

Unit-level environment template (REF5b)

Institution: Liverpool Hope University (LHU)
Unit of Assessment: B11: Computer Science and Informatics (CS&I)
<p>1. Unit context and structure, research and impact strategy</p> <p>The CS&I Unit of Assessment (the UoA) at LHU (the University) comprises all eligible staff from the School of Mathematics, Computer Science and Engineering (the School or 'MCS&E': total 12.5 FTEs) along with 1 FTE from the Business School working on multi-disciplinary research themes. Among the 13.5 FTE submitted, five are Early Career Researchers (ECR). The UoA is a lively and energetic unit, supporting a strategic range of mathematical, computational, and robotics research.</p> <p>Over a decade ago, the School set out to redefine and refocus itself as an active centre of research and teaching devoted to aspects of mathematical and computational sciences associated with LHU's core strengths in humanities-shaped and liberal-arts inspired curriculum. We have followed this route consistently throughout the last ten years, building momentum over this assessment period. In doing so, we have been forging a unique research vision of CS&I research as an interdisciplinary set of practices, methods and techniques clustered around the roles of mathematical and computational modelling in individual creativity, social connectivity, medical applications of AI and Robotics, and Virtual and Augmented Reality (Spatial Computing).</p> <p>This major re-focusing was undertaken to meet both external factors (in particular, an increase in student numbers) and changes in the strategic direction of the University. This in turn has led to a significant shift in staffing profile. The re-focusing has also shifted the emphasis from primarily Information Systems provision to Mathematical and Computational Science, including AI and Robotics areas, and has helped to establish a healthy postgraduate programme as well as to develop a vibrant research environment.</p> <p>The research environment described in this document is one that has been built consciously to support interdisciplinarity and transdisciplinarity across the University, enabling us to work closely with LHU's strongest, most successful, and most innovative schools/departments. This environment has helped to strengthen and consolidate our research profile in our chosen fields, enabled application of the research, and provides the basis for continued development.</p> <p>The School structures and manages its research activity around three groups that represent the School's core areas of research strength:</p> <ul style="list-style-type: none"> • Intelligent and Distributed Systems (IDS) • Spatial Computing and Robotics (SC&R) • Mathematical Sciences Research (MSR)

IDS: Led by Reid, this group aims to build computational models for understanding biological and social intelligence found in nature, with particular interest in neural information processing in the brain and the organising principles of neural and morphological development from the evolutionary perspective. The group is also concerned with developing efficient computational algorithms, inspired from natural intelligence and built on mathematical models, for solving complex real-world problems, targeting problem spaces in high value-added engineering domains as well as domains in autonomous systems such as swarm robotics, healthcare and bioengineering with strategic societal impact.

SC&R: Led by Secco, the expertise of this group overlaps with IDS, utilising Immersive Technology (AR/VR) and Robotics, with a growing focus on Spatial Computing and Embedded Intelligence (SEI). Example outcomes of this research activity include: High Altitude Platform Stations (HAPS) for the provision of broadband and internet services especially in rural, underserved and disaster areas; Haptics for Immersive Technologies (Tactile Internet); and a Portable Pollution-Monitoring Internet-of-Things (IoT) system. This group is involved in a set of multiple branches of Robotics, such as insights on Human Robot Interaction (HRI), Bio-mimetic Robotics (BM), miniaturized haptic-based sensors and actuators, and Haptics.

MSR: Led by Xenitidis, this group aims to encompass research from pure and applied mathematics. The skills within the group are wide and far-reaching but complement each other. Themes within the group include Complexity, Singularity Theory, Differential Geometry, Dynamical Systems, Integrable Systems, Theoretical Physics, and Particle Physics/Quantum Computing. With many of the research areas overlapping, there has already been collaborations within the group and with the other groups (e.g. complexity analysis for self-organised HAPS).

The group leaders serve as representatives on the School's Research Committee (SRC) and its Knowledge Exchange Steering group, where issues such as strategy implementation, KE strategy, and research investment are addressed. **Figure 1** below describes the various committees, research groups and their relationship with the University committees. The membership, areas of interest and expertise of these groups are not mutually exclusive, and collaborative research occurs frequently between them, together with other Schools/Departments in the University (e.g. Business, Psychology, Creative and Performing Arts, Health Sciences), and with national and international partners (e.g. partner HEIs in India). All School staff are co-located in the Frances Mary Lescher building with close proximity (along the same corridors) to teaching and research laboratories, which helps to facilitate a vibrant academic and research community of staff, PGR students and undergraduate students, especially with our curriculum that emphasises research-informed teaching.

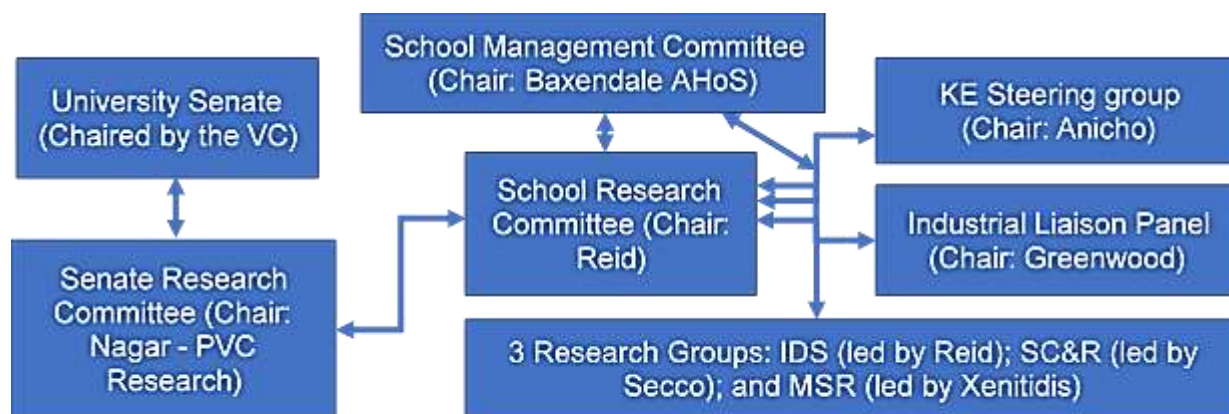


Figure 1: School committees/panels/groups and their relationship to University bodies.

