Unit-level environment template (REF5b)   **REF2021**
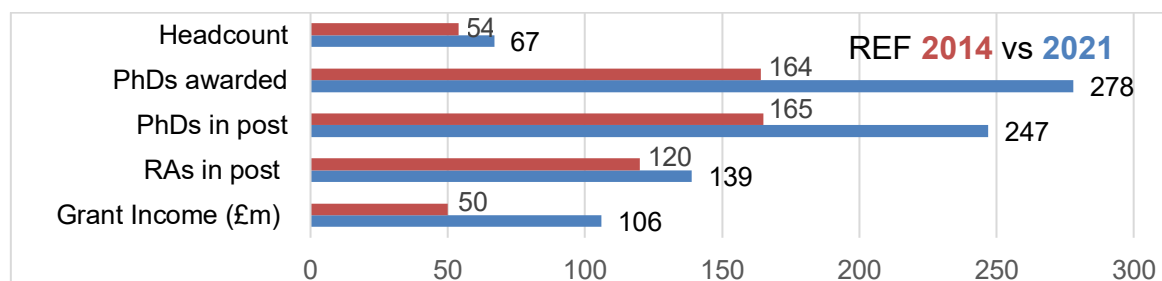
| Institution: Imperial College London |
| Unit of Assessment: 11 Computer Science and Informatics |
| 1. Unit context and structure, research and impact strategy |

1.1 Unit context and structure

The Department of Computing is comprised of 67 academics, 139 research staff, 247 PhD students and 1,050 taught-course students, making it one of the largest computing departments in the UK. By being part of the Faculty of Engineering, we are committed to computing as an engineering discipline, but we also engage in theoretical and foundational computer science research. The Department's research is organised around 9 themes: *Analysis & Verification*, *Artificial Intelligence*, *Data Science*, *Programming Languages*, *Security*, *Software Engineering*, *Systems*, *Theory & Algorithms* and *Visual Computing*. We value innovative and collaborative research in core and applied computing, and its application and translation to solve real-world problems.

The Department promotes and fosters research excellence and impact through the following strategic mechanisms, whose effectiveness is evidenced in the bar chart below:

- **Attracting and developing academic leaders.** The number of staff submitted has increased from 54 in REF2014 to 67 in REF2021. We recruit international academics of the highest calibre, making our Department vibrant and sustainable – 40% of submitted staff were appointed since REF2014. Our recruitment strategy has focused particularly on attracting and developing early-career researchers (ECRs) – 16 are submitted.

- **Expanding the research pipeline.** Our research income over the REF2021 period has more than doubled to £106m (£50m in REF2014) and we have 42% more researchers and PhD students. Our focused research support has helped secure large, highly competitive grants and fellowships: our staff obtained more than 30 major awards (>£1m), 3 Royal Academy of Engineering Chairs, 5 prestigious ERC awards and 8 external fellowships (EPSRC, Royal Society Wolfson).

- **Training the next generation of researchers.** Our PhD students have increased by 50% between 2013 and 2020, and the number of PhDs awarded has increased by 70%. We compete for the very best national and international PhD candidates, awarding full fees and stipends to 85% of our students. Our diverse PhD population comes from more than 40 countries with 72% from outside the UK.

- **Translating research into impact.** We encourage entrepreneurship, which has led to a large number of startups in the REF period. These include GraphicsFuzz (acquired by Google), Fabula AI (acquired by Twitter), FaceSoft (acquired by a large technology company), Ariel AI (acquired by Snap), Magic Pony (acquired by Twitter), SLAMcore, Surreal Vision (acquired by Oculus/Facebook) and Xayn.

REF **2014** vs **2021**

Category	2014	2021
Headcount	54	67
PhDs awarded	164	278
PhDs in post	165	247
RAs in post	120	139
Grant Income (£m)	50	106

We believe that computing must play a major part in securing the UK's economic health and contributing to quality-of-life improvements. The Department's impact areas include:

- **Industry.** Between 2014 and 2020, the Department has engaged with more than 50 national and international companies through joint appointments, collaborations (e.g. joint research centres with Dyson (see SLAM impact case study), HeartFlow, Intel and Syngenta), development of startup companies (see GraphicsFuzz, Infer and 3D Analysis impact case studies), patenting and technology licensing.

- **Public health.** The Department's research on new technologies for diagnosis and intervention has been adopted by clinicians and led to improvements in patient care in UK and overseas hospitals and large-scale NHS clinical trials (see IXICO and 3D Analysis impact case studies). We also train the next generation of PhD students in clinically relevant AI methods through our AI4Health CDT and the joint Smart Medical Imaging CDT with King's College London (KCL). We contribute to NHS trusts through the Imperial College Academic Health Science Centre (AHSC) and the London Medical Imaging & AI Centre for Value Based Healthcare.

- **Public policy, engagement and outreach.** The Department engages with the UK Government and EU Commission to inform and shape public policy, particularly in AI, security and privacy (see Section 4.2.2). Our research is disseminated through public lectures, media engagement and outreach events (see Section 4.2.3).

1.2 Research strategy

The Department of Computing is ranked among the top 10 departments in the world for research and education. Our objectives remain mostly unchanged from 2014:

- to pursue research excellence and innovation in core computer science;
- to conduct world-leading interdisciplinary research that recognises the pervasive nature of computer science in all areas of society;
- to develop novel, sound and applicable computing techniques that meet the evolving needs of science, industry and society;
- to work with industrial collaborators on research translation into economic and societal impact;
- to offer innovative education based on foundational research that fosters technical excellence, originality and breadth of vision in students.

To achieve these objectives, the Department's research strategy combines fundamental curiosity-driven research and applied problem-driven research. Our 9 research themes cover a broad set of core computer science topics, which feed into 3 cross-cutting research topics:

- Artificial Intelligence (AI)/Machine Learning (ML)/Data;
- Health;
- Security.

The Department's strength in these topics enables us to demonstrate critical mass in order to establish and lead a number of College-level research initiatives (see Section 1.2.1a).

The Department's research themes directly contribute to the Faculty of Engineering's research strategy as follows: *Theory & Algorithms* contributes to "Transitions to a sustainable zero-pollution economy"; *Data Science* and *Security* to "Engineering resilient and secure infrastructure"; *AI* and *Visual Computing* to "AI and machine learning for engineering applications"; and *Systems* and *Visual Computing* to "Affordable technologies for an ageing society". This facilitates interdisciplinary collaborations with other engineering departments (see Section 4.1).

Our research strategy also places a strong emphasis on academic recruitment, career development and investment in people. We have attracted ECRs of the highest calibre and supported them to become global leaders in their fields (see Section 1.2.1b). Over the REF period, AI and ML have been a thematic recruitment focus, substantially increasing the Department's activity in this area. Tactically, the Department has worked on supporting academic staff to fund research through large long-term projects and fellowships and on extending its industrial funding streams (see Section 1.2.1c).

The research strategy is agreed by the Departmental Management Committee, chaired by the Head of Department; each term, the Departmental Research Committee, open to all academics, discusses related opportunities and challenges. The strategy is reviewed at the annual Away Day.

1.2.1 Strategic research goal achievements since 2014

(a) Cross-cutting research topics that result in research leadership
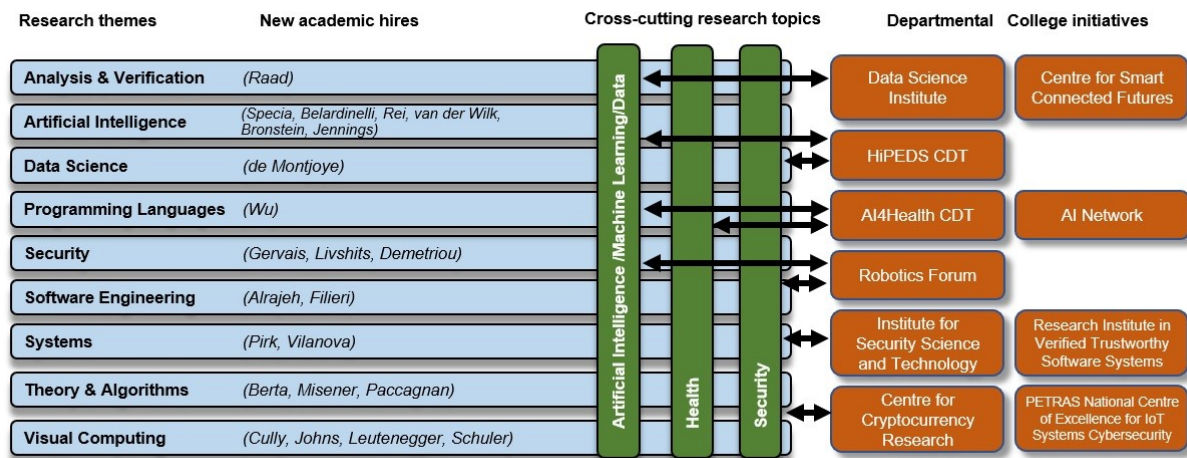
Our cross-cutting research topics (shown in the figure above) are explained below:

(i) Artificial Intelligence (AI)/Machine Learning (ML)/Data is a new cross-cutting topic that evolved from the data science topic, which has now become a core research theme. This topic amplifies our capabilities from the *AI*, *Data Science* and *Visual Computing* themes to satisfy the escalating demand for research and education in this area. It was a new strategic growth area in REF2014 and this led to the successful recruitment of 6 academics.

(ii) Health is a cross-cutting topic that leverages our research in *AI* and *Visual Computing* and demonstrates it via collaborations with medical departments and hospitals within Imperial (e.g. Imperial College AHSC) and externally.

(iii) Security leverages our strengths in the *Security*, *Software Engineering* and *Programming Languages* themes to solve real-world security, safety, reliability and privacy challenges.

