

All new staff appointed to the Unit have strong links to international collaborators evidenced, for example, by collaborative grants and joint publications with leading international institutions including Stanford University, Carnegie Mellon University and INRIA. It is planned to continue to leverage these connections to increase our international visibility e.g. via international grants and

the hosting of international conferences. For example, a series of extensive mutual visits is already planned between the Unit and the University of Turku (Finland), from 2022 to investigate tractable classes of word equations. This will be coordinated by Unit ECR Day and funding is being sought from the Academy of Finland. Plans are also in place to strengthen existing links to the University of Göttingen, Germany, to cooperate at the intersection of combinatorial and algorithmic properties of bio-sequences. ECR Mercas' visit to Florin Manea's group at Göttingen in spring 2021 has been delayed due to the COVID-19 pandemic. In the meantime, Unit staff have contributed to a number of virtual international seminars, hosted by the Universities of Waterloo (Canada) and Göttingen. Further plans include collaborations on connected vehicles (Austrian Institute Of Technology) and internet routing (Adelaide University).

### c) Sustaining and enhancing impact creation

Building on the successful impact strategy currently in place, we will follow three refreshed strategic impact objectives:

1. Introduce *Impact Champions* (Li, Lock, Meng, Soltoggio) based on their research grant profile, industry engagement and experience in delivering impact.
2. Support early-stage impact projects and identify and support new opportunities. Two have already been identified: embedded computer vision for sandwich making automation, and deep learning-based handwriting pen path recovery.
3. Build *Impact Consortia* bringing together R&D partners with complementary skills and to focus on significant new impact development (e.g., AI for Free Roaming in Immersive TV Content). The first has already formed comprising ARM, Sky TV and SMEs: TSC Simulation, Imaging CV, and Your Tour.

### 1.5 Open Research Environment

The University has been a pioneer of the 'Open Agenda', actively supporting Repositories for text-based outputs (since 2005) and data (since 2015), working beyond funder (including REF2021) open access requirements. Our landmark Open Research Position Statement, supported by the Unit, committed to depositing the full-text of 100% of our primary research outputs in our now unified (2019) Research Repository (including on closed access where unavoidable) from 2020. From 2020, the Unit has deposited 100% of its journal papers in the repository.

The Unit is active on open-source software, especially in the rapidly developing deep learning area, and also contributes to the research community by maintaining outputs in repositories such as Github, sharing research methods, data and code. For example, Tso maintains his open-source Fruit Operating System (FruitOS) in Github. Tso is also a GitHub Campus Advisor providing support and promotion of 'open source' through Github across the University.

### 1.6 Culture of Research Integrity

The Unit commits to maintaining the highest standards of rigour and integrity in conducting research as embodied in the Concordat to Support Research Integrity (2012). All those engaged in research are responsible for observing the principles of the UK Research Integrity Office (UKRIO) Code of Practice for Research (2009), from initial concepts through to final dissemination. The UUK Concordat and the UKRIO Code of Practice are integral to the University's Ethical Policy Framework, which applies to all research activities. This is supported by Loughborough's Ethics Committee and follows the University's Research Misconduct and Whistle-Blowing policy to maintain a culture of research integrity without fear of recrimination. All Unit staff attend the compulsory training on research integrity. The Unit checks all projects involving human participants, military applications or animal testing. All potentially affected projects have comprehensive ethical clearance documentation checked by the Research Coordinator, ADR and, if needed, the Ethics Committee, e.g., the "Prostate Imaging Self-

assessment and Mentoring” project, which involved recruitment of NHS staff, received ethical approval as did the InnovateUK funded SnooZeal-Connect project for its MRI scan trial. The process has recently been streamlined by introduction of a new ethics system (LEON).

## 2. People

### 2.1 Staffing and Recruitment Policy

All academic staff are active in to teaching, research and enterprise. We expect and incentivise collegiality from the earliest career stages. Academic staff have open-ended contracts, while research staff are on fixed-term contracts related to projects in line with sector norms. Part-time working is welcomed and 3 Unit staff work part-time (2M/1F).

The Unit regularly assesses its succession needs and uses new appointments strategically to ensure critical mass and leadership in the research Themes. All appointments, including replacements, need to be justified by strategic planning. Since REF2014, the University approach to recruiting excellent staff at all career stages, from postdoctoral and early career researchers (ECRs) through mid-career and senior roles, has radically changed, driven by the University Strategy. The University’s ‘Excellence100’ campaign was based on pilot campaigns to recruit outstanding ECRs which were managed centrally and focussed unequivocally on excellence. Building on this, recruitment to established posts is now conducted through biannual recruitment rounds, managed centrally but with significant School input, rather than piecemeal replacement hires. With excellence as the primary criterion, these rounds deliver better international recruitment and improved diversity. All staff involved in recruitment undergo rigorous EDI training and all panels are mixed gender. Of the 16 new appointments, 56% were BAME. Of further note is Han’s appointment, on a 2-year partner fellowship scheme associated with his female partner’s appointment to another School.

