

Institution: The University of Manchester
Unit of Assessment: 11 (Computer Science and Informatics)
1. Unit context and structure, research and impact strategy

1.i) Research Structures

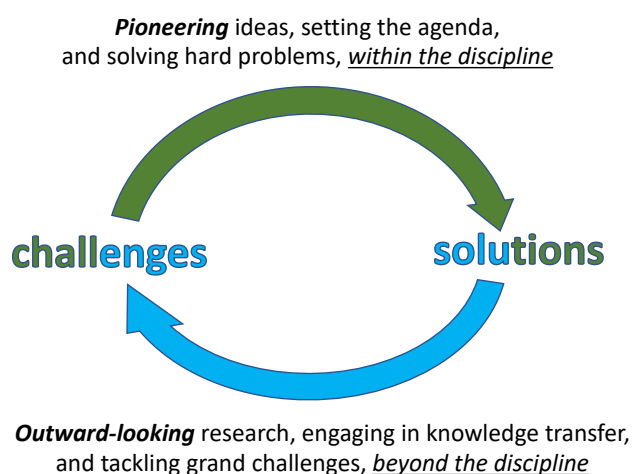
Computer Science (CS) is central to modern societal challenges, and UoA11 activity stretches across the University. Connections are facilitated by the institutional *Digital Futures Platform*, a network of over 1000 researchers across 30 disciplines. The **Department of Computer Science** is at the core, delivering the fundamental CS that underpins University capabilities: housing 54/58 Unit staff, with 4 in the Medical School. In the REF period, income per FTE increased 79%, and Unit staff published over 1200 peer-reviewed outputs; partnered with 46 UK universities, and 660 EU organisations (e.g. contributing leadership in the EC FET Flagship *Human Brain Project*) and received 14 competitive fellowships, including an RAEng 10-year Chair, a RS Wolfson Research Merit Award, and a UK Parliamentary Fellowship.

The Department is part of the wider School of Engineering – connecting us to a breadth of expertise from electronics to materials, and reflecting our commitment to CS as an engineering discipline. Faculty, School and Unit strategies work synergistically to support research and its impact, providing economies of scale and barrier-free interactions. We pursue 6 themes: **Data Science, Artificial Intelligence, Human-Centred Computing, Theory & Foundations, Software & e-Infrastructure, and Future Computing** – each with an assigned academic lead – with cross-theme support from a Director of Research, Impact Lead, Outputs Champion, and Director of Business Engagement. Each of our academics self-identifies as a member of (at least) one of 9 research groups, which comprise the expertise to pursue our themes: *Advanced Processor Technologies, Autonomy & Verification, Formal Methods, Human Computer Systems, Imaging Science, Information Management, Machine Learning & Robotics, Nano-Engineering & Spintronics, and Natural Language Processing & Text Mining*. The *themes* provide **breadth**, while *groups* provide **depth**, supporting subject-specific nurturing of talent.

To bridge disciplines, we support joint appointments (currently 11), channelling impact across boundaries. *Data Science/A.I.*: 4 staff (imaging science) are joint with the Medical School; and 4 joint with the Manchester Institute of Biotechnology. *Future Computing*: 3 staff based in CS, work in device nano-engineering (returned with UoA12).

1.ii) Research Strategy

In the REF2014 statement, our strategy was to foster a “*virtuous circle*” of pioneering and outward-looking research, illustrated in the figure below.



The plan for the REF period named 5 actions, for which we now review outcomes:

- **promoting studentships within the virtuous circle:** Of 245 current PGRs, 15% are co-supervised by other Units, facilitated by 4 interdisciplinary doctoral programmes (fuelling outward-looking research). The Unit spent GBP5,500,000 (see 2.viii) to support 178 PGRs unrestricted in topic, fuelling either *outward-looking* or *pioneering research*
- **encouraging models of collaborative research:** We promoted a range of collaboration through pursuit of diverse funding: e.g. UKRI (104 projects overall including 4 programme grants), EU (52 projects); KTPs (12); and CASE/iCASE studentships (14).
- **engaging with our industry club:** Our Industry Club has 200+ organisations (double 2014). This provides PGR recruitment pathways, and new research (e.g. we initiated a 5-year BBC Data Science Partnership, raising challenges in ethics, data science, and psychology).
- **supporting sabbaticals and extended visits:** Our flexible processes (2.iv) mean we regularly achieve our target of 10% of academics on sabbatical: many industry or public sector, e.g. one impact case builds on a sabbatical at NASA.
- **encouraging different forms of dissemination:** Our research was profiled at high-profile events (e.g. BlueDot 2018-19), TV, media and local events (4.iv).

To ensure critical mass covering both directions around the circle, we invested to link our themes:

- **Data Science/A.I.:** Following a worldwide talent search, Kaski took up a “President’s Chair in A.I.”, and a role as Research Director for the UoM *Christabel Pankhurst Institute for Health Technologies*. This is a **prime example of the virtuous circle** – Kaski, well-known for fundamental ML, now leads research in an institute with focus on applications.
- **A.I./Human Computing/Theory & Foundations:** We built cross-theme bridges by hiring Cangelosi in cognitive robotics, and Fisher/Dixon/Dennis in verification of robotic systems. This includes a RAEng 10-year *Emerging Technologies* Chair (Fisher), developing automated reasoning theory (**pioneering**) applied to responsible autonomous systems (**outward-looking**).
- **Theory & Foundations/Future Computing:** Building links to the UoM *Digital Trust & Security Initiative*, we recruited to grow cyber-security: in **pioneering** theory (Lammich) and **outward-looking** applications in UAV firmware security (Cordeiro), and secure networks (Mustafa).
- **Future Computing/A.I.:** 5 new academics including Petoumenos, using Deep Learning for compiler analysis (**pioneering**); and Rhodes, developing computational neuroscience models on our ground-breaking *SpINNaker* machine (**outward-looking**).
- **Human Computing/Software & e-Infrastructures/Future Computing:** “*People-Data-Chips*” was an integrative initiative in ubiquitous computing, hiring Kotselidis/Clinch/Freitas. Kotselidis is now 0.5FTE industry (3.v), and Freitas is 0.5FTE with the UoM Cancer Research institute, **both closing the virtuous circle again**.

These actions enabled significant outputs, where the virtuous circle is evident.

As examples of pioneering ideas within the discipline: In our **A.I.** theme, Kaski contributed a new Deep Learning paradigm for differential flows that learn stochastic differential equations. In **Future Computing**, Koch developed the first method to detect malicious FPGA configurations by directly investigating binaries – the security patches adopted by Amazon Web Services. In **Theory & Foundations**, Cordeiro developed the first algorithms to verify multi-threaded software using shared-memory synchronization, identifying previously unknown vulnerabilities in Intel firmware. Voronkov/Reger made major advances in first-order logic theorem proving, implemented in the award-winning *Vampire* theorem prover - established as the world’s most powerful (with CASC/SMT competition victories and industrial deployment) theorem prover for first-order logic – with implications for adjoining areas such as verification and program analysis.

As examples of outward-looking research: In **Future Computing**, Rhodes/Furber demonstrated the world's first real-time simulation of a cortical microcircuit with over 300 million synapses, utilising our million-core *SpiNNaker* neuromorphic machine. Bridging our **Future Computing/Theory & Foundations** themes, Korovin developed the world's first implementation of a non-deterministic Turing Machine using DNA, confirmed with in-vitro molecular biology. In **A.I.**, Cootes/Lindner transformed the challenge of shape model-matching in medical images – the methodologies were commercialised and form an impact case, focusing on bone fracture assessment. In **Human Centred Computing**, Jay developed ECG visualisations for diagnosis of life-threatening conditions by non-specialists; subsequently shortlisted for the Parliamentary and Scientific Committee's *STEM for Britain Awards*.