The Department's strength in these cross-cutting topics allowed us to bid successfully for 4 centres for doctoral training (CDTs), including the following 2 Department-hosted ones:

- **UKRI CDT in AI for Healthcare (AI4Health)** (Director: *Faisal* (joint appointment/returned with UoA12)) currently trains 41 PhD students and 5 Clinical PhD Fellows in AI-themed clinical methods. In addition to UKRI's £15m contribution, the CDT has secured £4.5m in external funding. Activities stemming from the CDT comprise two NHS-X Health & Care Awards and AI & Healthcare regulation workshops with the entire UK's regulatory pipeline (Office AI, BEIS, MHRA, HRA, NICE, CQC, NHS-X).

- **EPSRC CDT in High Performance Embedded and Distributed Systems (HiPEDS)** (Director: *Luk*) has admitted 76 PhD students and trains them in systems research, ranging from smart sensors to secure cloud services. Operated jointly with the Department of Electrical and Electronic Engineering (EEE), the CDT produces technological leaders with a systems (hardware and software) perspective, filling an important skills shortage in industry. The CDT has engaged with 24 industrial partners (e.g. Arm, Coerain, dunnhumby, Dyson, Intel, Jump Trading and Microsoft).

The cross-cutting topics also align with the College's strategic research themes: AI/ML//Data aligns with "Smart society"; Health aligns with "Healthy society"; and Security aligns with "Resilient society" (see institutional statement). This alignment has enabled the Department to pursue new leadership roles for cross-Faculty Institutes, Centres and Networks at the College level (also shown in the figure above):

- **Data Science Institute (DSI)** (Co-director: *Guo*; members: *de Montjoye*, *Heinis*) involves the whole life cycle of data, from acquisition and exploration to analysis and visualisation. The Imperial/Huawei Data Science Innovation Lab, hosted by the Institute, is a joint partnership with

Huawei. The institute led the EU eTRIKS project (£26m) on a new platform for the analysis of large datasets used by pharmaceutical companies.

- **Centre for Smart Connected Futures** (Lead: *McCann*) is a research network covering industrial IoT and cyber-physical systems. Its interdisciplinary research themes involve 3 engineering departments (Computing, EEE, Design Engineering): connecting people with their environment; designing future connected systems; and trusted control machines.

- **AI Network** (Speaker: *Faisal*) is a new College-wide forum for interdisciplinary research on AI. It consists of 219 academics (48 from Computing) from all 4 Faculties and more than 200 postdoctoral researchers/PhD students. The network has galvanised funding bids, industry and outreach events and hosted delegations from the UK Government (e.g. Number 10, Office of AI, BEIS, DH) and EU/Asian countries.

- **Robotics Forum** (Management committee: *Johns, Leutenegger*) is a College-wide network for robotics research that connects 44 academics (9 from Computing). Its scope ranges from the manufacture and production of robotic systems, to applications in healthcare, transport, energy and the environment.

- **Institute for Security Science and Technology (ISST)** (Director: *Hankin* (until 2019); Associate Director: *Lupu* (until 2020)) conducts interdisciplinary security and defence research. It has created an innovation ecosystem on Imperial's White City Campus with industry, the MOD Defence & Security Accelerator and NATO. Research projects include the EPSRC Security, Privacy, Identity and Trust Engagement NetworkPlus (SPRITE+) (Fellows: *Demetriou*, *Hankin*, *Lupu*) with 5 universities/14 partner organisations, and the NCSC/EPSRC Research Institute in Trustworthy Inter-connected Cyber-physical Systems (RITICS) (Director: *Hankin*) with 13 universities. The Institute has contributed to Imperial's recognition as an NCSC/EPSRC Academic Centre of Excellence in Cyber Security Research (ACE-CSR) (PI: *Lupu*), bringing together 25 academics. The related Research Institute in Verified Trustworthy Software Systems (VeTSS) (Director: *Gardner*) focuses on program analysis, testing and verification; the PETRAS National Centre of Excellence for IoT Systems Cybersecurity (Deputy Director: *Lupu*) involves 16 UK universities that collaborate on IoT privacy, trust and reliability.

- **Centre for Cryptocurrency Research and Engineering** (Director: *Knottenbelt*) partners with industry (Blockchain, Outlier Ventures, Coinshares) to establish a research programme on cryptoeconomics, blockchain interoperability and digital assets. It has resulted in a spinout (Interlay; co-founded by *Knottenbelt*/*Gervais*'s PhD students) and a regulated EU financial benchmark (CGCI). The related FinTech Network (Co-lead: *Parpas*) draws together researchers across College who share an interest in innovation in financial systems and technology.

(b) ECR recruitment and strategic growth

We have achieved our REF2014 objective of academic recruitment of ECRs: of the 67 submitted staff (16 ECRs), 27 are new appointments over the current REF period, including 20 Lecturers, 2 Senior Lecturers, 1 Reader, 3 Professors and 3 Research Fellows. From full-time staff submitted to REF2014, 5 have left (*Bradley*, *Lee*, *Przulj*, *Wolf*, *Yang*) and 7 retired (*Eisenbach*, *Hodkinson*, *Kramer*, *Magee*, *Rustem*, *Sergot*, *Sloman*).

As shown in the figure above, recruitment has been largely balanced across the themes. An exception has been our strategic focus on *AI*, with new expertise in natural language processing (*Specia*, *Rei*), ML (*Bronstein*, *van der Wilk*) and multi-agent systems (*Jennings*, *Belardinelli*).

(c) Long-term prestigious research funding and industry streams

We have established a robust funding base (see Section 3.1) with mostly collaborative and often interdisciplinary projects, including 8 EPSRC Programme grants and 1 Platform grant, 5 EPSRC Fellowships, 5 ERC grants, 3 RAEng chairs and 12 large (>£1m) grants funded by UKRI, EU and industry.

The Department has expanded its funding streams from industry through new strategic partnerships. Examples include the EPSRC/Dyson-funded Prosperity Partnership for Computer Vision Research (£5.3m; *Davison/Leutenegger*); the HeartFlow Project for Modelling Blockages and BloodFlow in Arteries (£1.1m; *Glocker/Rueckert*); the Future Digital Ocean Innovation Centre with China

Shipbuilding Corporation (£1.3m; *Guo*); Huawei-funded projects on Future ML Systems (£1.4m; *Pietzuch*); the Lloyds Foundation/Turing project on [Resilient and Robust Infrastructure](#) (£1m; *McCann*); and the Innovate UK [London Medical Imaging & AI Centre for Value-Based Healthcare](#) (£1.5m; *Rueckert/Glocker/Kainz*).

1.2.2 Research theme achievements

Each research theme consists of multiple research groups. Research groups may be associated with more than one theme, which encourages collaboration and the flow of expertise among themes. Each research group consists of academics who lead a team of researchers and PhD students.

(a) Analysis & Verification. This theme has provided mathematical reasoning techniques and tools for establishing the correctness of real-world software systems. Representative outcomes are *Donaldson*'s GraphicsFuzz tools (see GraphicsFuzz impact case study), which combine fuzzing and metamorphic testing to generate tests for graphics device drivers, and the Gillian multi-language platform with Facebook for compositional symbolic analysis (*Gardner*). Major achievements are an EPSRC Established Career Fellowship and a Programme grant (*Gardner*), an EPSRC Fellowship (*Donaldson*) and a Roger Needham Award (*Donaldson*).

(b) Artificial Intelligence. This theme has resulted in new approaches for autonomous system verification (*Belardinelli, Lomuscio*), fake news detection and automated fact checking (*Bronstein, Toni*), human-like AI (*Muggleton*), multimodal machine translation (used by Facebook) (*Specia*) and explainable AI (*Toni*). Theme members have been co-leading 3 new CDTs, Imperial's [AI4Health](#), [Safe and Trusted AI](#) and [Smart Medical Imaging](#) (the latter two with KCL). High-profile achievements include *Lomuscio*'s RAEng Chair in "Trusted learning-based autonomous and robotic systems"; *Toni*'s RAEng Chair in "Argumentation for explainable AI"; and *Bronstein*'s ERC Consolidator grant in "[Geometric deep learning](#)". A commercial success is the acquisition by Twitter of spinout [Fabula AI](#) (*Bronstein*) for fake news detection.

(c) Data Science. The focus of this theme is applied ML, data analytics and issues of data privacy, storage and visualisation. *de Montjoye* has investigated questions of data access while preserving privacy – a crucial research direction, particularly in the context of medical applications. It has had significant public policy impact in the UK (e.g. contributing to the UK Data Protection Act 2018), the EU (e.g. the EDPB guidance) and worldwide (e.g. US Supreme Court). Major funding successes include *Guo*'s funding for research in medical analytics (£26m; EU [eTRIKS](#)) and data science (£2.7m; HNA Innovation); and *Heinis*'s EU-funded initiative on using DNA for data storage (€2.9m; [OligoArchive](#)).

(d) Programming Languages. The work in this theme has addressed theoretical and practical challenges in the design and implementation of programming languages and program analysis techniques, with the goal of enabling performant and correct software. Outcomes include language semantics around type systems and logics for concurrent and distributed computing (*Gardner*, *Drossopoulou*, *Wu*, *Yoshida*); compiler and language implementation with automated validation, concurrent garbage collection and acceleration (*Donaldson, Field*); and weak-memory concurrency semantics (*Raad*). The theme has developed strong industry links: *Drossopoulou* has a joint appointment leading Facebook's programming tools group; *Donaldson* co-leads the Android graphics quality efforts at Google; and *Yoshida*'s session types are used by Red Hat and VMWare.

