Institution: Middlesex University

Unit of Assessment: 11 - Computer Science and Informatics

1. Unit context and structure, research and impact strategy

Computer Science and Informatics research at Middlesex enjoys a thriving and vibrant environment undertaking internationally leading applied and foundational research across the subject area. During the REF period, through cultivation of strong research leadership and investment, the unit appointed talented computer science researchers and sustained the fostering of an environment that encourages inter-disciplinary collaboration with international partners. Implementing the strategic plan laid out in REF2014, where the unit was the 5th largest Computer Science unit in the country with 53.1FTE staff submitted, makes this possible. That submission was part of the sustained growth building upon REF2008 when 22.3FTE staff were submitted and reflecting the history and tradition of computer science research at Middlesex. The unit has participated in every research exercise since 1992.

Results of research at Middlesex in Computer Science and Informatics over this REF period include: antibiotic resistant bacteria can now be studied biologically using information theory; infants' lungs are non-invasively and inexpensively measured and monitored; oesophageal cancer can be inexpensively detected at an early stage using automated video recognition from endoscopy; and visual analytics changes the approach police forces internationally adopt in the prosecution of crime.

1.1 Unit Structure

The unit is located in the Faculty of Science and Technology and comprises 69 category A staff- 64.55 FTE. All staff in the Department of Computer Science (CS) are submitted and 14 from the Department of Design Engineering and Mathematics (DEM), one colleague from the Department of Natural Sciences (**Tizzard**), and one colleague (**Comley** the University's Director of Research) outside of the Faculty structure. All staff eligible for the REF in CS are included in this unit, and staff in DEM not included are submitted to UoAs 3 (Allied Health), 4 (Psychology), 14 (Environmental Studies) and 24 (Sport Sciences).

Research leadership within the unit is reflected in both organisational, management and academic structures. Research is managed formally through a Deputy Dean for Research and Knowledge Exchange and two Heads of Departments who are also professors all submitted here. Further operationalisation is achieved through the unit professors. At Faculty level, the Research and Knowledge Exchange Committee ensures research needs and outcomes are disseminated across the Faculty.

Staff submitted are substantively located in one of five major areas of research but the nature of the research submitted means that there is a creative and welcome overlap between the areas that the unit exploits through inter-disciplinary work. These five areas are:

Interaction Design: This area evolved from the internationally recognised Interaction Design Centre originally founded 27 years ago, to one that now conducts world leading visual analytics research. Staff in this area conduct research in usability, visualisation and manipulation of complex data as well as visual interface design for games and language interaction. Led by Prof **Wong**, the group includes Prof **Walker**, Assoc Profs **Attfield**, **Duncker**, **Fields**, **Ham**, **Springett**, **Whitney**

and **Xu**, and Drs **Herd**, **Kolar**, **Passmore** and **Zhang**. Expertise in user-interface design (**Fields**, **Passmore**, **Springett**, and **Zhang**) covers games, bespoke interfaces, and language interaction.
13 Colleagues – 11.2 FTE

Algorithms and Software Engineering: This area is primarily concerned with formal modes of analysis, ranging from fundamentals such as logic and graph theory through to model-based systems. The area includes activity that is concerned with meta-analysis such as applying theorem proving to security cases, verifiably correct systems, model-checking and quantum algorithms. The area enjoys outstanding industrial relationships such as with Facebook Research and Amazon Research. The group consists of Profs **Barn**, **Bornat**, **Nagarajan** and **Raimondi**, Assoc Profs **Kammueller**, **Novak**, and **Tizzard**, and Drs **Androutsopoulos**, **Baskent**, **Elmer**, **Gorogiannis**, and **Rahanu**. **Baskent** is an early career researcher.
12 Colleagues – 10.4 FTE

Intelligent Environments: Strategically strengthened after REF2014, this is aligned with Ubiquitous Computing and investigates how to develop Context Aware systems supported by a Smart Environment. User-centred system development processes are used to create these environments, resulting in a physically deployed network of sensing and actuation, making decisions supported by adaptive artificial intelligence algorithms. Challenges being addressed include: spatio-temporal reasoning, conflict management, user identification, dynamic user priority adaptation, and automated user habit learning. Other research covers mapping collaborative strengths in cross national groups, and supporting the development of teams, particularly in educational settings. The group is led by Prof **Augusto** and consists of Prof **Dafoulas,** Assoc Profs **Evans**, **Jones**, and **Smith,** and Drs **Daryanani**, **Loveday**, **Moseley**, and **Saleeb**.
9 Colleagues - 9 FTE

Networks and Distributed Systems: This area focuses on the technical and theoretical aspects of distributed systems and underlying network technologies such as scheduling for network traffic management. A particular emphasis is on wireless technologies, including areas such as cellular handover algorithms, and emergent properties and trade-offs between energy consumption, and performance. Also addressed are intelligent transportation systems (**Mapp**) and adaptive mechanisms to support a range of applications such as Industry 4.0 and Digital Twins. The networks group is led by Profs **Nguyen** and **Zhou**, and Assoc Prof **Mapp**. It includes Assoc Prof **Lasebae**, and Drs **Aiash**, **Colson**, **Hara**, **Le**, **Luo**, **Rahman**, **Shah**, **Sule**, **Trestian** and **Vien.**
14 Colleagues – 13.75 FTE

Artificial Intelligence: The AI research group concentrates on machine learning, computer vision, robotics, computational neuropsychology and biological algorithms. Other areas include work on ethics and AI, machine learning applied to social media analytics and research in machine consciousness. This group has had a notable presence for over 20 years with research in neural computing, categorisation and computer vision. The excellent facilities for robot development (see section 3) make this area a centre-piece of our research. It consists of Profs **Comley**, **Gao**, **Huyck** and **Karamanoglu**, Assoc Profs **Belavkin**, **Currie**, **George**, **James-Reynolds**, **Mitchell**, **Windridge**, and **X. Yang**, and Drs **Cheng**, **Chinellato**, **Gamez**, **Gandhi**, **Geng**, **Kotsia**, **Menendez**, **Quattrone**, **Panagakis**, and **Z. Yang**. **Menendez** and **Quattrone** are early career researchers.
21 Colleagues - 20.2 FTE

For REF2014, our strategic goal was to improve our "power rankings" – i.e. demonstrate substantive growth in high-quality computer science research at Middlesex so that our research could be sustained into the future and reflect the vibrancy, range and scale of the discipline. Our 141% increase in the size of the submission was one of the largest increases (of meaningful numbers) in the unit.

Increasing size allows us, through a CS research management team, to proactively and flexibly allocate funds and other resources, such as staff time, to accomplish our ongoing research strategy of conducting excellent fundamental and applied research. Most importantly, by developing inter-collaborative relationships that span computer science, engineering and mathematics, we are submitting staff from two Departments, Computer Science and Design Engineering and Mathematics. Inter-Department collaboration has allowed us to establish a pioneering presence in two critical areas (Ageing Society, and Future of Mobility) relevant to the UK Industrial Strategy published in 2017. The pipeline of research, its application to problems and then onto societal impact is evidenced.

1.2 Research and Impact During the Assessment Period

The aim of our strategy is to undertake both excellent fundamental research and applied research. We recognise that the nature of our discipline requires interplay between both types of research. Our decision to substantially grow computer science research allows us to open new avenues of research, including several inter-disciplinary areas, adding vitality to the subject area at Middlesex.

For the REF2014 research strategy, we planned for a future where:

- all eligible staff would be submitted;
- our theoretical work in the Algorithms and Software Engineering area would be used to underpin applied impact;
- we would develop inter-disciplinary opportunities at the intersections of mathematics and engineering;
- continue to enhance our taught provision through research;
- and significantly strengthen our core areas.