The research groups provide a forum for focussed discussion, feedback (on presentations, manuscripts, and research proposals), and collegial support through regular meetings. Research groups are also expected to be outward-facing to enable multi/inter-disciplinary research. In addition, members of research groups are expected to encourage academics from elsewhere to visit LHU and to foster wide academic networks. Furthermore, and consistent with the mission of the University for a positive impact of our research in people's lives, research groups are expected to work to establish and maintain links to stakeholders (e.g. AI applications for memory and learning disorder in children with Sickle Cell Anemia being jointly done with the Indian Council of Medical Research (ICMR)) for whom the translation of research into practice is important. These links are especially critical to ensuring that research from the UoA has impact.

Research strategy:

Our strategy for research culture involves growing a viable and sustainable research community in each area/theme, consisting of academic staff, research assistants and students, visiting professors as mentors, and collaborators from industry. Whilst growing research communities is a long-term and ongoing undertaking, there have already been significant notable successes as described below. To fulfil this strategy, we have prioritised the development of a strong and active research culture, alongside the maintenance of an international profile and the provision of a rich and satisfying environment for research students. The research culture consists of an intensive research-informed teaching environment that advances knowledge, develops technology, and provides highly-trained scientists and engineers to meet the needs of industry and society. Contributing to the UK economic competitiveness and quality of life, the development of this culture fulfils the University's mission of engaging with the world beyond academia to 'make a difference' – preparing our students for the world of work, and for the work of the world.

Achievements and evaluation of strategic aims during the assessment period:

We have met the following REF2014 strategy and research targets.

1. Focus on fostering research in carefully-selected growth areas of MCS&E and their applications.
 - ✓ Creation of active and sustainable research thematics in key areas that build on the strengths established through repositioning, refocusing, and rebranding of the School, as well as the creation of the three research groups. Key staff appointments including promotions (details in **Section 2**). Of the 13.5 FTE staff returned, 9.5 were appointed after REF2014.
2. Raise output quality and visibility by publishing in high-quality, peer-reviewed, mainstream and internationally-respected venues/outlets (including Open Access).
 - ✓ The School is well-represented on the programme/organising committees and editorial boards of the top international conferences and journals in the field. Open Science is firmly embedded in our work.
 - ✓ Research quality is evidenced by increased publications in top-quality outlets (e.g. various IEEE Transactions) and key archival conferences such as International Conference on Robotics and Automation (ICRA); launch of the Springer Algorithms for Intelligent Systems (AIS) research series; hosting of a major Soft Computing conference (SocProS-2019) series with proceedings published by Springer.
3. Increase the quality and quantity of Ph.D. students; proactive efforts towards increasing external grant income in order to attract researchers and visitors.
 - ✓ Growth in PhD student numbers from 2 in 2013 to 10 in 2018/19, with under 4-year completion rate for doctoral degrees (**Section 2**). Includes two externally-funded scholarship PGRs who joined during 2019/20.
4. Improve laboratory equipment provision.
 - ✓ Improved research infrastructure, including strategic investment in excellent facilities and environment (**Section 3**).
5. Increase external research, knowledge exchange and technology transfer collaborations.
 - ✓ Key collaborations in robotics and mathematical computing; increased academic as well as industrial collaborations and networks (**Section 4**).

Future research strategy, aims and goals for sustainability: The researchers in the UoA continue to set for themselves the objective of pursuing both fundamental and applied research at the forefront of scientific and technological development, as well as responsiveness to national and international initiatives and priorities, e.g. AI and Robotics. This strategy will continue to be adopted and developed, leading to continued growth in our high-quality outputs and already fruitful activities and their effects. We will continue the policy of developing strength in depth with an

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emphasis on interdisciplinarity, building upon existing themes and diversifying in a carefully controlled fashion, and achieving international excellence in aspects of our portfolio. We will achieve this capacity and capability through our staff development procedures, by emphasising and encouraging synergy, and by attracting active researchers in relevant areas (e.g. recent appointments being made in the Cybersecurity area). A conscious effort will continue to be made to ensure relevance and timeliness of research and its translation into practice.

Within the framework of this strategy, the School will pursue a set of well-identified goals over the next five years. These include:

- 1) responding to the challenges presented by the explosive growth of AI, IoT, robotics, haptics and wearable systems areas, including the emerging area of HAPS being led by the School;
- 2) continuing to focus on exploiting our core skills and strengths by prosecuting both fundamental research and applications as diverse as HAPS and eHealth;
- 3) continuing to raise the quality of publications to higher standards and outlets through target-setting in performance reviews, staff development, and mentoring;
- 4) ensuring that we continue to emphasise sustainability through research grants; increasing the number of research funding bids; ensuring the importance of collaboration as a further impetus for external funding;
- 5) undertaking knowledge-exchange, commercial exploitation and patenting of our findings;
- 6) continuing to support less-experienced researchers in research teams including through mentoring by more-experienced researchers and visiting professors;
- 7) further increasing the critical mass of our PGR student body and maintaining successful research degree completion.

Unit's Open Science Statement:

The UoA's strategy is that all stages of the research lifecycle can be made open, within the bounds of the associated good governance and conditions of the research, ranging from opening up research methodologies through to pre-registration, sharing notes, software, simulation, and data, and publishing open-access. This approach has already enabled greater visibility and wider distribution of our research, thereby unlocking access to knowledge and generating new opportunities for collaboration and participation (e.g. our developing collaborations with Avealto Plc).