(e) Security. This theme has investigated malicious data detection, security and privacy in IoT environments (*Lupu*), the measurement of security and identification of critical components (*Hankin*), vulnerabilities and adversarial attacks in ML (*Lupu*, *Maffeis*), hardware security mechanisms for trusted execution (*Pietzuch*), as well as blockchain scalability and security (*Gervais*). Imperial was one of the first recognised Academic Centres of Excellence in Cyber Security Research (ACE-CSR), playing a significant role in the national cyber security programme (see ISST in Section 1.2.1). Commercial activities include spinout [Xayn](#) (*Huth*) to develop private AI technologies; and *Livshits'* role as Chief Scientist at [Brave Software](#).

(f) Software Engineering. A research focus has been on formal foundations and automated techniques for software development and requirements/performance engineering. Work on software reliability (*Cadar*) has made evolving software more dependable. Requirement specifications have enabled inductive synthesis techniques for automated refinement and adaptation (*Alrajeh, Russo*) –

such a framework for distributed applications was transitioned into an IBM tool, and a verification tool for serverless computing is now used commercially (*Russo*). Research on probabilistic symbolic execution was integrated with NASA's [Symbolic PathFinder](#) system (*Filieri*). Control-theoretic approaches for trustworthy unmanned aerial vehicles are used by Mitsubishi and the Argentine National Agriculture Institute (*Uchitel*). Major funding successes are an EPSRC Fellowship and ERC Consolidator grant (*Cadar*). Prestigious awards are: HVC Most Influential Work 2017, CCS Test of Time 2016, Roger Needham Award 2019 (*Cadar*) and Houssay Prize 2015 (*Uchitel*).

(g) Systems. This theme covers the design, implementation and evaluation as well as verification and analysis of software/hardware systems, and theme members lead the [HiPEDS CDT](#). Notable research outcomes have been new approaches for adaptive emergent systems engineering (*McCann*); advances in custom computing and accelerator systems (*Luk*) and software performance optimisation (*Kelly*); and systems for secure and data-intensive ML (*Pietzuch*). Substantial awards are the Suffrage Science Award 2018 and the President's Medal for Research Excellence 2020 (*McCann*). Major funding successes are an EPSRC Programme and a Platform grant (*Luk*, *Kelly*); and industry funding (>£2m) from Huawei, Intel, BP and Alibaba (*Pietzuch*). The theme impacts industry: *Luk's* spinout [BlueBee](#) was acquired by Illumina; and *Pietzuch* is a Visiting Researcher at Microsoft Research Cambridge.

(h) Theory & Algorithms. Research in this theme reflects the broad applicability and impact of theory and algorithms to society. It has addressed fundamental and applied problems in concurrency, optimisation, quantum computing, stochastic modelling, control and computational psychiatry. Major awards are the AIChE 2020 CAST Outstanding Young Researcher award for *Misener's* work on optimisation and petrochemical process network design. Funding successes include an RAEng Research Fellowship and an EPSRC Research Fellowship (*Misener*); an ERC Starting grant (*Berta*); and 2 EU H2020 projects ([DICE](#), £2.9m; [RADON](#), £3m) co-ordinated by *Casale*. The work on blockchains and cryptocurrencies resulted in the [Interlay](#) spinout.

(i) Visual Computing. This theme has conducted research on topics in computer vision, medical image computing, robotics, graphics, audiovisual processing and intelligent behaviour understanding, exploiting synergy with the *AI* theme. Funding successes include an ERC Starting grant (*Glocker*), an ERC Advanced grant (*Rueckert*), the EPSRC SmartHeart Programme grant (*Rueckert*), an EPSRC Fellowship (*Zafeiriou*), 2 Royal Society Wolfson Fellowships (*Bronstein*, *Rueckert*) and the EPSRC [FACER2VM](#) Programme grant (*Pantic*). Significant industry funding established the Dyson Robotics Laboratory (*Davison*) and the HeartFlow Laboratory (*Rueckert/Glocker*). Commercialisation activities have led to spinouts, including FaceSoft, Ariel AI, SLAMcore and Surreal Vision (see SLAM/3D Analysis impact case studies).

1.2.3 Future research strategy

The Department's research is driven by both curiosity and societal challenges that relate to the Faculty of Engineering's and College's strategic aims. We will maintain this successful approach and continue to lead – through CDTs, Institutes, Centres and Networks – collaborative research that influences technological change. The plans for our three strategic focus areas are as follows:

(a) Cross-cutting research topics

(i) AI/ML/Data. In 2020, we established a major strategic College initiative in this area at Imperial's new White City Campus, with a working title of **Imperial-X** (Co-director: *Pietzuch*). This will be a laboratory for the university of the future by exploring and implementing new models for research, teaching and technology transfer in AI, ML and data engineering. In addition, Imperial-X will provide an extra 3,000m^2 of high-quality space, allowing 30 academics and 150 researchers to be co-located with industrial partners, other departments and spinout companies.

(ii) Health. We will extend our successful collaborations with Imperial's AHSC and external NHS trusts on AI-enabled diagnostic technologies, aligning with the AI4Health CDT. We plan to add seamless image acquisition, decision-support loops and trustworthy causality analysis as new thematic areas.

(iii) Security. We plan to build new capabilities (through targeted grant proposals) related to security/privacy issues in edge-based ML, e.g. security/privacy for personal monitoring during the

pandemic. We will leverage ongoing work in the *Analysis & Verification* theme to provide secure and bug-free software on edge devices.

(b) Academic recruitment and growth

Our academic recruitment will continue to focus on the *AI* theme, building further capacity to contribute to Imperial-X, to benefit from funding opportunities and to satisfy teaching demand. With 50–70 PhD students in AI-related topics starting in the Department each year, there is a strategic need to increase supervision capacity. In addition, we want to strengthen our theoretical computer science research (algorithms, complexity theory, cryptography, quantum computation), opening up new collaboration avenues with the Departments of Mathematics and Physics.

(c) Long-term research funding

We regard Imperial-X as a strategic vehicle to generate extra research income for new, ambitious "moonshot"-style research initiatives through industrial and philanthropic partnerships, further diversifying the Department's funding portfolio. We will identify key technology companies and sector-specific SMEs that can become strategic partners for the Department and Imperial-X. This will exploit our London location and new intellectual property (IP) and licensing models offered by Imperial-X.

1.3 Impact strategy

A key priority for the Department is to maximise the impact of its research on industry, government, the healthcare sector and the wider community. This takes advantage of Imperial's embedding of entrepreneurial culture across research and teaching, in accordance with its publicly stated mission "to achieve enduring excellence in research and education in science, engineering, medicine and business for the benefit of society".

1.3.1 Impact strategy achievements

Our impact strategy has achieved successful impact by exploiting a range of mechanisms:

(a) Stimulating intellectual property generation and commercialisation

(i) Staff encouragement and reward. The Department encourages staff to exploit inventions or spend time in industry. Our academics can spend 20% of their time (up to 80% with approval) on impact, commercialisation and outreach. Such activities are considered in annual appraisals and promotion cases. Impact is also a key component when mentoring PhD students, researchers and ECR staff. Entrepreneurial activities have benefited from recent College changes: Imperial's [Reward to Inventors Scheme](#) now provides staff with a share of revenue (£267,000 over the REF period) from licensing College IP; through its [Founders Choice](#) scheme, the College retains only 5–10% equity in startups (compared with 50% previously). These changes have directly catalysed several startups; 5 are featured in our impact case studies.

(ii) Spinout companies. The Department, facilitated by the new Industry Partnerships and Faculty Commercialisation teams, has a robust process for staff and students to create startups. The Faculty team supports IP generation, protection, technology transfer, company incubation and investment. An Innovation Fellow (*Knottenbelt*) acts as liaison, helping identify commercialisation opportunities, and the current Head (*Huth*) brings experience from a recent two-year industrial secondment.

Since 2014, our staff and students have filed 44 patents, established 17 licensing agreements and founded/co-developed 11 companies. Our impact case studies describe: [GraphicsFuzz](#) acquired by Google (*Donaldson;* 2018), FaceSoft acquired in a confidential deal (*Zafeiriou;* 2020), [Ariel AI](#) acquired by Snap (*Zafeiriou;* 2020); [SLAMcore](#) (*Leutenegger/Davison*) and [Surreal Vision](#) acquired by Oculus/Facebook (*Davison*'s PhD students). Other spinout companies include: [Fabula AI](#) acquired by Twitter (*Bronstein;* 2019), [Magic Pony](#) acquired by Twitter for $150m (*Rueckert*'s PhD students; 2016), [BlueBee](#) acquired by Illumina (*Luk;* 2020), [Interlay](#) (*Gervais*/*Knottenbelts*'s PhD students); [Liquidity Network](#) (*Gervais*); and [Xayn](#) (*Huth*).

(b) Engagement and collaboration with industry

(i) Industrial leadership roles. Our academics can spend up to 80% of their time on secondments to industry. Current industry roles are AI Scientific Research Lead, Facebook (*Pantic*); Head, Graph

ML Research, Twitter (*Bronstein*); Senior Research Scientist, DeepMind (*Shanahan*); Chief Scientist, Brave Software (*Livshits*); Chief Scientific Officer, Corerain (*Luk*); Founder, GraphicsFuzz (*Donaldson*); Founder, FaceSoft (*Zafeiriou*); Founder, Ariel AI (*Zafeiriou*); CTO/Co-founder, Xayn (*Huth*); Founder, Liquidity Network (*Gervais*); Co-founder, ChainSecurity (*Gervais*); and Visiting Researcher, Microsoft Research (*Pietzuch*). Past industry roles include Research Director, Samsung AI Centre (*Pantic*; 2018–20); Founder/Chief Scientist, Fabula AI (*Bronstein*; 2018–19); and Principal Engineer, Intel (*Bronstein*; 2012–19).

