

<b>Institution: University of Lincoln</b>
<b>Unit of Assessment: UOA11: Computer Science and Informatics</b>
<p><b>1. Unit context and structure, research and impact strategy</b></p> <p><b>1.1 Context and Structure</b></p> <p>UoA11 includes the School of Computer Science (SoCS) and elements of the Lincoln Institute of Agrifood Technology (LIAT). SoCS has the strategic aim to curate and advance the field of computer science from both theoretical and application points of view, with a particular focus on cutting-edge research on robotics and agri-food, medical imaging and computer vision, human-centric interaction and interactive technologies, empowered by machine learning and artificial intelligence. The Global Centre of Excellence in Agri-robotics research (Lincoln Agri-Robotics, LAR) is a major new research Centre, funded by the UK Government's Expanding Excellence in England (E3) Fund through Research England with £6.3m in 2019 for a three year period. It is a joint centre that has been spun out of the complementary research excellence of the Lincoln Centre for Autonomous Systems Research (L-CAS) of SoCS and LIAT.</p> <p>UoA11 fully embraces the vision put forward in the University of Lincoln (UoL) Strategic Plan 2016-21: "We will work closely with our communities to ensure valuable impact from our research to make a meaningful contribution to our world". Accordingly, our research is both global-to-local (bringing worldwide significant topics into our research agenda), as well as local-to-global (bringing local research issues to national and international levels), through collaborations with relevant stakeholders. It primarily focuses on Grand Challenges identified by the UKRI, including agri-robotics and smart agriculture, healthcare and precision medicine, artificial intelligence, also keeping the human at the centre of human computer interaction and design.</p> <p>The University's Strategic Plan emphasises the academic freedom of individual researchers to choose their field of research but encourages the organisation of research into focused areas. In SoCs, researchers are principally organized into four research groupings: Lincoln Centre for Autonomous Systems (L-CAS), Laboratory of Vision Engineering (LoVE), Machine Learning Group (mlearn) and Interactive Technologies Lab (intLab). Within LIAT, the LAR group pools the UoA11-relevant expertise in agri-robotics.</p> <p>L-CAS, a member of the UKRAS network of leading robotics labs and led by Duckett, specialises in perception, learning, decision-making and control for autonomous systems, such as robots, and the integration of these capabilities in applications including agri-food (Esfahani, Cielniak, Fox, Millard, Hanheide, Duckett), healthcare and social interaction (Baxter, Cuayáhuil), intelligent transportation (Yue, Duckett), nuclear robotics (Esfahani, Hanheide) and service robotics (Bellotto, Hanheide). It collaborates closely with LIAT, the National Centre for Food Manufacturing (NCFM) and Lincoln Institute of Health, around interdisciplinary research in applications of robotics and AI to the food industry and health, respectively. L-CAS builds complete autonomous systems, including mobile robotics and robotic manipulation, particularly focusing on long-term autonomy.</p> <p>LoVE, led by Allinson (who is submitted under UoA09), has a unique capability within the UK research landscape - namely the expertise and resources to develop new imaging modalities and systems from sensor design and provision (Allinson) to medical image analysis/computer-aided detection and quantification of abnormalities in different organs, including the eyes (Hunter, Al-Diri), the brain/lungs/colon/esophagus (Ye, Lambrou, Bidaut who is submitted under UoA3, Brown) and breast (Janan), to assist with the full clinical workflow and personal long-term healthcare management (Ye, Lambrou), as well as the general computer vision area, e.g. agri-food, animal tracking and behaviour analysis (Ye, Duan, Al-Diri, Zhang, Brown). LoVE collaborates with major hospitals across the NHS and abroad, leading national and commercial research facilities and industries.</p>

Mlearn, led by Kollias, in collaboration with Parsons, undertakes innovative research and development in the field of machine learning and artificial intelligence. The aim is the creation of machines with intelligent behavior (Cutsuridis), which are able to reason, predict and adapt to changing environments, assisting humans in both their everyday and professional lives. The related activities focus on big data and multimedia information analysis, abnormality detection in industrial, agri-food, social environments and healthcare (Yu), optimization (Jiang), all relying on and contributing to the University's strengths in agri-food, computer vision, culture and creativity.

IntLab specializes in both theoretical and applied research around user engagement and social impact with interactive, social and mobile digital systems. IntLab's work is cross-disciplinary, largely underpinned by experience-centred Human Computer Interaction (HCI) design (Holopainen, Dickinson, Maior). IntLab focuses on applications (Bachour, Hicks) including entertainment, games, cultural heritage and citizen engagement.

LAR brings together large expertise in robotics, artificial intelligence and agriculture (Sklar, who is Research Director, Bosilj). Its research foci encompass both foundations and real-world applications, including autonomous agri-robots that can efficiently tend, harvest and quality-control high-value crops with reduced human intervention, improving agricultural productivity and environmental sustainability, and addressing the demands of a growing population.

## **1.2 Achievement of Research Strategy**

*The research strategy of UoA11 in REF 2014 was to pursue quality research spanning theoretical studies to transformative applications in both scientific and commercial/social domains, whilst remaining open to developments and needs across the existing disciplines and beyond.*

This strategy has been the basis for our developments in the current period. In addition, UoA11 has significantly expanded its research activity over the census period, reflecting growth and recruitment. In particular, there are 28.8 FTE academic staff returned in REF 2021, compared to 14.5 in REF2014 (98.6% increase). The research income of SoCS was £10.27m over the census period, compared to £1.85 m in REF 2014 (455% increase). There were 27 Ph.D completions, compared to 12 in REF 2014 (125% increase). In particular, UoA11 has kept developing on all fronts since its submission to REF2014, being proactive to new Challenges and emerging disciplines. A new area, Machine Learning and Data Science (with the mlearn Group), was added to existing School's portfolio, by recruiting five new academics at both established and early career levels. In parallel, new staff were also appointed to supplement and strengthen the other research areas (3 new academics in L-CAS, 3 in LoVE and 3 in intLab).