What we learnt: The “*virtuous circle*” works well as a high-level strategy. However, a **finer-grained** approach is necessary to have continued meaningful influence on our environment. In the period, **our strategy has evolved with time**, maintaining the “circle”, but expanding its influence.

In the REF2021 period, our major policies/initiatives/actions can be summarised as following a set of **guiding principles**, which also form the basis for our future strategy. These articulate our vision for what it means to be a world-class environment, and are intentionally light-touch, and “people-focused”. These align with University priorities (e.g. parity of support/esteem between research discovery/application, see REF5a 2.iv). Throughout this document, we highlight (where not self-explanatory) how the Principles were implemented.

Principle 1: Critical Mass & Complementarity. *Ensuring we have an appropriate spread of intellectual capital to solve hard CS problems, tackle interdisciplinary grand challenges, and grow future leaders for both.* For example: our recruitment strategy (2.i) targets individuals to naturally interface with colleagues across the new UoM Engineering structure (REF5a).

Principle 2: Empowerment & Support. *Ensuring our researchers feel trusted, with the weight of the University behind them, with the time/motivation to take our Unit in new directions.* For example: our duties assignment process supports short-notice secondments; the approval process for PGR training funds (2.x) encourages autonomy (**empowerment**), whilst mentoring/training (2.iii) provides essential ECR **support**.

Principle 3: Ambition & Curiosity. *Ensuring we tackle ambitious real-world and interdisciplinary challenges, targeting “quality over quantity”, whilst also valuing curiosity-driven research with no short-term application.* For example: we have increased interdisciplinary PGR activity, and promoted the “*quality-over-quantity*” agenda for all, with emphasis for ECRs as they launch careers.

Principle 4: Responsibility. *Ensuring our environment fosters open research and reproducibility, and is committed to equality, diversity, and inclusion.* We have (i) engaged in leadership of the open research agenda; (ii) monitored/maintained EDIA as a key element of hiring policy, taking affirmative action where necessary; and (iii) continued to promote open research to all staff.

The Next Five Years

The Principles form a framework for future strategy. In the current period, we have made strong progress, though we see further areas to address for each.

In **Principle 1**, we will continue to support our current investments: *robotics and formal verification; data science for healthcare, and hardware/software security*, whilst strengthening capabilities in the fundamentals of A.I. via a new pan-University centre exploiting the appointment of Kaski. In **Principle 2**, we will increase ECR involvement in leadership roles, within/beyond the department. In **Principle 3**, we will exploit the new UoM Engineering structures, increasing engagement in cross-disciplinary challenges. In **Principle 4**, we will pro-actively seek to recruit individuals with “non-traditional” career paths, bringing a diversity of perspectives to the environment.

1.iii) Fostering Impact

Our strategy is founded on collaboration (exemplars in Section 4) and the institutional infrastructure for business engagement (3.ii). We support, enable, and incentivise our researchers in as broad a range of impact as possible, letting the talent speak for itself – the following actions implement Strategy Principle 2 (*Empowerment/Support*) and 3 (*Ambition*).

Support:

Shortening Pathways to Impact: The UoM company “*Innovation Factory*” (*IF*) accelerates all IP opportunities: e.g. legal issues, and *Click2Go*, a web-platform for licensing software. The *Manchester Enterprise Centre* develops/supports entrepreneurship via events/courses. **Outcomes:** IF assisted in founding 3 Unit spinouts (*ExGence*, *Eurimatics*, *Data Value Factory*); and *Click2Go* deployed the *BoneFinder* software (see impact case).

Faculty Impact Officers and Business Engagement Teams: The Faculty retains 3 full-time *Impact Officers* whose duties include liaison between industry/academics at the point of exploitation. The *Business Engagement team* (3.ii, also REF5a 4.1), provides opportunities, via regular events and connections to major organisations.

Strong support for EPSRC IAAs/KTPs as a catalyst for long-term activity, supported by a dedicated *Knowledge Exchange* team (5FTE) at Faculty level. **Outcome:** We held 29 IAAs (GBP851,359) and 12 KTPs (100% success rate, total GBP2,610,767, e.g., cross-disciplinary KTP with Bott&Co. Solicitors).

Enablers:

Fostering partnerships: We have long-term partnerships (e.g. ARM, BBC, BAE Systems, AstraZeneca, Pfizer), via one-to-one contacts, and our wider Industry Club activities (e.g. invitations to the PGR Symposium provides opportunities). For academics, this affords collaboration, and for PDRAs/PGRs, a pathway to impactful careers. **Outcomes:** In the period, 20% of visitors were industry-based, and our club grew from 50 to 200+ members.

Releasing time via workload adjustments: We award 0.1FTE reduction for fostering a recognised potential REF impact case, and *ad-hoc* adjustments for any (non-REF) impact activity. Sabbaticals can be used for impact (2.iv). **Outcomes:** Embury took two semesters (2018-19) to build relations with ARM, returning with an ARM/RAEng Industrial Fellowship.

Providing people & bridging funding: The Faculty funds PDRA “Impact Fellowships” (currently 18, 6-24 months). UoM employs a baseline-funded team of Research Software Engineers (3.ii). Strategic funds are available from Unit or central sources, to bridge PDRAs on flagship projects between contracts. **Outcomes:** One Fellow supports a potential impact case on virtual reality for amputee rehabilitation. The Unit provided bridging funding for a REF2021 impact case (*SpiNNaker*), supporting the long-term ambition in the project.

Enabling PGRs to play a role: Impact and public engagement are part of PGR training (2.x), and PGR internships are encouraged. **Outcomes:** PGR Seaton (2015, supervisor Lujan) interned at Oracle, with results built into a product, *Graal/VM*. PGRs also engaged via the IAA account, e.g. Del-Pinto worked at SNOMED International, implementing sub-ontology generation, with the outcome built into the company’s strategic roadmap.

Incentives: Impact is an explicit factor in promotions (2.ii), and recognition/reward structures (2.vi), whilst a culture of supporting the parity of esteem for impact/fundamentals is embedded in all departmental communications.

Future vitality is supported by growing our ability to influence industrially-relevant funding programmes (e.g. Goodacre is *Challenge Director* for UKRI's GBP75,000,000 ISCF "*Digital Security by Design*"); and attracting researchers with interests in impact, e.g. our staffing strategy (2.i) explicitly pursues part-time appointments. **Future sustainability is supported** by: (i) duty roles for impact, e.g. public engagement (Reger/Cordeiro, each 0.1FTE); and Impact Champion (Embury 0.15FTE). (ii) supporting staff contributions in all areas (REF-eligible or not, see 4.iii); (iii) leadership, e.g. Jay in the UKRI Software Sustainability Institute (1.vi).

Linking Strategies to Impact Cases:

- **Biorelate:** A programme of research on contextual text-mining (led by Nenadic) was commercialized by a PGR, aided by a GBP10,000 grant from the *Manchester Enterprise centre*, and Nenadic's pre-existing *partnership with Pfizer*.
- **SpiNNaker:** Original funding (EPSRC) was bridged to the EU funding via GBP250,000 UoM internal *impact funding*, retaining key PDRAs as they constructed the million-core machine. A *sabbatical* (2016) for Furber gave time to build up demonstrators for the machine, and *SpiNNaker* workshops were entirely coordinated by PGRs/PDRAs.
- **NASA spacecraft:** Barringer (retired) was introduced to a problem in runtime verification of spacecraft command sequences while on *sabbatical* at NASA. Barringer/NASA co-created a solution, used in space missions that continue to date. Reger (then PGR, now Category-A) contributed the QEA formalism, significantly reducing computational complexity, making it more attractive for NASA.
- **Facial Performance Capture:** Taylor/Cootes led basic research in face image modelling, stimulated by applications in face recognition, tracking, and synthesis, with early-stage support from *IF*. PDRAs Edwards and PGR Walker led commercialisation of the ideas in two companies: ImageMetrics (both) and Cubic Motion (Edwards), with major impact in films and computer games.
- **Improving Healthcare & Animal Welfare:** Cootes/Taylor led research stimulated by challenges in medical imaging, on fundamental work for statistical models of shape and appearance of anatomical structures. Its success led to spin-out company, iMorphics, supported by the *IF*.