We have made significant progress across all these objectives described below.

Growth and the synergies between research and teaching

Since that strategic plan, we have achieved 100% submission of all eligible staff, with no CS Departmental staff on the "practice-based route" used by the institution to delineate non-research staff. This allows us to ensure that all of our teaching is underpinned and enhanced by systematically exploiting our research capability. For example, our MSc Data Science draws significantly from our research strengths in machine learning, image processing, visual analytics and legal and information ethics. Similarly, MSc Cyber Security and Pen Testing, which is among the first in the UK to teach Penetration Testing, draws substantive benefit from the unit's research expertise. These research-led Masters programmes provide experienced students for future post graduate work, continuing a virtuous teaching research cycle. Example papers arising from these collaborations with students include papers on preservation of digital evidence, On-the-Fly Image Classification to Help Blind People, and evolutionary art.

Application of Theoretical Algorithms

Algorithms for fusing multi-parameter clinical measurements obtained from the data produced from electrical impedance tomography have been developed and are used for data acquisition for cardio-respiratory intensive therapy for neonates, and more recently Covid-19 patients. Our

research in algorithms, correctness, and security of networking protocols has been applied. There is ongoing success in a range of machine learning applications including medical imaging, societal impact of Airbnb, malware detection, and optimisation.

Strengthen Adjoining Areas

The unit's 2014 REF environment statement set the goal of developing the adjoining areas of mathematics and engineering. The case for doing this was further strengthened by the publication of the UK Industrial Strategy in 2017. As a consequence, these areas have been extended with considerable research in robotics (e.g. the fast walking neuromorphic robot); mathematics; and computer systems engineering (e.g. network traffic management). The latter led to the formation of the Vehicular Adhoc Network (VANET) group specifically addressing the Industrial Strategy grand challenge around mobility.

Expand Three Core Research Areas

In 2014, the unit's organisation was based around three core research areas (Algorithms and Software Engineering, Networks and Distributed Systems, and Interaction Design). These areas have continued to grow and expand in the breadth of research conducted. The Algorithms and Software Engineering area developed provable systems (**Raimondi, Popescu,** and **Kammueller**) (e.g., see Verified Systems in section 4). The research area is also the base for three impact case studies: Digital Twins (**Barn** and **Nguyen**), EIT (**Tizzard**), and MAYOT (**Barn**).

In the 2014 REF, AI and machine learning were a part of the Algorithms and Software Engineering group and have particularly flourished through receipt of several research awards (see sections 3 and 4) such that the research management team of the unit determined that AI and ML was a critical component for our strategy for the next five years (see Future Research and Impact Strategy below) and it now forms a research area of its own. Successes here include neuromorphic embodied agents that learn (**Huyck**), fast walking neuromorphically controlled robots (**Geng**), warehousing images (**Gao**), determining the effects of mutation rate plasticity (**Belavkin**), dream like simulations to support self-driving cars (**Windridge**), the firefly and bat machine learning algorithms (**X. Yang**), and applications of machine learning such as detection of oesophageal cancers (**Gao)**, classifying faces for emotion (**Kotsia**), detection of face spoofing (**Windridge**), and analysing Airbnb use in London for societal impact (**Quattrone**). Many software applications are evident in the outputs, and beyond.

There is continued growth in the Networks and Distributed Systems area with further development of mobile communications, and the development of an important area of research and impact - the Vehicular Adhoc Networks group. There are significant advances in quality of experience of video communication on wireless networks (**Trestian**), real time detection of denial-of-service attacks (**Loo**), and quality of service vs. power trade-offs (**Nguyen** and **Vien**).

Our strategy for the Interaction Design area resulted in similar actions, consolidating our strategy of growing our research in core areas. The Interaction Design area continues to prosper. It is enhanced through productive industrial collaboration (e.g. **Wong** with Genetec and Mitre, and **Attfield** with BAE). The group is making significant advances in mHealth (**Fields** and **Herd**), sensemaking (**Attfield**), visualising time (**Wong** and **Xu**), and human-centred machine learning (**Zhang**). The area also contributes national and international impact though the VALCRI case study.

A pleasing affirmation of the buoyant and focussed activity since 2014 is the successful incubation of the Intelligent Environments group from within Interaction Design into a mature, sustained

component of the unit that will be important for our strategy for the next five years (see below). Intelligent environments has had marked success through external funding, for example in the internet of things, where systems have been deployed to help citizens with specific conditions in meaningful daily life contexts. Examples include supporting people with asthma, cognitive decline, or Down's syndrome (**Augusto)**, aiding cardiac rehabilitation, education (**Smith**), and gamification for physical activity. Recognising the interplay between this area and our Networks and Distributed Systems, notable advances have been made in secure sensor networks for smart living. Work in haptics, robotics, networking, and vision have also contributed in this area. Further examples of excellence include computer supported cooperative work (**Dafoulas**). Reflecting the rapid development of this group, the area contributes the Intelligent Environments case study as a contribution to the grand challenges of an 'Aging Society' as outlined in the UK Industrial Strategy.

Goals Developed and Achieved Since Last REF

While the aims and goals from the 2014 REF statement were an important starting point for this REF cycle, strategy within the unit is evolving. The key driver of future sustainability and continued expansion required positive action to enhance support and leadership from senior colleagues. The CS research management team was developed to broaden the leadership of research within the unit. The team was formed in 2018, is led by the CS unit professors (including the heads of the CS and DEM Departments), and includes all colleagues submitted for the unit, and junior colleagues not eligible for submission. The team meets regularly in different configurations to reflect the priorities at that time. These meetings provide opportunities for meeting colleagues at different levels of experience and seniority encouraging a collegial environment that is coaching based while improving our research.

The planned interaction between computer science and engineering research is particularly successful, for example the establishment of The London Digital Twins Centre. Digital Twin research is identified as an important breakthrough technology and we are developing applications across manufacturing, building design, supply chain management, sustainability and enterprise decision making. As such, we have positioned our centre as one that can be used to spearhead innovation and impact in multi-disciplinary settings that require data science, mathematics and engineering. The research centre is uniquely positioned in the UK landscape and currently houses several international projects across domains such as Manufacturing 4.0 and structural health monitoring. Sponsors of the centre include Ericsson and Ansys. Formation of the centre reflects our approach of flexible and agile deployment of resourcing to identify opportunities for innovation and impact. Middlesex is a leading partner with Siemens in their "Connected Curriculum" strategy of partnering with universities working at the forefront of Industry 4.0. Our research in Digital Twins has had significant international impact through the Digital Twin impact case study reported in this submission (**Barn, Nguyen**).

Open Source and Research Integrity

The enhanced research leadership for this unit is further underpinned by the commitment of the unit to Open Source and Ethical Research. The unit has a strong open access ethos and has contributed to and applies all policies specified in the Open Access and Open Data section of Middlesex's REF5a. We have strongly supported initiatives related to Open Science including ORCID registration, with all submitted staff having registered. Our mechanism for green open access publication is our Eprints repository, many of our publications are externally published open source, and we are increasing the percentage of open source publications. Where necessary, dependent upon the open access publication requirements of the publisher, resources to support Gold access are made available. We deliberately take a flexible and agile approach to supporting Gold open access publishing. The University also provides a Figshare repository to

support open access to data. The unit develops large data sets, such as a database of face images by age, and a database of hospital images that are publicly available. Artefacts and code for simulations are made available on a variety of platforms with some description of how to use the code, for example the MIRTO robot.