Since the economy of Greater Lincolnshire region is heavily weighted towards agri-food production (primary agriculture and food manufacturing), support for the agri-food sector has been a main UoA11 strategic priority. Since 2016 when LIAT was established, L-CAS has provided LIAT with advanced and basic robotics expertise to handle key agri-food challenges, which led to creation of LAR. L-CAS, in collaboration with Universities of Cambridge and East Anglia created the world's first Centre for Doctoral Training (CDT) in agri-food robotics which provides training for 50 doctoral students, supported by major industry partners. Moreover:

L-CAS evolved to gain 8 major EU-funded consortium awards (Horizon 2020 and FP7 projects), as well as many EPSRC, BBSRC and Innovate UK projects in agri-robotics. It has expanded to possess complementary expertise covering all major computer science components required to build complete long-term autonomous systems, including mobile robotics and robotic manipulation, in dynamic real-world environments.

LoVE managed to advance proton imaging and develop PRaVDA, which is one of the two operational proton imaging systems in the world. It also produced the first direct comparison of calibrated x-ray and proton CT in biological samples, and 5 published - 4 awarded patents on

system design concepts and CT reconstruction methods. LoVE coordinated the REVAMMAD EU Marie Curie Initial Training Network program aiming at combatting chronic medical conditions including diabetes and hypertension through retinal imaging, and also successfully developed several novel applications related to healthcare (computer-aided diagnosis of abnormalities using multimodality medical images) and computer vision (in the areas of agri-food, animal tracking and behaviour analysis) from many funded projects, including EPSRC, FP7, BBSRC, CRUK, NC3Rs.

IntLab focused its research on design, development and evaluation of interactive technologies for human use in social contexts, engaging diverse stakeholders (students, citizens, associations, public authorities and researchers). It established quality of life and democracy as its central concerns, aiming to promote a more equitable society through, and with, technology.

Mlearn has produced outstanding research results, developing novel deep neural networks architectures and applying them to significant sectors, including anomaly prediction in nuclear power plants, as well as in gas turbines (Siemens), plant growth prediction (agricultural), food supply chain safety and reduction of energy consumption, neurodegenerative disease diagnosis through medical imaging, cultural content analysis and creative reuse. High quality papers appeared in NeurIPS, AAAI, NCAA, IJCV, IEEE Transactions and other journals.

### **1.3 Achievement of Impact Strategy**

*The impact strategy set up in REF 2014 by the existing Laboratories focused on: (i) expanding in real-world applications and establishing stronger links to national and global industries in agri-food technology; (ii) providing clinically-approved software platforms and contributing to disease diagnosis and screening; (iii) addressing societal and personal good.*

The achieved impact strategy has mainly focused on: autonomous solutions and AI-enabled agri-food technology; long-term autonomy for robots in-the-wild; personalised healthcare and people's well-being. In particular:

L-CAS produced robotic solutions throughout the food supply chain "from farm to fork", underpinning the UoA11 Impact Case Study on "Autonomous Systems for Agriculture" through its long-term autonomous navigation solutions. It created robotic facilities on three sites, including a new robotics centre at UoL's agriculture campus at Riseholme, the NCFM at Holbeach and laboratories in the Isaac Newton Building. L-CAS is part of the National Centre for Nuclear Robotics EPSRC RAI Hub and partners with industry partners through various innovate UK and ISCF projects, delivering high-TRL solutions into the UK markets. It deployed systems in real-world settings, including a specialist mobile robot at the Natural History Museum, and fielded the highest ranked UK team in the RoboCup Worldcup competition 2017. It also developed integrated Active Assisted Living solutions for the elderly people at home and in institutional care in the UK and Europe.

LoVE installed, for the first time, a proton CT system in the NHS Christie Proton Beam Therapy Centre, Manchester, to form part of the national research infrastructure, moving closer to commercialisation and worldwide adoption for the benefit of cancer patients. It conducted a major longitudinal study of hundreds of participants to provide a reference set to monitor the earliest signs of retinal change as a disease indicator. It also set up quantification of focal breast density as a reliable imaging risk biomarker, developed systems for ultrasound fetal measurement, detection and quantification of brain tumour in MRI, and personalized health monitoring systems.

IntLab collaborated with Royal Air Force, contributing to the RAF100 public engagement campaign with a freely downloadable Augmented Reality app for Android and iOS devices; with Frequency Digital Culture Festival, since 2017; with the Finnish Museum of Games, contributing to game archival activities; with the UoL School of Psychology, in the development of the 'Eyelander' game for children with homonymous visual field loss.

Mlearn developed strong collaborations with industrial companies and end-users, testing research developments in real-life environments. The UoA11 impact cases 'AI-enabled safe and efficient food supply chain' is based on R&D produced by Mlearn and LoVE academics in collaboration with LAR/LIAT, NCFM and industrial users, including Tesco, IMS, OAL.

#### **1.4 Research Strategy for the next 5 years**

SoCS research has historically contributed to the fields of Computer Vision / Medical Informatics, Robotics / Autonomous Systems and HCI / Games Computing. During the current REF period, the School has also expanded its establishment in the field of Machine Learning, which spans and assists the existing research fields. SoCS' vision for the future builds upon current research, bringing in new and exciting research, both at national and international level, through our close collaborations with European and Chinese academia and industries. The research strategy targets expansion of expertise in each of the four research groups, whilst monitoring and being proactive towards future scientific and technological innovations.

The research strategy of LAR is based on the vision to become the UK HEI's first significant and coherent basic research group that secures the delivery of Robotics, Autonomy and Artificial Intelligence (RAAI) across the agri-food sector. The aim is to provide the UK with a unique research pipeline flowing from concept inception through to application, thus providing a base to consolidate this new discipline. Expansion will be around three specific themes, i.e., Agri-food Robotics, AI and Machine Learning for Agri-food systems and navigation and autonomy in field environments.

Both SoCS and LAR plan the expansion and focus of their research efforts to meet the most challenging problems in the respective fields, including:

- *Advancement of autonomous robotic systems*; generating robots and systems that move, operate, or offer services in an autonomous way is an ongoing research challenge in the robotics area. L-CAS will extend their innovative, theoretical and experimental research in the area, and in collaboration with LAR and LIAT, they will fully exploit the potential of RAAI in agri-food systems, by fusing robotics and AI expertise with that from agriculture, food technology, engineering and supply chain analysis.
- *Precision medicine & personalized healthcare monitoring and prescriptive systems*; LoVE targets the next generation instrument for installation on the treatment gantry in state-of-the-art delivery systems. By further analysis and understanding of medical needs and workflows, it targets to provide clinical-quality imagery in real time and assist in selecting optimal adaptive treatments. LoVE will continue to focus on image reconstruction, AI-empowered computer-aided abnormality early detection, segmentation and quantification for trusted medical diagnosis and prognosis.
- *Generation of intelligent human assistants*; SoCS will contribute towards the new generation of intelligent human assistants, based on robots and other physical or virtual systems able to sense and adapt to specific environments, to understand human behaviours and needs, to reason and effectively assist humans, including elderly and other people in need in their homes, or other social environments.
- *Interpretable deep learning and generation of AI-based industrial and social systems*; Mlearn, in collaboration with the recently appointed Global Professor (Parsons), will extend high level research in machine and deep learning, reasoning, knowledge adaptation and explainable AI, tackling the Challenge of 3<sup>rd</sup> Wave AI and its applications, particularly linked to big data analysis, mobile robotics, RAAI, healthcare, social and creative environments.