1.iv) Supporting Interdisciplinary Research

The University supports the Unit via several "Interdisciplinary Institutes" and platforms: some physical, some virtual, all resourced with staff-time. The *Digital Futures* platform (led by Taylor) involves Unit members in multiple multi-disciplinary challenges. The *Institute for Data Science & A.I.* cuts across UoM, connecting e.g. Physics and CS, in a Turing A.I. Fellowship (Scaife, UoA9). The *Thomas Ashton Institute* interfaces with the UK Health & Safety Executive (Jay leads on *Digitalisation of Work*; Ananiadou leads *A.I. in health/safety*). The *Christabel Pankhurst Institute* (led by Taylor/Kaski) channels expertise in A.I. for healthcare technologies.

The University also enables high-profile partnerships relevant to the Unit: e.g. the GBP10,000,000 Smart-City *CityVerve* project interfaced with local government/SMEs, and a 5-year institutional *BBC Data Science Partnership* (led by the Unit) raises challenges in data science/ethics.

Within the Unit, our *virtuous circle strategy* requires that clusters of interdisciplinary expertise be **sustained** and **recognised**, implementing *Principle 3 (Ambition/Curiosity)* of our strategy.

Sustaining inter-disciplinary expertise is enabled by: a recruitment policy (2.i) that supports bridging compatible disciplines; a staff development strategy (2.ii) that supports diverse career paths (2.v); a sabbaticals policy (2.iv) that supports a range of leave types; an infrastructure for fostering partnerships (2.v) to support ambitious new endeavours; a PGR funding model and 4 inter-disciplinary doctoral programmes (2.vii, 2.viii) that encourage interdisciplinarity; and our seminar culture – 60% of Departmental seminars (from 200+ in the period) were tagged as 'interdisciplinary'.

Recognising inter-disciplinary expertise is enabled by: our strategy (1.ii) based fundamentally on the “virtuous circle”; promotions (2.ii) that explicitly recognise interdisciplinarity and impact; reward/recognition structures for all staff/PDRAs/PGRs (2.ix, 3.vi) that value a range of contributions; an institutional Open Research Policy (1.v) stating *freedom of choice for the publication outlet*; and ensuring ECRs have sight of interdisciplinary role models (e.g. Cangelosi in robotics/psychology; Furber in chip design/neuroscience; Goble in biology/e-infrastructure; Taylor in medical imaging/machine learning).

Evidence of Success:

- **Funding:** Awards from 8/9 UKRI councils, and collaborative grants with *all* UoM faculties and major organisational units.
- **Outputs:** We published in journals across 191 Scopus areas, and contributed to the REF2021 return of **7 other UoAs** (see 4.i).
- **PGRs:** 10 Unit staff co-supervise 29 PGRs in other departments, e.g. Mathematics, Psychology. The reverse is also true: 36/245 PGRs in CS are co-supervised by e.g. Law, Physics. 8 staff co-supervise 10 PGRs beyond UoM, e.g. Edinburgh, ETH Zurich.
- **Leadership:** Taylor leads the national UKRI-funded *NewMind* Technology for Mental Health Network (4.v), building a multidisciplinary UK community of over 450 academics, clinicians, patients, and industrialists. Nenadic founded the UK healthcare text-analytics network, *HealTex*, with 250+ members.

1.v) Our Open Research Environment

The institutional strategy (for details, see REF5a 2.v) is set by the Open Research Strategy Group and the *Open Research Working Group (ORWG)*, co-founded/chaired by Jay. ORWG defines institutional policy, which states that (i) *outputs will be as open as possible, as early as possible*; (ii) *researchers have freedom of choice for the publication outlet*; and (iii) *the University is committed to responsible metrics*. The policy implements the F.A.I.R. principles, constructed by an international consortium where the Unit (Goble) was a contributor.

Open Access is an institutional commitment, with library staff supporting the procedures. Web-based systems enable depositing outputs, paying fees, and managing embargoes. Institutional spend on Gold OA for the Unit was GBP165,022. The UoM *OpenAccess+* scheme uses a Media Team for press releases and professionally edited articles (e.g. *The Conversation*).

Our staff support and lead Open Research: **Locally:** Our MSc/PhD programmes have open research and reproducibility embedded in the curriculum. **Nationally:** We play key roles in the UK Software Sustainability Institute (co-founder: Goble, Research Director: Jay). **Internationally:** Harper founded the *ACM Emerging Interest Group on Reproducibility*; Goble is UK representative on the *European G7 Open Science Working Group*, and sits on the *UK Open Research Data Task Force*.

1.vi) Ensuring Research Integrity

The Institution maintains a *Code of Good Research Conduct*, articulating our commitment to research integrity, mirrored by a *Code of Practice for Investigating Concerns on the Conduct of Research* – ensuring strict but fair investigatory procedures (REF5a 2.v). The overall approach is to raise **awareness** and monitor **compliance**.

Maintaining ethical standards.

Awareness: a 3-hour Research Integrity course (renewed every 3 years) is mandatory for PDRAs/academics, with PGR training (**2.x**) provided by the Unit. A quarterly University-wide Ethics e-Newsletter, and (in the Unit) a monthly staff newsletter highlights relevant events.

Compliance: Research Ethics Committees (REC) are in place across the Institution, reporting to the University REC (UREC). Departmental Leads (Vigo/Clinch 0.1FTE) act as gateway to procedures. There are five levels of approval, from departmental (low-risk PGR projects), to UREC (high risk, staff/PGR), to national regulations (including NHS REC). The Unit processed 184 applications (161 approved) 2014-20, at all levels, supported by a bespoke online ethics system.

Meeting legal obligations.

Awareness: Training (mandatory for all academics, renewed biennially) includes: Export control (2 hours), Information Security & Data Protection (1 hour), EDIA (3 hours). *Data Management:* All proposals are required to engage in Data Management Planning (supported by the Library) via dmponline.ac.uk.

Compliance: The *Research Lifecycle Project (3.ii)* includes enterprise-grade systems for confidential data, requiring the highest security. *Data Sharing:* The central legal team coordinates NDAs/data-sharing contracts — e.g. recent arrangements include AstraZeneca, Oracle. *Employment Law:* All staff involved in PGR admissions and any recruitment panels must take an *Unconscious Bias* training course.

Exemplars of Contributing to professional standards:

- In programming languages, **Pop** sits on the *OpenMP Language Standards Committee*.
- In robotics/ethical autonomous systems: **Fisher** is a member of the BSI's AMT/010/01 *Ethics for Robots and Autonomous Systems* standards committee. Work by **Dennis/Fisher** was cited in BS8611 (“Guide to the ethical design and application of robots and robotic systems”), the first published standard related to robot ethics.
- In web-accessibility, **Harper** is a member of *W3C WAI Coordination Group*.
- **Jay** led the *Software Sustainability Institute* on REF2021 software guidelines (**4.v**).