The UoA has already embedded the principles of Open Science that go beyond simply making publications open access. Our Visiting Professor John Wood (CBE and Former Secretary-General Association of Commonwealth Universities) was invited to advise colleagues in the School regarding the 'Open Research and Open Science' (OR&OS) agenda (with his expertise in implementing OR&OS in Europe working as a consultant for CERN). The University has launched

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an *Institutional Open Access Research* platform called InOAR (developed by the School). Colleagues use/lodge data (e.g. TCGA data, ImageNet, Eurostat, OpenGL libraries); some have pre-registered studies prior to publication (e.g. Foulkes and Garron on arxiv.org), and others are involved in the public dissemination of science, e.g. through British Science Week (BSW) and bespoke public science engagements, such as at Liverpool Business Festival (Reid). We have also introduced OR&OS into our UG/PG curriculum (e.g. GNUplot, RProject, CYGWIN, Pytorch) in order to begin to foster OR&OS practices among our students. We seek to increase the proportion of colleagues engaged in activities supporting OR&OS through an ongoing programme of staff development and mentoring.

Impact strategy: The research scope of the School covers a broad range of activities including, for example, developing tools and techniques for teaching science and mathematics to visually-impaired school children (a REF2014 case study), medical robotics and sensors (Secco and Ranasinghe). Our wide-ranging activities enable a breadth of impact, with a focus predominately in areas where system-interaction-design, modelling and simulation, and technological development have a key role, or where there is a particularly strong policy influence (e.g. HAPS research leading to policy impact on the Commonwealth Telecommunication Organisation's (CTO) strategy). Public-engagement and outreach also play a major role (**Section 4**).

Our approach to, and mechanisms for delivering, Impact have been achieved within the context of the University's mission of engaging with the world beyond academia. The University's values of 'being the critic and conscience of society' and 'making a difference' are mirrored in various strategies within MCS&E. In the School there is clear expectation, articulated in staff recruitment and annual monitoring and promotion policies, for staff to demonstrate wider contribution both within and beyond the academic world. The work of MCS&E therefore draws on contacts and expertise from elsewhere in the University, and over the years it has nurtured extensive, and in several cases deep, external associations. The School continues to facilitate staff to engage in this wider contribution (including by funding: e.g. targeted impact calls such as 'Route to Impact', 'REFine', and 'REFlect'). Besides helping staff to innovate and to expedite production of research output, this facilitation enables staff to engage with research users as the work develops. The School, in conjunction with the University's Business Gateway team, have held research open days and summer schools to show-case on-going research in various ways (e.g. the SocProS-2019 conference had an industrial track and an exhibition/poster session).

The School has taken a number of different approaches to ensure impact from its research, ranging from a broad-sweeping approach to raising the impact-awareness of its researchers to specific and targeted impact activities that have the potential to achieve significant impact. These impact activities, which are focused around research themes/clusters and individuals, are undertaken through various approaches such as: (i) **Interactions with Users/Industry** (e.g.

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Barclays Plc. and Tendo Plc.) – see **Section 4**; (ii) **targeted efforts to establish and develop research themes and activities** that are more industrially-focused but still deliver innovative and excellent research and science, often bringing researchers with multidisciplinary backgrounds together; (iii) **funding and supporting impact potential** of research, a particular success here being the REFine and REFlect grants, through usage of the devolved budget of the SRC; (iv) the **role of public engagement and outreach**, an area in which the School is particularly active (e.g. iCure funding to engage stakeholders on Visual Secret Sharing (VSS) project – see **Section 4**); (v) regular **review mechanisms to assess progress and effectiveness, and for forward planning**; (vi) regular **staff-development workshops** intended to contribute to a culture shift whereby impact is a key part of the overall research-development consciousness; and support at the various stages of the impact life-cycle (planning, beneficiary engagement and involvement, achieving, evaluating, and providing evidence).

The School's future impact strategy is: Plan it (as part of Research from the beginning), Action it, Evidence it, Communicate and Showcase it, and Reward and Celebrate it.

Impact awareness (including staff development and mentoring): The School will encourage the development of impact for every researcher by increasing the importance of impact within performance-review and staff-development opportunities.

Enhancing interaction with Industry/Users: The School will deepen these relationships by building upon Open Day as an 'Industrial Showcase Event' and as a networking opportunity that engages local industry with the research community within MCS&E. Further networking events will involve Daresbury Laboratory (Warrington, Cheshire) and Liverpool Science Park and Sensor City, with whom we are already collaborating/interacting.

Targeted impact: The School has already been employing this strategy, investing in research laboratories and equipment (such as 3D Printers, HPC machine, variety of robotics equipment, HAPS, VR and AR equipment – details in **Section 3**).

Recruitment of staff: The School targets key academic appointments in areas that strengthen industrial collaborations (e.g. the recently-appointed Dr Mark Greenwood, who chairs the Industrial-Liaison Panel, is a professional tutor and brings valuable industrial background).

Relationship to submitted Impact Case studies (ICSs): The various approaches taken by the School are reflected in the make-up of the submitted ICSs. (i) the **e-Health ICS** (Nagar) is directly linked to influencing the work of IBM, the UAE Health Ministry, and NGOs in North India working for underprivileged sections of society, with a direct impact on enhancing the productivity and quality of life; and (ii) the **HAPS ICS** (Anicho and Nagar) has crossed disciplines through

engagement with CTO and communication professionals, achieving impact by influencing Spectrum Allocation policies.

2. People

The UoA maintains a rigorous staffing policy, and recruits research-promising academics as well as high-calibre early-career researchers (e.g. Dev and Anicho). The staffing strategy is designed to meet objectives set by the research and impact strategy, alongside the requirement of the University to deliver teaching. The strategy must be understood in light of two key objectives: to recruit the very best academics that will help achieve our strategic goals; and to develop the academics already in post to be able to perform as best as possible (through building skills and networks). For example, we have recently recruited Garron, a particle physicist, as we are expanding our directions of research and developing our provision in Quantum and Non-conventional Computing. In addition, we seek to achieve these objectives while fostering a spirit of equality and inclusivity across all colleagues within the UoA. Moreover, as part of the annual performance review, the research achievements, aspirations and development needs (e.g. bids and grants writing) of staff are explored and acted upon.