All of our key areas of research fit with UKRI and other major funders' priority areas, aligning especially well with current grand challenges.

Our approach will be to demonstrate excellence and inspire new generations of researchers into the sectors, whilst expanding our human resources, attracting and supporting early career researchers (ECRs), who are UoA11's strength towards sustaining and contributing to emerging and evolving disciplines.



In this framework we will target a variety of aims:

- i. To continue PGR expansion, by doubling our PGR and particularly our Ph.D. students; this will provide a clear add-on to the richness and diversity of our research. Current Ph.D. completions (27 vs 12 in former period) are expected to surpass 45 in the forthcoming period.
- ii. To gain new CDTs in the above-mentioned fields. The acquired CDT is our first step towards this goal.
- iii. To submit 45 FTE in the next period (an increase of about 150%), especially hiring ECRs, who will be the driving force for novel research and impact generation.
- iv. To increase SoCS research income from £10.27m currently to more than £15m; generating a similar income by LAR.

Furthermore, it is well known that ethical issues can be met in all these targets and require careful and expert consideration. Both SoCS and LAR will devote specific manpower to consider ethical and democratic issues related to development and use of new AI technologies (transparency, trust, fairness, responsibility).

### **1.5 Impact Strategy for the next 5 years**

In line with UoL's research strategy, UoA11 considers research with impact, as well as industrial and public engagement with research, central points of its mission. Impact is viewed to include measurable economic and health benefits, development of solutions to real world problems, changing perceptions and attitudes in non-academic audiences.

There is a focus of UoA11 on RAAI applications that are prioritised in the Industrial Strategy Grand Challenges (Artificial Intelligence and Data) and can have a transformational impact on agri-food labour and non-labour productivity. RAAI technologies provide a novel and timely opportunity to step change agricultural productivity, whilst reducing environmental impact. The related agri-food industry is immense, both at national and international level, with an impact to increase sector productivity, reduce food waste, optimise supply chains, increase consumer safety via optimised supply chains, new skills and export market opportunities for RAAI companies.

L-CAS prepared, in collaboration with EPSRC UK Robotics and Autonomous Systems Network, a White Paper on the future of agricultural robotics, influencing research funders, especially concerning the UK government's recent £90m Industrial Challenge Fund Investment ("Transforming Food Production: from Farm to Fork"). Generating similar contributions in all related fields is a main target in UoA11 impact strategy. L-CAS and LAR joint impact strategy is to have a leading role in the agri-robotics field and developments. This is expected to increase the generated income and to improve sector's productivity, by involving new processes and technologies in agri-food prediction, management and production and by spreading them through nationwide network of collaborators and companies, including spin-outs.

LoVE's major focus is on providing complete solutions that fit with clinical workflows, cost implications and regulatory needs, including various imaging modalities and protocols, in collaboration with major hospitals across the NHS and abroad. The overall impact goal in the healthcare research is to ultimately bring positive change and improvements to existing medical practice; all studies will be driven by clinical needs, with very close involvement of clinical and other professionals. Healthcare, especially early disease detection, diagnosis and treatment selection, will be a main topic in LoVE's strategy, involving the large network of collaborating central and local NHS healthcare centres and units, so as to achieve high impact of developed technologies.

Mlearn focuses on developing novel ML/AI technologies. It will extend its current developments on agricultural data analysis; contribute to the Confederation of Laboratories for AI Research in Europe (CLAIRE) Network on Trustworthy and Human-Centred AI; further extend its R&D

collaboration with the 'Europeana' Digital Library on semantic enrichment and creative re-use of data by museums, libraries, archives, audiovisual archives and creative industries.

IntLab's approach is theory-driven and practice-led, with main focus on the user, to design interfaces to fit human requirements, needs and values at the micro-level (human-factor), the meso-level (social actor) and the macro-level (political actor). It experiments with public activism, active ageing, media analysis, education/training and gameplay; older and younger citizens with different skills; various computational artefacts with a distinctive focus on Virtual and Augmented Reality and game engines. Impact will be obtained through Lincoln Game Research Network and Digital Game Research Association.

To achieve these goals, all Staff in UoA11 will be involved in public engagement and participation activities, conferences, public events, exhibitions and festivals.

### ***1.6 Approach to Interdisciplinary Research***

All Research Groups in SoCS perform inherently interdisciplinary research and generate many conference and journal contributions from across Computer Science, Engineering, Healthcare, Life Sciences, Arts, History and Culture, Neuroscience and Psychology. Almost all of our external funded projects are collaborative and involve working together with a range of disciplines and sectors. We promote collaboration within University groups and Schools through provision of time for research co-investigators for funded research activity, as well as through financial support for strategically important collaborations and networking activities.

We have created an internal procedure, through which we were able to provide 5 new Ph.D. posts, especially to ECRs in SoCS, whilst requesting interdisciplinarity of supervising teams and Ph.D. topics. This approach has achieved many goals, such as assisting the best ECR research with Ph.D. students and prioritising interdisciplinary research between UoA11 and other Schools. Moreover, the creation of the University of Lincoln Medical School, in collaboration with the University of Nottingham, provides a great new opportunity for increasing the multidisciplinary aspect of our research. Especially in the health diagnosis domain and in generation of novel healthcare applications and services, targeting both the East Midlands and other nearby rural areas, as well as global research developments.