Since 2014, our main recruitment requirements have been to replace a large number of staff members retiring from CS, recruit to the new Institute for Digital Technologies in LUL and to add growth. Sixteen new staff have joined the Unit (12 Lecturers, 3 Senior Lecturers, 1 Research Fellow), illustrating our main aim of recruiting early career staff with transformational potential. The Fellow (Day) was recruited to a prestigious 2-year Doctoral Prize Fellowship scheme (under Excellence100) for researchers within 2 years of PhD completion. Day was subsequently recruited to a lectureship.

Notwithstanding how staff work across Themes, the distribution of primary affiliations confirms how each has been strengthened: VAAH 8, NetSys 3 TCS 5. The Unit now has a significantly different demographic in which very few retirements are expected in the next decade. Within SSci, the management roles of the Departments, while also important in their own right, are important for succession planning by helping to identify and develop future research leaders at School and institutional level.

### 2.2 Staff Development Strategy

The Unit is committed to developing academic staff into research leaders with international influence.

Loughborough’s Organisational Development offers a wide spectrum of training opportunities and support for Unit staff at all career stages. Courses range from earliest stages (Welcome to Loughborough) through essential training (Information security training, Unconscious Bias) to training for staff becoming senior managers (Coaching conversations for managers, Recruitment and selection).

All academics are expected to obtain Fellowship of the Higher Education Academy (HEA). For new lecturers, this is integral to their dedicated development programme. More experienced

colleagues are supported through our 'Recognition of Experienced Practitioners' scheme which requires preparation of a dossier of evidence to support their application.

Unit staff can access financial support for research visits, e.g. to prepare international grant applications or develop industry collaborations for impact generation. For example, Soltoggio attended meetings in the US to develop his Lifelong Learning Machines proposal, now funded by DARPA. Furthermore, new staff receive a start-up grant (£2k per year for three years). Visits are further facilitated by flexibilities such as adjustment of teaching timetables. Unit staff can apply for **research and impact leave**, under University or School Fellowship schemes, which allow focus on exceptional activities for a fixed term. Chung's leave was critical at an early stage of his Computer Aided Safety-Engineering ICS.

Following the principles of the *Concordat to Support the Career Development of Researchers*, the University provides structured **support to postdoctoral researchers** (21 in this Unit in this REF period) for career progression and development, including preparation of applications for funding. Our influential Research Staff Association (LURSA) runs a mentoring programme and introduced (2017) the Fellowship Inaugural Lectures to promote Research Fellows' work. Unit postdoctoral researchers are integrated into a support group through meetings and seminars, and they provide mentoring support to PhD researchers, which is a development opportunity for them too. They regularly secure academic posts e.g. Loughborough (Day, Cai), Oikonomou (Bristol), Zhao (Manchester Metropolitan) and Wang (NEU, China).

Under the **New Lecturers' Programme (NLP)**, all new lecturers are guided by an experienced and trained academic colleague from the Unit who acts as Adviser. NLP (formerly academic probation) was substantially revised in 2017 and includes the full spectrum of research and impact activity (publication, funding applications, collaboration, public engagement, non-academic partnerships). New lecturers have a reduced workload in teaching and administration (33, 50 and 67% of departmental norms in consecutive years), which enables the establishment of a full academic profile in research, teaching and impact at a manageable pace. In addition to an extensive training programme leading to FHEA, the New Lecturer meets four times annually with their Adviser though many more informal meetings are the norm. New Lecturers are allocated a University-funded PhD studentship within their first two years, for co-supervision with an experienced colleague. Supervision is a requirement to pass the programme, alongside a minimum expectation on research output production, and the submission of at least one substantial grant application. During the assessment period, three Unit staff competed NLP and one has subsequently been promoted. Six Unit staff are currently completing NLP.

Support for **mid-career and senior staff** is provided via a buddying scheme where more senior staff mentor colleagues through the promotion process. As careers develop, we also expect broader leadership contributions. For example, 2 Unit staff served on the University Senate, and Edirisinghe and Phillips served on the SSci SMT as ADE and Director of Academic Staffing, respectively. Workload model allocations ensure appropriate research activity is maintained.

All members of post-probationary staff in the Unit have an **annual PDR**. This University scheme was totally updated in 2017. A supportive one-to-one discussion between the reviewee and a trained reviewer reflects on achievements over the past year and agrees objectives across the full range of activities including CALIBRE-aligned goals for research and impact activity. New PDR is a transparent way to recognise performance exceeding expectations with additional financial **reward** and allows much fairer identification of candidates for promotion. The new scheme has particularly benefitted our research staff for whom a rigorous developmental discussion was previously sporadic and consideration for reward a rarity. Institutional-level analysis against protected characteristics has resulted in process revisions and improved training arrangements e.g. 'The Art of Inclusive Performance Conversations' programme.

