Institution: Queen Mary University of London
Unit of Assessment: 11 Computer Science
1. Unit context and structure, research and impact strategy

1.1 Unit context and structure: The 68.8 FTE staff in UoA11 are from the School of Electronic Engineering and Computer Science (EECS), which was formed in 2008 through merger of the CS and EE departments. EECS is run as a single administrative entity with no distinction between the two pre-existing departments. Our vision is that research in the discipline speaks to both fundamental science and the engineering of large-scale technological systems, and that linking these activities in the same academic unit benefits both, though they remain reportable separately at REF (UoA11 and UoA12) and by HESA (cost centres 119 and 121).

UoA11, like UoA12, has had great success delivering the REF2014 strategy to make QMUL the premier institution for engineering, material and computer science research. The UoA11 REF2021 submission consists of all units of Computer Science and two additional EECS groups; the **Centre for Digital Music** (C4DM) and **Multimedia & Vision** (MMV), which include computer science oriented research under the umbrella of digital economy. This has been driven by expanding expertise in the five groups submitted to Computer Science in REF2014 (**Networks**, **Theory**, **Risk Information Management**, **Cognitive Science**, and **Computer Vision**). This submission also includes two new groups (**Game AI and the Operational Research Lab**, **Communications Systems**).

1.2 Key UoA11 achievements in REF2021

- An increase of UoA11's REF submitted staff headcount from 55 to 75.
- Growth in annual PGR recruitment by 31% from 51 in 2013/14, and growth in PhD awards by 41% from 29 in 2013/14.
- Current PGR population/staff FTE = 3.68 (Russell Group 90th Percentile for 2018/19 =3.03).
- Growth in PGR training provision: EPSRC CDT in Media and Arts Technology renewed in 2013/14 and 2019; two new EPSRC CDTs AIM, and IGGI (joint with York); a share in Wellcome Trust DTP; a QMUL/BBC funded CDT (DAME).
- An active grant portfolio of £37.2m (89 grants; £541k/FTE).
- Coordination of four EU projects (€12.2m), plus two ERC grants (£3.2m).
- Major UKRI grants include FAST-IMPACt (£5.2m); PAMBAYESIAN (£1.5m); EARL (£2m).
- Published 3,042 Scholarly Outputs (SciVal) = 44.2/FTE (@9/7/20)
- Consultations with 24 different companies and founding/co-founding 13 new start-up companies.
- 18 staff are Alan Turing Institute Fellows.

1.3 Strategy

1.3.1 Research strategy: Interdisciplinary research remains a key strategy and the spread of collaborators has been considerably enhanced (§4.1). Staff appointments have been used to grow, strengthen and deepen existing areas of research excellence or support the development of new research opportunities, exemplified by the creation of the new research groups (18 new academics §2.1) and the strengthening of all existing UoA11 groups with new academics (Table 2.1).

We have recognised the growing importance of AI and this is now a core thread that runs through much of our research, with the creation of the GAME-AI group and with all other research groups

embracing AI. This was aided by a major investment (2019/20) in 10 new academic staff in AI and Data Science, with appointments across research groups. This strategy aligns with the UK-Government Industrial Strategy White Paper (2017), the Royal Society and the RAEng (Hall & Pesenti's) review that recommended more PhD places in AI/Machine Learning.

We have continued to enhance research in the Creative Industries sector (C4DM, COGSCI), which is the UK's fastest growing sector. Bazalgette's 'Independent Review of the Creative Industries' highlights the "importance of the music industry" as of "central importance to the UK's productivity and global success". Exemplifiers are the recent AIM, IGGI and DAME CDT awards and new staff recruitment (Table 2.1).

This strategy is derived through the interplay between the EECS Senior Management Team (SMT), Research Group Heads (RGH) and Research Committee via the Head of School and the Director of Research, and aligns with the QM2030 Strategy [REF5a].

Looking forward, our strategy for research growth, all of which cross group boundaries are focused on the following areas:

- Artificial Intelligence (all groups)
- Autonomous systems (CIS, MMV, CSR, GAME)
- Better modelling of human cognition (COGSCI, RIM, VISION, MMV, GAME)
- Beyond 5G Systems (CSR, NETWORKS)
- Creative Industries (GAME, C4DM, MMV, NETWORKS, CIS)
- Cyber-physical systems & robotics (COGSCI, C4DM)
- Data science (C4DM, NETWORKS, RIM)
- Digital Health (MMV, RIM, CIS, COGSCI)
- Multimodal environmental sensing (domestic, urban, natural, global) (CIS, C4DM)
- Quantum systems (computing etc.) (THEORY).

We will increase industrial engagement through Innovate-UK, KTPs and KTAs and improve our commercialisation of research through a revised frame of reference for the Industrial Board and developing on-line events such as "Research Week 2020", which attracted 285 attendees through 10 themed webinars.

1.3.2 Impact strategy: Impact, innovation and engagement are central to all UoA11 research activity. Operational support is provided at Faculty and School levels by Impact Managers and Faculty Impact Officers led by the Deputy Vice-Principal for Research and Innovation (position launched 2018). Research commercialisation is supported by Queen Mary Innovations Ltd (QMI). QMUL's award winning Centre for Public Engagement (CPE) (§4.3) provides expertise and funding for relevant impact generation activities [REF5a].

An Academic Impact Champion (Reiss) is responsible for identifying research with impact potential and realising impact via a range of institutional support routes. Impact excellence is integrated into staff induction, probation and annual appraisals, at all levels of seniority. Major impact activities are recognised annually at QMUL's Engagement and Enterprise Awards. Since 2014 UoA11 staff have (§4.2):

- held consultancies with 24 different companies,
- founded/co-founded 13 new start-up companies, and
- had 16 awarded patents, plus 15 currently filed.

Eight Impact Case Studies were shortlisted for REF submission and each involves successful, high growth spin-out companies, including AIM-listed Actual Experience and LandR, an online music mixing service with over 2.8m users. They demonstrate measurable impact on:

- Policy (Causal Bayesian Reasoning, Actual Experience [UOA12]),
- Law (SeeQuestor, Causal Bayesian Reasoning),
- Societal behaviour (Psychology Online, Bela).

All involve disruptive innovations (e.g. Monoidics, LandR, Dragonfly [§1.4.9]), building on high impact, transformative research. Additional research activities leading to spin-outs are listed in §4.2. **Looking forward**, we will exploit the full potential impact of our research by tracking impact opportunities and sharing best practices. Increasing collaboration across research groups, Schools and Faculties will enable high impact activities that would not otherwise be achieved (e.g., DTP Health Data in Practice with Blizard Institute; CDT DAME). Industrial collaboration will be enhanced by maintaining strong links through increasing KTPs, placements from CDTs, enhancing our Industrial Board (§4.2), plus spreading annual networking events to a wider audience, e.g. Faculty Industry-Research Engagement days. We have recently increased our links with Tech Industry (e.g. CDT IGGI), and have attracted nearly £1m in studentship donations.

In September 2020 QMUL launched a £15m investment to create the Digital Environment Research Institute (DERI), supporting ambitions to maintain UK leadership in data science and AI [REF5a]. DERI builds on globally recognised expertise at QMUL, fostering new collaborations across all Faculties and developing existing partnerships with key organisations including Barts NHS Trust and Turing Institute. Its Director (Slabaugh, Professor of Computer Vision and AI) joined EECS from Huawei Technologies R&D.

QMUL was recently awarded University Enterprise Zone (UEZ) status (one of twelve in the UK) with £1.5m funding to enhance engagement and impact generation with innovative businesses within East London, with a focus on Medical Technologies and Digital Health innovation [REF5a].

1.4 Research group summary and future strategy

1.4.1 Centre for Digital Music

Academic Staff	12 (11.7 FTE)
Professor	Bryan-Kinns, Dixon, Reiss, Sandler (0.7)
Reader	McPherson
Senior Lecturer	Fazekas, Stockman, Barthet, Benetos
Lecturer	Phan, Saitis, Stowell
Fellowships	4 EPSRC/RAEng Fellowships, 3 Turing Fellows, one RS Wolfson Research Merit Award, one FREng
PGR Students	68
Number Scholarly Outputs (Scival)	614; 52.5/FTE

C4DM is one of the world's foremost multidisciplinary groups in the field of Music & Audio Research and the UK's leading Digital Music research group. Research covers everything in digital music and audio: from analysis, understanding and retrieval, to delivery, synthesis, sound rendering, music interaction and digital musical instruments.

Major achievements: C4DM led the EPSRC Programme grant FAST-IMPACt, bringing together Nottingham University's Mixed Reality Lab and Oxford University's e-Research Centre, plus international advisors and collaborators from industry and academia.

C4DM leads 3 full CDTs: MAT, renewed in 2013/14; AIM, new in 2019; and joint QMUL/BBC DAME (2020). It has an EU PhD ITN, 'New Frontiers in Music Information Processing'.

Bela has become a leading open-source hardware platform for creating interactive music systems [REF3]. Open-source contributions include: *Sonic Visualiser*, widely used in corporate and academic research, for music and audio analysis; *Tony*, for speech analysis; and *Sonic Lineup* for comparing multiple performances. Commercialisation includes several successful spinouts, from Landr [REF3] (valued >£25m) to Augmented Instruments Ltd (which seed-funded Bela via Kickstarter campaign) to the Warblr birdsong app.