UoA11 closely works with all UoL entities that are industry and sector facing, i.e., LIAT, NCFM, LIH, and through them to external non-academic partners. Moreover, Mlearn and Intlab have collaborated in co-organising with UoL's Centre for Culture and Creativity, School of Arts & History, and the Media Archive of Central England, the Heritage Dot Conference, bringing together researchers and practitioners and involving cultural, creative and technology disciplines. This collaboration resulted in a 3-year Creative Europe project which UoL coordinates, in which mlearn provides metadata semantic analysis and enrichment. Moreover, Kollias was selected member of European Commission Expert Group on Cultural Heritage in 2019.

### ***1.7 Progress towards Open Research Environment***

SoCS targets continuous interaction and dissemination of research results, possessing a professional software development and research paper repositories.

We have a policy of putting our research code and datasets online for open access, for use by other researchers, thus following the University of Lincoln's central policy on open access. We created <https://lcas.lincoln.ac.uk/wp/research/data-sets-software/> as an open research environment on robotics, also publishing several related datasets. We also created public datasets of Proton imaging data (over 10 TBs) to the worldwide research community, together with widely used retinal dataset (<http://www.aldiri.info/Image%20Datasets/Review.aspx>) and other computer vision datasets (<https://www.visioneng.org.uk/datasets/>).

<http://mlearn.lincoln.ac.uk/> provides a database on Parkinson's, with thousands of MRIs and DaT Scans.

In addition, both SoCS and LAR are promoting the use of open research for RAAI, actively supporting the development of the Robot Operating System (ROS), the architecture adopted by international academia for robotics research.

### **1.8 Support for Research Integrity**

Coherence of vision and interaction of academics across all groups is a key School strategic target under oversight of the School's Research Steering Group (RSG). RSG naturally encourages open and constructive dialogue across all academics in the School, supporting research integrity. This strategy and strong multidisciplinary research culture also nurture junior staff who receive personal support and mentoring towards producing high quality collaborative research, whilst also contributing to all School educational and organizational targets. RSG follows the University's Code of Practice for Research, as well as the University's Ethics Policy, as the main instruments for the creation of a comprehensive framework for good research conduct.

## **2. People**

### **2.1 Staffing Strategy**

The staffing strategy of UoA11 is in accordance with the targeted expansion described in Section 1 of this Statement. This includes the increase by 98.7% of the staff FTEs submitted in REF 2021 compared to REF 2014 (28.8 versus 14.5), as well as the expansion of the research groups (from 3 to 4 in this submission) and the members of each research group (ranging from 9-10 FTE for L-CAS and LoVE, and to 4-5 FTE for mlearn and intLab).

In SoCS, new research areas are determined by RSG, chaired by the School Director of Research, involving the Head of School (HoS), Professors and Heads of the research groups. For example, in 2016, we decided to create a fourth research group, to complement our existing groups in robotics, vision and human-computer interaction, and concluded that a group in Machine Learning (ML) would best complement our existing research portfolio. We proceeded with recruiting the Head of the Group (at Professorial level), providing also a Ph.D. studentship, and in the first semester of 2017 we recruited four Lecturers/Senior Lecturers in ML & related fields, i.e., as data science, reasoning, signal/image analysis, brain-inspired AI. The Mlearn Academics have attracted 3 RAs and & Ph.D. students, funded by projects that the Group has managed to acquire.

In LAR, the three specified research themes are underpinned by new appointments, targeting a critical mass of 18 members that has been defined as necessary, for performing research and seeking collaborative projects with industry and other HEIs.

Our staffing strategy targets the strengthening of the research and impact creation capabilities of UoA11, in the context of our overall research strategy and those of the specific Groups. As an evidence of the effectiveness of our policy, it should be mentioned that in the referenced period, 15 new members have been recruited and added to the academics of SoCS, including 4 Professors (Parsons, Kollias, Bidaut, Sklar), 5 Senior Lectures (Holopainen, Cutsuridis, Jiang, Fox, Millard) and 7 Lecturers (Bachour, Yu, Esfahani, Brown, Hicks, Maior, and Zhang). The average h-index (e.g., in Google Scholar) of the new Professors has been about 40; in the case of Senior lecturers it was 16; in the case of Lecturers it was about 9. These have been added to the existing Staff of the School of Computer Science, creating a Field Weighted Citation Impact (FWCI) in the census period of 1.82, an International Collaboration Rate of 60.2% and a National Collaboration Rate of 17.1%, which are higher than the respective sector means.

The following can be mentioned regarding the characteristics of the UoA11 staff:

- Our staff includes a rather high number of young academics: 20.8% are 25 - 34 years old; this indicates the dynamic composition of our staff and our ability to attract young ECRs for facing new challenges and evolving research directions.
- There is a large number of SoCS staff that have been for many years with us and constitute the backbone of our R&D efforts: 39.9% of our staff are 45-54 years old.
- There is a high number of international staff members in SoCS, reaching 56.9% of the total: this provides our UoA with a great extroversion, leading to many collaborations both at national and at international level.
- There is large proportion of BAME staff members, in particular, 41.1% of our staff: this is the reason of many collaborations with Asian countries.

Staff promotion is a continuous procedure supported by the University. During the assessment period two of our Readers were promoted to the Professor level (Hanheide, Ye) and two Senior Lecturers were promoted to Associate Professors (Bellotto, Cielniak, Al-Diri), following an application and evaluation procedure at School and University level. It should be added that senior BAME members have reached a 17.1% of the total staff.

## 2.2 Staff Development

Staff development has been a main target of the School of Computer Science; LAR is sharing the same target as well. We recognize that development is of key importance for our Early Career Researchers (ECRs) to form and implement their own research and to participate in International Conferences and fora. Support for ECRs includes:

- The appointment of ECR Leads for the School.
- Training for ECRs, study review meetings with more experienced staff members, or among themselves in e-research seminars, to discuss journal articles and research bids prior to submission.
- In SoCS, all new members of academic staff are provided with a mentor, who is a senior member of staff, encouraging them to have regular meetings, so that they can surpass any problem or difficulty they may face. Research Group leaders also provide mentoring to staff, usually focusing on the research aspects of the role.
- Annual appraisals and individual research plan reviews with a senior member of staff, as an opportunity to review progress, identify needs, discuss career plans, targeting career progression and continuing professional development through the appraisal process; these are part of ECR's progress evaluation.
- Annual research planning meeting with SoCS research group leads, to discuss all aspects of research, such as outputs, income and impact, as well as a three-year research plan envisioning future goals and practices. We are using the Individual Research Planning (IRP) process, which serves two purposes: Developmental – it provides ECRs with a structured opportunity to annually review their research attainments, to set research goals and plans with the advice and critique of an experienced reviewer, and to set a strategy for attaining research objectives; IRP data feed into UoL's overall planning for research, development of REF profile and income generation, and is used as part of the process to identify individual contributions to REF.
- Training and development, at Institutional and College of Science level, for personal and professional development. UoL provides Continuing Personal and Professional Development (CPPD) scheme which was designed as a holistic and inclusive framework to enable all staff members to plan their careers.
- Reduced teaching load for ECRs, especially in their entry year(s) to the School, to provide them with more time to focus on research.