All staff work within a strong ethical framework. The University's well-established and comprehensive Code of Practice for Research, enshrines the highest standards of research conduct and integrity. Its principles and practices are based on the Research Councils' Statement on Safeguarding Good Scientific Practice (2000) and the Concordat to Support Research Integrity (2012). An independent University Research Ethics Committee ensures that high standards of integrity are upheld through well-established approval processes and has oversight of our Faculty based research ethics committee that includes **Baskent**, **Hara**, **Menendez** and **Whitney**, and is chaired by **George**. All research projects conducted by students and staff must attain approval from this committee before commencement of work. The CS Department and DEM Department each have two Academic Integrity Tutors. This adherence to ethical research has been and will continue to be a grounding principle within the unit.

Papers

The scale and quality of our research activity and outputs across our key thematic areas is increasing. As a result, many of our papers are published in Core A* conferences like IJCAI, CHI, CVPR, WWW, and POPL; and in journals such as IEEE Pattern Analysis and Machine Intelligence, the Lancet, Parallel Distributed Systems, Information Fusion, and Nature Communications.

Case Studies

The impact arising from our research has increased. In this submission, the unit submits five case studies that are representative of our research. VALCRI develops visual analytics techniques, integrated with machine learning, to aid criminal intelligence analysts; portions of the intellectual property were purchased by Genetec and are widely used to support analysts. MAYOT, mobile apps for youth offending teams, is focused on marginalised young people in conflict with the law; it is being used by several Youth Offending Services in the UK. Intelligent Environments advances and develops practical implementations; these help people with Down's syndrome, provide ambient assisted living support for older people in their homes, and encourages citizens to be more physically active. Digital Twins developed new agent programming technology for simulating and analysing complex enterprise systems and twins for infrastructure maintenance; it is being used and sold by Tata Consultancy Services as TwinX™ to develop complex enterprise systems. Electrical Impedance Tomography (EIT) is a non-invasive imaging system that has been advanced by the unit; it is used in neonate lung imaging, and other applications, including Covid-19 patient monitoring; aspects of these developments have been patented and products are being developed in collaboration with industry (for example Sentec).

1.3 Future Research and Impact Strategy

After two REF cycles of strong growth and improvement, we are confident that our current environment and operating strategy to undertake both excellent fundamental research and applied research is appropriate and relevant for the future. Our ambition is that aspiring Early Career Researchers will see Computer Science at Middlesex as a beacon for establishing a base for excellent research and impact.

Under the leadership of our new Vice-Chancellor and British Academy of Management President, Nic Beech, Middlesex University is currently formulating its ambitious 2030 research strategy with the intention of becoming world leading in:

- Equity and improvements in health and well-being;
- Inclusive socio-economic development; and
- Sustainability of communities and the environment.

The research and impact in this unit will aim to contribute strongly to that mission.

In the next five years, the unit will build on recent achievements and current dynamism. We will seek to consolidate and sustain our performance on our key objectives of further strengthening of our five main research areas, developing stronger international collaboration, growing doctoral student numbers, and strengthening our pathways to impact. A particular focus will be exploiting our research that resides at the boundaries of our core discipline area using research centres such as the London Digital Twin Centre.

Strengthen Five Existing Core Areas

The units' foremost goal is strengthening the existing core areas by continuing to increase the amount of world class research. We will do this by providing leadership and advice on further raising the quality of publication outputs, and ensuring that appointments are made that either enhance these areas or allows us to exploit or increase inter-disciplinary working between these areas. The London Digital Twin Research Centre is expected to spearhead such inter-disciplinary work. The leadership is being further enhanced through an updated research strategy for the University that has a focus on key global challenges. Through this renewed emphasis and alignment, there will be increased provision of PhD studentships, specialist equipment, and enhancing the pipeline of doctoral students from our flagship MSc Data Science programme. Engagement through increased intensity of collaboration with industry and external stakeholders is also planned.

Develop Stronger Internal and External Collaboration

The unit will extend its internal collaboration, both within the unit and across the broader University, and improve its external collaboration, both with industry and other academics. The unit collaborates internally, e.g. roboticists collaborate with AI practitioners and telecommunications colleagues to develop cognitive robotics. Collaboration within the University is ongoing, e.g. **Chinellato** recently received a £300K grant from the Dunhill Medical Trust with Franco (Psychology) as the lead investigator. **Fields** collaborated with Psychology on Small Talk Saves Lives. Colleagues collaborate with industry, e.g. **Raimondi** is currently on sabbatical at Amazon and **Gorogiannis** at Facebook, and **Barn** collaborates closely with TCS research and **Windridge** with FIAT; we will extend our collaboration with these and other companies. Colleagues will continue to collaborate with other national and international universities, e.g. **Mapp** with Cambridge, **Wong** with British Columbia, and **Cheng** with Hong Kong. In addition to the positive influence on researchers of engagement, an important aspect of our strategy is to ensure that collaboration, both internal and external, is promoted, supported and valued. So, colleagues benefit both implicitly and explicitly from engagement. We will continue with outward facing events such as the STEM festival and Eurobot and develop new events.

We will improve our collaboration by actively engaging, monitoring, and supporting best practice, and actively seeking industrial collaboration. A new working group is extending our industrial collaboration; the group leverages existing industrial partners, and supports unit colleagues to develop industrial connections. To encourage collaboration, the CS research management team

has a collaboration agenda item for each meeting. Middlesex also has overseas campuses in Dubai, Malta, and Mauritius. Colleagues submitted to this unit collaborate with staff on these campuses and they are integrated into our research environment, though overseas colleagues are ineligible for submission to this exercise. For example, interactive technologies for education are being developed cooperatively by colleagues in Malta and unit colleagues (**Smith** and **Windridge**). Expanding productive relationships with colleagues at overseas campuses extends the capacity and breadth of unit research.

Continue to Build Synergy between Teaching and Research

Taught programmes in the unit's research specialisms will continue to introduce cutting edge research to students. Students who are interested and talented will be encouraged to return to pursue post-graduate research degrees, or move to other universities or industry, thereby fostering and growing a network of future collaborators. Programmes in our research specialisms that generate synergies between research and teaching will continue to be developed. For example, our MSc in Computational Neuroscience, a joint program between Computer Science, Psychology and Neuroscience, is currently under development, and will extend our collaboration within Middlesex. It and the MSc in Cooperative Intelligent Transport Systems will run for the first time in 2021.

Impact

Our approach to impact is integral to and embedded in our overarching aim of producing excellence in fundamental and applied research. It is informed by three objectives: (i) to produce research relevant to policy makers and wider society; (ii) define and respond to practical grand challenges as well as to debates driven by academic concerns and; (iii) routinely involve stakeholders. We also recognise that impact is contingent on the nature and maturity of the research.

Applied research, such as our case studies, other work on digital twins, and our work on verified systems, can be exploited through industry, patents and application to society; further funding opportunities will be explored, including contract research; sabbaticals will be used to support application; and graduates trained for rolls in these now industrially applicable technologies will continue to collaborate. We will work with our Research and Knowledge Transfer Office to exploit avenues for research that is nearing application, such as our work in evolutionary information theory, machine learning for optimisation, intelligent transportation systems and fast walking robots. Such avenues could include patents, productization or open-source availability.

By continuing to position our research within the wider UK and international policy context, we will endeavour to explore appropriate pathways to impact and have embedded in our ways of working engagement as a primary tool. Central to the impact strategy is developing systematic use of Innovate UK or DASA like funding streams to exploiting our more fundamental research such as our work in computational neuropsychology and quantum computing. Intellectual support from colleagues will be used to guide that approach.

The re-affirmed focus on research at University level following the appointment of our new vice-chancellor, Prof Nic Beech and our own history of research excellence provides confidence and assurance that our unit will continue to enjoy, attract and inspire world class academics to make their home in this Computer Science unit.