2. People

Staffing Strategy and Staff Development**2.i) Staffing and Recruitment Strategy**

We seek researchers from a range of backgrounds, guided by 4 processes, each of which is derived from one of the 4 research strategy principles.

- **Develop/maintain critical mass** (implements Principle 1: Critical Mass & Complementarity).
 - o **Actions:** We recognise and build on clusters of expertise: establishing leadership, and ensuring a continuous flow of new talent through succession planning.
 - o **Outcomes:** **New leadership** in cognitive robotics (Cangelosi), Machine Learning (Kaski), and computer architectures (Goodacre, 0.4FTE joint appointment with ARM). We **ensured a flow of talent** by hiring at least 2 ECR academics every year 2015-2020, covering all 6 of our themes). **In total 20/58 staff are new in post (14 ECRs) since 2014.** We **maintained critical mass** via succession planning within the Future Computing theme (hiring Rhodes), and in Theory & Foundations (hiring Fisher/Dennis/Dixon).
- **Seeking input from staff** (implements Principle 2: Empowerment & Support).
 - o **Actions:** The HoD actively solicits input from all staff on our recruitment strategy. When investment is available, the Head of Department (HoD) polls all academic staff on what the 'Next Big Thing' will be, and for names of rising stars in their area. All are encouraged to take a role in shaping the Unit, contributing their expertise/experience.
 - o **Outcomes:** Our *People-Data-Chips* initiative (1.ii), was suggested by an academic without a leadership role, and recruited 3 ECRs in ubiquitous computing (Kotselidis, Clinch, Freitas) who all secured external PI funding within 2 years of appointment.
- **Bridging compatible disciplines** (implements Principle 3: Ambition & Curiosity).
 - o **Actions:** We use strategic hires to bridge clusters and avoid 'sole-traders', through e.g. advertising complementary new posts simultaneously.
 - o **Outcomes:** In 2017 we bridged cyber-security/formal methods by hiring Cordeiro and Lammich. In 2018 we hired Cangelosi in cognitive robotics, naturally interfacing with the new UoM Engineering structures. In 2020, activity in robotics and formal verification was bridged by hiring Fisher/Dixon/Dennis.
- **Pursuing equity in applications** (implements Principle 4: Responsibility).
 - o **Actions:** All academic job postings are run through software to identify gender-biased language. All shortlisting uses a 'second-look' policy to ensure equitable reasons for inclusion/exclusion. All panels involve at least one female academic, and all undergo mandatory EDIA training. Part-time appointments are considered for all posts and explicitly pursued when appropriate (e.g. personal reasons, or to maintain industry roles).
 - o **Outcomes:** Our Category-A gender profile (at the census date) is 26% female, versus 22% nationally (source: 2019 HESA centre 121), and 30% of all in-period appointments were female. The breakdown by gender profile is below. At the census date, among **all research and academic staff**, 19% are BAME – compared to 14% in the UK working age population (source: *BCS Diversity Report 2020*).

	FTE	Headcount	#male : #female	% female
Lecturer	13.3	14	9 : 5	36%
Senior Lecturer	14.9	16	13 : 3	19%
Reader	4.8	5	2 : 3	60%
Prof	20.1	23	19 : 4	17%
Total	53.1	58	43 : 15	26%

To ensure long-term critical mass (*Principle 1*) and provide career stability (*Principle 4*), we have no short-term Category-A contracts.

2.ii) Staff Development

Our staff development strategy (see also PDRA-specific support in 2.iii) pursues three goals, that emerge from our guiding principles.

- **to identify/support upward trajectories** (*P2: Empowerment*): We recognise that our variously talented staff benefit from specific resources to continue their trajectory. This is enabled via regular appraisal, mentoring, and support to pursue fellowships (e.g. feedback rounds on drafts, and mock interviews).
- **to actively consider ‘growth opportunities’ at critical career points** (*P3: Ambition*): When career-defining opportunities arise, individuals benefit from specific encouragement/support breaking into leadership roles. This is enabled via interlinked senior staff meetings (e.g. *Promotions Committee* makes recommendations to *Duties Allocation committee*, which assigns leadership roles and in turn recommends sabbaticals to the *Leave of Absence Committee* (2.iv).
- **to ensure diverse career paths are recognised** (*P4: Responsibility*): Excellent people come from a wide range of backgrounds, and many have non-traditional career paths. Recognising this, recruitment and promotions policies acknowledge a range of contributions.

Further details on how the strategy is implemented:

Mentoring is mandatory for ECR academics, via trained staff balanced in gender/seniority. Many ECRs benefit from early/mid-career mentors, who have empathy with their situation. The University “Manchester Gold” scheme provides cross-discipline mentoring, matching junior/senior staff (e.g. Cangelosi mentors a UoA12 PDRA). **Appraisal/individual development needs** are supported via line managers in annual Performance & Development Reviews, offered to all academics/PDRAs. Individual ambitions and training needs are discussed, and action plans agreed. This is iteratively refined, and reported back to the *Probation Committee* (for ECR academics) and to the HoD. **Fellowship** eligibility/deadlines are tracked (see support teams in 3.i), and cases actively solicited.

Probation lasts 3 years: specific tailored objectives are agreed during induction, discussed annually with managers, reviewed by the Department Promotions Committee. Expectations are set at Faculty-level, in 4 categories: (*Research, Teaching, Knowledge Transfer, Service/Leadership*), with precise wording, e.g. “*Submission of at least one research proposal per year that achieves good reviews*”.

Promotions are considered annually, assessing 4 areas: *research, teaching, service/leadership, and knowledge transfer* – where parity of esteem is emphasised. Expectations have unambiguous language and measurable outcomes. Two meetings consider cases and provide feedback; each applicant has an assigned “*shepherd*” from the committee, to develop their case. As some demographics tend to underestimate their chances, the committee actively solicits cases. Off-schedule one-off pay increments are possible under a separate “*Rewarding Exceptional Achievement*” policy, for any academic/PDRA.

Training: The VITAE Researcher Development Framework maps directly to a portfolio of 38 courses (1-5 hours each) across 5 areas: Career Management, Research & Enterprise, Communication, Leadership & Management, Teaching & Learning. UoM holds a *European Commission HR Excellence in Research Award* for the Concordat Implementation Plan, awarded in 2011, retained in 2020 after external review. The *Inspiring Leaders* programme provides 50 hours over 6 months for senior leadership. The Unit provides CS-specific training: e.g. role-playing mock EPSRC panel to clarify how funding decisions are made. Encouraging female leadership is a priority: four staff (Zhao, Jay, Clinch, Batista) were funded for leadership training (StellarHE, AdvanceHE Aurora).

2.iii) Support for Early Career Researchers

The Unit develops ECRs (PGRs, PDRAs, and new academics) through: (i) training that provides a foundation for a diversity of careers; and (ii) the provision of time/resources that launch independent research careers – *implementing Principle 2 (Empowerment/Support)*. **The Institution** assists with full implementation of the *Concordat to Support the Career Development of Researchers*, which permeates our environment (REF5a 3.3.2).

Training: The institutional “*New Academics Programme*” comprises a mandatory 50 hours (HEA-accredited) over 18 months, also available to PDRAs (2.ii). For research, this includes e.g. grantsmanship, PGR recruitment. For knowledge transfer/impact: e.g. IP, and public engagement. In the Unit, a budget is available for national ECR events, e.g. CHERISH-DE “Digital Economy Crucible” (Batista/Clinch). **PDRA support:** ECR academic, Mustafa, holds a duty (0.1FTE) as “*PDRA Champion*”, fostering a PDRA culture of social/professional development. All PDRAs are informed of (and encouraged to participate in) the various opportunities in the Researcher Development programme.