ECRs are encouraged to participate, as Co-Is in submission of proposals together with more experienced researchers, so as to obtain the necessary expertise and then submit their own proposals; they are also active members of the research groups, acting first as second supervisors of Ph.D. students and then as first supervisors. An example of ECR success in the mlearn group is Jiang, who is a new ECR with an excellent publication record: 5 papers in IEEE Transactions on Evolutionary Computation, 3 papers in IEEE Transactions on Cybernetics and 2



papers in Soft Computing; whilst being Co-I in the European 'Smartgreen' project, leading the data prediction and optimization task, being 2<sup>nd</sup> supervisor of a Ph.D. student and collaborating with Parsons and Kollias on blending ML and AI.

Recognition and reward of every staff member achieving excellent research results and impact is provided by SoCS, in terms of: balancing other duties, providing some part of the indirect costs back to PIs to use for equipment, or travel; providing resources, e.g., Ph.D. studentships to boost research and impact. We assist all Academics to increase their networking and research/impact potential, facilitate exchanges between academia and businesses, and provide sabbatical leaves to Staff who bring such a request to Head of School. Cuayáhuatl spent a six months period at Samsung, with a leave of absence from SoCS. Bellotto spent three weeks in China, presenting research seminars on machine perception of human in robotics, collaborating with Science University of Science and Technology, Guangzhou, Shenzhen and Tsinghua Universities. We encourage close collaboration of UoA11 Academics with European and International Academia (for example, Cielniak with Norwegian University, Yue with many Chinese Universities).

UoA11 assists its academics with travelling, participating in international conferences, organising workshop and publishing papers. Expenses are covered, either at individual level, through direct requests to Head of School, or at research group level, providing the groups with budget for covering such expenses. Consequently, UoA11 Academics are very active in participating and presenting papers at national and international conferences, in organising workshops and serving as conference program chairs and session organisers (as mentioned in Section 4).

### **2.3 Support for PGR students**

In UoA11 we are nurturing a research culture, which includes opportunities for training PGR students, post-doctoral staff and fellows. Especially towards PGRs, we target to support them by:

- Generating an inclusive, friendly, professional and supportive research environment that encourages collaboration, engagement with stakeholders and nurtures ambition, creativity and innovation in both fundamental and applied research; all PGRs, including those of the CDT, get involved, as active members, in some projects and collaborations. SoCS runs monthly seminar series and PGR meetings, to provide forums for PGRs to network.
- Creating individual and collective minds that are open to new ideas, responsive and flexible; all PGRs get involved in research tasks, seminars, collaboration-across-group events and publications.
- Inspiring them to become knowledgeable and enquiry-driven scientists; from their entering UoA11 they are in close collaboration with their mentors, supervisors and research colleagues.

UoA11 is committed to the development and support of PGRs. The success of our CDT Programme will assist PGR linking with external bodies, industrial and social partners, by visiting and working in their environments; this will help improving PGRs' understanding of real-life problems and related career prospects.

Moreover, and following UoL's Institutional Environment Statement:

- UoA11 seeks funding from major funding bodies, obtained directly, or through project development, at both national and international level. The CDT, together with the large networking capabilities of LAR, provide further opportunities for engaging more PGR students in R&D collaborations with industry. CDT students are treated as a cohort getting support from a wide selection of supervisors. Also, UoL recently obtained EPSRC Doctoral Training Partnership (DTP) award, through project proposal assessment, three ECRs in SoCS have received studentships to become 1<sup>st</sup> supervisors of new Ph.D. students on interdisciplinary topics.

- PGR students, both at M.Sc. and Ph.D. levels, participate in:
  - \* weekly meetings and presentations at Group / Laboratory level
  - \* monthly research presentations at School / Centre level
  - \* monthly journal club at Group / Laboratory level
  - \* seminars and open days across UoA11
  - \* talks by Academics in events organised by Lincoln Institute of Advanced Studies
  - \* combined meetings between different research groups (e.g., L-CAS and Mlearn).
    - Progress of PGR students is discussed with their 1<sup>st</sup> and 2<sup>nd</sup> supervisors in monthly meetings and respective reports are produced and monitored by SoCS / LAR. Yearly progress reports are completed and evaluated and important dates, e.g., of viva, or transfer to Ph.D. status, are respected, being considered necessary for successful completion of postgraduate/Ph.D. degrees.
    - Organisation of the research seminar series is rotated among UoA11 groups to ensure a variety of invited external speakers (about 6 seminars per year), which, as we have found, increases cross-fertilization of ideas and approaches to research.
    - Organisation of meetings and events with industrial partners and other institutions happens, where dissemination of achieved research results and investigation of possible future collaborations, as well as discussion on opportunities for PGRs to work. We could also mention the 'Life Beyond the PhD' event, which has run in conjunction with the Doctoral School, for supporting postgrads in this framework.

## **2.4 Equality, Diversity and Inclusion**

UoA11 supports and encourages all under-represented groups, promotes an inclusive culture and values diversity. Our approach to equality, diversity and inclusion (EDI) is informed by UoL's Policy. The Eleanor Glanville Centre leads the equality work, providing centralised support around the Athena Swan Gender and race Equality Charters and disseminating best practice (see Institutional Environment Statement). We also ensure that all our staff attend EDI training.

SoCS's Athena SWAN Self-Assessment Team was set up in April 2014. After an open call for expressions of interest, the team was put together ensuring that its membership represented a range of career levels and different work-life experience. The team has held regular meetings since then. Our Athena SWAN preparations have included staff-wide consultations and meetings on gender diversity, developing our appreciation of the role of positive action in this regard. As a result, the School achieved the Bronze Athena SWAN Award in 2015 and identified many areas of good practice.