The University has also revised the criteria for **academic promotion** (Senior Lecturer and Reader / Professor), to ensure that the research components align with the University Strategy

and CALIBRE. Evidence for cases can be based on research, teaching, enterprise (impact) or any combination to encourage balanced portfolios of work. We judge 'Excellence and International Reputation' and 'Academic Leadership and Influence' rather than traditional metrics based on quantity and not quality. This focus allows panels to take into account statements from promotion applicants describing how personal circumstances, such as caring responsibilities, may have affected their profile. Several Unit staff have been promoted based on research excellence and contribution to wider aspects of the Unit's activities: Meng (Prof), Lock, Li, Tso, Soltoggio (SL).

### 2.3 Research Students

Research students are key to the research of the Unit. The average number of PhDs awarded each year in this period has increased by 15% to 11.9 since REF2014. In the recent Postgraduate Research Experience Surveys 2019, our PGR students (84.7%) are satisfied with the experience of their research degree programme, which is well above the national average.

The Unit attracts **funding** to maintain its PGR population (c.40 students) via University scholarships, industry funding, international scholarships, UKRI funding including Centres for Doctoral Training (CDTs), and high-quality self-funded students. The funding mix is approximately 30% from internal funding, 15% from CDT and industry, 35% from overseas governments and 20% self-funding. University scholarships are also available to cover international tuition fees. Unit members are encouraged to bring third-party funding for match to internal or CDT funding. During the REF period, the Unit participated in the Loughborough-led EPSRC Centre in Embedded Intelligence (CDT-EI) - 9 studentships with £40k industrial contribution for each. Four more studentships were funded from industry such as DSTL, Rolls Royce, while 31 studentships were funded by the government funding bodies (Saudi, Oman, Brunei, Thailand, China CSC, DARPA) during this REF period.

We require all potential supervisors to have undertaken training on Bullying and Harassment, Recruitment and Selection, Respecting Diversity, and Mental Health Awareness. Supervisors are then required to develop PhD **recruitment plans** that include approaching underrepresented groups (special mailing lists, diversity-related web-resources, conferences). All funded and non-funded projects are posted on the School website and the highly visible e.g. FindAPhD website. We arrange remote or in-person interviews of shortlisted candidates to ensure high quality students are recruited. Decisions are taken by two members of staff.

The Doctoral College runs an **induction** event for new starters, complemented by School specific inductions. All students have at least two **supervisors** with whom meet at least monthly and usually more frequently, with minutes recorded in the University's dedicated online Co-Tutor tool. During the first year of PhD studies, there is an initial 6-month review followed by annual reviews, based on a report and viva with an independent examiner, at which student progression is decided.

Within Schools, quality assurance of research degree programmes is provided by the ADR. Schools also have a Director of Doctoral Programmes (supported by a Deputy in CS) who **monitors progression** and arranges subject specific training. Further specialist **support** is available from the Mathematics Learning Support Centre, the English Language Support Unit, the Student Advice Centre, the Careers Network, and the Student Wellbeing and Inclusivity Service. Schools have elected PGR student representatives who are members of the Staff-Student Liaison Committee.

The Doctoral College offers over 200 **skills development** events annually. Students attend seminars in their Theme and more widely in the Department and the School, often being the speakers. They are encouraged to publish and are also supported by grants to attend conferences (£2k across their PhD). All students have an opportunity to gain teaching experience (c.25% take it up) by assisting in labs and tutorials, after completing the University's



Teaching Skills course designed for PhD students. Doctoral College runs the Annual Conference, Summer Showcase, Three Minute Thesis competition and the 'Diversity in Research' workshops. In addition, SSci holds the annual "Science Matters" conference, organised by PhD students as a professional development opportunity with popular lectures from prominent external speakers, student talks and poster presentations, and awards for outstanding contributions of doctoral students.

## 2.4 Equality and diversity

EDI matters are led by Schools and all make strong commitments. For example, CS actively participates in a range of School-level EDI activities, including Women in Science lecture series, Pride in STEM research showcase (talks by LGBT+ scientists), Black Excellence in STEM events, panel discussions about experiences of Black students and staff in STEM, and the Diversity Allies Campaign (encouraging staff and students to be better allies to underrepresented groups).

All colleagues complete a Respecting Diversity mandatory course and pass an online Unconscious Bias course. School SMTs receive bespoke Unconscious Bias training. SSci and WS hold Bronze Athena SWAN (AS) Awards and LUL has an application in preparation. Unit member Phillips is an experienced AS assessor.