Time/resources: To establish research, new academics “ramp-up” to full teaching/administrative duties: initially 40% of their FTE (whether full/part-time), increasing 20% annually. All new academics (regardless of FTE or contract) receive GBP5,000 unrestricted funds and a PhD studentship. An induction pack welcomes all academics/PDRAs, and an informal but professional culture is supported with frequent social events. A bi-monthly ECR Lunch is hosted by the HoD, on themes chosen by ECRs: e.g. supervision skills, and managing workload.

Evidence of success: In the period, we hired 14 new Category-A staff (Lindner, Olivier, Petoumenos, Lammich, Rhodes, Mustafa, Cordeiro, Freitas, Kotselidis, Battista, Mu, Clinch, Reger, Vigo) All of these obtained funding as PI/Co-I within 2 years of appointment; 5 with competitive fellowships (Lindner, Batista, Pop, Mustafa, Petoumenos). Two hold major awards as PI: Cordeiro, (EP/T026995/1, **GBP1,721,559**), Reger (EP/V000497/1, **GBP1,034,989**).

Many PDRAs grow careers within the Institution: 5 of our Category-A staff were PDRAs in REF2014 (Vigo, Kotselidis, Batista, Rhodes, Reger). Others choose industry: e.g. Ghasempour (PDRA 2012-15, now Head of Machine Learning, The Hut Group); Sechidis (PDRA 2015-18, now Senior Scientist, Novartis); Haines (PDRA 2014, now institutional Head of Research IT, also *UK Society for Research Software Engineering* co-founder).

2.iv) Policies for Research/Impact/Sabbatical Leave

The policy: Academics are eligible for sabbaticals of 1 semester after 3 years’ service, or 1 full year after 6 years. These are unconstrained; on-site, cross-departmental, or international, and target outcomes are broad: e.g. industrial/social impact, grant preparation, or re-focus of research area. We allow ‘**mini-sabbaticals**’ from duties like tutorials/projects, to protect contiguous blocks of time. We encourage multi-year leave, e.g. two second semesters, enabling longer-term activity.

Procedure: Cases are solicited annually, including actively seeking applications, and taking recommendations from other senior committees. Cases are prepared with line manager support, and reviewed by the *Leave of Absence Committee*, with membership monitored for diversity.

Outcomes: 29 took major leave: 13 for a single semester, 16 for a full year, and 10 had ‘mini-sabbaticals’. Nenadic took a 2015 sabbatical to shift focus to temporal text-analytics – enabling BBSRC grant (GBP730,460, BB/N019547/1) on modelling veterinary health records.

2.v) Fostering Interfaces for Knowledge Exchange

Our impact strategy (1.iii) is further supported by fostering relationships, via 3 key activities which together implement *Principles 1 (Critical Mass/Complementarity) and 3 (Ambition)*.

- **We pursue and maintain strategic partnerships:** We engage with both top-down MoUs (e.g. *ARM Centre of Excellence*) and bottom-up (e.g. personal contacts at local SME, Peak.ai). **Our Industry Club** is a stepping-stone to deeper relationships – the 200+ members are invited to events (e.g. PGR Symposium) and informed of activity via quarterly newsletters.
- **We recruit from diverse career paths, e.g.** 4 academics had industrial careers of 5+ years (Cordeiro, Goodacre, Kotselidis, Rhodes) prior to Manchester, and 5 Category-A staff have joint industrial appointments (Voronkov, Paton, Goodacre, Kotselidis, Pavlidis). Secondments can be taken at short-notice, and duties adjusted – e.g. a short-notice part-time post at ARM Ltd (Brown), led to a patent and investment (GBP50,000) to the Unit.
- **We connect MScs and PGRs to the pipeline:** The early stages of a relationship require small-scale interactions, which we achieve by engaging new researchers — in the period 64 industry-partnered MSc research projects, and 9 PGR internships, were arranged.

Further outcomes: We enjoyed major new collaborations with e.g. AstraZeneca, BBC R&D, Oracle (4.ii). We hosted 14 CASE/iCASEs (6 in REF2014). We supported the foundation of 3 spinouts by staff/PGRs (**ExGence, Eurimatics, Data Value Factory**), and growth of two others (**Cogniscience, iMorphics**), both of which aided our impact case portfolio.

2.vi) Recognising, Rewarding, and Supporting Research with Impact

Details of how we **support** the achievement of impact from research are in 1.iii, 3.v, and 4.ii. To **recognise/reward** successes, a variety of mechanisms are in place. Examples: *In Abstract* is a Faculty-level web-archive of world-class papers, with press releases curated by Marketing & Communications, recognising success regardless of subject. *Better World* is an institutional ceremony for research with social impact, and *Postdoc Appreciation Week* has web-profiles/interviews with PDRAs, and funded social events. Personalised letters from the President recognise major successes (e.g. fellowships). In the Unit, the weekly newsletter names and celebrates all successes, from PGR prizes to Professorial Inaugurals.

Our Postgraduate Researchers

2.vii) PGR Recruitment

The recruitment of diverse and excellent PGRs is central to our mission, enabled by initiatives which implement *Principle 1 (Critical Mass and Complementarity) and 4 (Responsibility)*. These are (i) **dedicating significant resources** to recruitment; (ii) having a **diversity of programmes** (iii) pursuing a **diversity of candidates**; (iv) **achieving the ‘right fit’** through meaningful engagement.

(i) **Resources:** Processes are unified across the Faculty, ensuring applicants can be recommended cross-departmentally. In the Unit, academic roles: PGR Director (0.2FTE), Deputy (0.1FTE), PGR Marketing lead (0.1FTE), are supported by administrative staff, and in-house software to distribute applications, collect feedback, and send out offers. The average time from application to decision is 4 weeks. At institutional level, Nenadic is Faculty PGR Committee Chair.

(ii) **Diversity of PGR Programmes:** We participate in 4 interdisciplinary doctoral training programmes: 4IR-STFC CDT in Data-Intensive Science, ESRC Data Analytics & Society CDT, EPSRC Graphene NOWNANO CDT, and a psychology/robotics programme with the Italian Institute of Technology. A new EngD programme was established (2019), to support PGRs based primarily in industry, and we changed progression timings to support extended internships.

(iii) Diversity of Candidates: We offer 50+ annual fee waivers for the China Scholarship Council; and UoM advertises 100 *President's Doctoral Scholarships*, the first annual round restricted to overseas applicants (10 in-programme). We “grow our own” via Manchester MSc/UG programmes aligning with research strengths; e.g. of 245 current PGRs, 9% came from our UG programme, and 28% hold a Manchester degree (UG/PGT, any discipline). **EDIA:** Disability Support is advertised widely, and we provide structural adaptations to the environment (**2.xi**).

(iv) Achieving the right ‘fit’: Virtual and physical PGR Open Days allow candidates to meet staff, and experience the environment before committing. Interviews for all admissions/funding, have a rotating panel of 5 academics (membership, and interviewees, monitored by PGR Director for equity in gender, ethnic origin, and research area). In the period, 15 PGRs have opted for part-time enrolment to suit personal circumstances (9 in-programme).

Outcomes: Our programmes have attracted applications from all over the world (34 countries; normally 70% overseas). In the period, 16 declared a disability, with 7 receiving explicit funded support (e.g. screen-readers and adapted office space).

2.viii) PGR Studentships

To enable a high-quality, diverse PGR cohort - following strategy *Principle 4 (Responsibility)* - we access a broad range of funding sources, and Departmental funds/fee waivers support PGRs without funding. Departmental funds support new academics’ start-up packages, strategically important proposals, and areas of research growth. In addition, UoM provides *Dean's Awards* and *President's Doctoral Scholarships* to outstanding candidates, competitive across the University.