New members of staff are mentored by more experienced senior academics and visiting professors, who provide guidance and help. Wherever possible, new members of staff carry out at least part of their research work in conjunction with other colleagues (e.g. joint supervision of PhDs). Funding is provided for recruiting Graduate Teaching Assistants (GTAs) who are enrolled for a PhD degree and support the School's research and teaching. During the assessment period six Vice-Chancellor's PhD scholarships were awarded, and we currently have two externally-funded scholarship PhD students. We are a relatively young School and no staff reach nominal retirement age within five years. The UoA has a sound staff profile, with a good balance between (i) research leaders (Nagar, who established the Department (now developed into a growing and vibrant School) in 2008 as foundation professor of Mathematics), (ii) experienced researchers (Reid, Secco, Xenitidis, Foulkes, Naguib, Garron), (iii) new and emerging researchers (Ranasinghe, Baxendale, Dev, Buckley, Anicho, Reeve), and (iv) visiting scholars and professors. Nagar works in a number of areas across the unit, and with his mathematics background contributes to enriching and mentoring the research of emerging and ECRs.

The School's supporting and nurturing environment allows colleagues to develop their academic profile from which all staff benefit. Indeed, this also means that some colleagues move on to promoted positions elsewhere. For example a colleague, after being fast-tracked to Associate Professor, was appointed full Professor at Leeds Beckett (2015); Hu received support from the School resulting in a successful 3-year EPSRC grant on which a postdoc was being appointed when he moved to Exeter; Kirpichnikova moved to Edinburgh Napier to lead their Data Science

developments; and Caliskanelli, due to her Distributed Systems expertise, was attracted by the UK Atomic Energy Authority; and another member of staff whose PhD was fully funded by the School later moved to the University of Manchester.

The organisation of the UoA's research, divided into three research groups as described in **Section 1 (Figure 1)**, facilitates the efficient deployment of resources, effective coordination of research, multidisciplinary collaboration and subsequent transfer of knowledge and expertise. Day-to-day management of research activities is coordinated by Reid (SRC Chair) supported by the research group leaders and Nagar (Head). This ensures a coordinated approach and facilitates the cross-fertilisation of ideas and projects, as well as the integration and mentoring of new and upcoming members of staff, encouraging the development of junior researchers, identifying publication targets and drafting applications for funding and internal peer-review.

Colleagues benefit from **short sabbaticals** taken in the form of **consolidated research time** (CRT) which allows staff the opportunity to step back from other responsibilities to focus on research. Over the census period most staff have benefitted from at least one period of CRT (e.g. Baxendale to finish his PhD thesis in 2019).

Research funds are available from the devolved SRC budget and central University funds (managed by the PVC Research). Priority is given to staff presenting papers at mainstream conferences (e.g. ICRA), tutorials, workshops or chairing/organising special sessions at conferences. During the current research assessment period, all staff members presenting papers at recognised conferences have been supported with funding to do so.

Risk assessments and ethics are managed by dedicated ethics lead reporting to the School Ethical Approval Committee and to University Sub-Committee on Ethics (a sub-committee of Senate Research Committee). We recognise that our research culture must embody the values of ethics, good practice, and scientific and professional integrity, so that others can have trust and confidence in the methods and the findings of our research. We view our commitment to OR&OS practices (see **Section 1**) as an important mechanism to ensure this trust and confidence.

The PGR community is fundamental to delivering a sustainable research environment, participating fully in the research of the School. As part of our strategy to further develop a PGR critical mass within the School, we have recently (from 2019) modified our PGT provision in order to stimulate PG research activity. Meanwhile, a funding mechanism has been agreed by the PVC Research that allows future PGT recruitment to link in a scaled and sustainable manner to the offering of PGR bursaries, with the goal of facilitating growth and adding to the recruitment of self-funding students. The target is to carefully recruit up to 5 high-calibre PGR students per-annum, reaching a minimum of 15 PGRs at any given time. We have already identified an income stream

to support the potential growth in academic staff (2 per-annum) and PGRs (5 funded bursaries per-annum) between 2020 and 2023.

Several VC PhD studentships were created from QR funds during the current REF period. Since REF2014 we have supervised 7 high-quality PhDs to successful completion, and 2 more PhDs have had successful Vivas since July 2020. Our PGRs have been successfully employed: 1 PhD is now working for Google Labs (having also worked for IBM in California), 3 PhDs are in academic positions (2 in the UK and 1 in Oman), 1 PhD student is employed by a major Italian Telecommunication company, and a further PhD student is working for a major Manufacturing company based in Coventry. The School carefully selects its research students, keeping in mind the research strengths/expertise and supervisory capacity of staff members. Research supervisory status is approved by the Research Degree Sub-Committee (RDSC), a sub-committee of the Senate's Research Committee.

Research students are based in a dedicated PGR laboratory space in the School, situated alongside staff offices. They are required to attend the School's Research Seminar series, and also informal meetings where research-active staff encourage discussions and create an excellent research 'buzz'. All research students undertake a Research Skills programme as well as interactive workshops, seminars and group activities, and participate in PGR skills and Poster sessions. Meanwhile, School staff are also involved in delivering University-wide PGR sessions, and a supervisor training programme has run since the University achieved RDAP in 2009. Success in generating a productive atmosphere for research students is evidenced by the healthy under-4-year completion rate for our cohorts.

Research students are supervised by teams, all of whom receive appropriate supervisor training sessions (including: processes and procedures; how to supervise; examining a thesis; and LHU doctoral regulations) and are allotted dedicated time for supervision. The team may (and frequently does) include external people chosen for their specific expertise (e.g. a former Airbus engineer on the HAPS project). Generic research training is provided centrally, and covers topics such as research ethics, project planning, thesis writing, Viva examination, and presentation skills. Specific training is provided at School level, e.g. attending appropriate MSc modules or external courses and events, and is tailored to individuals, e.g. funding to attend a summer school on Medical Imaging in Italy. Research students are encouraged to deliver papers at the first available opportunity, taking advantage of 'research student-friendly' conferences and events where senior researchers provide feedback and encouragement to students and new researchers. An example is the dedicated special session for PhD students held at the Soft Computing for Problem Solving Conference (SocProS). At SocProS-2017 an LHU student won a best paper award, and in 2019 the event itself was held at LHU.