Formal **flexible working** requests are submitted and approved by HR with support from the School. One Unit member moved to 0.8FTE, another temporarily moved to a 0.6FTE, triggered by requests relating to caring responsibilities. Staff teaching may request up to one hour each day free from timetabled teaching to accommodate e.g. school runs. School meetings are restricted to core hours of 10am-4pm. Academic staff may also work flexibly or remotely on an informal basis so long as responsibilities are fulfilled. In other circumstances, such as caring for a family member in poor health, staff can request caring leave for immediate issues or longer term flexible working for ongoing responsibilities.

**Remote working** is facilitated via the VPN (with secure multifactor authentication) that provides access to all University online resources, as well as through the choice that academic staff have between a desktop computer or a laptop. During lockdown, a chat room was created for staff to discuss issues and seek advice in a collegiate environment. These policies and supporting infrastructure have eased the transition to effective home working during the COVID-19 pandemic from March 2020.

**Funding applications** are supported as described in 3.1. Annual equality audits are conducted to ensure that support is provided to all colleagues, including those with protected characteristics. EDI committees collect information about grant success rates and studentship applications by protected characteristics and seek support from the research committees (both at the School and the University levels) to promote a culture of equality and diversity in the research resource distribution.

In addition to University-level support, the **Unit supports staff returning from parental, maternity, adoption, caring responsibility, sick or other long-term leave** by giving them phased workload reintroduction extending over 2 years. Staff are further supported by Occupational Health to determine accommodations to allow them to continue in their role, including staff with disabilities. Compassionate leave exists for circumstances, e.g., death of close relative, which several staff have received.

Staff and research students with caring responsibilities are supported by a **carer's fund** of up to £200 each year to support additional costs associated with conference attendance. An annual equality analysis of staff conference attendance is undertaken each year, and action plans drawn up if required. The Schools fund female staff in leadership roles to attend the Aurora Leadership Programme (Fatima) and SSci has a dedicated fund to support travel to UK diversity-related events.

**Wellbeing support:** The Unit has two Mental Health First Aiders with externally accredited training, who provide immediate support to staff and research students. The **Wellbeing Advisor** provides support to research students. The **University Counselling Service** is available for emergency meetings and long-term treatment. The University also subscribes to the **Employee Assistance Programme** providing 24-hour telephone counselling and repeated sessions for staff with complex issues.

## 2.5 EDI in REF Submission Construction

Following the University's REF Code of Practice (CoP), the Unit created a REF Submission Team (2 White, 2 BAME) covering all Themes. The submission team completed EDI and unconscious bias training. All colleagues were asked to nominate and self-assess potential outputs for inclusion. In line with our Responsible Metrics Policy, these were peer assessed for originality, significance and rigour by a team of reviewers representing all research Themes and covering different career stages, age, gender, race, and ethnicity. Output selection was based solely on excellence as set out in the CoP, and did not set out to ensure even distribution across individuals or Themes. Throughout our REF preparations, equality impact assessments (EIAs) were carried out to assess both institutional processes and our draft return, including outputs selected, against protected characteristics, and to monitor whether further action was required. EIAs confirmed no issues required attention. 20% of outputs selected are attributed to staff identifying as female (21% of Unit staff identify as female).

## 3. Income, infrastructure and facilities

### 3.1 Research Funding and Strategies for Generating Research Income

External funding is vital to the Unit's ambitions in research and impact and all Unit staff are expected to pursue external funding for research to obtain the necessary resources - research staff, PhD students and equipment - to deliver projects across our Themes in areas such as AI and robotics, IoT, cloud and edge computing, security and encryption.

In line with REF2014 strategy, we have obtained grants from a greater variety of funding sources, e.g. EPSRC, NERC, Newton Fund, InnovateUK, KTP, EU, DARPA and industry. We have achieved 172% growth to £670k/year income in 2019/2020 from 2013/2014. This upward trend will continue into the next REF period based on new and ongoing grants, such as:

- "Foundations of the Finite Model Theory of Concatenation" (Freydenberger, EPSRC, £400k, 2021-23),
- "Neuromorphic memristive circuits" (Edirisinghe, EPSRC, £966k, 2020-23),
- Further active grants from AHRC, InnovateUK (7) and five KTP grants.

To secure funding, we monitored opportunities using tools provided by the University's Research and Enterprise Office (REO) (e.g., Research Professional) and created project teams, often including academic and/or industrial partners. This led to awards such as: RegNet (Dogan, InnovateUK, 2020, £104k) in collaboration with RegulAltion and UCL to develop privacy-preserving data access network for regulated sectors; SnooZeal-Connect (Meng, InnovateUK, 2019, £167k) in collaboration with Signifier Medical Technologies to develop an intelligent device for personalised diagnostic, treatment and management of sleep breathing disorders. For KTP projects, 7 over the REF period, Unit staff often collaborate with other Loughborough Units.