Future strategy: C4DM aspires to be the world's best university research centre covering the widest diversity of topics in the science and technologies of Music and Audio. To achieve this C4DM will continue developing world-leading strengths in DSP, Semantic Web technology, and Music Informatics. It will expand research in Audio Engineering, Augmented Instruments and Music-Human Interaction. It will establish new themes, including:

- Data Science for Music, Audio and Bioacoustics
- AI for Music, including intelligent instruments
- Music Computational Creativity, including machine-assisted creativity
- Virtual and Computational Acoustics for immersive audio, instrument synthesis
- Performance Science: scientific techniques to better understand musical performance
- Multimodal Music and Audio Processing (with CIS).

CDTs MAT and AIM will be a significant force for achieving these aims.

For external partnerships C4DM will:

- Enhance interactions with the Turing Institute, co-creating its AI for Arts theme.
- Strategically partner with the BBC, and spread this across QMUL.
- Continue collaborating with other world-leading centres such as McGill, NYU, Polimi, Georgia Tech, Barcelona and IRCAM.

1.4.2 Cognitive Science

Academic Staff	11 (9.2 FTE)
Professor	Curzon (0.9), Healey, Lappin (0.2), Liakata (0.8), Poesio, Purver (0.5)
Senior Lecturer	Ma (0.8), Pearce
Lecturer	Hough, Naeem, Zubiaga
Fellowships	2 British Academy Fellows, 4 Turing Fellows, one ERC Advanced Fellow
PGR Students	38
Number Scholarly Outputs (Scival)	307; 33.4/FTE

COGSCI is a multi-disciplinary group that studies human cognition, action and interaction on scales ranging from individual experience up to the languages, cultures and dynamics of whole societies.

COGSCI combines empirical and computational methods and has critical mass in Human Interaction, Natural Language Processing, Outreach and Education, and Social Data Science. COGSCI is distinguished internationally by its focus on human-human interaction, understanding the computational mechanisms at the heart of human capacities such as creativity and musical appreciation and its outreach work.

Major achievements: COGSCI leads Computer Science for Fun (cs4fn) and world-leading public engagement work, including the multi-award winning Clapping Music app (>350k downloads) and the 2020 IEEE Computer Society Taylor L. Booth Education Award. COGSCI has a wide track record of funding from AHRC, EPSRC, ERC, ESRC, MRC, Wellcome. Recent major grants include:

- EMBEDDIA (£3m, H2020)
- Health Data in Practice (£5.5m, Wellcome DTP - led by the School of Medicine and Dentistry (SMD))

COGSCI led a 'Topics in Cognitive Science' special issue on 'Miscommunication' in 2018, which was selected as one of thirteen 'Visions of Cognitive Science' to mark the 40th anniversary of the Cognitive Science Society. COGSCI regularly hosts international meetings including 2017's 7thJoint Action Meeting (JAM), 23rd Semantics and 2019's Pragmatics of Dialogue Meeting.

Future strategy: COGSCI provides major opportunities for social and economic impact, especially in healthcare where good communication is essential for diagnosis and treatment. This directly addresses major UK policy priorities including the 2019 Topol Review, the NHS long-term plan, and UKRI health and ICT research priorities. COGSCI is building on its high impact novel healthcare technologies through new partnerships with Barts Health NHS and the Turing Institute's *Health Programme*. COGSCI promotes gender balance in CS and EE through its world-leading outreach work §4.3, teacher training initiatives (e.g. CPD network 'Teaching London Computing') and advice to government.

1.4.3 Communication Systems Research

Academic Staff	7 (6.2 FTE)
Professor	Nallanathan, Yang (0.2)
Senior Lecturer	Bodanese, Elkashlan
Lecturer	Jaber, Liu, Pan
PGR Students	29
Number Scholarly Outputs (Scival)	670; 108/FTE

CSR spans the areas of wireless communications and statistical signal processing, with emphasis on communication theory, information theory, optimisation, machine learning and random graph theory. CSR is internationally renowned for its contributions towards: 5G Networks; Internet of Things (IoT); Bio-inspired Molecular Communications; and technologies developed to address practical issues concerning multi-gigabit wireless for mobile backhaul, energy efficient ultra-dense small cells, low latency wireless cloud access, self-organizing unmanned aerial vehicles (UAV) and massive IoT networks. CSR also specializes in the Internet of Nano Things, enabling connectivity between nano-devices and bridging the gap between bio-signal processing and nano-precision healthcare.

Major achievements: CSR was founded in 2017 and has grown to ten academic staff. Recent projects include:

- M3NETs: signal processing for massive machine-to-machine networks.
- SENSE: full-duplex dense networks in scalable service provisioning.
- MiMiWaveS: high speed millimetre wave communications for 5G.
- SWIFT: energy harvesting for wireless powered communications.
- MMIMO: massive MIMO enabled heterogeneous networks.

These projects link the group with UK and US governments and industrial partners (BT, InterDigital, NPL, Huawei, Thales). Research outputs include >100 IEEE journal papers and 60 top conference papers (CSR members receiving best paper awards in IEEE GLOBECOM'2017 and IEEE VTC'2018, with Nallanathan named a AI2000 Internet of Things Most Influential Scholar in 2020).

Future strategy: 5G and beyond networks are considered a global game changer from technological, economic, societal and environmental perspectives with very aggressive performance levels in terms of latency, energy efficiency, wireless broadband capacity, elasticity etc. CSR will tackle challenging research in reliable near-instant unlimited wireless connectivity, distributed computing, context-dependent wireless connectivity and artificial intelligence for serving the requirements of vertical applications. CSR aspires to be one of the top research groups for 'beyond 5G' research.

1.4.4 Game-AI

Academic Staff	9 (8.2 FTE)
Professor	Colton (0.6), Cowling (0.6), Lucas
Senior Lecturer	Woodward, Perez
Lecturer	Gow, Rauber, Rossi
Research Fellow	Cook
Fellowships Held	1 Turing Fellow
PGR Students	22
Number Scholarly Outputs (Scival)	282; 34.4/FTE

GAME uses games as a test-bed for AI research, and as a creative industries application domain for advancing areas such as general game playing and computational creativity. It leads several areas of General Video Game AI research, including the GVGAI framework and high-performance statistical planning algorithms such as Rolling Horizon Evolution. Its work on automated game design (e.g. ANGELINA) and procedural content generation is world-leading and has led to spin-out apps such as WEVVA that introduced thousands of high-school students to code-free game design. It collaborates with games industry partners such as Unity Technologies and Spirit AI in the development of next-generation tools for game development (e.g. Danesh), and applies Game AI to real-world applications.

Major achievements: Founded in 2017, GAME has grown to nine academic staff and more than 35 people and is the leading academic Game AI group in the UK (by staff, publications, citations and best paper awards.) By applying advanced AI to real-world planning and optimisation problems GAME was awarded five DSTL-funded projects (variously joint with Warwick, Nottingham, ITU Copenhagen and an industry partner NSC). GAME's genetic improvement software is used daily to

fix bugs in mission-critical software. The Intelligent Games & Game Intelligence (IGGI) EPSRC CDT (£3m for UoA11) was renewed in 2019. The group organised and hosted the first IEEE Conference on Games in 2019, the largest academic conference in the world focussed on games and game AI with >400 delegates.

Future strategy: The focus is on establishing QMUL as a world leader in the development and application of Game AI to complex decision making and game design tools, and to build on significant recent advances in learning world models and in efficient parameter tuning to increase the capability of AI agents to learn to play or design a range of games. GAME's statistical forward planning algorithms provide an inherently more explainable type of AI than pure deep-learning approaches and work on forward model learning will enable applications to more real-world problems. Lucas is taking a 1-year employment at Facebook (Dec 2020/21) to apply Game-AI to the Facebook platform. GAME will lead the way in providing next-generation tools that enhance the skills of both expert game developers and newcomers.

1.4.5 Multimedia and Vision

Academic Staff	5 (4.3 FTE)
Professor	Izquierdo, Patras
Senior Lecturer	Tzimiropoulos (0.3), Zhang
Lecturer	Hao
PGR Students	22
Number Scholarly Outputs (Scival)	260; 60.5/FTE

MMV has made substantial contributions in several fields of multimedia signal processing (video compression, visual information retrieval, and video analytics for security applications). MMV enjoys research cooperation with key players from industry including Thales, BT, BBC, Huawei, United Technologies, Philips, Telefonica, STMicroelectronics, Alcatel-Lucent Bell and Disney Research, and key European research groups such as Fraunhofer/Germany and INRIA/France.

Major achievements: MMV developed an improved fully scalable video encoder and made several contributions to MPEG standards. Related research was published in eight high impact IEEE transactions papers and led to £2m funding from the EU, DTI and EPSRC. It developed effective tools for content adaptation (up-sampling) and enhancement, and an improved, standard compliant, high efficiency video encoder/decoder system for UHD services (The Turing Codec). This codec exploits deep-learning technology, vastly outperforms state-of-the-art techniques, and has high commercial potential. MMV also made inroads in video analytics for security applications, utilising cooperation with Metropolitan Police and European police forces. MMV received over £3m funding in six cooperative projects to address critical security application. The group organised the prestigious IEEE Conferences Visual Communications and Image Processing (2017 and 2019), and organised/hosted the largest IEEE Conference Multimedia (2000), attracting >600 delegates.