With reference to recruitment of Ph.D. students, UoA11 has adopted a transparent procedure, according to which each potential student submits an application, describing their intended area of research, which reaches all Academics; the ones who declare their interest can further discuss with the student, who makes the final suggestion and then inserts the postgraduate programme. The selection procedure does not pay attention to any protection characteristics of the student. Our aim is to attract students of high quality that are able to work and produce innovative research.

Our cohort of PGR students is rather young in age, with 64.0% being younger than 30 years of age. This shows the dynamic nature of our PGR cohort. Moreover, 61.3% are international students; this is a characteristic of our PGR cohort, which attracts our close attention, so as to provide equality and inclusion to all our PGRs.

UoA11 supports broader attitudes and approaches to flexible ways of working, e.g., part time working, compressed working hours, and working from home. We promote "core hours" of 10am – 4pm in consideration of staff or research students who have caring responsibilities. Meetings are always held within these hours, being arranged using 'Doodlepoll'. Remote working has also been adopted throughout UoA 11 during the Covid-19 pandemic.

The wellbeing of our staff and students is considered of primary importance for UoA11 objectives' achievement. We strongly believe that our organisational performance is linked to the well-being of our members and that this is much more efficient when our members are satisfied, participating, and contributing to a peaceful and participative working environment.

The Head of School, assisted by specific members of School's Administration Unit, is responsible for the smooth operation of SoCA activities. Our organizational approach turns away from the usual hierarchy-based management to an agile network of interconnected Groups. The Groups have been empowered to take decisions and actions without constant referral to higher levels. This is only achieved by creating a UoA11 environment where members have the right soft skills in communication and alignment towards our common goals.

The key variables that are considered to achieve this, at individual UoA11 level, are: i) personal satisfaction; obtained when our collaboration is in line with everyone's personal values, ii) personal and working life well-being, iii) own motivation; each one acting to successfully achieve their objectives in accordance with UoL's ones, iv) trust; relying upon UoA11 management, group leaders and colleagues.

### **3. Income, infrastructure and facilities**

#### **3.1 Research Income**

UoA11 has facilitated and embedded an environment where creation of high-quality research and recognition of research income sit at its very core. Recognising that generation of research income requires strong research teams and dedicated support, we are driving this forward centrally, so as to meet the needs of the growing cohort of researchers within SoCS and LAR.

Generation of research income is enabled by university structures and processes, strong engagement with service users and companies. A specific focus on promoting outcomes to society and industry. In particular, to enable income generation, SoCS and LAR work closely with their diverse network of industrial partners, including end-users and technology providers. There is also close collaboration with UoL's Research & Enterprise Entity, which provides support for research income generation activities, including research grants and contracts, KTPs, IP and academic enterprises.

UoA11 research income has been £10,273.977 in the census period, with a 455% increase over the respective research income, £1,854,987, reported in REF 2014. There have been 207 bids submitted for funding, with a success rate of 33.0%.

Classified by funder type: 46.9% were funded in UK; 17.9% by Research Councils; 25.6% by European Union; 9.2% were funded by Industry. It is noted that funding at European level has been a significant proportion of the total funding; this shows our large collaboration and networking with groups leading research at European level.

It should be further mentioned that 21.3% of the bids were in collaboration with one or more different UoAs of UoL; indicating the significant interdisciplinary work done in UoA11.

In particular:

L-CAS has run a variety of projects, including: Advanced Robotic Breast Examination Intelligent System (Cancer Research UK, 2020-21); Haptic-guided Mobile Manipulation (NCNR, 2020-21); Co-manipulated Robotic Training and Skill Assistance for Telem Manipulation in Nuclear Settings (NCNR, 2020-21); Human-Guided Learning and Benchmarking of Robotic Heap Sorting (ERA-NET CHIST-ERA, 2019-22); Intra-Logistics with Integrated Automatic Deployment: safe and scalable fleets in shared spaces (Horizon 2020, 2017-20); Spatial-temporal information processing for collision detection in dynamic environments (Horizon 2020, 2016-20), National Centre for Nuclear Robotics (EPSRC, 2020-21); Synthesis of remote sensing and novel ground truth sensors to develop high-resolution soil moisture forecasts in China and the UK (STFC, 2016-19); Robotics and Autonomous Systems for Berry Production (IUK, 2017-19); 3D Vision-

based Crop-Weed Discrimination for Automated Weeding Operations (BBSRC and IUK, 2016-18); Structured Deep Learning for Autonomous Driving (Toyota Europe, 2017-18); Application of machine learning and high speed 3D vision algorithms for real time detection of fruit (BBSRC, 2017-21); Autonomous Field Rover for Agricultural Research (BBSRC Seeding Catalyst, 2017-18); Autonomous Field Rover for Agricultural Research (Horizon 2020, 2015-18); Enable Robot and Assisted Living Environment for Independent Care and Health Monitoring for the Elderly (Horizon 2020, 2015-18); Spatio-temporal Representations and Activities for Cognitive Control in Long-term Scenarios (EU FP7, 2014-17).

Focusing on agri-food robotics, RAI and related technologies has been a major decision of SoCS and UoL towards income generation. Creating LAR and obtaining the CDT for agri-food robotics, in collaboration with the University of Cambridge and the University of East Anglia, have been major pillars for generating income and for boosting research collaboration with all participating companies, thus providing more future potential income. In total, this collaboration led to winning 24m of collaborative funding (to all partners) in agri-food research.

LoVE research income mainly comes from the healthcare sector, i.e., early diagnosis, quantification and prognosis of various diseases, proton imaging work, by engaging with clinicians, entering into clinical trials, pursuing regulatory approval and cooperating with healthcare industries. Related projects are: OPTIma: Optimising Proton Therapy through Imaging (EPSRC, 2018-2022); Predicting the location of lung nodule occurrence from low-dose CT using convolutional time-to-event networks (Cancer Research UK, 2019-2020); Computer-aided detection (CAD) for Robotic Colonoscopy (Cancer Research UK, 2016-17); Assessment of retinal vascular geometry in patients with age related macular degeneration (Fight for Sight, 2015); Interoperability Hub for Aggregating Lifelogging Data from Heterogeneous Sensors and its Applications in Ophthalmic Care (EPSRC, 2014-16); Proton Radiotherapy Verification and Dosimetry Application (Wellcome Trust, 2013-16); Retinal Vascular Modelling, Measurement and Diagnosis (EU FP7 Marie Curie, Coordinator, 2013-16); Demonstration of 4D Digital Avatar Infrastructure for Access of Complete Patient Information (EU, FP7, 2013-16).