2. People

The vitality of our research environment arises from its dynamic lecturers, professors, and PhD students. Research groups meet for focused discussion, and our collocated people are immersed in an exciting ongoing research conversation.

2.1 Staffing strategy and staff development

Staffing Strategy

Our people and staff development strategy is in close alignment with our research strategy. That is, all staff hiring, promotion and mentoring focuses on well-rounded academics who are excellent researchers in either applied or foundational areas and are excellent teachers.

Since 2014, we have sought to strengthen our research leadership, develop junior researchers, reinforce existing areas of research and identify new opportunities. Our future strategic development will match the University's current formulation of its 2030 people strategy, entitled "*Changing lives – A world class community in a world class University*".

Adjustments to workloads and teaching are made for staff with substantial research grants. Similarly, teaching will be reduced for less experienced staff to focus on grant application writing, working with an industrial partner, or exploring a particularly thorny research problem. Newly appointed colleagues always have a reduced teaching load.

Most unit colleagues are employed full-time. Some staff on sabbatical retain a fractional appointment. These are particularly useful where staff on sabbatical in an industrial setting are able to immediately transfer knowledge back into an education setting. Three colleagues are on reduced work-load (**Colson** 0.75, **Kolar** 0.8 and **Bornat 0**.2), all recently full time and transitioning to retirement. **Ham** (.2) is developing our partnerships in Korea, and **Walker** (.2) is helping with public engagement in science through his media activities as part of our STEM development agenda (see Thrills in section 4).

The unit has gone through a period of consolidation. Sadly, three professors (**Albrecht** and **Ghanem**) and the head of the CS Department (**Petridis**) have died in post during this assessment period. Several staff have left to take positions at other excellent research institutions (for example **Loureirio** to UCL, **Martin** to Durham, and **Popescu** to Sheffield), and industry (**Boender** to Hensoldt Cyber GmbH); though formally no longer part of our research community, many of these former colleagues remain engaged. For example, **Loureiro** is currently involved in Middlesex PhD supervision. Five lecturers (**Baskent**, **Chinellato**, **Elmer**, **Le**, and **Menendez**) have been hired in this period, one has been promoted from associate lecturer, and the number of researchers submitted to the unit has increased from 56 to 69 (53.1 FTE to 64.55 FTE). Our retired colleagues contribute to the unit through mentoring and other "critical friend" activities (**Loomes**).

Our current submission includes 5% lecturers, 42% senior lecturers, 34% associate professors, and 19% professors.

As the University embarks on its 2030 strategy, approximately 10 lecturers and senior lecturers will be recruited by the unit over the next three years as a core strategic aim to ensure a sustainable research base. New colleagues recruited at the lecturer level and above will be in areas aligned with our existing research areas of Interaction Design, Algorithms and Software Engineering, Intelligent Environments, Networks and Distributed System, and Artificial Intelligence whenever possible. New colleagues will be selected based on a research profile that is both

evidenced and aspirational. Potential for internationally excellent future research will be required. On arrival, new colleagues will be proactively integrated into our research environment and appropriate groups. Past successes in first grant acquisition suggest that our mentoring mechanisms are effective.

Staff Development

From 2014, the University undertook an institution-wide staff mapping exercise to ensure all staff were correctly placed in terms of level and development pathway. Development pathways are either "teaching & research", for those with a significant responsibility for research (returned in our REF submission), or "teaching & professional practice". In this unit, the CS Department is submitting 100% of their staff. That is, no one is mapped to the "teaching & professional practice" route.

The unit is committed to an inclusive approach to supporting all colleagues' development, ensuring both vitality and sustainability in its research environment. Rather than seeing competition as the route to improving academic performance, we have a strong ethos of mutual support, collaboration and development. This coaching culture is now a central part of the Middlesex 2030 strategy.

Staff development needs are formally explored annually as part of the appraisal process. Staff complete a Research Plan, reporting on outputs, research income, engagement with practice, and other research activities and how they intend to build on them. Individuals are offered development packages to meet needs identified in this process; for example, the unit funded **Gamez** gaining an MSc in Data Science. The support emphasises high levels of assistance rather than monitoring arrangements. We make the explicit assumption that all academics, even senior academics, benefit from development, learn from their colleagues, and function best in a collegial environment.

New colleagues work with a named mentor. The mentor introduces the member to researchers and groups both within and beyond the unit.

The unit's collaborative environment and group structure naturally support mentoring of junior colleagues by senior colleagues. Grant proposals from junior colleagues in particular, receive extensive support and development from professors with one usually leading the support. Further review and feedback is provided at the Faculty level. During this REF period, the highly competitive EPSRC New Investigator Grant applications have been supported by senior staff and awarded to **Chen**, **Giannopolis**, and **Martin** (see section 3). The collaborative environment also benefits senior staff, PhD students, and the broader population.

All staff are able to benefit from the University's sabbatical policy, entitling them to apply for 12 months away every seven years of service. This can be used to develop collaborations, write a research related book, or another form of research development. For example, **Raimondi** is currently on a 12-month sabbatical with Amazon (collaborating on verifiably correct systems) and **Wong** spent 24 months with Genetec, working on the commercial rollout of the VALCRI project (see section 1 Case Studies and the study itself). In practice, however, the Department and the Faculty is usually able to facilitate breaks less formally through careful workload management and the unit's collegial mode of operation.

Enabling staff time to teach and research requires careful management of workloads. All staff have a balanced workload comprising teaching, research and administration. Teaching timetable models ensure that most staff get either at least two clear days each week for research or blocks of time, depending on their preferences and the courses being taught.

Colleagues are supported for travel to one research conference each year from the Departmental budgets, and for developmental courses. Further ad hoc support is available from the Faculty research budget. It is not unusual for the Faculty to fund an individual researcher to attend several research conferences in one financial year. The Faculty systematically encourages grant application submission by providing internal funding on external proposals for PhD studentships. For example, **Geng**'s EPSRC fast walking robot grant had a unit funded PhD student for three years to parallel the EPSRC grant. This provides a mechanism to fund PhD studentships and stipends that increases the likelihood of receiving a grant, doubly rewards successful grant proposals, and increases the impact of the grant.

There are four specialist seminar series: the Artificial Intelligence series, the Interaction Design series, the Software Engineering series, and the Intelligent Environments series. Staff and PhD students attending conferences are encouraged to present in these seminars with staff being timetabled to attend their specialist choice. There is also a Computer Science Departmental Colloquium that has enjoyed particular success during the COVID-19 pandemic due to its online nature.

The unit hosts prestigious events, for example the Algorithms and Software Engineering area was able to attract and hold the premier computer science conferences and workshops –BCTCS 2015, TABLEAUX 2019, FroCoS 2019 and MAD (Middlesex Algorithms Day) 2014. In particular, BCTCS 2015 included eminent international prize winning scholars Sir Tony Hoare, Sir Tim Gowers, Per Martin-Löf, and Joseph Sifakis as invited speakers. Ed Awh (U. Chicago), and Tim Gowers (Cambridge) also presented at unit events.

The effectiveness of our focus upon staff development is reflected in the strong advancement of staff. One colleague (**Gamez**) has been promoted to lecturer from associate lecturer, five to senior lecturer (**Chinellato**, **Elmer**, **Gamez**, **Trestian**, and **Le**), **Windridge** was promoted to associate professor. Three colleagues were promoted to professor (**Augusto**, **Dafoulas** and **Nguyen**). All professorial promotions have significantly added to the research leadership in the unit.