Future strategy: has three pillars:

- Turing Codec and the recently completed Cognitus system will be exploited to strengthen cooperation with the BBC and potentially a joint research lab focused on future broadcasting industry needs. The technology is showcased in BBC's 'blue room', enabling deeper

cooperation and strengthening the QMUL-BBC data science partnership. (https://www.bbc.co.uk/rd/projects/cognitus).
- Deepen research on video analytics for security applications exploiting acquired partnership with police forces across Europe. Three large ongoing projects in the field will be used to enhance MMV's research and to attract additional funding.
- Expanding ongoing work on histology image understanding for improved cancer treatment with key medical schools such as Karolinska/Sweden, La Sapienza/Italy and QMUL-Barts.

1.4.6 Networks

Academic Staff	11 (11 FTE)
Professor	Uhlig
Reader	Philips
Senior Lecturer	Mondragon-Ceballos, Poslad, Schormans, Tyson
Lecturer	Antichi, Clegg, de Castro Arribas, Doyle, Gill
Fellowships Held	4 Turing Fellows
PGR Students	30
Number Scholarly Outputs (Scival)	346; 31.5/FTE

Networks is active in key areas of networking including Internet measurements, quality of service, mobile communications, content delivery and network analysis. Networks has an international reputation for excellence; its work is regularly published in prestigious venues such as ACM SIGCOMM, IEEE INFOCOM, ACM IMC, ACM CoNEXT, WWW, IEEE ICNP, AAAI ICWSM and premier IEEE/ACM Transactions (e.g. ToN, TPDS, TC, ToMM). Networks has been leading evolution/development of the *Big Data* MSc, with significant investment in new staff for distributed systems and Cloud computing research.

Major achievements: have been in the areas of data communications, Internet measurements, and Big Data. Major grants on Software-Defined-Networking (SDN) include:
- ENDEAVOUR (H2020 coordinator, €4.4m)
- EARL (EPSRC, £2m, with Cambridge University).

Networks organised the premier conference in data communications, ACM SIGCOMM (2015), and ACM SIGCOMM Internet Measurement conference (2017). These activities have significantly raised the group's International reputation, evidenced by Uhlig's ACM SIGCOMM executive committee membership; Editor-in-chief of SIGCOMM CCR journal; steering committee Chair of the Passive and Active Measurements conference; TPC chair of IFIP Networking 2019 and IEEE ICNP 2019. The group leads a very successful MSc in Data Science (>100 students/yr).

Future strategy: The group will establish itself as one of the world-leading groups in Internet measurements, and one of the top UK research groups in data networking. The strategy is to lead, building on recent successes, in areas such as SDN, Internet measurements, Cloud and Big Data.

1.4.7 Risk and Information Management

Academic Staff	7 (6.5 FTE)
Professor	Fenton (0.7), Neil (0.8)
Senior Lecturer	Constantinou, Marsh, Roelleke, Smeraldi
Lecturer	Hsu
Fellowships Held	5 Turing Fellows
PGR Students	11
Number Scholarly Outputs (Scival)	161; 24.8/FTE

RIM conducts interdisciplinary research on problems of decision-support under uncertainty in applied areas (health, law and forensics, transport safety, finance, and cybersecurity). It works with domain experts and uses methods from CS, statistics, machine learning, and psychology to solve challenges presented by scale, complexity and variability. RIM is world-leading in its development of causal modelling algorithms and applications (Bayesian networks), and its unique combination of data-centric methods with hypothesis-driven approaches in which the power of advanced computing and data analytics is combined with the insights of human expert judgements, especially with respect to causal factors. RIM has coined this the 'smart-data' approach.

Major achievements: Major grants include:

- BAYES-KNOWLEDGE (ERC Advanced Grant, €1.7m)
- PAMBAYESIAN (EPSRC Digital Healthcare Technologies Project, £1.6m)
- Bayesian Artificial Intelligence for Decision Making under Uncertainty (EPSRC UKRI Innovation Fellowship, £0.6m).

Outputs from this research are exploited by Agena (directors Fenton/Neil), who have incorporated it into their widely used software platform [REF3]. RIM members have acted as expert witnesses in major criminal and civil trials, and invited to speak in the UK Parliament and the International Criminal Court in The Hague. Fenton led the six-month Isaac Newton Institute Cambridge Programme in 2016 on Probability and Statistics in Forensics. Fenton and Neil's book 'Risk Assessment and Decision Analysis with Bayesian Networks' has proven to be exceptionally important in decision science with 752 Google Scholar citations (@2/12/2020). RIM's extensive network of collaboration with clinicians and other medical experts has led to the 'smart-data' approach being evaluated and adopted in a range of areas such as trauma care, diabetes and rheumatoid arthritis.

Future strategy: A quiet 'causal revolution' is taking place within the data science and empirical science community. Turing Award winner Judea Pearl's message is that big data and machine learning's algorithms can only learn 'associations' and hence are insufficient for true AI which requires learning of 'interventions' and 'counterfactuals' via causal models and expert knowledge. Essentially RIM's 'smart-data' approach, this is beginning to resonate with researchers who previously assumed that Big Data alone could be sufficient. At the *causal revolution* forefront, RIM is unique in developing practical algorithms/methods that enable causal modelling to solve real-world risk and decision-making problems. RIM will apply these methods in critical applications where either expert judgement alone or data alone are used. It will continue working on law and forensics, and cybersecurity, especially focusing on medical decision-making, extending partnerships in large-scale projects and targeting a range of chronic conditions.

1.4.8 Theory Group

Academic Staff	8 (6.7 FTE)
Professor	Distefano (0.2), Malacaria, Robinson
Reader	Oliva, Riis
Senior Lecturer	Tzevelekos
Lecturer	Rezaei-Khouzani, Tautschnig (0.5)
Fellowships held	1 ERC starting grant
PGR Students	7
Number Scholarly Outputs (Scival)	120; 17.9/FTE

THEORY is a world-leading centre for research on logical methods for reasoning about computer systems. Its work has spearheaded several developments – separation logic, logic for continuous systems, information theory for security, process types for web services, game semantics for programming languages – in which novel theoretical developments have been brought to bear in new application areas. Its Infer open-source software has enabled automatic verification of memory violations and is used by leading companies (including Amazon, Spotify, Uber, Mozilla) [REF3]. It has made fundamental contributions in pure logic (model theory, proof theory, categorical semantics), complexity theory and computational linguistics.

Major achievements: the group's work has won many test-of-time awards and major prizes including:

- POPL Most Influential Paper: 2019 Distefano, 2018 Kohei Honda
- ETAPS2019 Test of Time Award: Honda
- OOPSLA2018: Distefano
- LICS2018: Honda
- Alonzo Church Award for Outstanding Contributions to Logic and Computation (2017): Malacaria
- Royal Academy of Engineering Silver Medal: Distefano.

Alumni have received significant awards - O'Hearn (FRS, FREng), Martin (FREng, CBE). Theory has an ERC Starting Grant and is a partner in an EPSRC Programme Grant. It has successfully developed close contacts with industry, and some of its academics work part-time in industry to apply their research - Distefano (Facebook), Tautschnig (Amazon Web Services), Yorsh [2013-19] (Jane Street).

Future strategy: To concentrate on areas where potential application helps motivate and guide top-quality foundational research. These include applications in cybersecurity, systems engineering, and the structure of social interaction. It will seek to maximise impact through its industry links (e.g. Facebook, IBM, Microsoft, BAE Systems and Google), and its involvement in both EPSRC/GCHQ research institutes in Cybersecurity. It will strengthen its wide-ranging research team, working on Logic, Combinatorics, Information Theory and Game Semantics, applying its research to solve crucial problems such as the quality and certification of software, and systems analysis.

1.4.9 Vision Group

Academic Staff	5 (5 FTE)
Professor	Cavallaro, Gong
Senior Lecturer	Hansard
Lecturer	Oh, Wang
Fellowships Held	2 Turing Fellows
PGR Students	23
Number Scholarly Outputs (Scival)	281; 56.4/FTE

VISION is world-leading in work on person re-identification in multi-camera networks and internationally influential on zero-shot learning, domain transfer learning and deep learning for object recognition, sketch analysis, and multi-camera multi-object tracking. Internationally recognised research on object recognition with privacy by design, multi-modality intelligent sensing, and on visual saliency modelling, have been applied to vehicle and people detection, object tracking, crowd analysis, people search in public space CCTV, law enforcement agency video forensic analysis, and for commercial advertising.

Major achievements: Research is funded by a range of grants from government to industry, including: EU, TSB, EPSRC, EPSRC-MOD CASE, Innovate UK, Royal Society Newton Advanced Fellowship, Turing Institute, as well as industry with FBK on Audio-Visual Sensing, OMRON on sketch retrieval for mobile, SeeQuestor Deep Learning for Video Analysis. The Dragonfly spin-out is an AI bio-inspired predictive visual analytics software solution enabling the analysis and identification of what will grab a human's attention, with major clients in commercial advertising. VISION became the first Nvidia Deep Learning Supercomputer Research Site in Europe, with two Nvidia DGX1s deployed (2016), underpinning its deep learning research in computer vision.

VISION's person re-identification research won the 2019 Bruce Dickinson Entrepreneur of the Year Award, and the 2019 QMUL Innovation Award. The group's Impact Case Study, built on its patents and software has:

- Won a Global Frost & Sullivan Award for Technical Innovation for Law Enforcement Video Forensics Technology (2017).
- Won a 2017 Aerospace Defence Security Innovation Award for "revolutionary solution to reviewing CCTV footage".
- Contributed to winning a major commercial contract on law enforcement post-event video forensics and analysis deployed across > 40 UK police forces.