LoVE has also actively worked in intelligent vision, e.g., animal tracking/ behavior analysis and agri-food projects: PIGSustain: Predicting the Impacts of Intensification and Future Changes on UK Pig Industry Resilience (BBSRC, 2017-2021); Smart Systems Approaches for Climate Resilient Livestock Production (NERC, 2019-2020); Towards an open-source, equipment-agnostic framework for automated welfare monitoring in the home cage (National Centre for the Replacement Refinement & Reduction of Animals in Research, 2020-23); Mushroom Robo- Pict- Development of an autonomous mushroom picking robot (IUK, 2017-2019).

IntLab research income generation came through: the RAF 100 Ceremony project, where intLab created and widely spread an App for young audiences, realistically recreating RAF100 flypast using Augmented Reality; the Eylander project, coordinated by WESC Foundation (funded by Comic Relief and Paul Hamlyn Foundation, 2015-18) for development of the 'Eylander' game for children with homonymous visual field loss; a project with Chordata to develop software for their motion capture hardware; the H2020 PieNews project and the COST action Sharing and Caring, in collaboration with the University of Trento in Italy; project in games for wheelchair user, in collaboration with Back Up Trust and WheelPower UK.

Mlearn has run ML/AI projects: Nuclear Power Core Monitoring Techniques and Experimental Validation and Demonstration (Horizon 2020, 2017-21); SmartGreen: Smart agri-food using Machine & Deep Learning (EU Interreg North Sea, 2017-21); WeHope: Semantic Metadata Interoperability for Cultural Content (Creative Europe, 2019-22); Deep Learning for Optical Character Verification of Food Packaging Images (OAL/IUK, 2017-19); Intelligent Refrigeration Systems (Tesco and IMS-Evolve, IUK, 2017-19) for optimising defrosting cycles that account for thermal inertia pertaining to food, thus cutting energy costs down; Engineering Transformation for Integration of Sensor Networks (CEH and Oxford University; NERC/UKRI, 2019-20) for soil moisture monitoring, prediction and enhancement of environmental observations.



**3.2 Infrastructure and Facilities**

UoA11 has achieved large support from UoL in infrastructure and facilities in the census period, with which we supported staff and PGRs in their research and development activities.

In particular, a new building of £28m has been created for SoCS in 2017, under the name of Isaac Newton Building (INB), bringing together all laboratories, staff and postgraduate students, with co-located state-of-the-art facilities and research infrastructure. A variety of events have been organized in INB to bring UoA11 developments closer to our industrial, societal and educational audiences. Bellotto and Lambrou organised twice (2017, 2019) the BMVA Computer Vision Summer School in INB, using rooms, laboratories and social interaction areas. Many demonstrations of the L-CAS achievements, including sections with autonomous robots and food manufacturing demonstrations were organized in INB L-CAS Laboratory and free space areas.

L-CAS joint facilities include dedicated robotics research labs, demonstration farm, experimental food factory, fleet of diverse mobile and social robots, advanced compliant robotic manipulators, swarm of micro robots and state-of-the-art agricultural robots. The CDT for agri-food robotics also constitutes a scholarly infrastructure supporting research and impact in UoA11. Moreover, L-CAS and LIAT, through E3 award, set up the LAR infrastructure at UoL's Riseholme Campus, whilst UoL provided the LAR building, as in-kind contribution.

LoVE facilities provide a unique capability within UK universities, namely the design of custom CMOS sensors, up to the level where out-sourced fabrication is possible; this boasts full CAD platforms, both academic and commercial, and advanced characterisation systems for imagers. IntLab has the capability to develop Virtual, Augmented and Mixed Reality environments; this was used for development of Apps for games, education and entertainment environments.

Mlearn possesses a research and development infrastructure for state-of-the-art machine and deep learning and big data analysis, including servers with GPUs and associated memory availability, used for research and project development.

On top, SoCS provides research students and visiting research staff with required equipment, whilst using, if necessary, major research facilities in nearby UK institutes. Everyday operation and predictive maintenance is supported by SoCS technical and support staff.

**4. Collaboration and contribution to the research base, economy and society****4.1 Research Collaborations, Networks and Partnerships**

In the current census period, UoA11 academics have developed a large variety of research collaborations, networking and partnerships with academic colleagues from other Universities and Research institutes in UK and internationally. Almost all of our external funded projects are collaborative and involve working together with different disciplines and sectors. Our research collaborations are reflected both in the co-authorships in our research publications and in the joint research projects with academic colleagues in other institutions.

Publications

It can, indicatively, be mentioned that in 87 publications of our staff in international journals and conferences in 2018, 73 (84%) were co-authored with one, or more, academics from other Institutions. In particular, 33 articles (34% of this category) had co-authors from other UK Universities, 33 articles (34% of this category) had co-authors from European Universities and 29 articles (32% of this category) had co-authors from international Universities (mostly from China, USA, Australia). This is an evidence that SoCS has a strong presence in research both at national and at European and international level. Many publications originate from participation of our Academics in international projects. We are especially expanding to Asian markets, working closely with UoL's Department on International Collaborations.

Networking

UoA11, through L-CAS is member of EPSRC Robotics and Autonomous System Network, and euRobotics AISBL, a non-profit association for all stakeholders in European robotics. It has a large network of collaborations, including: ABB, major UK-based robotic supplier; Stelram, small specialist UK developer of robotic solutions; Saga Robotics, CBS Ltd.; National Centre for Nuclear Robotics; University of Sydney's Australian Centre for field Robotics; HVM Catapult.

L-CAS and LAR have a large collaboration network: Littleport Mushroom Farms, a major UK mushroom supplier; Berry Gardens Growers and Ekeberg Myhre; Collaborative Training Partnership for Fruit Crop Research; NIAB EMR; NERC centre for Ecology and Hydrology; Chinese Academy of Meteorological Sciences; Punjab Agricultural University; UK Agri-EPI Centre; ASDA; Food and Drink Federation, OAL Group; National farmers Union; Environment Agency. L-CAS leads the EPSRC network on Internet of Food Things

Through LoVE, UoA11 collaborates with major hospitals in NHS and abroad: Christie NHS Foundation Trust, UCL Hospitals NHS Foundation Trust, Cambridge University Hospitals NHS Foundation Trust, Moorfields Eye Hospital, London, St George's Hospital, Churchill Hospital Oxford, Karolinska University Hospital, Sweden, Center for Proton Therapy, Paul Scherrer Institute, Switzerland, Breast Cancer Screening and Prevention Center, Jules Bordet Institute, Brussels, also with Cancer Research UK.