Our enduring commitment to **interdisciplinary research** has enabled us to win large research grants to address fundamental research problems. For example, Meng collaborated with Aeronautical and Automotive Engineering at Loughborough to win a £1M EPSRC grant (2012-16) developing biologically inspired approaches to decision making with uncertainties for autonomous vehicles; Edirisinghe collaborated with Physics and Chemistry to secure the recent £966k EPSRC grant exploring memristive neuromorphic mechanisms to analyse image-streams and to make decisions and choices by mimicking neural process in a brain cortex.

The Unit's strategic objective to diversify funding sources, particularly for **international collaborations**, has secured important grants. YOBAN and Air Pollution (both Meng) are in collaboration with Shenzhen Institutes of Advanced Technology (SIAT), Chinese Academy of Sciences, in addition to two industrial partners. YOBAN (Newton Fund, £380k, 2017-19) is developing a companion robot to assist walking, sitting down and standing up for older people; Air Pollution (Newton Fund, £131k, 2018-20) investigates triple-network based air quality monitoring, prediction and carbon credit trading for sustainable urban environments.

From our strategy to **address stakeholder priorities**, we take proactive actions to develop ideas. The NetSys Theme set up several PhD projects in promising research directions on IoT, routing and caching mechanisms in future generation networks. This proactivity has been rewarded by several related grants such as EU grant ISS-EWATUS (Yang, £115k, 2014-17) developing integrated support system based on IoT sensory information for efficient water usage and resources management. Results from PhD projects on network protocols attracted the interest of DSTL, leading to a recently funded PhD studentship and a recent funded project (DSTL/QinetiQ, £347k) to support fundamental research into novel wireless network protocols, and how they would enable agile and dynamic services on Future Internet of Battlespace Things.

Our **supportive research environment** has enabled our new lecturers to be successful in funding applications through experience sharing, proposal peer review and support from senior staff. For example, Fang recently secured a KTP project (£198k) and an InnovateUK project (£56k) with the support from Meng as a project team member and proposal peer reviewer. Both projects extend the Unit's AI expertise to provide novel capabilities in strategic planning and operational decision-making.

One of our research funding strategies is to **join larger Research Consortia** to address national and international challenges. This strategy has led to research awards such as the two examples here:

- Tso worked with Glasgow, Southampton and Cambridge on the £909k EPSRC project FRuIT developing a federated Raspberry Pi micro-infrastructure testbed.
- Soltoggio collaborated with six international universities including Stanford University, UT Austin, UC Irvine, INRIA, and IT University of Copenhagen, and secured the Lifelong Learning Machines (L2M) project (DARPA and the US Air Force Research Laboratory, £487k, 2017-21), aiming to advance the lifelong learning abilities of machine learning.

The Unit's research funding enables us to collaborate with partners in industry, generating impact beyond our current Impact Case Studies. For example, Li's KTP project (2019-21) in collaboration with Millitec Food Systems on food robots is now at the final trial stage with food manufacturers and already attracts wide media reports (e.g. Engineering & Technology, January 2020).

Our research grants have also achieved world leading results and **generated high quality outputs**. Meng's EPSRC grant on autonomous vehicles developed novel algorithms for distributed task allocation for multi-robot systems with time constraints under uncertainties, and the results were published in prestigious IEEE Transactions, and in the top robotics conferences (IEEE International Conference on Robotics and Automation and the IEEE/RSJ International Conference on Intelligent Robots and Systems). Tso's EPSRC grants resulted in novel algorithms and systems for network management, which exploit heterogeneity among networking devices and topologies for network function composition in data centre and edge networks. The results have led to 6 journal publications in IEEE Transactions on Parallel and Distributed Systems, IEEE Transactions on Network and Service Management and IEEE GLOBECOM.

### 3.2 Organisational Infrastructure Supporting Research and Impact

Staff benefit from Unit workshops where successful proposals are analysed so that strengths and weaknesses can be better understood. Peer review by experienced academic colleagues is normal and CS has an internal repository of grant applications to share successful practice. Alongside Unit support, staff also access one to one support with their School's Research Development Manager (RDM) or Partnership Development Manager (PDM) from the REO. They also attend regular drop-in sessions from REO to discuss topics such as grant application and intellectual property. This support has been particularly important as the Unit has recruited so many ECRs during this REF period. Freydenberger's recent New Investigator Award is one example of where support was provided by colleagues in his School, including peer review, and from his School's RDM.

The KTP Office within the REO provides full life cycle support for KTP projects from meeting with industrial partners with the KTP advisor and writing proposals to supporting delivery of the projects, including project finance data support and KTP associate training. All our InnovateUK, KTP and consultancy projects, where there is close collaboration with industrial partners, require contractual agreements, especially to cover how to share and commercialise IP after the project. Some of our projects have international partners, making the agreements more complicated. The University's Contracts Team provides the required specialist legal service support, negotiating with our partners, developing agreements and monitoring commercialisation opportunities.