Future strategy: Produce effective widely used computer vision and machine learning models for understanding and analysing perception, human actions and interactions from visual data, and multi-sensory and multi-source heterogeneous Big Data. Develop machine learning and deep neural networks for large-scale visual recognition problems, with increasing awareness to privacy concerns, distributed data and user data protection. Develop deep learning for multi-view scene analysis, visual sensor networks and visual recognition in distributed internet of things, and on industrial funding to develop existing work in human detection and interpretation of interactions.

1.5 Research centres

We have two formally constituted *Research Centres* offering cross-fertilisation across the wider QMUL community and industry.

1.5.1 Centre for Intelligent Sensing (CIS) focuses on models to analyse streams of high-dimensional data from cameras, microphones, wearable sensors, smartphones, and robots that can sense their surroundings. The core disciplines of CIS are computer vision, machine listening, tactile sensing, and natural language processing. CIS applies AI and machine learning to interpret sensor data while accounting for user privacy.

Major achievements: Leads the project CORSMAL (Collaborative object recognition, shared manipulation and learning), supported by the EU Future and Emerging Technologies (FET) programme through the CHIST-ERA co-operation of national research funding organisations. Leads the cross-Faculty initiative on sensing and privacy with the Schools of Law and Business and Management.

The Erasmus Mundus Joint Doctoral Programme in Interactive Cognitive Environments is a collaboration with four leading European Universities. It led to a joint PhD degree with Genoa University (first of its kind in ICT). CIS collaborates with industry (Honeywell, Thales, CEA, and Aselsan) through the Marie Curie Industry-Academia Pathways and Partnerships project CENTAUR, and the Innovate UK/ARTEMIS project COPCAMS. The COPCAMS object tracker ranked first among online trackers in the international evaluation 'Multiple Object Tracking Benchmark' (MOT2016). CIS contributes to the sensing tasks of the National Centre for Nuclear Robotics.

Future strategy: Focusing on strengths in physical analytics through multiple modalities (visual, sound, touch, motion, text) using advanced machine learning methods, it will exploit the pervasiveness of sensors in everyday devices and mobile robots to enable personalised services. To maximise impact through industry links and involvement in international collaborative projects and continue organising specialist training and knowledge dissemination activities for PGR's (including the annual *Intelligent Sensing Summer School* and commercialisation boot-camps).

1.5.2 qMedia: Established in 2009 as a unified brand for our research in Audio, Music, Video, Media & Arts, Interaction Design and Cognitive Science, while providing a collaboration forum for cognate research in Humanities and Social Science (e.g. Film and Drama).

Major achievements: Forged strong links with MPEG standardisation and has successfully published research into Ontologies as MPEG Standards. The qMedia Research Manager (Kudumakis) was Chair of the UK delegation to MPEG, appointed by the BSI. Recent activities include the Media Value Chain Ontology (MVCO, ISO/IEC 21000-19) which facilitates rights tracking for fair and transparent royalties payment. The Audio Value Chain Ontology (AVCO, ISO/IEC 21000-19/AMD1) extends MVCO to address issues arising from content re-use and sharing in the audio domain. Early in this REF period, qMedia was the brand used for our interactions in Digital Shoreditch, which was an annual festival (2010-15) for the Digital Creative and Tech industries in Shoreditch, London, attracting up to 14,000 attendees (https://en.wikipedia.org/wiki/Digital_Shoreditch).

Future strategy: To support the creation of a University Research Institute in Creative Industries and to continue promoting the international standardisation of QM research.

2. People

2.1 Staffing strategy

Appointments are used to grow and strengthen existing areas of research excellence or support the development of new research opportunities. Since 2014, CS has established two new research groups:

- Game-AI (seven new academics): Led by Lucas (Prof. Artificial Intelligence) - see §1.4.5
- Communications Systems Research (five new academics + two existing): Led by Nallanathan (Prof. Wireless Communications) - see §1.4.4

In addition, we have strengthened all existing UoA11 research groups with new academics (Table 2.1).

Group	New Staff	Areas enhanced and expanded
C4DM	6	Linked data and ontologies; affective computing; Internet of Musical Things; haptics and interactional audio; immersive, AR ad VR audio; bioacoustics; musical acoustics and psychoacoustics; Digital Signal Processing; Machine and Deep Learning
COGSCI	6	Natural Language Processing and social sensing; natural interaction including verbal and non-verbal co-ordination; the strategic bridge to ARQ
MMV	1	2D and 3D face alignment, Neural networks and face alignment, Human pose estimation
NETWORKS	6	Software-defined Networking; Big Data; cloud computing; Green Computing: Networked architectures; Programmable dataplanes; Distributed computing; Network economics
RIM	1	Bayesian Artificial Intelligence for causal discovery; intelligent decision making under uncertainty
THEORY	2	Cybersecurity; model-checking
VISION	2	Self-supervised visual learning; Deep learning-based image restoration; Semi-supervised image segmentation; 3D image/video processing

Table 2.1 Groups expanded by new staff

Since 2014, CS has recruited 37 new academic staff (8 Professors; 5 Senior-Lecturers; 22 Lecturers; 2 Research Fellows) (Table 2.2). During this period 20 academic staff left, of whom 13 have taken more senior posts in major UK or International Universities, four have taken senior industry posts, two have retired and one is deceased. We have in total 22 professional services staff with a primary role of research support within EECS.

UOA11 STAFF	REF2014	13/14	14/15	15/16	16/17	17/18	18/19	Jul-20
TOTAL FTE	30.5	56.3	57.75	61.45	58.95	61.25	65.35	68.8
INCREASE (from 13/14)		0%	3%	9%	5%	9%	16%	22%

Table 2.2 UoA11 academic staff FTE

2.2 Staff development

New academic staff benefit from start-up packages to ensure that research momentum is maintained, involving institutionally funded PhD studentship(s) and funding for key equipment/research costs. Staff new to academia are protected from significant administrative roles during the standard three-year probation period with reduced teaching load enabling focus on establishing research. A pro-active probation system ensures support to develop independent programmes of research, focusing on attracting external research funding and producing high-quality outputs. A senior academic acts as a mentor for teaching and research staff during probation, in addition to RGH mentoring.

Research impact is supported at Institutional, Faculty and School levels (§1.3.2). Since 2014 several academics have been allowed reduced FTE in order to work with individual companies and or spin-outs (British Library, Agena, Facebook, Fujitsu Laboratories, NodeNs Medical and Amazon Web Services, plus two supported by RAEng schemes).

A workload model equalises loads and achieves a balance between responsibilities, typically ring-fencing 50% for research activities, and noting special probationary requirements. A QMUL-wide annual appraisal process monitors progress and sets future aspirations. The appraiser is a senior colleague who discusses teaching, research plans, publications, research funding, impact, public engagement and professional development.

All research groups run research seminar series. Over a typical year, our research groups run over 160 external seminars. The 'Distinguished Lecturer' research seminar series present high-profile speakers, giving talks on subjects relevant to wide audiences. New academics present a summary of their research at School Meetings to aid collaboration.

From 2018 a new promotion process supports applicants by requiring them to discuss applications with RGHs, appraisers or mentors before submission (plus access to the Director for Staff Development for additional advice). Late-draft applications are read by the School Promotions Panel (HoS, T&R Directors, RGHs), and a final edit plan prepared. Tables 2.3 and 2.4 summarise promotion statistics, showing 58% of 53 applications were successful.

Promotion to	2014	2015	2016	2017	2018	2019	2020	Total
Prof				2	2	1	1	6
Reader	2	2	1					5
Senior lecturer	3	4	5	1	2	3	2	21
Total	5	7	6	3	4	4	3	32

Table 2.3. UoA11 academic staff promotions (@1/10/20)

Number	2014	2015	2016	2017	2018	2019	2020	TOTAL
Applications	8	8	9	8	9	4	7	53
Successful	5	6	6	3	4	4	3	31
Successful	63%	75%	67%	38%	44%	100%	43%	58%

Table 2.4. UoA11 academic staff promotions success rate

Colleagues are also encouraged to take on senior university positions (e.g. Burke: Faculty Vice Principal 2015-2018; McOwan: Vice-Principal (Public Engagement and Student Enterprise) 2012-2018), and attend QMUL's 'High-Potential Leadership' training programme.

2.3 Support for Early Career Research staff

QMUL holds the HR Excellence in Research Award awarded by the EU [REF5a]. The *Vitae* Concordat is fully supported through the Researcher Development (RD) team, part of the Queen Mary Academy [REF5a]. Researchers are represented in the Research Committee that convenes termly and is chaired by the Director of Research with membership by HoS, RGHs, Research Services Team (RST), two PGR's and one PDRA representative.

We have a strong PDRA community (table 2.5) with PDRA/REF-Academic-FTE at an average of 1.18 over the REF period and 35% BAME for UOA11 in 2019/20. Support for PDRAs includes:

- Participation in the QMUL wide appraisal scheme
- Encouragement to apply for grants individually, or in collaboration with academics.
- Faculty selection processes for individual fellowships, with formal feedback and mentoring to complete applications, including mock interview panels (8 UoA11 individual fellowships won since 2014).
- QMUL Careers events support STEM researchers considering alternative careers options, especially transition from academia into industry.