Academics also serve on advisory boards, e.g. EPD Dynamics, Relation Therapeutic (*Bronstein*); Nimiq (*Gervais*); Kheiron Medical Technologies, Definiens (*Glocker*); IXICO, Magic Pony (*Rueckert*); ZhongGuanCung, Lizhi (*Guo*); ThinkSono, Cydar Medical, Ultromics (*Kainz*); Surreal Vision, Hadean Supercomputing, Deep Render (*Kelly*); Five AI (*Lomuscio*); SUGA, CCB Fintech (*Luk*); IPSOS, Realeyes, Emotech, Lloyds Register (*Pantic*); and GN Store Nord, fluent.ai, SensAura Tech (*Schuller*).

(ii) Industrial collaborations. Most of our research includes industry collaborations, e.g. through partnership in UKRI/EU projects or direct funding. Examples are research on facial appearance modelling, now used for realistic facial capture in cinematic visual effects by Disney's MEDUSA system (*Ghosh*); research on session types in the Scribble project, now commercialised by Red Hat (*Yoshida*); research on adaptive ML, now transferred by Huawei to its MindSpore platform (*Pietzuch*); and work on the quality of machine translation, used by Facebook (*Specia*).

(iii) Industrial boards. Our Corporate Partnerships Programme (CPP) gives companies a forum to engage around student-focused activities. It has 18 member companies (e.g. Amadeus, Amazon, ARM, McLaren, Microsoft, Morgan Stanley, Ocado, Winton), which have funded PhD studentships (see Section 1.3.1c(iii)), offered internships and provided PhD travel/hardship funds. The Industrial Liaison Board (ILB) advises on the industrial relevance of our research/teaching strategies. Board members (Barclays, Babylon Health, Bitcom, CAP Gemini, Entrepreneur First, IBM, JPMorgan, McLaren Applied, Microsoft, NHS Digital, Ocado and Solidatus) have contributed funding (e.g. *Toni's* RAEng Chair, partly funded by JPMorgan) and enabled consultancy.

(c) Knowledge and technology transfer

(i) Joint industry chairs and research centres. In addition to academics who hold industry appointments (see Section 1.3.1b(i)), our 3 RAEng Chairs (*Lomuscio*, *Muggleton*, *Toni*) also focus on knowledge-transfer activities. We use our joint research centres for knowledge transfers to specific sectors, e.g. the PETRAS Centre to transfer IoT security solutions; the Imperial College AHSC, a partnership between the Institute of Cancer Research and 3 NHS trusts, to transfer research to the NHS; the AI4Health CDT to impact clinical NHS training and practice; and the Centre for Cryptocurrency Research and Engineering to affect financial regulation.

(ii) Impact funding. We exploit UKRI funding streams for knowledge exchange and impact projects, offering a basis for subsequent commercialisation. We hosted 14 impact acceleration account (IAA) projects, including: the CLsmith/GPUVerify projects that led to the impact in the GraphicsFuzz impact case study (*Donaldson*); the EuroExa project that enabled FPGA hardware acceleration in weather/climate modelling (*Luk*); a collaboration with the National Crime Agency on intelligent crime linkage that developed tools for policing child sexual offences (*Alrajeh*); and the creation of an image segmentation tool used for a clinical study of 17,000 patients at Addenbrooke's Hospital (*Glocker*).

(iii) PhD students and research staff. PhD students and postdoctoral researchers are another potent pathway for transfer, especially to the UK industrial base. During the REF period, 278 PhD students graduated, and almost half went directly to industry; about 40% of more than 400 research associates joined industry, research institutions, the public sector or became self-employed. Startups formed by PhD students include Magic Pony, Surreal Vision and Interlay. Over 40 industrial PhD studentships have technology transfer in their remit. These include 13 CASE awards with major UK-based companies (e.g. Airbus, ARM, Arup, Detica, Dyson, Huawei, Microsoft, Schlumberger, Shell) and directly funded PhD studentships (e.g. Google, HeartFlow, JPMorgan, IBM, Intel, Microsoft, Qualcomm, Oracle).

(iv) Consultancy. Our staff are encouraged to undertake consultancy work through Imperial Consultants with 41 projects since 2014. Staff engage with large multinational companies (e.g. Audi,

Barclays, Disney Research, Dyson, Facebook, GSK, Huawei, Microsoft, NEC, Samsung, SAP, Syngenta), legal firms, government and international organisations (e.g. GCHQ, BCS, Barbican, International Tennis Federation) and SMEs (e.g. Accountancy Cloud, Becrypt, Cambridge Quantum Computing, Circle Cardiovascular, Hexagon, Tindall Riley).

(v) Open-source software. Our research produces open-source software that is used in industry and academia: KLEE, a symbolic execution engine with >70 contributors, is used by e.g. Baidu, Bloomberg, Fujitsu and Samsung (*Cadar*); TensorLy has >600 users, including Amazon, Facebook, NVIDIA, INRIA and Apple (*Pantic*); Devito is now supported by spinout Devito Codes and is used by >100 companies, with funding from BP, DUG, Microsoft and Shell (*Kelly*); TranSMART is the most widely used big data analytics platform for medical research (*Guo*); GraphicsFuzz is now maintained by Google (*Donaldson*); JMT for performance modelling (>38,000 downloads) is used by e.g. Carleton University, IBM and NC State University (*Casale*); TensorLayer (>6,000 GitHub stars) is a popular platform for deep learning (*Guo*); Haskell's Generic Lens Library is used by >200 projects and companies, including Target and Tweag (*Wu*); Liquidity Network has >2,000 users (*Gervais*); and Unsaturated Type Families are added to the widely used Glasgow Haskell Compiler (*Field*).

1.3.2 Impact case studies

The influence of our impact strategy on submitted case studies is shown in the table below.

Case study	Impact strategy influence	Sector
IXICO	Interdepartmental and multi-institution collaboration, spinout (2004)	Healthcare, pharmaceutical
GraphicsFuzz	IAA funding, open-source software, spinout, industrial collaboration, reward to inventors	Information technology, SMEs
Infer	Multi-institution collaboration, spinout (2009), open-source software, industrial collaboration	Information technology, SMEs, government
SLAM	Consultancy, spinout, PhD transfer to industry	Manufacturing, information technology
3D Analysis	Licensing, spinout, reward to inventors, industrial and multi-institution collaboration	Information technology, telecommunications, healthcare

1.3.3 Future impact strategy

We will continue our multi-pronged impact strategy, which recognises that impact occurs through a variety of channels. We plan to enhance impact activities by:

(a) establishing new strategic partnerships with industry, especially in the context of our CDTs and Imperial-X with its co-location concept for industrial collaboration. Imperial-X will bring new models for industry projects, e.g. through pooled IP arrangements;

(b) encouraging staff to work with Imperial's Industry Partnership and Faculty Commercialisation teams to determine impact opportunities for their research, to make use of the Techcelerate programme for entrepreneurial activities by ECRs and the advanced hackspace for prototyping research ideas;

(c) enabling closer interaction and advice from our industrial boards on strategies that encourage a higher level of societal and economic impact, e.g. expanding our well-established Applications of Computing in Industry lecture programme;

(d) continuing support and mentorship for staff to apply for impact funding, industrial fellowships, sabbatical leave for impact-related activities, and part-time industrial appointments;

(e) continuing support for staff to engage in policy advisory roles, public lectures and outreach activities (see Section 4);

(f) conducting horizon-scanning exercises to identify emerging opportunities for new partnerships with industry, healthcare and government, especially in growth areas such as explainable AI, federated ML, distributed ledger technology and quantum computing.

1.4 Open research environment

The College is committed to an open research environment and has played a leading role in open access (OA) discussions with publishers (see institutional statement). The College's [OA policy](#) is overseen by the Scholarly Communications Office, and the Department promotes the publication of research outputs in green/gold OA modes. Staff can apply for College-managed funds to cover OA publishing charges. All our submitted outputs are freely available from institutional repositories. Accepted paper versions must be published in the College's [Spiral](#) repository, if allowed by the publisher.

The Department has an OA Champion (*Pietzuch*) and promotes openness and transparency in reproducibility through [artefact evaluation](#) (AE), open source software releases and research data management. Our academics regularly participate in AE processes (e.g. for ACM, USENIX, VLDB) and serve on AE committees. Source code is typically made available as open-source software on repositories such as GitHub, GitLab and BitBucket (see Section 1.3.1c). Many research datasets have been publicly released (e.g. [Singapore Environmental Sensing](#), [City Scale LPWAN](#), [KANFace](#), [Mobiface](#), [VaFRIC](#), [Normal-whispered-silent Speech](#), [AgeDB](#), [300W](#)).

1.5 Research integrity

The College is a signatory to the [Concordat to Support Research Integrity](#) and is committed to maintaining the highest standards of rigour and integrity in all aspects of research. The Vice-Provost for Research is responsible for oversight of research integrity, advised by the Advisory Group for Research (see institutional statement). The Department adheres to the College Research Integrity policy, and policy matters are discussed at the Faculty Management and Research Committees.

Dedicated mechanisms to ensure research integrity exist. PhD students are required to attend [Graduate School](#) courses on research integrity, impact and ethics/compliance (plagiarism, IP, copyright). The [Postdoc and Fellows Development Centre](#) (PFDC) offers similar courses for the professional development of postdoctoral researchers.

Ethical reviews of proposals take place within Imperial's [Ethics Code of Practice](#), and research involving human subjects, animals or human tissue is reviewed by the Research Ethics Committee. To address ethical issues specifically in technology research involving human subjects, a new Science, Engineering and Technology Ethics Committee (former member: *Sergot*) was established in 2018. A communications strategy across the Faculty has raised awareness of ethics approval in non-medical research in our Department.