PGRs' progress is monitored annually through an Annual Monitoring Review process (AMR) that includes a report by the supervision team, a review of the student's training record, and an interview carried out by an Independent Chair and the Supervisory team. Progression is subject to satisfactory performance in AMR and the approval of the RDSC. The School's policy of discouraging students from switching to part-time mode without good reason has resulted in maintaining completions within 3–4 years. Structures for supporting our research students were commended as areas of good practice by the 2016 School Review.

It is important to the UoA that we achieve our goals while both promoting and supporting **equality, diversity and inclusion (EDI)** as only then will our efforts to give all colleagues the opportunity to produce high-quality, impactful research have longevity. We take the view that a sustainable future will only be achieved if these issues of equality, diversity and inclusion are at the forefront of our thinking. In fact, awareness of EDI has informed all aspects of our practice from re-thinking new research-informed curricula to recruiting, developing and managing colleagues and in how we think about the membership of research groups and the academic committees supporting research. In line with the University mission of establishing a collegium and a research community, the UoA has taken clear steps in embedding a culture of openness, support and opportunity in relation to EDI so that voices from protected groups are heard.

As with most similar departments/UoAs, the ratio of male-to-female academic staff and research students remains disproportionately high. The School is working actively to address this issue as part of the University's EDI policy (e.g. recent appointments, after the census date, of Yaroson in Logistics and Natsheh in Cybersecurity to strengthen research and provision in these areas). A number of steps have been taken since REF2014 to address EDI, especially in relation to female and senior staff members e.g. Ranasinghe has been appointed to the University Research Committee. The UoA has led events at the annual BSW (in 2017 and 2018) focusing on the Role of Women in Science and Society. The outcome is that we are making progress in addressing the historic barriers to academic career progression for women. The School has always had an international profile (with staff from 11 countries during the census period); currently 64% of its staff have an international background.

The relatively modest size of the UoA makes it difficult for us to evidence a similar approach to that used for gender with respect to other protected characteristics. Colleagues within the UoA must complete appropriate training (e.g. Equality and Diversity, Mental Health Awareness) and are encouraged to join EDI-related networks (e.g. LHU's Women's Network) and participate in data capturing exercises (e.g. Stress Audit, Mental Health Survey) that help in improving our approach to EDI issues. The UoA is, nevertheless, mindful of the need to be alert to complacency. To ensure we work according to best practice, the UoA has an EDI lead (currently Anicho) who has a formal responsibility for ensuring open dialogue (through provision of information and

through a dedicated online newsletter facilitating the circulation of relevant research), monitoring our practice and progress and reporting to committees on EDI issues.

3. Income, infrastructure and facilities

The UoA supports research through a set of linked funding mechanisms including: direct allocation of QR income from the University to the School; the workload-allocation allowing for $\frac{1}{3}$ time-allocation for Research and Scholarship for all staff; the development and maintenance of research infrastructure and equipment; support for research-related activities (e.g. conference attendance and other marginal costs); and bursaries for PGR students. While our grant income is currently modest, the UoA also benefits from a reallocation of overhead/indirect income from grant and other awards; $\frac{2}{3}$ of all such income is returned to the School for discretionary spending on supporting research.

As in the research strategy, increasing research income is a priority and important for maintaining a vibrant research culture. Hence researchers are expected to apply for external funds within their research plans and this forms part of the Performance Review process. All colleagues have applied for grants during this review period and we have had some modest successes, which has helped us to identify key areas of strength described in this statement, namely, mathematical computing, and HAPS research. On the basis of applications in progress, we estimate a steady state of at least £250k income per-year from 2021 composed e.g. of *New Investigator Awards* (from Anicho and Dev), and KTP awards (Buckley jointly with his colleagues from AskEddi, and Barclays). Given the age profile of our staff, this is sustainable subject to succession planning. Strengthened support from the University includes significantly increased investment in the School's equipment and laboratory facilities and in digital library research resources, and increased research support via the creation of a Central Research Support and Development Office/Research Facilitator.

The UoA benefited from the University's over £14 million investment (funded entirely from its own resources without borrowing) in the expansion of its Science-based (including Sports Science) facilities, which opened in 2016. The UoA utilises many of these state-of-the-art facilities, e.g. a double-height robotics lab to aid the building and testing of drones (HAPS project). There is a synergy of interdisciplinary collaborative research and knowledge-exchange between CS&I and Sports colleagues relating to the use of AI in the field of sports rehabilitation – particularly prosthetics and robotic-assisted technology, which is helping the University to engage with 'The Ageing Society', a key challenge of its Industrial Strategy. Nagar's PhD student has been using the functional near-infrared spectroscopy (fNIRS) available in the Psychology Labs for work that aims at computationally modelling memory-performance (joint work with the ICMR). Additionally,

the Unit has spent in excess of £80,000 per-annum on research equipment, the details of which are outlined below.

In 2014, the School created the **Vision research laboratory**, a dedicated dark room used for psychophysics studies. This dark room is used by Foulkes in his research on optic flow parsing in the periphery, which has resulted in publications on Visual Perception (e.g. Perception, 2015). Ongoing projects include investigating whether there is a bias in optical flow processing to those who suffer from migraines.