We have taken active steps to grow our PGR activity as a driver for research vitality. At the census date the unit had 245 in-programme PGRs (**a 91% increase, compared to 128 at the end of the previous period** – see REF2014 5b). Of these 42 were UKRI-funded: 28 EPSRC CDT/DTP, 11 EPSRC iCASE (e.g. BAE, EDF), 3 EPSRC CASE; 22 were funded by competitive President's and Dean's awards, 62 by overseas governments, 7 split-site funded by the Italian Institute of Technology, and 44 self-funded. Furthermore, we have significantly increased departmental investment in PGRs, with an average spend of GBP836,000 p.a. on a combination of studentship fee-waivers and stipends, up from GBP500,000 in REF2014 – **a 67% increase**. This resulted in full/partial funding for 178 of our current cohort, **up 254%** from 70 in 2014.

2.ix) PGR Support and Progress Monitoring

PGR Support

- **Supervisory teams:** Every PGR has a main supervisor, one or more co-supervisors, and a cohort advisor. Supervisors monitor technical progress; advisors provide pastoral support with weekly meetings in groups of 6, and on-demand one-on-one meetings.
- **Peer support:** All spend their first 6 months in the ‘PGR Home’ area (custom-built 2017 GBP60,000); where cross-group cohorts support multi-disciplinarity. Senior PGRs participate in our *PGR Mentors* scheme, and representatives sit on Staff/PGR committee.
- **Recognising/rewarding success:** The PGR Symposium is an annual highlight, with talks by 3rd-years, posters by 2nd-years, keynotes (2019: Simon Segars, ARM CEO), industry prizes (currently IBM Research), and two Professor's prizes for best paper/thesis.
- **Mental health:** In 2018, Research England and the Office for Students awarded funds for UoM's “*Well Bee-ing*” PGR Mental Health Project. Among the outcomes (implemented in UoM policy, recommended nationally by OfS) was to review length/structure of programmes, and to promote mindfulness in PGRs.
- **Extensive training** (for details see **2.x**)

PGR progress monitoring

- **An institutional electronic progression system** tracks PGR milestones, records training needs, and sets expectations at quarterly intervals, with supervisor and PGR Director sign-off. The annual progression process requires the PGR to deliver a report and presentation on progress and plans, with interviews by two academics outside the area.

Evidence of Success:

A step-change in **PGR pastoral care** (2017, e.g. cohort advisors) helped first-year progression: 75% (2014) to 98% (2018) to 100% (2019).

At international conferences, our PGRs **won 11 Best Paper prizes** with the PGR as first author – e.g. D’Antras *et al* 2017 (*PLDI Distinguished Paper*), and Arrelanes *et al* 2018 (*ICIoT Best Paper*); whilst a journal article resulting from a PhD thesis (Nikolaou, EPSRC CDT-funded) received an ACM Computing: *Notable Article of 2016* commendation (Nikolaou *et al*, 2016).

In REF2, **35% of our outputs have a PGR as first author.**

2.x) Details of PGR Training

Unit-level: All PGRs attend 4 full-semester courses on Scientific Methods (40 contact hours plus 130 offline), plus skills workshops (30 hours). Optional computing courses are available for cross-disciplinary PGRs. Attendance on MSc modules is encouraged to specialise knowledge. **Faculty-level:** All PGRs can take mini-courses across 49 topics: research (16), TA training (6), impact/engagement (12), career management (3), and wellbeing (12)..

Individual Training Funds: Every PGR has GBP3,000 to enhance training: e.g. conferences, regardless of publication – approval is light-touch, and via supervisor, group lead, or PGR Director. IT resources are separate, with machines replaced as needed. **EDIA:** Some PGRs were reluctant to request funds from their supervisor, so we heavily promoted the fund and alternative approval mechanisms (*implementing P2: Empowerment*).

We prepare PGRs for diverse careers. Industrial: 9 PGRs took internships, e.g. BBC, IBM. Outreach: 3 PGRs joined our *Project Malawi* programme; PGRs co-hosted 7 Nuffield Foundation placement pupils; 4 PGRs are STEM ambassadors. For academic careers, **EPSRC Doctoral Prizes** are a springboard (6 in-period) e.g. Nikolaou 2016, now senior RF, UCL Astrophysics.

2.xi) Equality and Diversity

Social Responsibility is one of three core goals of UoM, reflected in duty roles at Faculty, School, and Department level. Policies embedded throughout the Institution create the desired culture: for example, an appointments policy that implements a version of the *Mansfield Rule*. **At Departmental level, strategy is coordinated by the EDIA committee** (4 academics, 1 RF, 2 PGRs) meeting quarterly. For oversight/guidance, we follow charter schemes, e.g. Athena Swan Bronze award, renewed 2020 (for full list of schemes, see REF5a 3.2).

Commitment to EDIA in Career Pathways

Appointments: Adverts are vetted by a software gendered-text analyser. Part-time appointments are considered for all roles at advertisement-stage wherever possible. Internal research leadership roles are advertised to all and applicants are encouraged to have informal discussions with relevant senior staff. At all panels, a member of EDIA committee is required.

Support for promotions: Our ‘*shepherding*’ scheme (2.ii) ensures writing support for all applicants, strengthened by explicit support for social anxieties (3.iv), and three rounds of drafts/reviews before submission.

Support for acquiring funding: Statistics are monitored by Faculty, and corrective actions taken as appropriate, e.g. soliciting fellowship applications from under-represented groups (also 3.iv).

Part-time staff: Several academics choose part-time employment (11/58 individuals, 0.3-0.8FTE), for maintaining industry roles, or personal reasons. Reduced FTE does not restrict progression—all committees (e.g. promotions) explicitly acknowledge individual circumstances, scaling expectations. In the period we promoted one individual (0.4FTE) to Professor (teaching-focused), one (0.8FTE) to Reader, and one (0.5FTE) to SL; and 8 academics/senior RfS reduced FTE for flexible retirement.

Fixed-term staff: The UoM Policy Contracts of Employment (revised 2017) provides protection for fixed-term employees. At contract end a PDRA is placed on the *Redeployment Register* (enabling preferential consideration for internal posts).

Commitment to EDIA in Support of Staff/PGRs

The Leave of Absence Committee manages study leave via transparent processes. Membership ensures representation across ethnicity, gender, career-stage, and career track. We recognise many types of leave (2.iv). In the period, 29 took sabbaticals: 35% female, 14% BAME, 10% with disclosed long-term health issues.

Caring responsibilities are supported by a broad recognition of leave-types: maternity, paternity, shared, and adoption (3 staff took parental/adoption leave, and 2 reduced hours for child-care). Arrangements with local nurseries permit salary-sacrifice. A New Parents’ Room has a fridge and appropriate privacy. PGRs access *Equal Mobility Grants* (GBP500 per trip) for caring responsibility.

Long-term health issues are accommodated by workload adjustments (e.g. one individual was removed from teaching requiring a lot of typing, due to severe RSI). Arrangements for healthy working follow occupational health guidelines (e.g. 8 standing desks on-site, GBP2,000 spent annually on specialist seating). Exemptions are made to the policy norm (of off-peak and non-first-class travel) for health reasons (2 staff use Business Class when appropriate).

Returning from leave is supported by institutional phased return policies. New academics retain their FTE ramp-up, while PGRs receive 12-month interruptions for parental leave, and on return have a no-fees extension, phasing back to studies. In the period 60 PGRs interrupted for personal reasons (16 paternity/maternity; 4 switched full to part-time).