UoA11 PDRA Cohort	13/14	14/15	15/16	16/17	17/18	18/19	19/20
Total	62	61	60	72	75	88	91
Female	23%	23%	17%	18%	27%	25%	19%
BAME	23%	21%	20%	22%	33%	33%	35%
PDRA/academic FTE	1.10	1.06	0.98	1.22	1.22	1.35	1.32

Table 2.5. UoA11 PDRA cohort by year

2.4 PGR recruitment, training and supervision

2.4.1 Recruitment

Recruitment follows QMUL's Equal Opportunities policy and is monitored through our Athena Swan commitment. All posts are advertised and short-listing plus interview are undertaken by two academic staff. All interviewers are required to attend training in fair selection. The whole process is overseen and administered by the RST (6 full-time professional-services staff). Table 2.6 shows the source of PhD student funding.

PGR FUNDING SOURCE	FUNDED
International Scholarships, Bursaries, self-funded students	37%
CDTs, namely MAT, AIM and IGGI plus Wellcome Trust DTP	20%
Central QMUL funds	14%
School internal funds	13%
Research grants	8%
EPSRC, Doctoral Training Account (DTP)	4%
BUPT Joint Programme	2%
Industrial Case	1%
DTP-Case	1%

Table 2.6. UoA11 funding source for current PGR's (@1/2/20)

Our PGR recruitment over REF2021 has increased slightly above the increase in staff FTE (table 2.7). PGR current population is shown in Table 2.7b showing the population/staff FTE is well above Russell Group benchmarking. The Schools gender/BAME profile is shown in figure 2.1, along with sector benchmark figures from HESA.

New PGR enrolment (>12 months)	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	REF TOTAL
UoA11	51	48	56	51	61	66	67	400
PGR/Academic FTE	0.90	0.83	0.91	0.87	1.00	1.01	0.97	

Table 2.7a. PGR recruitment over REF period

UoA11 PGR POPULATION (@31/7/20)	
Current Population	253
Population/Staff FTE	3.68
Russell Group 90th Percentile 2018/19 HESA Benchmark	3.03

Table 2.7b. PGR current population

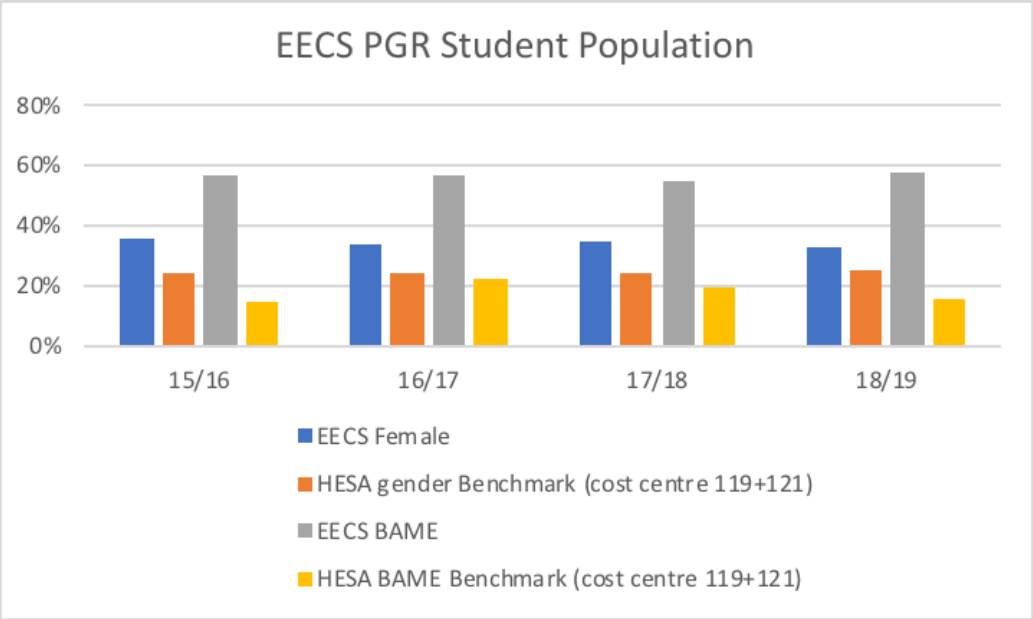

Figure 2.1. EECS PhD student gender/BAME profile as % of population

2.4.2 Training and supervision

PGR supervisors are responsible for academic progress and formal review meetings, along with a 'monitor' checking progress independently of the two supervisors. Academic progress is assessed in four review points - months 3, 9, 22 and 36 - all based on a progress report, presentation, plus viva with supervisors and monitor. Formal feedback is given via the Doctoral College electronic record and the student may progress, resubmit, transfer to MPhil, or be de-registered. Students may appeal the decision through a formal QMUL mechanism. Following each review meeting, a one-to-one student/monitor meeting takes place, providing the student opportunity to comment, in confidence, on any supervision issues.

All our PGRs are provided with a desk and computer, normally located in a mixed doctoral office, enabling interaction with colleagues researching in related areas outside of their supervisor's immediate group. Research groups run regular seminars and reading groups while Centres and CDTs organise events such as summer schools. Students participate in the annual School Industry Day where external industrial partners and representatives from the IEEE and IET attend. Students are empowered to run other activities (e.g IEEE student branch, MAT student G-Hack and experimental concerts/performances).

PhD students are encouraged to develop teaching skills through paid demonstrator roles working with undergraduates, for which they receive in-house training. Students are encouraged to present at conferences, for which funding is available via application to the QMUL's Postgraduate Research fund (max £1k) as well as the School supported research group travel fund (£90k/yr), and DTP support.

Table 2.9 shows the PhD timely submission rate improving over the REF period (most recent period affected by COVID19). Table 2.10 gives the number of PhDs awarded over the REF period, showing increasing number of awards per staff FTE.

UoA11 On-time submission	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
Cohort joined	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
Students registered after 13-months	45	43	43	45	49	45	49
PhD submission within 4yrs	60.0%	65.1%	74.4%	62.2%	69.4%	82.9%	80.0%

Table 2.9. PhD thesis submission rate

PhD Awards	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
UoA11 Total FTE	28.00	29.50	36.50	33.75	41.20	42.85	43.30
UoA11 Total/academic FTE	0.49	0.51	0.59	0.57	0.67	0.66	0.63

Table 2.10. PhDs awarded (HESA)

2.4.3 Doctoral College support

QMUL's DC enhances the PGR experience by cultivating an innovative cross- and inter-disciplinary community of researchers [REF5a]. PGR training is overseen by the DC with electronic records of training/supervisor meetings maintained. All new PGRs undertake a series of induction/orientation activities, organised by DC, introducing the wide range of services available. Students develop training plans in conjunction with their supervisors and the DC runs a points-based training system, including courses on presentation, time-management, writing skills and enhancing employability. Based on the Vitae Researcher Development Framework, each training element is mapped onto one Vitae quadrant. The DC provides PhD supervision training that all academic staff must complete before supervising students, with 'top-up' every two-years.

2.5 Equality, diversity and inclusion

A revised equality, diversity and inclusion (EDI) governance structure implemented in 2019 spreads best practice across QMUL [REF5a]. The structure is supported by an EDI team and leads in all Schools. EDI is an item on all meeting agendas. QMUL promotes the Dignity at Work and EDI policy to all new staff.

EECS holds an Athena Swan Bronze award. We have wheelchair access to all laboratories, teaching rooms and offices and QMUL has worked with DisabledGo for campus access. We have a long track record in outreach promoting EDI, working with national and regional bodies to support the uptake of the discipline by all, including the Faculty wide WISE initiative [REF5a]. This includes:

- Being a founding partner of the IoC, we are heavily involved with four of its five themes, having provided a major contribution on diversity (analyses of current demographics and using natural language processing research to produce analyses of across sector current materials provided to students).
- Since 2018 IoC has secured approximately £1m in studentships for under-represented groups (Female, BAME) for PhD, MSc and BSc supported by Google DeepMind, Tata Consulting Services, and others.
- A key agenda for magazine/website **cs4fn**, which has won several national and international awards (§4.3), for the last 15 years https://teachinglondoncomputing.org/celebrating-diversity-in-computing/.

- Hosting, over a weekend in 2019, an all-female Hackathon, tech industry careers fair, coding workshops run by Makers, Cisco and Capgemini, and a day of inspirational talks from Microsoft, JP Morgan, Lloyds, CodeFirst:Girls etc.

The EECS managed Equalities Committee (ECO), has 18 representatives (8F:10M), from different grades/roles (12 academic, 3 PS, 2 PhDs) and individuals with experience of part-time working, flexible working and caring responsibilities. ECO's team structure (Figure 2.2) has influenced School policy, including transparent workload allocation, core-hours policy, and parental leave provision which employs post-doctoral researcher to provide research continuity. During COVID19, ECO provided advice and support, including adapting the core-hours policy to enable carers to schedule work around family commitments. The co-chairs are ex-officio members of SMT, and report to the Faculty EDI Committee and University Gender Equality Self-Assessment Team. The priorities of ECO are to:

- Monitor and implement the Athena Swan Action Plan.
- Identify, implement and monitor new activities that promote equality and the progression of women at all career stages.
- Explore ways of embedding EDI into School and University culture.
- Leading on Athena-Swan applications.

These actions showcase our strong commitment to creating a diverse and inclusive working environment, which helps attract more women and retain and support those already here. EECS currently have 129 academic staff (19% female, 33% BAME) and 44 professional services staff (77% female, 27% BAME).