The **robotics laboratory** is a 78m² facility along with an adjacent **electronic engineering laboratory** (60m²). Robotics research is significantly growing and there are extensive research collaborations with institutions such as the Bristol Robotics Laboratory (BRL) and the Morph Lab (Imperial College). The laboratory houses a range of equipment, including manufacturing equipment (e.g. DWS XFAB2000 3D printer) and a wide range of robotics equipment, including:

- A 7-degrees-of-freedom industrial-grade robotic arm (Xarm-7) having human-like flexibility, and various SDK, ROS support, and access to multiple developmental platforms.
- A Visuotactile sensor and a Low-cost GelSight-like Sensor developed in-house (Ranasinghe and Abad) using a wide range of equipment and materials (e.g. WiFi endoscope camera, cosmetic Silicone sponges, Shore A hardness meter). This GelSight sensor uses UV marking that facilitates use as a high-resolution visuotactile sensor being used for texture recognition and tactile forces analysis.
- Ranasinghe developed a tactile actuator through the purchase of a variety of materials and equipment, including Dot Braille Cells, and is further developing fingertip tactile displays for haptic gloves that can be used in Virtual Reality applications and tele-robotic applications.
- An eMotimo TB3 pan and tilt unit and Dynamic Perception Stage R motion control unit allowing accurate positioning of a sound source under computer control was used in Robot Audition research (Baxendale and Secco) in collaboration with BRL, and this equipment made it possible to carry out a wide range of experiments underpinning research into automatic calibration of sound source localisation using multiple adaptive filter models of the cerebellum. This was also underpinned by investment in MatLab toolboxes (site-licence). In 2019 a 48-node SpiNNaker machine was purchased which is being used to investigate a neuromorphic approach to this research. The same system, along with Miro-e robots, facilitates related research into brain-based robotics, again in collaboration with BRL (and by association, indirectly with the Human Brain Project).
- A set of wearable and biomedical sensors, such as transducers for monitoring physiological parameters, body temperature, breathing rate, were used to design a portable platform and was presented to the international scientific community (Secco and Maereg). Fibre optics and optical amplifiers were used to develop a bio-mimetic finger which was embedded within the

design of a robotic finger (Secco and Maereg). A Virtual Reality (VR) headset, such as Oculus Rift was combined with vibrotactile actuators and marker-less motion capture system (Leap Motion) to design a wearable haptic system integrated with VR environmental exploration (Secco and Maereg). Robotic devices, such as the Open Bionic Robotic hand was employed to develop novel graphical user interfaces for robotic and prosthetic applications (Secco). Brain Computer Interfaces such as the Emotiv Helmet Headset were used to explore the possibility of controlling prosthetics through EEG signals (Secco and Ranasinghe). Other robotic systems include an Aldebaran Nao, Summit XL rover robot and PadBot P3 Telepresence Robot.

Our acquisition of equipment for **spatial computing research** includes a VICON marker-based motion capture system, MarvelMind navigation system, Leap Motion cameras, Oculus Quests, Windows MR headsets, HTC Vive headsets, Hololens 1 & 2 devices, Meta AR headset, Daqri AR headset, Pico Neo Eye VR eye tracking headset, Fove VR eye tracking headset, XTAL Ultra wide FOV VR headset, PiMax Ultra wide FOV headset, ZapBox AR adapters, Ps3 eye cameras, Intel Realsense D435 cameras, Tobii eye tracker, StereoLabs ZED mini AR camera, Shockwave VR Haptic Suit and full body tracker, Novint Falcon, MicroDrives Development Haptics Kit. This is a key area of research in the School, which has also been commissioned by the University to develop a new **Simulation Lab** for Research and Teaching. This lab has the potential to bring disciplines together including across STEM and arts, humanities and social sciences (e.g. Social Scientist working with Computer Scientist to simulate the needs of a blind person; a geographer to simulate a remote field trip, etc.) for experiential and immersive learning.

The **HAPS research** is an ambitious project that the Unit will continue to develop as one of its niche areas. The Unit is part of the HAPS Alliance (hapsalliance.org) – only the second UK University to be so. The research utilises equipment and accessories in developing unmanned aerial systems and related hardware/software. These equipment and accessories, which range from Taranis remote controls (mode 2 transmitters/receivers) to carbon fibre materials and V2 LiPO chargers, were procured for designing low-cost solar-powered Low Altitude Platforms (LAPs) for experimental/test purposes. The purpose of the HAPS research is to develop competencies around solar-powered, fixed-wing unmanned aerial vehicles (UAV) in order to investigate challenges implementing such vehicles for Stratospheric missions. In addition to the acquisition of UAV parts and accessories, the School has also invested in training/engaging unmanned aerial pilots who are essential resources for carrying out simulations and experiments involving unmanned aerial vehicles. The HAPS team has developed an in-house simulator and has established a partnership with Avealto Plc and the CTO to explore practical/commercial applications of this simulator.

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

All academics have evidence of invited/plenary lectures, membership of journal editorial boards, peer-review work, and national/international research collaborations. An illustrative (and far from exhaustive) list of particularly notable contributions and esteem indicators are summarised below **(all data pertain to the assessment period)**.

The vitality of the research environment is demonstrated by the number of international academic visitors. The UoA runs an active seminar series that invites eminent, high-profile researchers from around the world to describe their ground-breaking work to an audience of School-wide students and academics. Over the assessment period this has attracted a range of external speakers including international experts in the research areas for which the School is well-known. Some recent visitors include Professors Willy A. Hereman, (Colorado School of Mines, USA); Ashok Deshpande (University of California Berkeley, USA) and Drs Xia (Senior Research Scientist at Ericsson USA), Timofeeva (University of Warwick), Konstantinou-Rizos (Yaroslavl Demidov State University, Russia), Kokkinaki (Aristotle University of Thessaloniki, Greece), and Bansal (South Asian University, India), to list a few.

Visiting/Adjunct Professors are appointed as mentors, to support joint-publications and bids as well as supervising PGRs. These have included: Professors Konar (leading researcher in AI and Robotics); Giblin (OBE) (leading Mathematician with expertise in Singularity theory and its applications to geometry and computer vision, computer graphics); Subramanian (leading Theoretical Computer Scientist; expert in P-System); Deep (expert in Natural Computing); Thomas (Grammatical Inference); Arumugam (leading Graph Theorist); and Taylor (leading expert in Industrial Electronics). These visiting colleagues although not part of this REF submission hold fractional (0.11)/honorary contracts and work in close collaboration with the team.