Flexible/remote working is supported. Duties allocation processes acknowledge part-time working, various types of leave, and requests for caring/wellbeing issues. Departmental meetings are scheduled during core hours (10:00-16:00), and VPN access enables secure home-working. On-site, a fully multimedia-equipped room is used for Departmental Leadership meetings, enabling 2 staff to participate remotely (due to caring responsibilities/health issues).

Support for protected characteristics is embedded in University policies. Targeted promotions guidance is provided for under-represented groups. Occupational Health guidance is available to advise on reasonable adjustments for accessibility. Support for acquiring funding and accessing infrastructure is addressed in (3.iv).

Wellbeing is supported by the built environment and a culture of healthy-working. We have a rolling programme of refurbishment, e.g. daylight-LED lighting, and increased social space for serendipitous meetings. Monthly “Coffee with HoD” coffee-mornings (maintained virtually during lockdown) encourage mingling.

Commitment to EDIA in our REF return

In our return we increased the proportion of female REF-eligible staff: 20% (9/46) in 2014, to 26% (15/58) in 2021.

Our output return had multiple EDIA checks. **Unit-level:** A committee of senior and ECR academics estimated grades. The grading protocols and membership were under continuous revision to avoid bias. We examined attributions on gender/ethnicity for systematic bias. All submitted outputs were discussed 1-on-1 with authors. **Institutional:** Statistics were examined by an HR team with access to protected characteristics, reporting anomalies to Units where necessary – none arose for our Unit (across ethnicity, gender, and nationality, the number of attributed outputs matched the staffing profile). **Our environment statement** uses exemplars drawn from across the Unit. We polled staff 3 times soliciting “success stories”, and making clear that anybody, at any career stage, can contribute. **Our impact portfolio** was selected on merit alone, with multiple checks at Unit, Faculty, and University level, after polling staff for cases on multiple occasions 2016-2020.

3. Income, infrastructure and facilities

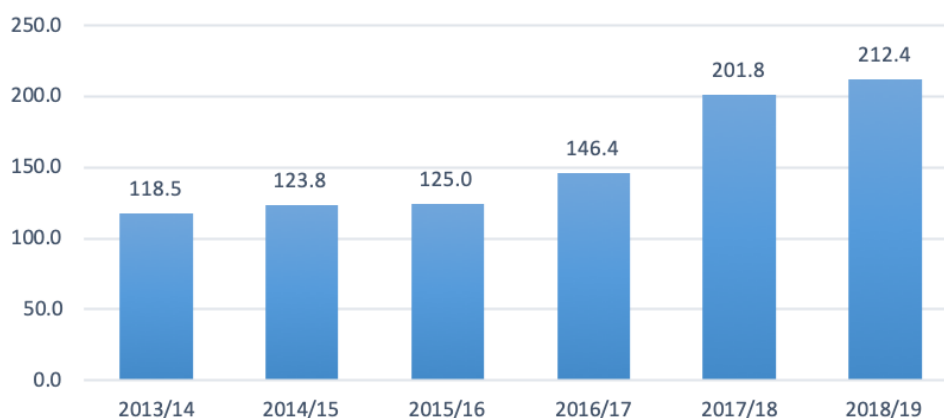
3.i) Research Funding

We aim to maintain a diverse funding portfolio, whilst increasing collaboration as much as possible. Our strategy is to **promote awareness** for a range of mechanisms, and **release scholarly time** to apply, all facilitated end-to-end by **support** staff.

- **Promoting awareness:** A monthly digest of diverse opportunities is distributed to all academics. Time-critical calls are monitored by the Research Support Manager, cascaded to staff. Annual fellowship cycles are tracked in an electronic system, with automated alerts.
- **Releasing 'scholarly' time:** Our workload system leaves 0.2FTE unassigned, enabling time for free-thinking. ECRs benefit from gradual duty ramp-up (**2.iii**), managed via fully-open workload formulae. Regular rounds of institutional seed-funding (light-touch review) support new ideas (e.g. 3 academics hired by our *People-Data-Chips* initiative were supported by GBP45,000 to establish a new IoT lab).
- **Peer support:** Examples of successful grants are shared, alongside an established internal peer-review culture by experienced staff, and internal workshops (e.g. an annual EPSRC mock panel) disseminate best practice. School-level initiatives encourage fellowships with a wider suite of engineering perspectives, supporting cross-departmental collaboration. Mock interviews are organised for fellowships, sourcing experienced staff from across UoM.
- **Administrative support:** The Unit has Research Support/Finance teams providing end-to-end support for project lifecycles, including all costing/administration of proposals, HR liaison, contracts, export control, and financial reporting. Each member of academic staff has a named Research Support and Research Finance officer to work with. Research Support Managers provide leadership to teams, and strategic support to the HoD.

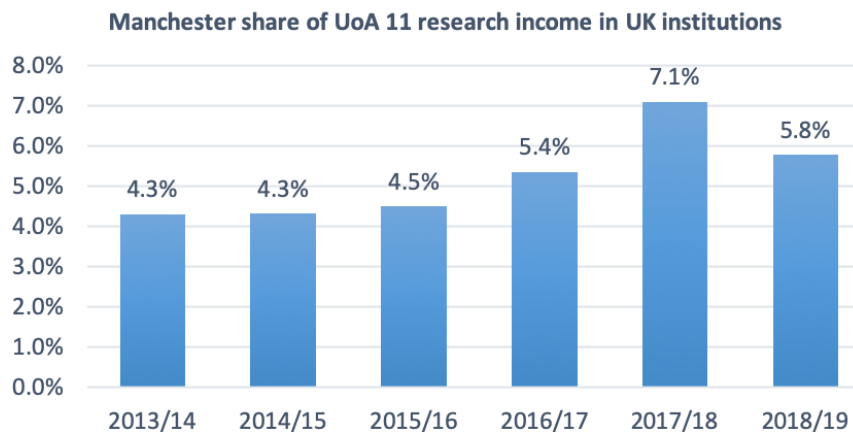
The average annual Unit income (sum of all REF4b categories) **increased 12%** to GBP8,348,693, with total EU government sources **more than tripling** in the period, from GBP5,238,585 to GBP17,968,580. Income per FTE, per year, is shown below – in 2013/14, the Unit ranked 12th in the UK for this metric, rising through the period (2017/18, 1st), and 2018/19 (3rd).

**Manchester (UoA11) research income
per FTE (HESA data £k per FTE)**



This income came from a diversity of awards (e.g. funding from 8/9 UKRI councils) with a total of **225 awards from 80 distinct funders**, equating to GBP80,905,374 revenue. The number of awards annually increased 54% in the period (26 in 2014, up to 40 in 2019). **Our ECR academics are successful** – of those in-post at least 2 years (8 staff), all were awarded external funding as PI.

Major awards (revenue to Manchester) include: 4 programme grants (totalling GBP4,699,231), H2020 EuroEXA (Goodacre/Lujan, GBP5,113,623), MMPATHIC (Ananiadou GBP2,923,765), EPSRC RAIN Hub (Furber, GBP4,131,580), EnnCORE (Cordeiro, GBP1,344,249), SCorCH (Reger, GBP1,034,990), ERC Advanced Grant BIMPC (Furber, GBP1,804,332), UKRI Software Sustainability Institute (Goble, GBP2,944,433).



Prestigious awards (i.e. highly competitive) include: EU FET Flagship Human Brain Project (Furber, 2013-23); 2x RAEng Fellowships (Pop 2015; Petoumenos 2019); RAEng 10-year Emerging Technologies Chair (Fisher, 2019); *CityVerve* SmartCity Demonstrator (Taylor, 2016); RAEng Industrial Chair (Lujan 2019), Wolfson Research Merit Award (Lujan, 2019).