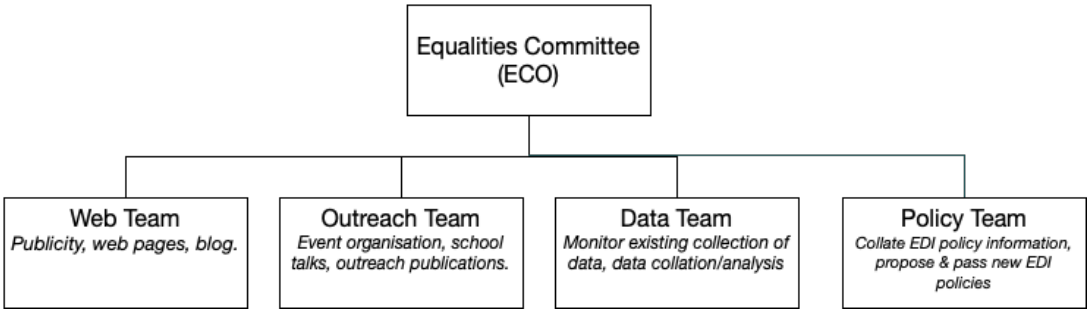

Figure 2.2 ECO team structure

Our academic recruitment processes ensure women and BAME candidates are encouraged to apply and that the selection process is both fair and welcoming. There is a requirement of a gender balance on all recruitment panels, with external panel members appointed if needed with all panel members having appropriate training ('Recruitment and Fair Selection' & 'Unconscious Bias').

Nationally, CS and engineering and technology fields show the largest gender imbalances, from current students, to graduates and the workforce figures. Since 2014 (Table 2.11), we lost seven female staff (two Professors to other institutions, three to more senior posts in UK academia, one to industry, one transferring to the Teaching and Scholarship post), and only hired two (one Professor, one lecturer). In 2019, we launched an action plan to address this issue including:

- Actively help women in CS to transition from PhD to PDRA to Fellow to academic.
- Proactively encourage female applicants to apply to specific posts.
- Encouraging applications at fractional FTE to all posts.
- Academic recruitment panels open to different research citation profiles for male/female candidates.

UoA11 academic staff gender/BAME	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
Staff	55	59	60	63	68	70	75
Female	18%	15%	17%	14%	13%	11%	8%
BAME	25%	24%	23%	22%	22%	23%	25%

Table 2.11. Staff gender/BAME profile.

3. Income, infrastructure and facilities

3.1 Income

All Mainstream QR income is distributed to the School and directly supports the research environment. Strategic grant applications (eg. Fellowships, large grants) and DTPs are supported by significant institutional matched-funding and incentivisation (e.g. internal funding of associated PGRs; distribution of grant overheads to match-fund major equipment). Table 3.1 shows a steady research income across the REF period, with the drop in 2019/20 attributed to COVID19. Table 3.2 shows the current active grant portfolio of £37.2m, with 64% of this portfolio being UKRI funded and with 21% EU as second largest funder.

Research spend £k	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
UoA11	£7,148	£6,677	£7,134	£6,457	£7,171	£8,055	£7,126
UoA11 FTE	56.5	57.8	61.5	59.0	61.3	65.4	68.8
Spend/academic FTE	£127	£116	£116	£109	£117	£123	£104
EECS=HESA cost centres 119+121	£8,960	£8,430	£8,725	£7,777	£8,933	£10,637	£9,949

Table 3.1. Research spend (£k)

Active grants 31/7/20	UoA11
Research Councils	£23,816,754
EU	£7,944,369
UK Government	£2,324,441
Charity	£1,062,254
Industry	£864,824
Alan Turing Institute	£809,073
Other Overseas	£424,266
Total	**£37,245,981**
Grant Count	89

Table 3.2. UoA11 current active grant portfolio by funder

Major grants (>£1.0m) active since 2014 include:

- **RCUK CDT MAT**, renewed in 2013/14 with EPSRC/AHRC funding of £3.7m (Bryan-Kinns). Key impact: presented at 49 international conferences; 10 journal publications; six book chapters; two best-paper and best-team (Hackathon) awards; exhibited by invitation at world-renowned Ars Electronica Festival (2018-2020); nine invited talks; appeared in 23 newspaper/media articles; several PhDs had spun-out companies. Led to 14 follow-on grants and 25 new collaborations were facilitated through student placements.

- **RCUK CDT AIM**, value £6.24m (Dixon, 2019). Key impact: through academic publications, software toolkits, commercialisation and standardisation activities, artistic engagement, industry integration and academic collaboration. 'In kind' industry support valued at £3.1m and direct funding at £1.5m.
- **RCUK CDT IGGI-2**, value £2.8m (Lucas, 2019; York University (lead) and QMUL). Key impact: All 60 IGGI 1 (2014-2018) students have industry placements with companies including AI Factory, Bossa Studios, Creative Assembly, Sony Entertainment, Microsoft Research, Ninja Theory and Google. The first cohort graduated with 100% tech industry employment (e.g. Bossa, Prowler.io) and academia (two lectureships). We hosted the 2019 IEEE Conference on Games, and are launching a Computer Games MSc for 2021 with industry backing.
- **EPSRC grant 'PAMBAYESIAN'**, £1.5m. (Fenton, 2017). Key impact: 48 publications (including Best Student Paper at the 2020 IEEE ICHE Conference); several new collaborations with clinical groups outside original consortium (cardiology, pelvic floor conditions, cancer). Currently in discussions with two medical devices companies to incorporate the technology. Awarded £50K pump priming grant to incorporate the technology into a health tech company platform that monitors rheumatoid arthritis patients for NHS Trusts.
- **EPSRC grant 'EARL'**, value £2m (Uhlig, 2017). Key impact: Turing Institute Partnership Project 'LIME', value £87K; EPSRC New Investigator Award, 'NEAT', value £392K.
- **ERC grant 'BAYES-KNOWLEDGE'**, £1.2m. (Fenton, 2014). Key impact: 37 publications, eight awards, 56 dissemination events; decision-makers in health, law, forensics, environment are using the results and tools from the project; new international collaborations/grants (including Newton Institute grant involving most of the world's leading forensic and legal argumentation experts); EPSRC project PAMBAYESIAN.
- **ERC grant 'DALI'**, £2m. (Poesio, 2016). Key impact: novel probabilistic aggregation methods; biggest crowdsourced corpus for coreference in NLP; 20 publications; several new international collaborations; and establishment of several successful workshop series, in particular 'Games and NLP'.
- **Wellcome Trust DTP 'Health Data in Practice'**, Value £5.5m (Dezateux (Blizard Institute, QMUL) with Healey (COGSCI) as one of three co-investigators, 2019). Key impact: Developing a clear understanding of how health data is generated and used for AI, forming vital new strategic links between SMD and CS.
- **US DoD grant to Centre for Trauma Sciences**, Value £1m (Marsh (RIM), Col; Nigel Tai (QMUL Trauma Sciences Centre), 2019). Key Impact: Clinical Decision Support tools that clinicians use to treat wounded soldiers on the battlefield. AI decision support is continuation of a long-term collaboration between RIM and SMD.

Major EU projects led by CS staff since 2014 are:

- **ENDEAVOUR** (Uhlig, €922k QMUL (Coordinator), total €3.3m). Key impact: Led to EPSRC grant 'EARL'.
- **ConCreTe** (Wiggins, €517k QMUL (Coordinator), total €2.5m). Key impact: 114 peer-reviewed publications advancing computational creativity, and concept construction; 40 dissemination events.
- **Lrn2Cre8** (Wiggins, €627k QMUL (Coordinator), total €2.5m). Key impact: 85 refereed publications advancing computational musical creativity; led to EU Launchpad grant, I2Cre8.
- **MIP-Frontiers**, Marie Skłodowska-Curie Innovative Training Network (Dixon, €0.82m QMUL (Coordinator), total €3.9m). Key impact: H2020 consortium (4 academic and 3 non-academic beneficiaries, plus 9 Partners) is training 15 university/industry based PhDs (2018-22); 32 publications.

Faculty-wide initiatives have been established since 2014 to support enhancement in research funding including:

- Research support fund: a structured approach to provide institutional support for large and strategic funding bids (researchers can request institutional support equivalent to 40% of residual overhead on a grant to be invested in equipment, PhD studentships etc.)
- Research enabling fund: from 2016/17 Faculty introduced this Fund, where research grant PIs receive 10% of their research overheads returned to support pump-priming/ preliminary-studies that enhance the likelihood of future successful grant applications.
- Coaching and mentoring (mock interview panels, etc.) to support ERC grants, Fellowships, Programme grants, etc.

Specific financial support for impact in the Faculty is via STFC/EPSRC Impact Acceleration Accounts (IAA) (~£260k p.a.) to exploit our research base (§4.2) with a focus on:

- An Innovation Fund (with additional support from HEIF) supporting the translation of research for economic or social impact.
- An Accelerator Programme to create high-value spin-out companies based on EPSRC research.
- Funding to match to Global Challenges Research funding.

UoA11 use of these amounts is at £382k since 1/1/14.

3.2 Infrastructure and facilities

Since 2014 QMUL has invested £185m in capital infrastructure [REF5a], which includes major investment in research infrastructure, including refurbishment of the Engineering Building. UoA11 occupies space in three buildings on the Mile End Campus: Peter Landin Building; Informatics Teaching Laboratory; Engineering Building.