2 People

2.1 Staff strategy and staff development

2.1.1 Academic staff

The Department pursues excellence by recruiting outstanding academics with leadership potential, nurturing ECRs (16 submitted) to maturity, and supporting all academics in their research activities. Of the 67 submitted staff (43% Professors, 16% Readers, 18% Senior Lecturers, 23% Lecturers and 4% Research Fellows), 27 (including 6 women) were appointed during the REF period: 18 Lecturers, 2 Senior Lecturers, 1 Reader, 3 Professors and 3 Imperial College Research Fellows (ICRFs). Our academic staff are predominantly appointed on full-time, open-ended contracts; some maintain part-time links to other institutions. In our REF submission, 10 academic staff are now part-time with external industrial/academic roles, and 3 have partly retired; of these, 4 have fixed term contracts: 2 industrial secondments and 2 retired, as well as the 3 ICRFs. Part-time staff supervise PhD students and postdoctoral researchers, apply for grants and are often involved in teaching.

(a) Academic recruitment. Our annual recruitment process attracts world-leading researchers. We align with the global academic hiring cycle (December to April) in competing for the top talent. When advertising posts, the Department encourages applications in any area of computer science, pursuing excellence as the main criterion (while considering our equality, diversity and inclusion (EDI) goals) and academics encourage "rising stars" to apply. This helps attract an international profile of academics from top-tier institutions: over the REF period, we recruited from CalTech (*Berta*), ETH Zurich (*Heinis, Gervais, Leutenegger*), UIUC (*Demetriou*), Lugano (*Bronstein*), Microsoft (*Livshits*), MIT (*de Montjoye, Pirk*), MPI-SWS (*Raad*), Politecnico di Milano (*Filieri*), UCSB

(*Paccagnan*) and Technion (*Vilanova*).

All academics in the Department are invited to review applications and contribute to the selection process. A Departmental Hiring Committee, with elected representation, draws up the final interview shortlist in consideration with our EDI policy. Shortlisted candidates visit the Department for two days, give an open research seminar, have one-on-one sessions with academics and group meetings with undergraduate/PhD students, as well as a formal panel interview. All academics can attend and assess the seminars and provide feedback from their one-on-one sessions to the committee.

To sustain and expand our research activity, the Department's emphasis has been on recruiting ECRs and developing them into world leaders. We attract such candidates to join us and develop their careers through a number of means: competitive salaries and support with London housing; a startup research package of about £130,000 to cover seed funding for equipment, travel and at least 2 PhD students; new academics either join an existing research group or create a new group; and to facilitate settling in, they have a reduced teaching load and no administrative duties for two years.

(b) Career development. New academics are assigned an academic adviser who provides mentoring, observes occasional lectures for constructive feedback and joins three probationary reviews. They also attend training courses in "Teaching and learning for engineers", "PhD supervision" and "Personal tutoring" and are offered courses on research project management. Academics are typically promoted by the end of their probationary period (e.g. *de Montjoye*, *Heinis*, *Leutenegger, Misener*). To offer flexibility to academics, the Department allocates 20% of grant overheads to PIs, thus providing them with discretionary funds for consumables, seed funding for new initiatives and bridge funding for research staff and students.

The Department supports academics in winning fellowships and grant awards. The Director of Research and senior academics help with proposal preparation, including funding strategy advice, feedback on draft proposals and mock interviews in the Department, followed by a Faculty mock interview. The College also offers one-to-one coaching (25 sessions used). As a success measure, almost all new academics obtain their first PI grant funding within 2 years, e.g. through EPSRC First grants (*Casale*, *Cully*, *Ghosh*, *Glocker*, *Kainz*, *Misener*).

(c) Sabbaticals. Staff are encouraged to spend dedicated sabbatical time in academia or industry, fostering new collaborations and gaining fresh perspectives. Sabbatical models are implemented in line with EDI policy, e.g. Imperial allows for "mini" or flexible sabbaticals for those with caring responsibilities. A Departmental Sabbatical Committee assesses applications annually, with EDI considerations applied. During the REF period, 10 sabbaticals (including 2 by women) were taken (3 more approved for 2019–20 but suspended due to the pandemic).

(d) Appraisals and promotions. The Department encourages ambition and rewards achievement. All staff have an annual appraisal with the Head of Department or a designated senior academic to discuss current activities, propose future development plans and raise concerns. Staff are promoted according to merit in an annual College-wide promotion round without quotas. The College is a signatory to DORA, ensuring that promotion procedures do not use journal-based metrics. Over the REF period, there were 26 promotions (9 to Professor).

(e) Administrative support. The Department uses support functions to reduce the time that academics spend on administrative and technical tasks. It employs 14 Teaching Fellows to perform much of the teaching administration as well as specialised roles such as Equality, Diversity, Outreach and Public Engagement (*Bell*), UG Senior Tutor (*Valera-Espana*) and PG Senior Tutor (*Lancaster*). This preserves a low average teaching load of 1.5 modules per year. Academics with substantial research groups, fellowships or major awards (e.g. ERCs grants) have a reduced teaching and administrative load (currently 10 academics). Academics on part-time secondment in industry still lead research projects and supervise PhD students (*Bronstein*, *Donaldson*, *Gervais*, *Livshits*, *Pantic*, *Shanahan*).

(f) Working together. The Department meets weekly as a community for well-attended "Wednesday lunches" – a forum for academics to present current research ideas, often leading to collaborations across areas. Our annual Away Days, which include teaching and support staff, foster discussion on departmental strategy and have enabled us to react quickly to emerging new research trends, e.g.

by updating research themes. Away Days have also helped new academics integrate into the Department.

2.1.2 Research staff

The Department supports postdoctoral research associates (RAs) in their career development by helping them reach permanent academic or industrial posts. We offer an environment in which research staff can secure funding and attend conferences to engage with the global research community. An RA Mentor (*Davison*) is available to all RAs for one-on-one career advice and general guidance. Elected RA representatives organise "Thursday lunches" and liaise with academics, including the Head of Department. We encourage RAs to apply for fellowships, including ICRFs of which 7 have been awarded (*Alrajeh*, now Lecturer; *Deisenroth*, was Lecturer, now Professor at UCL; *Clark*, *Sharmanska*, *Tuncer* submitted; 2 in external posts).

The College has fully implemented the [Concordat on Career Development of Researchers](#) and achieved an EC HR "Excellence in Research" badge. Imperial's [PFDC](#) provides skills and career development training, a personal development programme for women, bespoke ICRF development, the multidisciplinary Postdoc Reps Network and individual support, including entrepreneurship, management skills, coaching, funder showcases and mock interviews. The Department encourages research staff to use 10 annual development days. Over the REF period, research staff attended 31 training courses, 95 one-to-one PFDC sessions and participated in 34 mock interviews.

2.2 PhD students

The annual intake of PhD students now is 60–70, up from about 45 in REF2014. UK student numbers remained fairly constant (45–55), while EU/overseas student numbers rose between 2018 and 2020. Between 2013 and 2020, the PhD student population grew by nearly 50% (from 165 to 247). The PhD success rate has also improved: 89% of our PhD students submit within 4 years (compared with 76% in REF2014). The number of PhDs awarded has increased by 70% (from 164 to 278).

A major contributing factor to the increase in students has been the Department's strategic decision to increase PhD funding to more than £1.5m a year (excluding DTPs, CDTs and grants). The Department has a Teaching Scholarship scheme, which allows students to pursue a 4.5-year PhD while obtaining a teaching certificate. Overall, 85% of our students are funded through UKRI DTP/CDT awards, scholarships, grant-based employment, industry and the College (e.g. 17 competitive [College President's Scholarships](#)). The sustainability of our PhD programme is supported by our two hosted CDTs, [HiPEDS](#) started in 2014 and [AI4Health](#) started in 2019, and two partnered CDTs, [Medical Imaging](#) and [Safe & Trusted AI](#).

(a) Admissions. Our PhD application numbers have increased from 550 (in 2019) to 937 (in 2020) – home, EU and overseas students up 151%, 36% and 34%, respectively – in spite of the impact of Brexit and the pandemic. Candidates apply by submitting a research statement, their academic record and a CV. If they meet our academic criteria (typically a distinction-level Master's degree), an admissions decision is made after interview by at least two academics. Offers, for both admission and funding, include EDI considerations, e.g. the Department recognises that applicants from non-traditional backgrounds to cross-disciplinary CDTs (e.g. AI4Health) typically perform well.

(b) Support. PhD students are supported by the PhD team, consisting of the Director of Postgraduate Studies (*Filieri*), Postgraduate Tutor (*Wu*), Cohort Mentors (*Belardinelli*, *Specia*, *de Montjoye*) and PhD Administrator (*El-Kholy*). Each PhD student is given dedicated office space, a high-end computer, laboratory access and a £4,000 travel budget over their PhD. Research groups provide further funds for resources, equipment and travel.

To support completion within 4 years, the Department and its CDTs have comprehensive monitoring and progress procedures. An informal progress review is carried out after 3 months, and a formal review 6 months later, for which the student presents a literature survey and thesis outline, and the supervisor, second supervisor and an independent assessor provide feedback. After the 2nd year, the same team evaluates the thesis plan. A draft dissertation is assessed after year 3. The PhD Tutor and the Director of Postgraduate Studies monitor cohort progress quarterly.

(c) Mentoring. Each PhD student is assigned an academic Mentor and a "PhD Buddy", who is a senior PhD student. The Department offers bespoke training courses on academic writing and

communication skills, which include feedback from an academic and a communications expert from Imperial's languages centre. The Department also organises panel sessions on pursuing academic careers. In a "One Minute Madness" event, PhD students pitch their research and participate in a poster competition.

The College's Graduate School offers skills training courses, e.g. "Research skills and techniques", "Communication skills", "Networking and team-working" and "Career management". PhD students must take at least four. The Graduate School promotes interdisciplinarity between students by hosting research symposia, poster competitions and external lectures. It also organises participation in public engagement events, such as school talks, and in Imperial's annual science festivals.

PhD students participate in student-led events. The Department has an ACM Student Chapter, and students organise an annual public PhD student workshop to acquire skills in reviewing and conference management. For social interactions, the Department provides funds for a student-run "Friday cakes" seminar series. During the pandemic, the Department held several online cohort-building activities with external professionals, including an escape room and a hackathon. It has also provided partial funding for PhD students for home offices and offers a loan scheme for equipment and furniture.