2.2 Support for Postgraduate Research Students

Research students are integral to our research community. The number of students on the PhD programmes fluctuated over the REF period but was 41 in 2019/20. The PhD student body is highly diverse. 42% is female, and 74% come from Black, Asian, and Minority Ethnic (BAME) ethnic groupings, of which the largest is Asian (43%). In terms of age, 63% of students are aged 30 and over, 31% between 25 and 29, and 6% between 21 and 24.

47 students have been awarded PhDs by the unit between 2013 and 2019. Each PhD student has a Director of Studies (DoS), and one or more additional supervisors. Some students have a supervisor from an external organisation. Research and student oversight is further provided by two Research Degree Coordinators for the doctoral students submitted in this unit (**Augusto**, **Karamanoglu**); they monitor the progress of Departmental students, keep their supervisory teams under review (in liaison with the Deputy Dean for Research and KE) and actively promote their participation in Departmental seminars and workshops. Staff are required to attend a structured University level training programme before joining supervisory teams and at least one member of a supervisory team must have previously supervised to completion. The student meets with their DoS weekly.

All PhD students have a computer and desk space, most in our large open plan centre to facilitate collaboration with their supervisory team, and between PhD students. The centre seats 70 and is shared by unit PhD students, visiting researchers and relevant PhD students from across the Faculty to facilitate inter-disciplinary collaboration. Research students have full access not only to the well-resourced Sheppard Library on campus, including access to dedicated specialist databases (e.g. SpringerLink, ACM and IEEE), but also other major London libraries, such as the British Library.

Research students receive comprehensive research training through a three-year course, drawing on a wide range of expertise from across the University. The training is designed to prepare students for the milestones in their progression: registration, transfer and viva. The training is aligned to the Vitae research framework, preparing students for both the academic and professional world.

There are over 40 face to face and online PhD student training sessions available. Sessions cover writing (e.g. Writing a Literature Review, and Preparing for your Transfer/Viva Panel(s)), methodology (e.g. Quantitative Frameworks for Data Analysis, and Case Study: a mixed approach), applications (e.g. SPSS, and R Programming in Data Science: Setup and Start), and skills for career development (e.g. Developing a career in academia, and Intellectual Property). The University also runs an annual PhD student conference and most PhD students in the unit have presented posters or oral presentations here, many multiple times.

PhD students are also members of the research groups. They attend CS Departmental colloquia, the four specialist research seminars series, and impromptu research meetings. They frequently present their work in the specialist seminar series, extending communication with academics beyond their supervisory team, and with student colleagues. Presentations include current state of their research, early viva presentations, leading paper discussions, and early versions of conference or workshop presentations.

PhD students are encouraged to publish and are funded from the Faculty research budget to present a paper at a conference up to once a year. They are required to give a presentation at one of the four specialist seminars on the work they present.

Data from the Post Graduate Research Experience Survey is at the Faculty level so includes data from outside of the unit. The student feedback is positive about supervision, research skills, professional development and environment particularly around specialist facilities and digital resources.

Progress is monitored at the post graduate board of studies that takes place twice a year (since 2020, it is once a year); research student representatives are able to present concerns for discussion and resolution. This is further supported by the CS research management team, where PhD students are a standing agenda item. If students are struggling, extra support is given from outside the supervisory team. A member of the Registry is assigned to support research student administration needs. A weekly newsletter goes out informing students of upcoming events. The University runs an annual monitoring and evaluation process of research students at Faculty level.

2.3 **Equality and Diversity**

Equality, diversity and inclusion are core Middlesex values and are reflected in the Middlesex REF5a submission. The University appointed a pro-vice chancellor for equality, diversity and inclusion. Middlesex was the first UK University to receive the Corporate Gold/Embedded Charter

Mark from UK Investor in Equality & Diversity. Middlesex has about three times as many BAME staff as the typical British university. The unit benefits from a range of policies operating at University level (such as parental leave, a University nursery, and flexible working to accommodate family, health or other circumstances). The two Heads of Department contributing staff to this unit submission are both from a BAME background.

The colleagues submitted are ethnically and culturally diverse. While 22 of the 69 submitted colleagues are from Britain, the remaining colleagues come from over 16 different countries. It is difficult to categorise ethnicity, but using the British Census Ethnic Group categories, no ethnic group is in the majority. 45% of submitted colleagues are BAME.

The unit is making progress with respect to gender. In this submission. 14 of the 69 submitted colleagues are female. Attracting women to computer science remains an ongoing challenge and unit colleagues (**Gao** and **Karamanoglu**) participated in workshops organised by CPHC to improve gender representation. There is an effective Women in Computing group in the unit led by **Androutsopoulos**. In 2017, Rosie Hyde, a third year student, and member of our Women in Computing group won the People's Choice Award at the BCS Lovelace Colloquium for her poster entitled Can Stress and Anxiety be Tracked Through Wearable Technology?

Age diversity across the submitted colleagues is relatively even across the range of 30 to 65. Two colleagues are over 65.

The REF working group for the unit paid close attention to the University's REF code of practice, and was trained in equality, diversity and unconscious bias. Recognising that we all have unconscious bias, we have taken particular care with issues of diversity and inclusion. All outputs are marked with the same agreed mark sheet, and by at least two markers.

The unit supports the family and personal obligations of all members of staff, such as parents of young children. People with caring responsibilities can have flexible working conditions, protecting them from teaching and other duties that require University attendance in especially pressured times. Breaks in activity for any reason, such as maternity or paternity, compassionate leave, or illness, are managed sensitively. During the Covid-19 pandemic, the unit provides additional flexible working support for staff with family commitments.

3. Income, infrastructure and facilities

The major developments that have taken place in the period have been the result of strategic planning and investment, supported by strong governance and quality processes at all levels. The unit benefits from sustained investment but also a focused estate strategy. Income associated with REF 2014 (£800K annually) was returned to the unit, either directly or through PhD studentships managed centrally. The unit worked with the University to establish an additional, planned, long term strategy for investment in staffing from existing core funds, with the additional REF funding supporting growth in infrastructure, additional support for existing and new research areas and, critically, investment in high-risk ventures.

The unit spent £6,824,178 in external research income awarded from a wide variety of funders during the REF period (see Table 1). This supports the ongoing development of our excellent infrastructure and facilities. Our strategy focuses on sources of income where we have expertise and a track record. Funding is concentrated on UKRI and EU sources. Other avenues have been identified where our research strengths allow us to make a credible and authentic bid. In particular,

we chose to identify Knowledge Transfer Partnerships as both an income stream and a concrete pathway to impact.

Table 1: Annual Research Spend from External Sources

2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
£410,431	£1,207,104	£834,554	£1,197,646	£1,270,092	£1,028,941	£875,410

3.1 Income

Unit research income comes from many grant awarding bodies, industry, charities and other sources. This amounts to an almost doubling since the REF 2014 (£3.6m). Particularly noteworthy grants include:

EU Projects

An FP7 project (#608142), Visual Analytics for Sense-making in CRiminal Intelligence analysis (VALCRI), for £10.04m was led by **Wong**, with the unit receiving £2.08m. Another FP7 funded project, PersOnalized Smart Environments to increase Inclusion of people with DOwn's SyNdrome (#610840), for £401k was led by **Augusto**. Both projects demonstrate our plans to increase impact from our research and have led to two impact case studies in this submission.

Gao (AI group) led an FP7 (#269124) project entitled Warehousing Images in the Digital Hospital (WIDTH): Interpretation, Infrastructure, and Integration, funded for £463K. The project catalysed collaboration between Europe and China to explore medical imaging innovations and led to a large open source medical database.

Huyck and **Mitchell** (AI group) won grants totalling £336K as part of the Human Brain Project (#785907); this is described in section 4 under the NEAL grant.