### 3.3 Operational and Scholarly Infrastructure Supporting Research and Impact

Our specialist research laboratories are vital to project delivery and impact generation:

- The **Robotics, and AI Laboratory** was enhanced by a number of new facilities including 35 Deep Learning computers (>£100k) with the latest Nvidia GPUs including Tesla P100, two NAO robots and a Pepper humanoid robot, LiDAR, cameras and a number of deep learning embedded boards. The lab has several new research robot prototypes developed from research projects, including 30 intelligent mobile robots in the lab with the latest Intel Realsense cameras, and Intel Nano boards. The lab also contains devices such as programmable turtlebots, micro quad copters and 200 Arduino boards, eye tracker devices, video/audio recording and large multi-touch screens. The Lab has provided essential support for our research in AI, robotics, and computer vision under the VAAH and NetSys Themes. For example, it supported delivery of the YOBAN and Agri-robot projects, and provided user behaviour analysis facilities for the cancer screening project PERFORMS.
- The **Networks Laboratory** has been upgraded with facilities for cloud and edge computing. We have established a programmable network testbed, a cloud testbed, an edge testbed and a micro data centre testbed. Specific equipment includes a Barefoot P4 programmable network switch, programmable wireless access points, 200 Raspberry Pi computers and a number of rack-mount cloud servers. The specialist equipment in the lab has successfully supported the delivery of a number of projects from the NetSys Theme, for example, the EPSRC projects FRuIT (Federated RaspberryPi Micro-Infrastructure Testbed) and SYNC (Synergistic Network Policy Management for Cloud Data Centres)

The Unit also benefits from the **HPC Midlands Plus** (EPSRC, £3.2M, 2016), a 14,336 core supercomputer hosted at Loughborough on behalf of the Midlands Innovation partnership, particularly for deep learning and image processing tasks. We have used the HPC intensively to support some of our research projects and PhD projects, and to support our collaborations with industry. The Unit has access to **shared research infrastructure** in the form of the Tier 1 National level Archer supercomputer. The Unit has also recently joined a large facility grant "JADE: Joint Academic Data science Endeavour 2" led by Oxford (EPSRC), allowing us to access to a substantial number of GPU clusters to support our AI research.

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

Developing new and enhancing existing collaborations, networks and partnerships with academia and industry are core to the Unit's strategy for promoting our research and creating real-world impact. Much of our research is interdisciplinary; collaborating with world-leading researchers and industrial partners across application domains.

##### 4.1 Research Collaborations, Networks and Partnerships

Our most enduring partnerships are with 10 Chinese universities where we have expanded relationships founded on taught degrees into research partnerships, e.g., our collaboration with Northeastern University (NEU), China, in computer vision and AI has attracted three excellent academic visitors (since 2014) leading to a number of high-quality IEEE journal papers. A Unit postdoc also joined NEU (lectureship) and continues collaboration. The taught programmes provide excellent students; 12 continued their studies to PhDs at Loughborough.

Unit researchers maintain a large number of individual collaborations with field leading experts. Examples include:

- Salagean with Ferruh Özbudak (Ankara/Turkey), funded by the Royal Society, has involved a series of extensive mutual visits, leading to three publications on cryptography.
- Reidenbach with Jeffrey Shallit (Waterloo/Canada), initiated during a London Mathematical Society-funded visit from Shallit to Loughborough and has yielded two joint publications on combinatorial properties of codes.
- Mercas with Florin Manea (Göttingen/Germany), who have co-authored ten joint publications on formal language theory and algorithms since 2014.
- Schaefer collaborates with six academic partners (e.g. UCLM/Spain) and five companies (e.g. AstraZeneca) supported by EU AIDPATH project, leading to eleven publications on medical image analysis (e.g. on IEEE Transactions on Medical Imaging).

The Unit has also extended existing collaborations where additional synergies were identified:

- Soltoggio extended his previous collaborations with IT University of Copenhagen (Dr Sebastian Risi) through which he joined a consortium with new partners from HRL Laboratories, Stanford University, and University of California Irvine, resulting in award of the Lifelong Learning Machines DARPA grant.
- Meng was invited by Director Prof Guanglin Li of Chinese Academy of Sciences to visit Shenzhen Institutes of Advanced Technology. In subsequent discussions, Meng developed a relationship with Prof Peng Shang of SIAT with complementary expertise in assistive technology and IoT which resulted in the forming of the consortium that won two Newton Fund projects (service robots and air quality monitoring), enriching our robotics and AI research.

CALIBRE's Institute of Advanced Studies (IAS) now provides an additional platform for collaboration with internationally leading researchers. Through the IAS, Mercas and Reidenbach invited two world-leading experts in combinatorics on words: Prof. Antonio Restivo (Palermo) and Prof. Gwenael Richomme (Montpellier) to initiate new collaborations for our TCS Theme to be developed for the future.