The School has been engaging with **Nuffield Trust-funded Sixth-Form students** (an average 2 per-annum) who reside in the School gaining research and HE experience; and with other European Institutions, such as the École Nationale Supérieure d'Informatique pour l'Industrie et l'Entreprise, ENSIIE (Evry, France), the Institut National des Sciences Appliquées, INSA (Rouen, France), the Haute École HELMo (Liège, Belgium). Reid took 'Hope Bus with computers on-board' to local schools for the week of '**UK hour of Code**' programme. As part of BSW we celebrate a dedicated School Research Day, which reflects a broader commitment to the public understanding of science; and colleagues inform pupils from local schools and colleges, together with other members of the general public, about our facilities and research findings. During every BSW we offer a programme of talks from colleagues, PGRs and external speakers, e.g. in 2016 Dr Nikolay Andreev (Steklov Institute of Mathematics, Russia) delivered a talk on popular maths highlighting the applications and benefits of the discipline in the real-world.

Unit-level environment template (REF5b)

International links and networks: Formal research collaboration agreements are in effect with various institutions e.g. the Yaroslavl Demidov State University; Madras Christian College; Christ University in Bangalore; IITs; and SAU. There is also active collaboration with researchers from Christian Medical College in Vellore (India), Jadavpur University, the University of Madras, the Work Design Innovation Group at IBM (USA); De La Salle University in the Philippines (under the auspices of British Council TNE funding); Bristol Robotics Laboratory (since 2014, resulting in ongoing research into brain-based robotics); the University of Hamburg; and the universities of Moratuwa and Sri Jayewardanapura in Sri Lanka.

Nagar was invited (December 2013–February 2014) by the Government of India, **fully funded by the Department of Science and Technology (DST)**, for a **three-month sabbatical** to deliver staff-development sessions and PGR training at IIT Roorkee including a three-week course on Membrane Computing plus a series of three specialist lectures on his expertise in Complementary Bivariational Principles and their applications. The visit helped to develop new collaborations between the Indian institutions (e.g. Jadavpur University and SAU) and the School.

Awards and honours: Mc Auley was awarded ‘model of the month’ by the European Bioinformatics institute, Cambridge, October 2013 for ‘A whole-body mathematical model of cholesterol metabolism and its age-associated dysregulation’. Ranasinghe won the Franklin Taylor Memorial Award for the best paper at IEEE SMC 2013. Nagar won the best paper award in Fuzz-IEEE 2017.

Staff	Participation in review, advisory, funding and policy bodies:
Nagar; Naguib; Foulkes; Reid; Baxendale	Reviewers for UAE National Research Foundation (Emirates).
Naguib	FP7 “Virtual Physiological Human and Personal Health Systems”, 2014-2017; Horizon 2020 “AI for Health Imaging”, 2019-2020; CORONAVIRUS-2020-2B “Medical Technologies, Digital tools and AI Analytics to Improve Surveillance and Care at High Technology Readiness Levels”, 2020.
Foulkes	Member, Parliamentary and Scientific Committee (May 2020).
Nagar	AHRC Technical Peer-Review College (served two terms). Expert Reviewer for EPSRC, UKIERI-DST;
Naguib, Baxendale	Expert Reviewer for the UAE Ministry of Education Collaborative Research Programme Grant on ‘Engineering and Technology’ and ‘Medical and Health Sciences’
Nagar; Naguib; Foulkes	Qatar Research Foundation
Reeve	Expert Reviewer for Umm AlQura University (Saudi Arabia)

All members participate in **peer-review activities for top-quality Journals**, in many cases as regular reviewers. Xenitidis was awarded '**Outstanding Reviewer**' by Physica Scripta in 2018. some further examples include:

Staff	Reviewer for Journals (some examples)
Foulkes	Journal of Vision; Journal of Physics; New Journal of Physics; Nature Communications; Perception.
Reeve	Journal of Mechanics in Medicine and Biology; Computational and Mathematical Methods in Medicine
Naguib, Nagar	IEEE Access
Secco, Nagar	IEEE Transactions: on Biomedical Engineering; on Neural Networks and Learning Systems; IEEE Robotics and Automation Letters;
Secco	International Journal of Product Development.
Xenitidis	Physica D; Journal of Physics A: Mathematical and Theoretical; Physics Letters A; Applied Mathematics Letters; Symmetries, Integrability and Geometry: Methods and Applications; Proceedings of Royal Society A.
Ranasinghe	IEEE Transactions: on SMC; on Haptics.
Reid	Neurocomputing; PloS One; IEEE Sensors.
Garron	Physical Review D.
Nagar	IEEE Transactions on Fuzzy Systems; IEEE Transactions on Emerging Topics in Computational Intelligence; Mathematical Reviews; Chaos, Solitons & Fractals.

Staff	Keynote (K) address / invited (I) talks / Other (O)
Naguib	K: Annual IEEE International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, Manila, Philippines; 6 th International Conference on Developments in eSystems Engineering, December 2013 (UAE); IEEE International Conference on Advances in Science and Engineering Technology (ASET 2020), Dubai.
Anicho	I: Invited HAPS presentation and Panel Discussion Membership, Spectrum Management Conference 2019, organised by the CTO.
Xenitidis	I: Workshop on Hamiltonian Methods and Algebraic Structures for Integrable Systems (2016, 2019), Sanya, China, International Congress on Industrial and Applied Mathematics 2019, Valencia, Spain;

	K: International Webinar Series on Recent Advancements in Discrete Mathematics June 2020, Stella Maris College (India).
Reid	O: Radio 4 broadcast (Four Thought) on the Ethics of AI (2018); K: On AI and Ethics at International Festival of Business (2016); Why AI should be on the School Curriculum), Anfield Stadium (2019).
Ranasinghe	K: in ICSISCET-2020 at MITS (Gwalior, India);
Nagar	K: SocProS-2014 (India); the Kaleidoscope of Computation in Biology organised by the Sam Higginbottom Institute of Agriculture, Technology and Sciences (India); International Conference on Recent Advances in Mathematics and their Applications (ICRAMTA-2016), University of Rajasthan (India).