2.3 Equality and diversity

2.3.1 Commitment to equality, diversity and inclusion

The Department aims to create a fair, diverse and inclusive environment for all staff and students, irrespective of gender, ethnicity, religion and age, as indicated in the Department's new welcome message. The Department has appointed an EDI Champion (*Bell*), responsible for organising training events, monitoring compliance with College EDI policies and embedding EDI into everything that we do. Imperial's EDI Strategy is set by a committee chaired by the Provost, supported by the College EDI Forum with staff and student members and Faculty EDI committees (see institutional statement). The Department's Equality, Diversity & Culture Committee adapts this strategy, e.g. to address staff/student concerns submitted via anonymous feedback forms and regular Departmental surveys. The Department also participates in the Faculty's "Have your Say campaign" that develops College values and trains line management to support an inclusive culture.

Out of 67 submitted academics, 21% are women (14), including 8 professors, and 13% Black, Asian and Minority Ethnic (BAME), including 4 professors (13% not recorded). Only 15% of our staff are over the age of 60, and 24% (16) are classified as ECRs. Our academics were born in 26 countries (12 for professors). For research staff, 20% are women, 38% BAME and 38% white (24% not recorded). Over the REF period, 15–19% of PhD students were women, 57% of students white, and 32% BAME (11% not recorded).

Imperial has an Athena SWAN Silver award and the Department has a Bronze award (from 2017, currently applying for Silver). The Department works to improve gender balance, directing outreach efforts to school-aged students and communities to enable widening participation by under-represented groups. It offers DeepMind Scholarships to under-represented groups for MSc courses. PhD students and researchers who are women hold insight sessions to help PhD students into an academic career. The Department funds an active Women in Computing group to support networking.

The College follows transparent and fair hiring procedures (guided by Stonewall's Diversity Champions Programme, "Time to Change", Disability Confident Leader and Race Equality Charter) and all involved staff undergo regular bias training. The Faculty has also introduced Active Bystander training, which won a 2018 UHR Award, and new students attend the training during their first weeks. Our Department leads in-house Unconscious Bias training for 480 students each year. We encourage staff development for all through diversity staff networks (Able@Imperial for disabled staff; Imperial 600 for LGBTQ+ staff/postgraduates; Imperial as One for BAME staff).

Our commitment to EDI policies related to promotions is evident in that 60% of our professors are women and 43% are BAME. In addition, 57% of women and 55% of BAME academics have won prestigious fellowships and/or large grants, attesting to our funding support.

2.3.2 Flexible working

The College's Flexible Working Policy is a formal way to offer flexible working arrangements. Going beyond this, the Department promotes informal flexible working, e.g. for staff with caring responsibilities or travel challenges into London. Staff may request flexibility on their teaching schedule during the annual timetabling exercise. This is regularly used by staff of all gender identities to handle childcare duties, for example. The Department has a family-friendly policy in terms of scheduling meetings and events; events are often recorded for remote viewing. If staff are required to attend remote work events, such as conferences, they have access to Imperial's Carer Support.

During the pandemic, all staff have been working from home, with dedicated College webpages offering up-to-date guidance and wellbeing advice. Recognising the increased demands during the pandemic, the Department initiated a no-determent policy that protects the career progression of staff, across all job families, whose performance has been affected.

2.3.3 Sickness, caring and disability support

The College's sick pay entitlement allows staff up to 6 months off work on full pay and a gradual return to work after sick leave with 50% pay. Staff returning from long-term absence are encouraged to adopt a phased return, as recommended by Occupational Health.

The Department offers a range of family leave, irrespective of gender identity, sexual orientation, gender expression, biological sex or transitioning: maternity (used by 15 academics/RAs), paternity (8), shared (2) and adoption/surrogacy leave. Maternity (extended to paternity in 2017) returners can apply for an Elsie Widdowson Fellowship that supports one year of research focus (awarded to *Alrajeh*). The College won the Working Families Best for all Stages of Fatherhood Award in 2017. A total of 31 staff used the childcare vouchers scheme to help fund childcare costs.

The College is a Disability Confident employer, making workplace adjustments for disabled staff and students. It recognises that disabilities can be physical or mental, visible or invisible, and that mental ill health is an under-reported issue. The College's Equality, Diversity & Inclusion Centre (EDIC) provides advice for disabled staff and assesses staff for dyslexia and other learning differences. The Centre offers Calibre, a development programme for staff with long-term physical/mental health conditions. The Departmental Disability Officer (*Lancaster*) manages any special requirements due to staff disability or health needs, e.g. office furniture. The Department has 3 staff and 11 PhD students with declared disabilities.

(a) PhD student support. The Department implements the UKRI Leave of Absence policy, allowing students to take parental leave with a provision for additional stipend (up to 26 weeks in full). Students may also study on a part-time basis. After evidence from a clinician, the Department funds up to 12 weeks of sick leave, in most cases irrespective of the student's funding source. Over the REF period, 5 students took maternity, 1 paternity and 4 sick leave.

Students facing hardship are helped from Departmental funds, e.g. supervisor's personal research funds, remaining scholarship funds and the CPP hardship fund (used by 5 students over the REF period). Other sources include the College's Student Support Fund (started in 2015) and the Engineering Dean's Fund (used by 2 students), which receives alumni donations for financial hardship or specialist medical treatment, and the College provided additional funds for hardship due to the pandemic.

2.3.4 Wellbeing

The Department recognises that staff wellbeing is affected by the nature of roles, domestic situations, caring responsibilities and health. The College carries out regular wellbeing surveys; the most recent, in September 2020, highlighted specific concerns around managing workload, returning to regular campus work, travelling to work safely and the impact of long-term remote working. The College and Department have used this feedback to implement new online meeting protocols, no expectations for email responses outside working hours, working from home guidance, a Wellbeing Day (3 July) and increased flexibility for staff with caring responsibilities. The Department has recruited a 0.5 FT Wellbeing Officer (*Langan*) to support student wellbeing and mental health issues. Wellbeing resources are advertised on our webpages.

Unit-level environment template (REF5b)

The Department has a policy to allocate workload in a fair and transparent manner. The Departmental Management Committee regularly analyses workload distribution, and staff are encouraged to discuss workload allocation issues with the Head of Department. Individual workloads also feature in the annual Personal Research and Development Plan appraisal process.

During the pandemic, the Faculty has developed a Remote Working Development Hub to support line managers and staff with best practices. With this support, the Department was able to deliver the bulk of its research and teaching activities remotely. Access to research labs with equipment was made available based on need and Government/College public health guidelines. The Department has also invested in solutions for remote equipment-based research, e.g. in robotics. Staff training courses are now delivered as interactive video sessions.

2.3.5 Output selection

Staff were invited to submit up to 6 outputs with significance statements for consideration. All outputs were rated without bias according to the REF evaluation criteria by a panel of 9 members from the Departmental REF committee, and ratings and constructive comments were fed back to staff. All outputs were then ranked based on these ratings, and the committee selected at least 1 and at most 5 outputs from each staff member from this ranked order. A small number of borderline selections changed after discussion with staff members. The following table shows the number of outputs submitted with respect to gender, ethnicity and ECR status:

| Submitted outputs		Gender		Ethnicity			ECR
	Total	Female	Male	White	BAME	Unknown	
1	48%	22%	78%	63%	22%	16%	28%
2	16%	9%	91%	82%	0%	18%	36%
3	16%	27%	73%	73%	9%	18%	9%
4	12%	13%	88%	100%	0%	0%	25%
5	8%	40%	60%	80%	20%	0%	0%
Overall submitted:		21%	79%	73%	13%	13%	24%

As can be seen from the data, the distribution of submitted outputs largely follows the overall staff distribution.

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3 Income, infrastructure and facilities

3.1 Income

The Department's overall research income/expenditure over the REF period has more than doubled from £50m in REF2014 (£1.0m per FTE) to £106m in REF2021 (£1.8m per FTE). Diversifying our research funding sources has strengthened the vitality and sustainability of our research portfolio. As the chart below shows, the Department's RCUK/UKRI income increased by 78%, EU by 75%, industry by 198%, government by 506% and charities by 52%. Allowing for differences in the length of the REF periods, the total average income per annum increased by 51% (from £10.0m in REF2014 to £15.1m in REF2021). Based on current and already awarded grants, our partial projected income for 2020–21 is £14.2m, 2021–22 is £13.1m and 2022–23 is £10.1m, indicating good sustainability.