The REF2021 period has seen very significant investment in research infrastructure and facilities. Over £32m has been invested in a programme of refurbishment of the Engineering Building to provide the highest quality research/teaching environment. New/enhanced research laboratories and workshops that support UoA11 include:

- A multi-functional media experimental lab supporting two separate Kinect capturing sessions in parallel, eye tracker work area, space for using virtual reality headset, TV wall.
- New 4th floor for the north engineering building, providing academic and PhD space for C4DM (361 sqm).
- New 3rd floor for the north engineering building, providing electronics teaching/research laboratory (384 sqm).
- New research mechanical workshop combining previous separate workshops into one new space (190sqm) plus investment of £150k in new machine tools.
- New Empire House building (Whitechapel) housing DERI, including all the expanding GAME and part of the RIM Groups.

Within UoA11 there has been significant investment in new equipment/facilities, involving external funding and/or institutional investment. This includes the QMUL Strategic Facilities Investment Fund which aims to support major new strategic facilities development with a focus on providing matched funding to leverage significant external funding. Significant investment includes:

- Materials Processing Laboratory for CDT MAT programme: EPSRC-funded equipment includes 3D printers, laser cutters, digital embroidery, 2D materials printing (£314k).
- £430k for the CIS laboratory including sensors, robotic arm and quadcoptors.
- Nvidia DGX-1 deep learning supercomputer (2016), centred around the VISION group, this is specifically designed for deep learning and big data analysis. Several other computer clusters for big data have been installed.

- Hadoop Cluster: for big data research, £80K, installed 2014.
- Deep learning individual compute nodes: (Nvidia) 20 nodes installed 2015/16, £160k.
- Cisco VIRL virtual internet routing lab: NETWORKS, £10k.
- £200k for C4DM labs/studios and computing equipment.
- £450k COGSCI new office/lab space.

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

4.1 Supporting collaborations

Our interdisciplinary collaboration and engagement within academia, Industry and government spans the spectrum from within QMUL through national and international collaboration. This includes a large spread of collaborators:

- **Biologists**: forensics and security (MMV); using machine learning to decode animal vocalisations (C4DM), analysing animal behaviour by video (MMV).
- **Clinicians & Medical Researchers:** Image analysis (MMV); decisions in trauma/chronic medicine (RIM); tools for assessing quality of life (COGSCI).
- **Defence Analysts:** better real-world decisions, better military training games (GAME, THEORY); improved decision-making for intelligence agents (RIM).
- **Ecologists and Climate Scientists**: understanding climate change effects on natural ecosystems (COGSCI, Networks); detecting solar panel installations (C4DM).
- **Economists:** Game Theory and Decision Theory applied to Economics (GAME).
- **Educational researchers and practitioners:** developing more effective approaches to school level education (COGSCI).
- **Financiers:** compiler work optimising speed of financial systems (THEORY).
- **Historians/Museum Curators:** exploring the History of Computing, public engagement (COGSCI).
- **Human rights activists / organisations (UNHCR**): language processing methods applied to human rights work (COGSCI); improved risk assessment and project planning for major agricultural projects in underdeveloped countries (RIM).
- **Lawyers:** evidential reasoning (RIM).
- **Librarians:** cataloguing sound and music collections (C4DM).
- **Linguists:** computational models of complex linguistic phenomena; predicting patient adherence to treatment from dialogue; predicting clinical diagnosis and outcomes from patient interaction (COGSCI).
- **Mathematicians**: applying ideas from Logic and Proof Theory to mathematical proofs (THEORY); understanding the effects of climate change on natural ecosystems (COGSCI & NETWORKS)).
- **Musicians and Composers:** deeper understanding of the creative process and of the sensorimotor skill of playing instruments (C4DM).
- **Neuroscientists:** understanding brain mechanisms of auditory perception, for interplay between language and vision, representation of emotions (COGSCI, C4DM).
- **Psychologists**: causal reasoning and decision-making under uncertainty (RIM); developing models of attention (COGSCI).

We employ a wide range of mechanisms to support and encourage collaboration:

4.1.1 Bringing researchers together

At International conferences UoA11 staff have, since 2014 been general chair/co-chairs at 54 events, given 109 invited plenary talks, and received 42 best-paper awards.

Collaboration is supported through formal groupings such as:

- **Turing Institute**: In 2018 QMUL became one of eight new University members of TI. Of the 46 QMUL TI Fellows, 18 are from UoA11 attracting research funding jointly with the TI. QMUL's TI membership led to the creation of the Institute for Applied Data Science (IADS), a cross-disciplinary Institute which is the public interface to Turing, managing projects, Fellowship applications, seminars (several each month) and an annual conference. Our fellows have been prominent in IADS and TI events, leading to multiple new interdisciplinary research activities, e.g. TI funded KNIFE (Knowledge Discovery from Health Use Data, 2019, £100k).
- **Research Cooperation with BUPT**: We have a major teaching Joint Programme (JP) with Beijing University of Posts & Telecommunications (BUPT), with approximately 2,700 students. This has led to stronger research links including establishing a new 'Smart Communication' joint laboratory (2018). International workshops have been JP-organised e.g. Emerging Advances for 5G Networks and Beyond: Concepts, Technologies and Applications (2017); and a Russell Group UK-China Workshop on Intelligent Transportation Systems for Smarter Urban Mobility (2016).
- **CDT MAT**: Has been a major catalyst for collaboration, with PhD students having (lead/joint) supervisors across all research groups, as well as in the wider QMUL community (including SMD, Biology, Drama). Major impacts are described in §3.1. New collaborations facilitated through the student placements bring new industry and academic partnerships leading to further collaborations and exchanges. MAT has established collaborations with over 25 institutions including BBC, Georgia Tech (USA), Hunan Uni (China), McGill University (Canada), CreativeWorks London, The Barbican, London College of Fashion, Manchester School of Art, Yamaha. The CDT also led to a collaborative Masters with Hunan University (China), the first design-tech masters between China/UK.
- **CDT IGGI-1 and IGGI-2**: IGGI-1 (2014) was a collaboration between York University (lead), Essex University, and Goldsmiths. The Essex part of IGGI-1 moved to QMUL with Lucas and Perez in 2017, later joined by Goldsmiths IGGI-1 investigators Colton and Gow. York (lead) and QMUL now form IGGI-2 (2019) with an even split of students. IGGI is having a transformational effect on the games industry, with each phase funding more than 60 PhD students. All IGGI students have industry placements (minimum 3-months), ranging from indie games studios to tech giants. Major impacts from IGGI have been described in §3.1, and it has encouraged many international collaborations, resulting in papers published at leading Game/AI venues.
- **CDT AIM**: This 2019/20 CDT will produce world-class researchers who combine state-of-the-art ability in artificial intelligence, machine learning and signal processing with cross-disciplinary sensibility to deliver ground-breaking original research and impact within the UK Creative Industries and cultural sector. Partners comprise key players in the music industry (e.g. Abbey Road Studios, Apple, Deezer, Spotify, Steinberg, Universal Music), covering recording, distribution, electronic instruments and music software; plus a range of innovative start-ups (e.g. HyVibe, Sensing Feeling, Chordify, Le Sound) covering hardware and software for mainstream, alternative and experimental music. Partners contribute to AIM by: funding or co-funding students; providing training courses and seminars; internships to individual students; co-supervising students; and providing student project resources.
- **CDT in Data Centric Engineering**: This £1.6m award forms part of the UKRI Doctoral Mobility Pilot (Co-investigators Bryan-Kinns & Sandler). Recruiting its first cohort in 2020/1, the project will expand the number of scientists/engineers with data-science and engineering research, facilitating students to apply such methods in the industrial settings of partners including IBM, BT and the BBC.
- **CDT DAME**: This 2020/21 CDT in 'Data-informed Audience-centric Media Engineering', jointly funded by QMUL and the BBC, will produce world-class researchers in technologies that support future products and services in online media.
- **MIP-Frontiers**: QMUL led Marie Skłodowska-Curie Innovative Training Network of 4 academic and 3 non-academic beneficiaries, plus 9 Partners is training 15 researchers in a range of university-based and industry-based PhDs (2018-22).

- **CIS**: see §1.5.1.
- **qMedia**: see §1.5.2.

4.1.2 Support for collaboration

During REF2021, UoA11 activity supports:

- Incoming international visitors: 46 visits (average stay 6-months) from Assistant Professor/Lecturer and upwards, and 22 visits (average stay 9-months) from Postdocs/Fellows for periods in excess of five-days have taken place during this REF period.
- Staff Honorary Visiting Academic posts: Staff hold 26 visiting academic posts abroad, with 15 as Visiting Professor (8 Europe & Middle East, 18 Asia).
- PhD students to travel and present at international conferences via a £90k/yr budget plus Doctoral College administered central funds.
- Staff to hold 15 collaborative UKRI grants (with QMUL value >£100k) creating 23 collaborations spread over 20 institutions.
- National & International Collaborations: Defining a significant collaboration as one leading to a peer-reviewed co-authored journal/conference paper and/or funded research project, UoA11 has 320 independent international collaborations (Table 4.1), and 143 independent UK university collaborations with 50 institutions including 21 Russell Group members.

Americas	Europe	Asia	Other	Total
54	157	86	23	320

Table 4.1. Number of independent UoA11 international collaborations.

4.2 Industrial collaborations and impact

Our Impact strategy (§1.3.2) has yielded 8 Impact Case Studies prepared for REF2021 submission. These Impact Case Studies represent only the tip of the iceberg. UoA11 research activities have led to 13 new spin-outs (table 4.2), and seven staff continued with spin-outs created before 2014.