##### 4.1.1 Interaction with Key Research Users, Beneficiaries or Audiences, wider Contributions to the Economy and Society

Such interaction is core to our impact strategy and a strength of the Unit. We use funding mechanisms such as KTP, InnovateUK and Newton to build substantial relationships, backed up Masters / undergraduate projects and, in particular, PhD studentship sponsorship, to enrich simultaneously our academic environment and our long-term relationships with the companies.

We specifically encourage staff to work with companies to create KTP projects allowing transfer of our research knowledge to industry to generate real-world impact. This strategy is enhanced by REO who have made introductions to new partners and by access to the business community on Loughborough's Science and Enterprise Park (LUSEP), housing 80+ companies and organisations on our campus. This resulted in the award of seven KTP projects with Smartroof (automating and optimising information flow in roof construction), Millitec (automation for food processing), Satoshi (risk assessment in commodity supply chain), Xceptor (document processing for financial services), Apical (adaptation of mobile phone display to changes in environmental illumination; high dynamic range video delivery systems for ubiquitous devices) and Ice Communication (rendering for augmented reality).

Unit staff also actively attend events (e.g. INNOVATE 2017, AI Summit 2019) and engage with industrial partners to develop relationships, identify challenges and win funding. Ten collaborative InnovateUK and Newton Fund projects exemplify the effectiveness of this approach: Statmetrix (automated football action event detection), Motion Robotics (assistive robots for elderly people), Signifier Medical Technologies (intelligent device for sleep breathing disorders), Satoshi Systems and EEGSmart Intelligent Technology Co. (air pollution monitoring and prediction), Nantong Guangyi Mechanical & Electrical Co. and Innova Integra (autonomous agricultural robot system for precision spraying), Shelton Vision (automatic defect detection on patterned textiles), Surface Intelligence (handwriting trajectory recovery), Intelligent Distributed Controls Ltd (low cost wireless tracking systems), and RegulAltion (privacy-preserving data access network).

Our partnerships with industry are also developed through sponsored PhD studentships. During this period, the Unit has supervised thirteen such students. Examples include:

- Guan has developed her partnership with Rolls Royce in the area of Model-Based Systems Engineering with Quality-of-Service attributes in Embedded Real-time Systems. Rolls Royce sponsored two PhD students in this area and another via the CDT-EI.
- Edirisinghe provided his computer vision expertise to support the research of Apical's new business unit in Embedded Vision Systems in 2015, and the Spirit™ Computer Vision System. This technology is now embedded within 10 million CCTV cameras and was underpinned by the research projects of 3 sponsored PhD students.

#### 4.1.2 Engaging with Diverse Communities and Public

Unit staff actively engage with the popular media to disseminate their research to the wider public, frequently supported by the University's Marketing and Communications professional service. Li was recently interviewed by New Scientist: "AI pollution monitor could forecast harmful particles in the air" (March 2020). Her project on developing machine vision for the food industry was reported by Engineering & Technology in the article "Robots could harness AI to master sandwich making" (January 2020). Her InnovateUK funded project on football player performance analysis using computer vision and deep learning has also attracted wide public interest, as reported in AI Business: "Deep Learning can automate, enhance soccer analysis" and Interesting Engineering: "Want to Know Who the Next Footballer May Be? This AI Will Tell You".

Unit research is also shared in online, print and radio news. For example, Soltoggio has been invited to speak on BBC Radio Leicester eleven times since 2015. His work on machine learning applications to medical breath analysis was reported in numerous news articles and media websites including The Independent: "AI is acquiring a sense of smell that can detect illnesses in human breath" (June 2018), and The World Economic Forum: "Open wide: this AI could soon analyse your breath for disease". Adnane's work on cybersecurity and impact on working remotely during Covid-19 lockdown appeared in several online newsfeeds including BBC News (March 2020) and the Daily Mail.

## 4.2 Contribution to the Sustainability of the Discipline

Unit staff are actively engaged in activities in the computer science research and governance community and are members of professional bodies, shaping research agendas and roadmaps. Examples include IEEE Senior Members/Members (Tso, Li, Meng, Cosma) and BCS Fellow (Philips). Philips sits on the BCS Academy of Computing Board and on the Committee of the Council of Professors and Heads of Computing exerting wider influence in the discipline.

The Unit has **hosted national and international conferences** at Loughborough to promote the dissemination of recent research achievements and influence future research directions for our research community. For example, the Unit hosted the second EPSRC UK-RAS (Robotics and Autonomous Systems) conference (2019), where PhD students and ECRs exchanged their research results and heard keynotes from academic and industry speakers, the 20th Annual Conference in Medical Image Understanding and Analysis (2016), the 10th International Symposium on Computer Science in Sport (2015), and the 12th International Conference on Words (2019).