UoA11, through Mlearn, is a member of many European AI Initiatives: Confederation of Laboratories for AI Research in Europe (Claire); 'Europeana' ecosystem on Digital Libraries; UK Computational Statistics and Machine Learning Network.

IntLab is leading the Lincoln Game Research Network and is linked to the Digital Game Research Association.

UoA11 has also developed strong collaborations with other UK Academia, e.g. Universities of Cambridge, Cranfield, Surrey, Liverpool, Manchester, Leeds.

Partnerships

UoA11 groups and individuals have created key partnerships with Universities and Research Centres at international level, such as: with Norway in the robotics and agricultural field; with China in medical imaging and machine learning field; with Greece in machine learning and medical image analysis. These have been the basis for collaborating in joint projects, for developing common research outputs and for reaching greater impact.

We are also in partnership with the KDU Penang University College in Malaysia, which has led to common publications, research exchanges and new research collaboration possibilities, focusing on machine learning and robotics.

**4.2 Relationships with Users, Beneficiaries and Society**

UoA11 consistently collaborates with organisations beyond Higher Education, including users and beneficiaries of the developed research outcomes and the society.

Examples of implementation of this strategy include various robotics projects that L-CAS used to engage children in STEM: for example, in the 2016 and 2017 EU-funded LiGHTS festivals, brought hundreds of children onto UoL campus, to meet and interact with SOCS robots. One specific initiative was a collaboration with the Johnson and Mukherjee Brothers Trust to run an activity for about 200 primary school children across 14 schools in Lincolnshire specifically focused on AI and Robotics, intended to widen participation and raise aspirations for disadvantaged children.

SoCS has strong links with the University's Autism Research and Innovation Centre, where there are specific efforts to employ autonomous robots and affective assistants in the support of educational and therapeutic activities for both children and adults with autism.

LoVE has a long standing collaboration with NHS Trusts, Health Charities and patient groups. There were presentations, e.g., in Royal Society Summer Science Exhibition, in Science Festivals such as Gravity Fields, and others to leading manufacturers under NDAs, towards translation of technologies into commercial and practical healthcare environments, and to diverse groups such as charities and patient groups.

Mlearn has a close collaboration with Europeana, the European Digital Library and its network of Cultural Institutions all over Europe, as well as with the Michael Culture Association. Through these relationships the developments on cultural data enrichment and creative reuse reach researchers in the educational, cultural and creative sectors.

LAR targets developing RAAI technologies for agri-food and boosting agricultural productivity, with great impact on persons working in the agriculture or the food supply chain. LAR aims at using existing networks of farms for validation and adoption of the developed technologies, as a first step towards spreading the results towards the whole agricultural field.

#### **4.3 Wider Contributions to Research Base**

The Academics of the School of Computer Science greatly contribute to the Computer Science and Informatics discipline and the research fields of UoA11.  
In particular:

Prof. T. Duckett is Fellow of the Royal Society of Arts and full EPSRC College member. He is leading the EPSRC CDT and is Joint Director of LAR. He chaired the 7th European Conference on Mobile Robots, Sept. 2-4, 2015 at Lincoln and the UKRAS conference, April 17, 2020.

Prof. M. Hanheide was the Lead of the STRANDS Project Summer School on "Long-Term Autonomy for Mobile Robots", Aug. 27 – 31, 2015.

Prof. S. Yue co-organized INNS-BigData Conference in San Francisco, Aug. 8-10, 2015, and gave keynote speeches at i-Create, 14-18 July, Shanghai China and ICAMEchS, 28 Aug. - 02 Sept 2018, Zhengzhou China.

Prof. E. Sklar, Research Director of LAR, has been Head of the Centre of Robotics research at King's College London 2017-19, having spent more than 10 years in industry in USA. She is Founder Trustee of the RoboCup Federation. Her research was funded by US NSF, US Department of Education, US Army Research Lab, EPSRC and ESRC.

Prof. X. Ye has been a panel member of EPSRC Peer Review full College, and received recognition for an outstanding contribution to EPSRC Peer Review in 2018; she is also a panel Member of British Council Peer Review and the UKRI Future Leaders Fellowships Peer Review College.

Prof. S. Kollias is Fellow of the IEEE (since 2015) and has been a member of the Executive Committee of the European Neural Network Society (2007-2016), General Co-Chair of 5 Conferences, Programme Committee Member in 40 Conferences and Associate Editor in 20 Journals. He is member of recent EU AI initiatives (AI Alliance, Claire NoE, Europeana Pro).

Prof. S. Parsons, Global Professor in Machine Learning, has held academic positions at Queen Mary and Westfield College, Massachusetts Institute of Technology, City University NY, University of Liverpool and King's College London. He has been leading application of AI in agriculture and medicine, focusing on complex decision making and explainability.

Dr. T. Lambrou has many journal editorships and board memberships, e.g., in Informatics in Medicine, Radiology of Infectious Diseases and Computers in Biology and Medicine. Together with Dr. N. Bellotto, they organized the BMVA Computer Vision Summer School, in 2017 and 2019. Dr T. Lambrou and Prof X. Ye collaboratively organized the 19th Medical Image Understanding and Analysis Conference (MIUA) at the University of Lincoln in July 15-17, 2015. They are both members of the Steering Committee of MIUA Conference.

Dr. P. Dickinson was General Co-chair of the 2015 British Human Computer Interaction Conference. Dr. J. Holopainen was a member of the Executive Board of the Digital Games Research Association (2014 – 2019), Program Chair of the 9th International Conference on Intelligent Technologies for Interactive Entertainment (2017), and Associate Chair for CHIPLAY Conference (2018-2019). Dr. J. Holopainen and Dr. C. Headleand are active in Higher Education Videogame Alliance and Game Development Educator Network.

Dr. V. Cutsuridis has edited 5 books, including the 'Hippocampal Microcircuits: A Computational Modeler's Resource Book and the Perception-Action Cycle: Models, Architectures and Hardware'. He acts as an Associate Editor in several international journals including Cognitive Computation and Frontiers in Cognitive Science.