Windridge (AI group) is part of an H2020 consortium awarded a grant for £3.87m entitled Dream-like simulation abilities for automated cars - Dreams4Cars, (#731593). The unit received £467K. Windridge and colleagues developed a general framework by which an agent can generate simulated data to learn from to benefit the agent. This has led to, for example, **Windridge**'s Adaptive Behaviour paper.

The unit won several Erasmus awards. **Dafoulas** (Intelligent Environments group) was awarded a £93K grant for technologies to help Palestinian higher education institution (see section 4 computer-supported cooperative work). **Springett** and **Whitney** (Interaction Design group) received a £384K Erasmus grant entitled Gameplay for Inspiring Digital Adoption.

EPSRC Projects

An EPSRC sponsored grant for £456K entitled A Neuromorphic Control System for Agile Biped Locomotion EP/P00542X/1 (**Geng**, **Huyck**, and **Z. Yang** from the AI group) is developing a fast walking bipedal robot.

An EPSRC sponsored grant for £281K (£31K to the unit) for Verification of Resource-Bounded Multi-Agents Systems EP/K033905/1 included **Raimondi** (Algorithms and Software Engineering group) as a co-investigator. A systematic framework for modelling resource requirements for agents' actions that can be formally verified was developed.

Kammueller, **Jones**, and **Augusto** (Algorithms and Software Engineering and Intelligent Environments groups) have led a £200K EPSRC funded grant entitled Secure Accessibility for the internet of things (SUCCESS) EP/P016456/1. Two pilot systems were installed in our Smart Spaces Lab and are used for experimentation and demonstration of the SUCCESS toolchain.

Three colleagues from the Algorithms and Software Engineering group (**Chen**, **Giannopolis** and **Martin**) were awarded EPSRC sponsored first grants. **Chen** won a grant for £101K entitled Perturbation Analysis for Probabilistic Verification EP/P00430X/2, leading to a closed-form formulation of asymptotic perturbation bounds, and computational methods for two forms of those bounds. **Giannopolis** was awarded a grant for £96k entitled Fixed Parameter Tractability for Geometric Optimization Problems EP/N029143/1, which led to a proof that a disjoint union of cycles is the complement of a disk graph if and only if at most one of those cycles is of odd length.

Giannopolis also derived a subexponential algorithm running in time $O(2^{n^{\frac{2}{3}}})$ for Maximum Clique detection on disk graphs. **Martin** won a grant for £125K entitled Infinite-domain Constraint Satisfaction Problems (CSPs) EP/L005654/1. This work led to a proof that every discrete temporal CSP is in Ptime or NP-complete, unless it can be formulated as a finite domain CSP in which case the computational complexity is not known in general.

PNEUMACRIT EP/T001240/1 is a £1.8M EPSRC sponsored grant including **Tizzard** (Algorithms and Software Engineering group), the unit receiving £77K. This is developing a multi sensor wearable imaging system that will inform lung function diagnosis for infants and children with conditions that can lead to respiratory problems.

Other Funded Projects

CoRLEIT EP/V044036/1 is a UKRI funded project (involving **Tizzard** from the Algorithms and Software Engineering group) for £700K (£70K to the unit) to apply Electrical Impedance Tomography to Covid-19 patients. A key challenge for the Covid-19 pandemic is the requirement to monitor for deterioration and provide timely escalation interventions to an unprecedented number of patients at risk of respiratory failure.

Attfield (Interaction Design group) was awarded £233K funding from BAE Systems. This work explores Human Machine Interaction (see section 4 Industrial Collaboration).

Raimondi (Algorithms and Software Engineering group) was awarded a KTP for £160K to support Caritas Anchor House in the development of a software application implementing a Global Notice Board for charitable, humanitarian purposes. **Petridis** (AI group) was awarded a KTP for £210K with the London and Southeastern Railway providing insights into real-time patterns of passenger rail services run within the network.

Nguyen (Networks group) received a UKIERI grant for £162K entitled Digital Twin Modelling for Automation, Maintenance and Monitoring in Industry 4.0 Smart Factory. A further grant for £133K was awarded to **Nguyen** by the British council to examine the use of Digital Twins for early detection of large infrastructure deterioration (see the case study).

3.2 Infrastructure and Facilities

Research management infrastructure at the University level is provided through the well-established Research and Knowledge Transfer Office (RKTO), providing support for research and knowledge transfer work including doctoral teaching. Led by the University Director of Research (**Comley**), the RKTO provides a 'one-stop shop' that delivers a highly visible, supportive and

authoritative resource for research active staff in relation to research funding, delivering impact, managing research projects, knowledge transfer activities and doctoral student support.

Over the REF period, the unit extended our excellent research facilities within the Faculty to support both this unit and research at the edges of discipline boundaries. These include the AI lab, the HCI lab, and robotics development and engineering facilities. Our excellent library facilities and other facilities are described in REF 5a. As part of the investment in new areas of research following REF2014, the University provides the Smart Spaces Laboratory in the Farmside building for the Intelligent Environments group. It won the 2019 edition of the Real AI competition organized by the British Computer Society.

In 2016, Middlesex opened its new £18m Ritterman Building. This building includes extensive robotics, digital electronics, and networking facilities for research and teaching. It features adaptable space, which supports a range of research and collaborative activities.

The unit purchased a wide variety of new equipment. For example, in 2020, servers were purchased for £190K to support data science research and teaching. These were targeted toward the MSc in Data Science, and are used more broadly by unit colleagues.

The unit provided an initial £22K investment for VANET, a prototype Connected Vehicle Testbed for the larger systems later developed (see section 4 Intelligent Transportation Systems). Unit colleagues use several neuromorphic computing platforms; there are several SpiNNaker boards available for research and development. These are used, for example, for fast walking robot control.

Facilities in other units are available to UoA11 colleagues. Eye tracking equipment, EEG equipment, and magnetic brain stimulation (TMS) equipment is shared with Psychology; for example, **Chinellato** uses TMS to study kinematics and brain activity. While other units use expertise and facilities from our unit, practical data can also be gathered from other units. For example, the sports unit provides data from fencing, football and rugby games for analysis as yet another example of the breadth of data science work at Middlesex.

The networking labs are locally designed state of the art labs. They are equipped with the latest networking devices and tools to design, build and secure networks at access, distribution, and core layers. They have all intermediate devices for networking, layers 2 and 3 switches, routers and dedicated firewalls. In September 2020, the labs had a £50K upgrade to the latest available equipment on the market. The labs have 4221 routers, ASA 5506 firewalls, 3960 layer 3 switches, and WiFi routers.

The unit's robotics facilities are particularly formidable. We have even designed our own MIRTO robot that is used for research and teaching, and the design is publicly available. The unit also has a Rethink Robotics Baxter robot, two Alderban Pepper robots, and other robots. There are many effectors and sensors including two ABB IR120 robot arms, two Universal Robots UR10 robot arms, a Universal Robots UR5 robot arm, two Velodyne Lidar units and a Festo Industry 4.0 factory system. Our 3D printers include an Object Connex 500 Polyjet printer, a Markforge Mark Two Carbon fibre 3D printer, two FFormlab Form3 printers, and a Dimension D printer. These core robotics resources support the development, evolution, and maintenance of robots for a range of research activities. These facilities have supported several good publications, such as **Gandhi**'s EEG-based mobile robot control through an adaptive brain–robot interface.

In 2020, the unit invested £35K in two 'Digital Twin in a Box' bespoke designs mimicking a small production system purchased from Festo. Each unit contains three processes, mimicking a small production system providing both analogue and digital data. The systems also exist digitally, providing a realistic research workbench for creating digital twins for analysis of scenarios such as preventative maintenance, process improvement and cyber security applications.