We **respond to national priorities in the Government Industrial Strategy**. We have specifically targeted the grand challenges “artificial intelligence and big data” and “ageing society”. For example, “Intelligent business decision making in retailer sector” (KTP, Hui) investigates AI-based decision systems that learn from all relevant data to automate strategic and operational decision simulations in real-time for fast-moving consumer goods companies such as Unilever. The YOBAN project studies low-cost healthcare devices for elderly people with mobility difficulties.

The Unit also **responds to international priorities**. Highlights include Meng’s Newton Fund Air Pollution project which supports developing countries for environment protection by monitoring and predicting air pollution, and also linking air pollution with carbon trading encouraging low carbon emissions. The ISS-EWATUS EU grant combines the interdisciplinary efforts of specialists from water management and ICT research to develop an intelligent Integrated Support System for efficient water usage and resources management.

## 4.3 Indicators of Wider Influence

We encourage all staff to undertake roles that are important to shaping the future of the discipline.

Unit staff review proposals for a wide range of **international funding bodies** such as EPSRC, MRC, BBSRC, AHRC, STFC, Newton Fund, CRUK, Leverhulme Trust, Israel Science Foundation (Personal Research Grants 2019), Action Medical Research, Swiss National Science Foundation), National Agency for Scientific Evaluation in Spain, and Dutch Research Council. Staff are EPSRC college members (Cosma, Lock, Phillips) and have served as funding body panel members to contribute to proposal assessment and decision making. For example EPSRC ICT prioritisation panels (Guan: 2016, 2019; Cosma: 2017, 2019), EPSRC Healthcare Technologies prioritisation panel (Cosma), EPSRC prioritisation panel for CDT-AI call, outline stage, (Li, 2018).

We play key roles in **international conferences** and exert influence on areas of focus. An important example is our longstanding contribution to the world’s No.1 conference in Robotics and Automation, IEEE International Conference on Robotics and Automation, for which Meng has been an Associate Editor continuously from 2014-21. Reidenbach has been a member of the Steering Committee of the leading International Conference on Words series since 2019. Guan has been the Chair of IEEE International Symposium on Performance Modelling and Evaluation of Communication and Telecommunication Networks in Adaptive Networks and The Cloud from 2007-19, setting conference themes and organising the conference.

## Unit-level environment template (REF5b)

Unit staff have been invited to give **keynotes and invited talks** at international conferences. Highlights include:

- Li's keynote at the International Conference on Artificial Intelligence and Robots (2020), highlighting research on computer vision and AI for food robots and underwater robots
- Schaefer's keynotes for the 6th ECCOMAS Thematic Conference on Computational Vision and Medical Image Processing (2017) provided insight on the state of the art on medical imaging
- Meng's keynote for World Conference on Robotics and Artificial Intelligence (2018) presented the progress and future direction on service robots and agriculture robots
- Mercas' keynote at Developments in Language Theory (2017), one of the main conferences on automata and formal languages, provided an overview on challenges and new techniques on proving lower bounds on repetition avoidability.

Unit staff have actively contributed to research communities through **journal editorial roles**. New contributions are:

- Meng: associate editor of IEEE Transactions on Cybernetics (from Sept 2017) and editorial board member for Advances in Robotics & Automation (from Nov 2017) .
- Guan: editorial board member of Journal of Systems and Software (from May 2017).
- Reidenbach: editorial board member of the journal Discrete Mathematics and Theoretical Computer Science (from Feb 2016).
- Adnane: associate editor for Array (from June 2019)

The Unit also supports ECRs in such roles, e.g., Chen: Associate Editor for Services Transactions on Internet of Things (STIOT).

Unit staff have also organised a number of **special issues as Guest Editors**. For example,

- Adnane: "Recent Advances on the Emerging Technologies for Connected Vehicles in Smart Cities" *Transactions on Emerging Telecommunications Technologies*. (Call for Papers, March 2020)
- Meng: "Visual Perception Enabled Industry Intelligence" *IEEE Transactions on Industrial Informatics* (available online June 2020)
- Meng: "Emerging Algorithms and Applications in Vision Sensors System based on Artificial Intelligence" *Sensors Journal* (published 2019)
- Meng: "Theory and applications of complex networks" *Mathematical Problems in Engineering* (published 2015)
- Mercas and Reidenbach: "Combinatorics on Words" *Theoretical Computer Science* (initiated January 2020)
- Tso: "End-to-End IoT Security and Privacy" *International Journal of Distributed Sensor Networks* (published 2018)

These Special Issues cover areas of Computer Science where developments are particularly rapid, such as deep learning and trustworthiness in AI and robotics (VAAH Theme), and edge computing and IoT security (NetSys Theme). Our roles as Guest Editors underline the influential part that Unit staff play in promoting the most promising new research directions to a wide audience.