Research Income
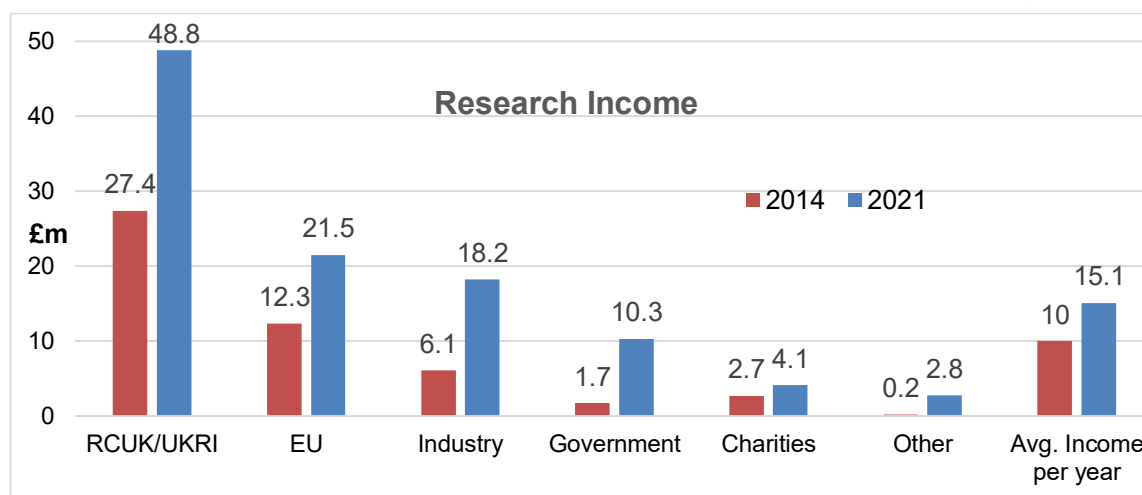
Our strategy for supporting research has been to focus on prestigious, large (>£1m) and long-term (>3 year) projects, and we have had 34 such awards. One of the largest is a Prosperity Partnership with Dyson (EPSRC: £2.1m, Dyson: £2.9m; *Davison/Leutenegger*). Other major grant awards were: 5 ERC Starter/Consolidator/Advanced grants (*Bronstein*, *Cadar*, *Rueckert*, *Berta*, *Glocker*); 3 Royal Academy of Engineering Chairs (*Muggleton* with Syngenta, *Toni* with JPMorgan, *Lomuscio*); 8 EPSRC Programme grants with substantial Departmental involvement (*Davison/Kelly*, *Donaldson*, *Gardner*, *Luk*, *McCann*, *Pantic*, *Rueckert*, *Yoshida*); an EPSRC Platform grant (*Luk*); 5 EPSRC Fellowships (*Donaldson*, *Gardner*, *Ghosh*, *Misener*, *Yoshida*); 4 large EPSRC grants (*Cadar*, *Lupu*, *Pantic/Zafeiriou*, *Pietzuch*); 3 large EU grants (*Rueckert*, *Pantic*, *Guo*); 2 large industry grants (*Guo*, *Glocker*); an Innovate UK grant for the London Medical & Imaging Centre (*Rueckert/Glocker/Kainz*); and a Gates Foundation grant (*Lo*).

Although we focus on large grants, we encourage grant proposals of all sizes, with more than 350 grants awarded during the REF period. Among the 67 submitted staff, 46 have been PI on at least one grant. Several of our funded industry collaborations came out of previous consultancies (*Casale* with SAP, *Davison* with Dyson, *Glocker* with HeartFlow). Special funding events, such as Faculty/Department workshops on AI applications, cybersecurity, robotics, autonomous systems and medical informatics have also fostered collaborations that led to grant funding.

3.2 Infrastructure and facilities

The College has a transparent funding model in which departments receive all income from teaching and research but contribute pro-rata costs for College operation. The Department has exploited this model to ensure that academics are well supported, both in obtaining funding and in conducting research. Each academic has access to a Departmental administrator to assist with the preparation of proposals and the management of projects.

The Department makes a significant investment to provide a Computing Support Group (CSG) with 8 staff members who support local ICT services for research and teaching. CSG provides an IaaS cloud service, a departmental HPC facility and bespoke research services, all leveraging the College's provision of email, networking, workstations and a larger HPC facility. Over the REF period, the College invested £25m in the Research Computing Service and the Department spent £2.9m on research infrastructure hardware.

The total number of research staff and PhD students increased from 283 (in 2013) to 386 (in 2020). To ensure that the physical environment meets research needs, the Department has invested substantially in both the quantity and quality of research space. In 2013, the Department had 2,500m^2 classified as research space; since then it has spent £3.5m (including £1.8m for the Data Science Institute) on repurposing and refurbishing space, increasing its research space footprint by 32% to 3,300m^2.

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

4.1 Research collaborations

Our academics collaborate extensively with other Imperial departments, supported by strategic joint appointments with Bioengineering (*Faisal*, UoA12), EEE (*Leung*, UoA12; *Jennings*) and Surgery (*Lo*). Many staff are involved in interdisciplinary collaborations with other Engineering departments, e.g. the EPSRC IRIS Programme grant with EEE (*Donaldson*); the EPSRC INHALE, MAGIC and PREMIERE projects with Earth Science and Chemical (*Guo*); an EPSRC project on neonatal imaging (EP/S013601/1) with Bioengineering (*Kainz/Glocker/Rueckert*); and the NEC Japan Smart Water labs with Civil (*McCann*).

Our collaborations and engagement with industry and academia extend to national and international levels. The Department has engaged in more than 40 funded industrial collaborations, with the largest being the Dyson Robotics Laboratory (>£10m; *Davison/Leutenegger*) and projects (>£1m) from Huawei (*Guo, Pietzuch*), Intel (*McCann*), HNA (*Guo*) and HeartFlow (*Glocker*). All fellowships and RAEng chairs include industrial collaboration. The Department's 8 EPSRC Programme grants are by nature multi-institutional (e.g. Cambridge, Edinburgh, Glasgow, KCL, Newcastle, Oxford, QMUL, St Andrews, Stirling, Surrey, UCL) and involve industrial collaboration (e.g. Amazon, ARM, BT, Facebook, FreeBSD Foundation, GridPP, HP Labs, IBM, Microsoft, Philips, Rolls Royce and Siemens). Both our hosted CDTs (AI4Health and HiPEDS) have large industrial networks and contributions (see Section 1.2.1a).

The Department is involved in high-profile international research consortia: *Lomuscio* is a primary contractor in the US DARPA Assured Autonomy Project with Stanford, Berkeley, Vanderbilt, UPenn and NASA; *Russo*, *Lupu*, *Jennings* and *Pietzuch* are PIs in the IBM-led "International Technology Alliance in Distributed Analytics and Information Sciences" (DAIS-ITA) funded by the US Army and the UK MOD, involving 10 US/UK universities. The Department also forms strong links through large UK/international networks (>20 academic and industry partners): Concordia Pilot Cybersecurity Competence Network (*Lupu*; 50 partners); MRC RASP-UK "UK Refractory Asthma Stratification Programme" (*Guo*; 49 partners); IMI2 IDEA-FAST on "Identifying Novel Digital Measures for Fatigue and Sleep Disturbances" (*Guo*; 47 partners); IMI2 PIONEER on "Prostate Cancer Diagnosis and Treatment through Big Data" (*Guo*; 37 partners); EPSRC-NIHR HTC Partnership Award 'Plus' MEDIAN for the UK medical image community (*Glocker*); and EPSRC Human Like Network (*Muggleton*; 21 partners).

The majority of our research projects are collaborative in nature. Using the *Visual Computing* theme as an example, collaborative medical imaging projects with other universities and the NHS include: the UKRI/InnovateUK London Medical Imaging & AI Centre with KCL/QMUL, 4 NHS Trusts (Guy's & St Thomas', King's College Hospital, South London & Maudsley, Barts Health), industry (Siemens, NVIDIA, IBM, GSK), 10 UK-based SMEs and the Health Innovation Network (*Rueckert/Glocker/Kainz*); the "Intelligent and Personalised Risk Stratification and Early Diagnosis of Lung Cancer" project with KCL, Guy's & St Thomas', Kings Healthcare and Siemens (*Glocker*); and the SmartHeart programme grant with Barts Health, Guy's & St Thomas', UK Biobank, Siemens, Philips and Spectrum Diagnostics (*Rueckert/Guo*).

Academics use their international networks to take leadership roles in EU collaborative projects: *Casale* co-ordinates the H2020 RADON project on serverless cloud computing with 8 academic and industrial partners; *Heinis* co-ordinates the H2020 OligoArchive project on DNA storage with CNRS, Eurecom and Helixworks; *Pantic* was co-ordinator of the H2020 SEWA project on automatic sentiment analysis with Passau, Augsburg, RealEyes and Playgen; *Guo* was co-ordinator of the IMI eTRIKS project on medical analytics with Roche, AstraZeneca, Sanofi, Pfizer, Merck, Lundbeck, Janssen, GSK, Lilly and Bayer; and *Casale* was co-ordinator of the H2020 DICE on cloud performance with 10 partners.

4.2 Academic leadership and contributions to the discipline or research base

The Department provides academic leadership, influencing and driving research agendas, strategy and policies, at both national and international levels.

4.2.1 Esteem and leadership

(a) Esteem and leadership roles. Evidence of the esteem in which our academics are held includes 8 Fellows of the Royal Academy of Engineering (*Davison*, *Gardner*, *Guo*, *Jennings*, *Luk*, *Muggleton*, *Pantic*, *Rueckert*); Fellow of the Academy of Medical Sciences (*Rueckert*); Fellow of the European Association for AI (*Jennings*, *Lomuscio, Toni*); 6 IEEE Fellows (*Bronstein*, *Jennings*, *Luk*, *Pantic*, *Rueckert*, *Schuller*); 19 Fellows of the BCS; and 5 Fellows of the IET.

Our academics serve in leadership roles: Chair, ACM SIGMETRICS (*Casale*); Chair, ACM Europe Technology Policy Committee (*Hankin*); Chair, RAEng National Engineering Policy Centre and Engineering Policy Committee (*Jennings*); Chair, ACM SIGOPS European Chapter (*Pietzuch*); Member at Large, ACM SIGSOFT (*Uchitel*); Member, ACM SIGSOFT Empirical Standards Definition Committee (*Filieri*); Member, BCS Awards Committee (*Donaldson*); Honorary Vice-Chairman, Chinese Association of AI (CAAI) (*Guo*); Member, European Cloud Computing Expert Group (*Guo*); Member, IEEE Big Data Steering Committee (*Guo*); and Board member, European Association for Programming Languages and Systems (EAPLS) (*Wu*). Past leadership roles include: Chair, ACM Europe Council (*Hankin*, 2017–19); Board of Directors, ACM SIGMETRICS (*Casale*, 2015–19); Chair, BCS Lovelace/Needham Awards Committee (*Gardner*, 2013–16); Trustee, Building Research Establishment (*Jennings*, 2015–18); and Board of Directors, MICCAI Society (*Rueckert*, 2011–15).