A team of 25 experienced technicians, managed through the Faculty, supports the unit's research equipment. The team has additional staffing resource through graduate assistants.

The facilities and infrastructure lend excellent research support for the students and for unit colleagues. Moreover, new needs are readily supported through our flexible resource allocation strategy and technical team. For example, **Barn**'s travel to India for collaboration with TCS in 2019 was funded from the research budget.

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

The unit contributes to the research base, including ground breaking research, in for example visual analytics and machine learning, and a wide array of other leading research. It contributes to the economy through contract research and industrial collaboration, and to society at large by developing students, interacting with the public at large, and working with governmental and non-governmental organisations.

4.1 Contribution to the research base

Colleagues submitted in the unit collaborate broadly, both internally and externally. Most colleagues review regularly for journals (for example Machine Learning Research (**Belavkin**), IEEE Access (**Cheng**) and Information Fusion (**Gao** and **Windridge**)), conferences, and funding proposals. Most have examined PhD students during the REF period. Many colleagues have roles on editorial boards (editor in chief (**Augusto**) Ambient Intelligence and Smart Environments, editor (**Wong**) Journal of Cognitive Engineering and Decision Making, and editor (**Trestian**) IEEE Communications Surveys and Tutorial); have been involved in organising workshops, conferences and other events; and have given keynote addresses and invited talks (AAAI **Augusto**, Confluence 19 **Mapp**, and U. Tokyo **Belavkin**). Colleagues are involved on several standards panels, e.g. **Whitney** (BSI Diversity and Inclusivity Advisory Panel, and security standard ISO/PC 317). All colleagues have collaborated with other academic institutions. Middlesex hosts conferences on campus, e.g., the workshop on Developments in ICT and Healthcare - Legal, Ethical and Social Aspects, the 12th edition of the International Conference on Intelligent Environments, and the Algorithms and Software Engineering group hosted the 31st British Colloquium of Theoretical Computer Science.

4.2 National and International Collaborations

The unit collaborates extensively with other academic researchers, industry, government, and society at large. Many of these collaborations are long-standing and demonstrate a sustainable network of collaborators.

The best illustration of our collaborations with industry and beyond are located in our five selected impact cases studies: VALCRI, Young Offenders, Digital Twins, Intelligent Environments, and EIT (see section 1 Case Studies, and the studies themselves). The VALCRI project with seven academic, five commercial, and five governmental partners is an example of scale of collaboration. The Digital Twins case study is an example of a research and knowledge collaboration that goes back to 2012. Other areas of excellence include verified systems; mutation, biological nets, and

robotics; collaboration with Middlesex's Malta campus; intelligent transportation systems; computer-supported cooperative work and supporting universities outside the UK; and medical imaging.

Verified Systems

Colleagues in the Algorithms and Software Engineering group have constructed, verified and analysed software systems to achieve a high level of assurance in their correctness, in terms of safety, confidentiality and integrity. This includes RacerD (**Gorogiannis**), a data race detector, and several systems for verifying information flow properties. RacerD addresses data race concurrency bugs that are hard to reason about and reproduce; it is used in the static analyser suite developed at Facebook London. It detects data races statically, so there is no need to build and execute the program; in addition, RacerD can perform without the whole program being available and has been proven to have no false positive reports under certain assumptions. RacerD verifies that systems do not have data race errors.

A scheme for the construction of web applications with formally verified confidentiality and integrity has been developed by **Raimondi** and **Popescu** in collaboration with researchers from the Technical University Munich, the University of Bremen and the Global Notice Board. The scheme has been applied to produce CoCon, a feature-rich multi-user conference management system with formally verified confidentiality. Other instances of this scheme are CoSMed, a prototype social media platform with verified confidentiality, and CoSMeDis, a multi-node distributed extension of CoSMed following a dispora* model. CoSMed and CoSMeDis have been developed in partnership with a UK charity.

Mutation, Biological Nets, and Robotics

Belavkin (AI group) has a particularly successful interdisciplinary collaboration involving mutation. The consortium, involving Manchester, Keele, and Cambridge, hypothesised that mutation rates are influenced by fitness. **Belavkin** showed, information theoretically, that this was the case, and included this assumption into a simulation reflecting mutation rate plasticity. Other members of the consortium then used this to show how bacteria evolve antibiotic resistance, supporting the theory with biological evidence. This work is supported by BBSRC grants for £621K (Adaptive landscapes of antibiotic resistance: population size and `survival-of-the-flattest') and £465K (The theory and practice of evolvability: Effects and mechanisms of mutation rate).

The AI group simulates biological neural nets (**Huyck**, **Mitchell** and **Chinellato**). The NEAL project developed agents that function in virtual environments, and an agent component architecture for the Human Brain Project (HBP), running in both simulation and on neuromorphic hardware (e.g. SpiNNaker). As a member of the billion euro HBP, the unit collaborates extensively with leading European labs (e.g. Heidelberg and Manchester). In related work, robotic forward models and a neural cognitive architecture, both in spiking neurons, have been developed. The group also decodes biological neural behaviour data, e.g. kinematics and hand pose configuration.

Members of the AI group (**Chinellato** and **Karamanoglu**) have done significant work including a pilot project on the back of an existing project (Good Start, Great Start), using robots in a classroom setting involving a consortium of primary schools in Birmingham. The aim was to see how robots could assist the classroom teacher and how they can help children with specialist needs, with field trials conducted in schools.

Collaboration with Middlesex's Malta Campus

Colleagues in the Intelligent Environments group and the AI group (**Smith** and **Windridge**), in collaboration with Middlesex's Malta campus, are working on collaborative interactive technologies for education. Stemming from strong learning and teaching collaborations between the two campuses, the group undertakes development and evaluates educational technologies and methodologies. They have particular focus on tangible user interfaces; augmented, virtual, and mixed reality; educational robotics; enhanced e-learning platforms; and AI recommender systems for education.

Intelligent Transportation Systems

Mapp, **Nguyen**, and **Shah** (Networks Group) have worked on vehicular ad hoc networks, developing analytical models and simulating and deploying Connected Vehicle Testbeds (CVTs). This program of research is helping the Department for Transportation (DfT) understand how intelligent transportation systems will work and has involved a large number of stakeholders including the DfT, Transport for London, Kings College 5G Lab, City of York Council, Lear Corporation, Cohda Wireless and Virgin Media. The underpinning research consists of the development of new analytical models, the use of simulation, and the deployment of CVTs. It first explored seamless connectivity in vehicular environments by looking at a vehicular simulation tool using the unit's previous research on the Y-Comm framework. Probabilistic models showed that seamless connectivity depends on the frequency and length of the beacon from the Roadside Units and the velocity of the vehicle. Next, several CVTs were built including a 4.2 kilometres CVT in York, one of the longest public CVTs in the UK; these confirmed the models. The research showed, e.g., that in order to build a national cooperative intelligent transportation network, a secure Connected Vehicle Application Framework to build applications for vehicular networks and a better understanding of the geographical nature and traffic characteristics of different regions were needed. This work supports the unit's development of the new MSc Cooperative Intelligent Transport Systems, which will create a body of skilled engineers capable of developing and managing intelligent transport infrastructure.

Computer-Supported Cooperative Work and Supporting Universities Outside the UK

Dafoulas (Intelligent Environments group) worked on many computer-supported cooperative work projects. One project created infrastructure, ran pilot studies, and collected and analysed communication and collaboration patterns in geographically dispersed teams of software engineering and computing students. This supported the integration of 'virtuality' activities in a postgraduate programme that is jointly delivered by six universities, three institutions in Egypt and three in Palestine. Another project investigated how 2-3 week projects challenged participating students and instructors, including universities from the US, Panama, Turkey and the UK; there were approximately 30 pilot experiments. Another project identified the factors affecting the performance of global software teams. Another enhanced the capacity of Palestinian higher education institutions in promoting cross border employability of graduates, providing them with the capabilities for effective cross border working.