Staff	Journal Editorial role: Editor-in-Chief (EiC); Guest Editor (GE); Reviewer Editor (RE); Editorial Board Member (EBM); Topic Editor (TE)
Naguib	EBM: International Journal of Networking and Virtual Organisations;
Xenitidis	TE: Symmetry
Ranasinghe	RE: Frontiers GE: Frontiers in Virtual Reality
Nagar	EiC: Springer's Algorithms for Intelligent Systems (AIS) - jointly started by: Bansal, Deep, Nagar; ISSN: 2524-7565; EiC: International Journal of Artificial Intelligence and Soft Computing; Inderscience (IJAISSC); EBM: Journal of Universal Computer Science. EBM: <i>Ganita Sandesh</i> (Indian Mathematics Journal). GE: Innovations in Systems and Software Engineering, Springer (a NASA Journal). GE: Swarm and Evolutionary Computation. GE: International Journal of System Assurance Engineering and Management.

Editors of International conference Proceedings: Nagar: Springer's Advances in Intelligent and Soft Computing published proceedings of the International Conference on Soft Computing for Problem Solving (SocProS) series (December 2013-present); Naguib: Associate Editor for Healthcare Information Systems and Telemedicine, IEEE-EMBS International Annual Conference, Chicago, USA (2014); and Healthcare Systems, Pacific Asia Conference on Information Systems, Chiayi, Taiwan; Secco: Guest Editor of Special Issue on Green Radio Networks, Sensors, MDPI (2020); Associate Editor for IEEE/RSJ International Conference on Intelligent Robots and Systems (2018-present); and International Conference on Robotics and Automation (Secco, 2019-present).

Six International, high-profile conferences and symposia were organised or hosted by the School; all staff acted as chairpersons of several conferences and workshops, and members of the organising committees. Nagar started, with support from colleagues in India, the Soft Computing for Problem Solving international conference series (SocProS); and the 9th version (SocProS-2019) took place at LHU. LHU co-hosted the SIAM-IMA Student Chapter's inaugural ECR Conference in 2019.

Adjunct/Visiting Professor: Nagar: IIT Roorkee, Madras, South Asian, and Jadavpur Universities (India); Naguib: De La Salle University (Philippine); Dai Nam University (Vietnam).

Staff	External PhD Examiners
Naguib	Hull (2014, 2016); Coventry (2017); Deakin (2018); De La Salle University, Philippines (various since 2014).
Xenitidis	UCL (2018); Essex (2020).
Garron	Clermont-Ferrand (2018).
Nagar	Bangor (2017); Brunel (2019); Leicester (2019); Indian institutions such as Banaras Hindu University, Universities of Madras and Gujarat, IITMs, IITs; IISc Bangalore.

Knowledge transfer, collaboration and contribution to industry, economy and society are an important part of our research activities. The University's educational philosophy is based on the quest for *Truth, Beauty and Goodness*. Within this distinctive context the School has a strong reputation for engaging with industries on a local, national, and international level, with outreach activities and direct engagement with a wide cross-section of the public and a wide and diverse network of collaborations with other institutions (academic, industrial, and public sector) across the UK, Europe and the World. The UoA has many formal and informal collaborative links with other academic institutions such as **Radox (Belfast)**, **Sensorcity (Liverpool)**, **Royal Liverpool Broadgreen University Hospitals NHS Trust** (eHealth project), amongst others described earlier in this statement.

It is critically important to note that we are not simply providing 'Computer Science, Mathematics, and Engineering' input to other projects, but we are a primary partner, pushing forward the boundaries into other disciplines and re-shaping the international research agenda in the light of new inter-disciplinary synergies; some examples include:

- Nagar's work with **ICMR and Christian Medical College Vellore** on Electrophysiological studies on Acetylcholine-Dopamine interaction on memory and learning; and Automatic leukocyte nucleus segmentation by intuitionistic fuzzy divergence;
- Secco's work on VR applications combined with Haptics (with **Facebook**);

Unit-level environment template (REF5b)

- Secco has also collaborated with world-leading research centres in bionics/prosthetics; he has been investigating and designing a multiple-sensor capture system for human-hand motion analysis; looking at novel human-robot interface development for prosthetics;
- Ranasinghe investigated Ambient Assistive Living (AAL); Wearable-Sensors, Robotic Rehabilitation, and VR for the simulation of Human-Robot Interaction; jointly with Secco, investigating architecture of humans' perception in haptic-based communication;
- Anicho and Nagar are developing HAPS solutions for telemedicine and broadband for rural areas (with **Avealto**);
- Garron's HPC work with **Nvidia** and **CERN**;
- Buckley has been developing an InnovateUK KTP proposal with **AskEddi** on Open-Data Project (to benchmark of multiple datasets, humanise data, and use the nudge principles to deliver predictive-analytics for the education industry);
- Buckley's work on Secret-Sharing and Visual-Cryptography with **Tento Plc.** is an example of successful translation of research into practice.

One of our PGR students was offered a fully paid (\$9000/month) internship for 6-months with Oculus in the USA demonstrating the calibre and quality of students we recruit. Another doctoral students was employed by IBM in California on a Future-workspaces/VR project which was related to his PhD; this student is now a senior scientist at Google Cloud AI and Industry Solutions.

Nagar is a member of the **Jisc research strategy forum** (since December 2018). Nagar, Xenitidis, and Foulkes are **Fellows of the Institute of Mathematics and its Applications (FIMA)**. Nagar has been serving as an adviser to develop **Bethlehem University's** Science and Engineering Research and helped **Stella Maris College (Chennai)** develop their Research in Data Science provision; Nagar also served as an adviser for **Banasthali University (India)** for development of their Research; and as a consultant produced software and reports (in Hindi/Sanskrit language) on 'Applications of Machine Learning for Defence Industry' for the **Defence Research and Development Organisation (DRDO) India**. Nagar actively contributes, as a **life-member**, to the **Indian Mathematical Society: Ganita Parishad**.

Jointly with **VIT Bhopal University (India)**, a **patent has been filed** (June 2020; Nagar et al.) for a USB data-blocker that camouflages the OS information of the host-machine, preventing malware attacks. The MoU with the **CTO** (February 2020); and membership of the **HAPS-Alliance** will facilitate cooperation for HAPS project development, research and training.