(b) Awards and prizes. Our academic leadership has been recognised with prestigious awards from external bodies: [BCS Lovelace Medal 2020](#) (*Jennings*); [Royal Academy of Engineering Silver Medal 2020](#) (*Bronstein*); [AIChE CAST Young Researcher Award 2020](#) (*Misener*); [IAPR Maria Petrou Award 2020](#) (*Pantic*); [BCS Roger Needham Award 2019](#) (*Donaldson*); [IEEE Computer Society Golden Core Award 2019](#) (*Schuller*); [Suffrage Science Award for Maths & Computing 2018](#) (*McCann*); [Fondation Dalle Molle Prize 2018](#) (*Bronstein*); [AMiner Top 10 Most Influential Scholars Award in AI 2018](#) (*Jennings*); Royal Society Wolfson Merit Award 2018 (*Bronstein*); [Royal Academy of Engineering Macfarlane Medal 2017](#) (*Misener*); [BCS Roger Needham Award 2017](#) (*Donaldson)*; Royal Society Wolfson Merit Award 2016 (*Livshits*); ACM Distinguished Scientist 2015 (*Uchitel*); Young Scientist of the World Economic Forum 2015 (*Schuller*); [EuroSys Jochen Liedtke Young Researcher Award 2015](#) (*Cadar*); and [MIT Innovators under 35 in Belgium 2015](#) (*de Montjoye*).

(c) Grant reviewing. Our academics review grant proposals for many UK and international funders in Europe, USA, Canada, Hong Kong, Singapore and China. They often chair or serve on funding panels, e.g. EPSRC (*Alrajeh*, *Cadar*, *Donaldson*, *Ghosh*, *Lupu*, *McCann*, *Pantic* and *Russo*); and EU ERC/H2020 (*Guo*, *Pantic* and *Pietzuch*).

4.2.2 Contributions to the discipline

(a) Editorships and journal boards. Academic leadership is reflected by our posts of editor-in-chief of international journals: *Computer Language and Speech* (*Specia*); Deputy, *IET Software* (*Alrajeh*); OUP ML Series (*Muggleton*, 2013–20); *Image and Vision Computing* (*Pantic*, 2006–19). Our academics also hold more than 55 associate editor/editorial board memberships, including for many IEEE/ACM journals and as guest editors for journal issues.

(b) Conference leadership. Academic leadership is measured by our service to conferences. On average over the REF period, each academic has been a committee member of 2–5 international conferences per year. Our academics led more than 50 conferences and workshops as Programme Chair (PC) or General Chair (GC), with recent examples including: ACM PLDI'20 (*Donaldson*, GC); EGSR'20 (*Ghosh*, GC); ACM ESEC/FSE'19 (*Russo*, PC); INTERSPEECH'19 (*Schuller*, PC); ECOOP'19 (*Donaldson*, PC); MIDL'19 (*Glocker*, GC); IEEE ICDCS'18 (*Pietzuch*, PC); Pacific Graphics'18 (*Ghosh*, GC); ACM SIGKDD'18 (*Guo*, GC); KR'18 (*Toni*, PC); ACM Middleware'17 (*Pietzuch*, PC); IEEE/ACM ICSE'17 (*Uchitel*, GC); BMVC'17 (*Zafeiriou*, GC); IEEE MASCOTS'15 (*Casale*, PC); IEEE SASO'15 (*McCann*, GC); and USENIX ICAC'14 (*Casale*, PC).

(c) Conference keynotes. Our academics gave more than 130 keynotes in the REF period, e.g. CVCS'20 (*Gosh*); IJCNN'20 (*Bronstein*); FPL'20 (*Luk*); WACV'20 (*Pantic*); CVMP'19 (*Ghosh*); China-UK Big Data & AI'19 (*Lomuscio*); MVA'19 (*Davison*); MIDL'19 (*Bronstein*); CICLing'19 (*Specia*); IFM'18 (*Cadar*); PSE'18 (*Misener*); COMMA'18 (*Toni*); HAI'18 (*Jennings*); CADE'17 (*Gardner*); IOT'17 (*McCann*); ISCV'17 (*Pantic*); Intelligent Trading Summit'17 (*Parpas*); ICCBDC'17 (*Guo*); ICFNDS'17 (*McCann*); DEBS'16 (*Pietzuch*); CAV'15 (*Gardner*); and IROS'14 (*Davison*).

(d) Advisory roles. Our academics currently serve in numerous advisory roles: EPSRC Council (*Jennings*); EPSRC Science Engineering and Technology Board (*Jennings*); Covid-19 Research and Innovation Task Force (*Jennings*); Member, AI for Screening Task Group, UK National Screening Committee (*Glocker*); EU Blockchain Observatory (*Gervais*); Monaco Digital Advisory Council (*Jennings*); Sino-British Fellowship Trust (*Luk*); Science Foundation Ireland Review Panel for Trinity College Dublin (*McCann*); INRIA France Distributed Programming and Software Engineering Review (*McCann*); and Steering Committee Member, Science Foundation Ireland (*McCann*). Past roles include: Wallenberg Foundation Program (*Jennings*, 2018); Witness, House of Commons Select Committee on AI (*Muggleton*, 2016); Member, World Economic Forum Network on AI, IoT and the Future of Trust (*de Montjoye*, 2016); Chair, INRIA Scientific Council (*Hankin*, 2015); Member, OECD Advisory Group on Health Data Governance (*de Montjoye, 2015*); and Vice-Chair, CONNECT Advisory Forum for DG CONNECT (*Hankin*, 2014).

4.2.3 Contributions to the economy and society

(a) Improving public health and quality of life. The Department's work on health-related research (e.g. on medical imaging and AI for health) has directly contributed to healthcare practice: EPSRC SmartHeart led to new cardiovascular imaging techniques (*Rueckert/Guo*); ERC MIRA enables machine intelligence for medical image representation (*Glocker*); ERC dHCP describes human brain connectivity (*Rueckert*); the London Medical Imaging & AI Centre pioneers new AI enabled healthcare (*Rueckert/Glocker/Kainz*); the HeartFlow Laboratory offers personalised heart disease diagnosis (*Glocker*); H2020 IDEA-FAST focuses on neurodegenerative and immune-mediated diseases (*Guo*); EPSRC MAHEVA achieves new neonatal movement assessment (*Kainz/Rueckert/Glocker*); H2020 DE-ENIGMA pioneers human/robot interaction for autistic children (*Pantic*); EPSRC ROAD2H develops new learning health systems (*Toni*); and *Bronstein's* research identifies new cancer beating molecules. Many of these projects, together with the AI4Health CDT, are collaborative with NHS trusts and the AHSC, thus providing fast routes for clinical translation. Our IXICO impact case study illustrates this for new drugs and therapies for neurodegenerative diseases; the 3D Analysis impact case study shows this for reconstructive facial surgery.

(b) Influencing public policy. The Department engages with Government at national and international levels: *de Montjoye*'s work on privacy has influenced policy through his roles on the Belgian Data Protection Authority and as a Special Adviser to EC Commissioners Vestager (Competition) and Reynders (Justice). He also served on the OECD Advisory Group on Health Data Governance; *Guo* is a Scientific Adviser in Big Data/AI to the Jiangsu Province Government, China; *Jennings* serves on the National Security Council, Science and Technology Committee. He was the Chair of the Science Advisory Council in the National Security Area and a member of the Technology and Innovation Futures working group; *Uchitel* is an adviser to the Chief of Cabinet and COVID Expert Advisory Board in Argentina; *Muggleton* provided advice to the House of Commons Select Committee on AI; *McCann* contributed to the DCMS consultation on the UK Government's regulatory proposals regarding consumer IoT security.

(c) Public and media engagement. Our public engagement activities seek to inspire interest, debate and discussion, e.g. by running an evening public lecture series or organising Ethics in AI events. Our academics often participate in media and public activities, e.g. lectures at Imperial Fringe and the Great Exhibition Road Festivals (*Bronstein*, *Casale*, *Cully*, *Davison*, *de Montjoye*, *Glocker*, *Edwards*, *Kainz*, *Knottenbelt*, *Leutenegger*, *Misener*, *Toni*); TED talks (*Pantic*, *Bronstein*, *McCann*); BBC Radio 4 (*McCann*); G7 Global Forum on AI for Humanity (*Muggleton*); Royal Society Summer Science Exhibition (*Pantic*); and Festival of Science Film (*Cully*).

Our research frequently attracts media interest and press coverage around the world, e.g. the work on privacy breaking re-identification (*de Montjoye*); blockchains (*Gervais*); medical AI and ML (*Glocker*); medical imaging (*Kainz*); AI/robotics for autism and facial recognition (*Pantic*); audio engineering (*Schuller*); cognitive AI (*Shanahan*); and adaptive robotics (*Cully*).

(d) Outreach. The Department organises many outreach events, including talks, workshops and demonstrations with schools, local societies, teacher groups and professional bodies. Staff are encouraged to become school governors. A specific Departmental focus (led by *Bell*) has been to inspire more women to pursue computing careers by organising outreach events for girls and women (e.g. Engineering Summer School for Girls, AnitaB.org initiative; MegaGame school event; the Junior

Hackathon for Girls). The Imperial Codelab (started in 2016) raises interest in programming for young girls and children from under-represented communities; the cZeus School League engages pupils in the joy of mathematics; and *Yoshida* has organised ACM Programming Language Mentoring Workshops. The Department is a STEM Club Champion for training secondary state-school teachers, and our undergraduate students can do an optional assessed module, working with school teachers on teaching projects. The Department has an annual Open Day to showcase prize-winning projects to schools and industry. As a result of the EDI focus of our outreach, the female student intake for our MSc cohort saw an increase from 20.6% in 2018–19 to 27.2% in 2020–21.