Colleagues in the Intelligent Environments group (**Dafoulas** and **Saleeb**) support universities outside the UK and beyond Middlesex. They have been critical for the training of four Georgian institutions as part of the MAHATMA project focusing on management practices in Higher Education, and are currently training staff at Akaki Tsereteli in e-learning practices. Colleagues have also coordinated transformation of educational systems in more than 50 institutions as part of ten capacity building projects training more than 1,500 academics, administrators and executives. **Dafoulas** is also leading the QA work packages for seven EU capacity building projects and coordinates an EU strategic partnership. The EQAC project involves 11 institutions in Azerbaijan, introducing a dramatic change across the sector.

Medical Imaging

Gao and **Windridge** (AI group) are having profound impact on public healthcare. Drawing extensively on developments in signal processing, machine learning, and computer vision in the unit over the last 20 years, particularly in areas with heterogeneous, complex data sources. Several systems have been developed that are in active use globally in medical procedures. Four particular examples include providing research and practical tools to assist clinical decision-making and to enhance further research development; for example, imaging methods developed with Alder Hey Children's Hospital were responsible for the first determination of the neural correlates of post-operative cerebellar mutism syndrome. Second, training junior clinicians in screening heart disease from electrocardiograms in use at Tsinghua First Affiliated hospital in Beijing. Third, improving clinical outcome and reducing waiting lists for image-guided neurosurgery currently in use at the Navy General Hospital in Beijing. Fourth, a real-time system to detect early stages of oesophageal cancers has been evaluated in the Endoscopy Unit in collaboration with Oxford John Radcliff Hospital.

Further Examples of Industrial Collaboration

During this REF period colleagues in Interaction Design (**Attfield** and **Wong**) have conducted a number of funded research projects involving collaboration with industrial partners. Many of these projects have been in the defence and security sector on a number of Ministry of Defence funded programmes including DHCSTC, DASA, HSSRC and SERAPIS. Companies include: Thales, Rina, BAE Systems, BMT, ARK, Mass Ltd and Trimetis Ltd. Colleagues have provided expertise in visual analytics, user-research, machine learning and user-interface design. **Attfield** led on a two-and-a-half-year BAE funded project for £236K collaborating with BMT, Trimetis Ltd, Thales, ARK and RINA; colleagues investigated the use of emerging human machine interface technologies in military scenarios with a focus on minimising cognitive demand, minimising training requirements and developing User Experience Design techniques for emerging technology.

Attfield also led on a partnership with Mass Ltd. exploring human automation teaming for the early recognition of kill-chains thus pre-empting attacks; a one year project in developing novel interactive computer visualisations for defence analysts performing Patterns of Life analysis; an eighteen-month project in collaboration with BAE Systems, Cranfield University and MASS Ltd. on novel display methods to improve the assimilation of multiple source information by military intelligence operators; and a two year project in collaboration with Trimetis Ltd. and Birmingham conducting experimental research to derive and validate principles of distributed sensemaking. **Wong** led a project and partnered with US-based MITRE Corp.; the project was based on how tactile reasoning user interface could be used for monitoring and re-constructing incidents such as accidents in ports.

Unit colleagues have collaborated with industry through KTPs (see section 3 Other Funded Projects). The AI group (**Huyck**) collaborated with Fountech to develop Prospex, a lead generation system.

The London Digital Twin Centre (**Barn** and **Nguyen**) includes several industrial collaborators such as Mallik Tatipamula the CTO of Ericsson Group Function Technologies & Architectures. The Centre is supported by Siemens, Ansys and others. Middlesex is one of four universities in the UK taking part in the 2-year pilot to use I4.0 technologies. Siemens and Festo provide a significant amount of in kind support, much of it used by the Centre. Projects within the centre include partnerships with universities from Vietnam and India. Automobile-based Digital-Twining using

perception-action hierarchies was a feature of the interaction with FIAT CRF (**Windridge**) in the context of the DREAMS4CARS project.

Twenty-four pieces of VALCRI IP produced by the unit team were acquired by Genetec, Inc., a Montreal-based, global security systems company, for an undisclosed but significant sum and an annual royalty payment stream. Genetec created a new business unit to market the new Valcri™ product. To enable the knowledge transfer, Wong and four key researchers from the Interaction Deisgn group were employed by Genetec in leading roles in the new Valcri™ Product Group. The VALCRI acquisition catalysed the investment by Genetec to set up a new Genetec UK head office in London in November 2019.

4.3 Engagement with Stakeholders

Collaboration with Government

The unit collaborates with government both locally and nationally. A unit robot testifying before parliament is described below in Robotics Engagement. Colleagues have participated in parliamentary advisory debates, e.g. **Huyck** (AI) and **Aiash** (Cybercrime). The research on mobile applications for youth offending teams has been presented to the Youth Justice Board and also the UK Home Office.

The unit shares close links with the local council, Barnet, with most unit colleagues actually based in the Hendon Town Hall, which Middlesex shares with the Barnet council. Colleagues in the unit have acted as data analysis consultants on numerous projects across the Young Barnet Foundation. Developed in response to the ongoing challenges facing the Children and Young People's sector, the Young Barnet Foundation brings together the public, private and voluntary sectors to effect positive change for young people. Colleagues have developed rigorous data collection techniques, research design, and data collection methods for the Foundation. **Augusto** received a grant for £120K, entitled Gamification for Healthier Lifestyles, in collaboration with Greenwich Leisure Ltd. and London Borough of Barnet.

Engagement with the General Public

All researchers are encouraged to see public engagement as a key part of their research activities, and the Faculty has systems in place to facilitate engagement with a long history of success. The unit engages extensively with the local community, nationally, and internationally.

Middlesex's annual STEM festival has substantial input from the unit, and this festival is visited by a large number of local citizens, and particularly by secondary students. The 2020 festival featured a hand washing robot in the early days of the pandemic. The 2019 festival included a virtual reality experience, interacting with data, and brain computer interfaces.

Kotsia presented an exhibit as part of a Live Science residency at the Science Museum that ran from February - March 2020. The exhibit used wearable brain-scanning devices to record the underlying neural activity to study the effects of music on the listener's brain dynamics.

Each year, colleagues participate in New Scientist Live, the world's greatest science festival. The unit has presented dozens of features including a life-sized Super Mario game in 2018, robots taking selfies in 2017, and conversational robots in 2019.

Thrills

Walker, our thrill engineer, has been seen on BBC2. Walker's thrill laboratory makes extensive use of virtual reality, and develops technology that entertains and enthuses people. E.g. Neurosis

is the first brain controlled thrill ride, featuring a six-degree-of-freedom motion simulator and virtual reality headset to immerse the rider in a surreal environment, controlled not by a ride operator, but by the rider's own brain activity.

Robotics Engagement

Robots are broadly accessible to the public, and their use continues to grow rapidly. The unit continues to interact with the public using robots to explain, teach, and excite. E.g. the unit is heavily involved in the Eurobot cup hosting the UK national Eurobot cup (https://www.eurobot.org/eurobot/eurobot-2019/national-contests), though the 2020 version was cancelled due to Covid-19. Its students participate each year and have won prizes in the competition.

A unit robot was the first robot to give evidence at the House of Commons. In 2018, a unit robot was the first non-human to give evidence to parliament, showing the potential and limitations of robotics and AI. The robot promoted discussion of the unit's current research using robots to help care for the elderly and outreach programmes at the University encouraging STEM uptake among would-be students.