Company name	Staff member
Tonz	Benetos/Reiss
Chorograph	Clegg
Imaginative AI	Colton
Dithen Ltd	Doyle
SeeQuestor Ltd	Gong
Dragonfly	McOwan (deceased)
TouchKey Instruments	McPherson
Augmented Instruments	McPherson
Cahtterbox Lbs	Purver
Fxive	Reiss
Teragence	Schormans
Warblr	Stowell
Acygn Ltd	Tzevelkos
Easy Advanced Systems	Woodward

Table 4.2. UoA11 spin-outs created since 2014

Examples of major societal impact [REF3]:

- Fenton's guidelines (based on RIM's Bayesian Decision support research) for lawyers and forensic scientists, led to the decision by the International Criminal Court in The Hague to

train all their judges and lawyers in the use of Bayesian methods to efficiently process pre-trial evidence.

- COGSCI's communication training programme for clinicians treating psychosis has been used by 12 NHS Trusts across the UK and 43 international institutions. COGSCI's natural language processing methods are applied in a commercial online CBT service (NHS available) treating approximately 1m patents in UK and USA.

QMUL supports new impact through a variety of internal funding means, including EPSRC Impact Acceleration Accounts (IAA) [REF5a]. The IAA Flexible Innovation Starter Fund (£5k) allows exploration of ideas with major impact potential, the IAA Large Grants (up to £50k) are awarded to enable high profile Impact activities arising from research. Proof of Concept funds (up to £50k), awarded by QMI, get research outcomes into shape for investment and full commercialisation. QMI launched the QMUL Enterprise Investment Fund, providing early-stage seed capital to academic and student spin-out enterprise. QMUL offers free legal/business advice to tech start-ups and new entrepreneurs through **qLegal**, and for financial issues **qNomics**, provided by the schools of Law and Economics. Notably, the 2019 Entrepreneurial Impact Ranking (https://octopusventures.com/entrepreneurial-impact-ranking-2019/) ranked QMUL 4th in the UK for its production of spinout companies, and successful exits, relative to the total funding received. A significant proportion of this success relates to spin-out activities arising from our research. Tables 4.3 and 4.4 list the patents and commercial agreements activity for UoA11 staff, the revenue generated in FY 2019/20 was £143.5k.

Group	Awarded	Filed
C4DM	8	2
COGSCI		1
CSR		3
MMV	1	3
NETWORKS	2	
THEORY	1	2
VISION	4	4
Total	16	15

Table 4.3. Summary of Patents undertaken since 2014

UOA11	Assignment	Collaboration/ Option	Evaluation License	License	Option	Tech Evaluation	Total
Total	3	1	7	26	8	1	46

Table 4.4. Commercial agreements undertaken with industry since 2014 (QMI)

UoA11 staff have consulting activities with 24 companies, including Intel, Yamaha Motors, British Telecom, Care Quality Commission. Three UoA11 staff have taken extended industrial secondment (see table 4.5), and Lucas (GAME) will join Facebook from December 2020 for 1-year.

Name	Group	Secondment FTE and period	Company
Distefano	Theory	0.8 FTE since 2013	Facebook
Fenton	RIM	0.3 FTE 2014-16	Agena Ltd
Tautsching	Theory	0.8 FTE since 2015	Amazon Web Services

Table 4.5. Staff taking industrial secondment

Our Industrial Board meets twice-yearly, having 23 industrial members taken from the wide range of industries relevant to research/teaching. Board meetings coincide with research open-days, where

research groups share their research through posters/demos given by PDRAs and PhDs. From 2020 the Board has been an enabler for showcasing Industry/Academia events offering both large scale meetings (QMUL/Cambridge Wireless Conference, Covid delayed Jan2021) to industry themed webinars (§1.3.1).

4.3 Public engagement of research

COGSCI's 2017 book 'Power of Computational Thinking' (Curzon & McOwan) has been translated into Chinese, German and Russian, with a 2nd Edition in press. COGSCI takes a lead role in the development of government policy: Curzon was appointed to the National Centre for Computing Education's Academic Board (one of six members); and advises Royal Society working group on AI and Outreach. QMUL's Centre for Public Engagement (CPE), founded by McOwan (COGSCI), was the first institution to achieve the gold standard for public engagement [REF5a]. Significantly influencing that award was COGSCI's cs4fn activity which has engaged school students and teachers in the UK and worldwide, with CS research topics for 15-years (twice yearly magazine, 20,000 print copies/issue, >100k downloaded to over 80 countries). Other cs4fn-related awards include the premier 'Richard Garriott Award for Leadership in Public Engagement' (2018) and the IEEE Taylor L. Booth Education Award medal (2020) for computer science education (Curzon).

Other significant activities:

- Hosting the public engagement website http://probabilityandlaw.blogspot.com (Fenton/Neil)
- Running annual Computer Science Royal Institution masterclass for the past five years. For 13-14 year-olds from local schools (cohort: 25-30).
- Children's Christmas Lecture series (with IET local network), engages local community promoting STEM in schools. Speakers present in the style of the RI Christmas Lecture.
- COGSCI are active in running a UK-wide CS education research network.
- Fenton co-presented the multiple award-winning (table 4.6) BBC documentary "Climate Change by Numbers".

4.4 Open research and data management

UoA11 fully supports QMUL's Open Access policy, and in addition to the centralised facilities for publications, we use, on a group-by-group basis, various facilities such as GitHub and OSF, to make our research code and data available. Exemplifiers of this are: H2020:EMBEDDIA, 57 repositories via GitHub, industry-facing software tools released under open-source license and via Docker for ease of uptake; GAME won the AIIDE2019 conference best artefact award for its Pommerman framework; C4DM http://isophonics.org.

Looking forward open access to our research code and data will increase in-line with the subject trends, were already some leading conferences/journals require code release or strongly encourage it for reproduction and comparative evaluation.

4.5 Significant leadership roles and staff esteem

Since 2014 UoA11 staff have:

- Provided funding body leadership roles as: EPSRC review college (27); EU (1); Royal Society (2); RAEng (3); IEEE (2); Non-UK national funding bodies (10).
- Provided journal editorial roles as: Editor (12, of which 5 IEEE), Associate Editor (36, of which 14 IEEE); guest editor (27, of which 4 IEEE); editorial board member (17).
- Acted as chair/co-chair for 54 international conferences, of which 13 are IEEE conferences.
- Been made Turing Fellows (18).
- Been elected FREng (Sandler).

Specific leadership roles include:

Cavallaro: Leads joint PhD programme in interactive and cognitive environments, with University of Genoa (since 2010); Chair of: Image, Video, and Multidimensional Signal Processing Technical Committee; IEEE Signal Processing Society (since 2020).

Curzon: Provided a leading role in computing education, collaborating with DfE, BBC, Royal Society, Greater London Assembly, Computing at School Working Group, Norwegian Parliamentary Working Group, Danish ministry of education. Leads on cs4fn.

Dixon: Coordinator of EU H2020 Innovative Training Network: MIP-Frontiers (2018-22); President International Society for Music Information Retrieval (2014/15).

Fenton: Major contributor to Turing Institute submission to House of Lords Science & Technology Committee inquiry into Forensic Science (2018). Expert witness/consultant in Criminal and civil cases including cases in the USA and Netherlands (since 2014).

Lucas: Vice-President (Education) of the IEEE Computational Intelligence Society (2017 – 2020).

Reiss: Audio Engineering Society: Chair Publications Policy Committee (since 2016); Co-Chair High Resolution Audio Committee (since 2014).

Robinson: Council of Professors and Heads of Computing (Treasurer 2014/18, Deputy Chair 2018).

See Table 4.6 for staff esteem. Ten submitted staff in World Top 2% of Scientists by Stanford University (Cavallaro, Dixon, Elkashlan, Gong, Izquierdo, Lucas, Malacaria, Nallanathan, Poslad, Uhlig).

Year	Academic	Esteem
2020	Gong	IET 2020 Achievement Award
2020	Cavallaro	IEEE Distinguished Lecturer, Signal Processing Society
2019	Distefano	POPL 2019 most influential paper award POPL (Principles of Programming Languages)
2019	Sandler	European Association for Signal Processing (EURASIP) Group Technical Achievement Award
2018	Bryan-Kinns	Fellow of Royal Society of Arts (FRSA)
2018	Cavallaro	Fellow of International Association for Patter Recognition
2018	Distefano	Most Influential OOPSLA Paper Award
2018	Yorsh	5-year EU-ERC
2018	Chew	5-year EU-ERC
2017	Cowling	Royal Society Wolfson Merit Award
2016	Distefano	CAV Award, “fundamental contributions to the field of Computer-Aided Verification for development of Separation Logic”
2016	Fenton	5-year EU-ERC
2016	McPherson	EPSRC 5-year Fellowship award
2016	Sandler	Elected FREng
2015	Benetos	RAEng 5-year Fellowship
2015	Fenton	(co-presented) BBC Documentary “Climate Change by Numbers” awarded; American Association for the Advancement of Science, Science Journalism Gold Award for best in-depth TV reporting; European Science TV and New Media for the best environmental issue Science programme.
2015	Izquierdo	IEEE Distinguished Lecturer, 2015-2017
2015	Sandler	Royal Society Wolfson Merit award
2014	Distefano	Awarded one of four annual RAEng Silver Medals
2014	Stowell	EPSRC 5-year Fellowship

Table 4.6. Staff esteem