Exemplars of funding enabling high-quality outputs:

- **PAMELA programme grant (EP/K008730/1)** enabled the *Distinguished Paper Award* at the PLDI conference (REF2: D'Antras *et al* 2017).
- **EPSRC CDT (EP/I028099/1)** supported PGR Nikolaou on an output which unified 20 years of work in Boosting algorithms, awarded "*ACM Computing Notable article of 2016*" (REF2: Nikolaou *et al* 2016).
- **A Royal Society URF** for Korovin supported research (REF2: Currin *et al* 2017) which developed the world's first implementation of a non-deterministic Turing Machine in DNA.
- **EPRSC grant (EP/N035127/1)** developed a unified statistical foundation for the stability of feature selection (REF2: Nogueira *et al* 2018).

Exemplars of funding enabling high-quality impact:

- **EuroEXA (H2020-754337, Goodacre)** investigated co-designing systems and low-level architectures in collaboration with an SME, *Iceotope Ltd* - leading to the company being named the UK's fastest growing hardware company (2,331% growth during collaborations, source: *2019 Deloitte UK Technology "Fast 50"*).
- **MRC grant (MR/L01078X/1, Ananiadou)** supported *RobotAnalyst*, a text-mining system to accelerate document screening in systematic reviews: the system influenced NICE guidelines, and is used by over 200 organisations worldwide. The techniques were adapted for **industrial impact via Pacific Life (PL) Insurance**, for text-mining to support underwriting in health insurance. In 2017, PL funded a project (GBP366,000) and extended 2019-21 (GBP580,000), to build this into a commercial system, *underwriteMe*, now used by several major insurance providers.

3.ii) Organisational Infrastructure (institutional level)

Institutional investment for Research Support: The *Research Lifecycle Programme* is a GBP15,000,000 series of investments (2017-22), with Taylor in the Unit as academic lead, aiming to transform research support, removing administrative barriers.

During the REF period, *Faculty Research Support Teams* and separate *Research Finance Teams* (totalling approximately 60FTE, where 5 support the Department of Computer Science) assisted with all aspects from outlines/costings, to HR-liaison for appointments, and end-of-project financial reporting. In parallel: a *Research Strategy and Innovation* team (9FTE) assist with strategic partnerships; the *Knowledge Exchange* team (5FTE) support KTPs/IAs, and the *Innovation Factory Ltd* (IF), a wholly-owned UoM company, handled commercialisation of University innovations - the Unit has an assigned IF “partner”, based in our building, who pro-actively pursues IP opportunities. A central *Contracts* team deal with all legal issues and NDAs.

Investment in Relevant Research Areas: The institutional *Digital Futures* platform stimulates and supports collaboration in digital technologies – UoM employs 6FTE support staff for this, and the Unit plays a leading role with Taylor as Director, and Jay on the Management Board. The *Pankhurst Institute* channels expertise in healthcare technologies: two Unit staff provide leadership - interim Institute Director (**Taylor**) and Research Director (**Kaski**), and investments from UoM, EPSRC, and *The Alan Turing Institute* provide a working budget of GBP25,000,000.

Technical/Support Staff: Research IT maintains 40FTE baselined staff: 2 group leaders, 25 Research Software Engineers, 13 infrastructure engineers. This enables an agile approach to tools and secondment, whilst supporting institutional memory. **Outcomes:** The Unit costed 33.5 years of RSE time into funded projects, e.g. a COVID rapid-response collaboration (Jay, COV0659, GBP412,720), an evaluation framework for the *Test & Trace programme*: two reports (using the software) delivered to Sage via SPI-M.

High Performance Compute: The Institution maintains a compute facility of 18,512 CPU cores (varying for workload) and 90 Nvidia v100s. This pool is regularly refreshed (2014-20, GBP4,000,000), plus GBP100,000 annual spend on AWS GPU time. The Unit utilised over 284 CPU/GPU years, e.g. large-scale GPU benchmarks against our *SpiNNaker* neuromorphic machine.

Subscriptions/Collections: UoM provides site licences for Overleaf, Dropbox, Office365, Zoom, Teams, and Mathematica — available for all staff/PDRAs/PGRs. CS-specific licences are paid by the Unit (e.g. Cadence for circuit design).

3.iii) Support Infrastructure within the Unit

Unit investment for recruitment into strategic research areas is covered in 1.ii.

Estate/Facilities: The Unit invests to support distinctive areas of research, for example – bespoke power/air-con space for *SpiNNaker* (GBP200,000), securing availability to the EU for the foreseeable future; and a ‘Living Lab’ for cognitive robotics research (GBP250,000). The Unit benefits from the ongoing GBP1,000,000,000 institutional master-plan, developing labs to support interdisciplinary research in robotics and computer engineering.

Technical and Support Staff: In the period, the Unit funded four technicians to support specialist research infrastructure, requiring expertise beyond that available from institutional Research IT – e.g. one provides extensive experience with chip design CAD software (helping PGRs/PDRAs), and another was a key contributor to *SpiNNaker*, assembling and fault-checking the final machine.

The Unit also baselined a Software Engineer who developed a comprehensive infrastructure to support our REF submission, also deployed across the entire Institution. This included a fully-algorithmic optimisation scheme to select/attribute outputs, (thus avoiding unconscious bias, and ensuring compliance with REF2021), collaboratively developed with academics (Brown, Pratt-Hartmann).

Unit-level environment template (REF5b)

3.iv) EDIA in Acquiring Funding/Accessing Infrastructure

We summarise some specific actions in the Unit, implementing *strategy Principle 4 (Responsibility)*. The overall EDIA initiative is detailed in Section 2.xi.

Individual Mentoring: We host highly-focused individuals, some challenged by social interactions. On 2 specific occasions during the period, individuals received additional mentoring (from a trained senior Professor) on grant-writing and PGR supervision.

Workload: The *Departmental Leadership Team* is conscious that individuals with protected characteristics are often requested to serve on institutional committees/initiatives – and can be overloaded, which may affect research. To avoid this, our duty-allocation system is fully-transparent, and statistics on such assignments are delivered annually to the HoD for any corrective action.

Opportunities: We heavily promote gender-specific opportunities (e.g. L'Oréal-UNESCO *For Women in Science Programme*), via the departmental newsletter.

Accessibility: All buildings are wheelchair-accessible. Visually-impaired colleagues (1 academic, 2 PGRs) receive support for meetings across campus. An office was converted to fully dark-space for a PDRA with light-sensitivity (cost GBP1,500). We repurposed 2 toilets to gender-neutral. We have 1 Stonewall-trained LGBTQ+ ally to support gender-transitioning staff/students. UoM provides licences for assistive technologies (e.g. *MindGenius* for dyslexia, *JAWS* screen-reader).

3.v) How we use our Infrastructure and Expertise for Impact

Significant institutional infrastructure exists to support KTPs/IAs, IP exploitation, and general acceleration of impact opportunities (1.iii for details).

Unit staff provided short-term consultancy for large organisations, e.g. ARM (Brown/Furber), GCHQ (Pettifer), BBC (Jay), Babylon Health (Schmidt), Elsevier (Goble), and for local SMEs: UrbanChain (Banach), Tachyum Ltd (Furber).

Examples directly relating to our REF impact portfolio and inward investment:

- **Cootes** consulted for *Aviagen*, one of the world's leading breeders of chickens, applying computer vision systems to improve health of their stock (**see impact case**).
- **Kotselidis** is 0.5FTE as Cybersecurity Manager for KTM A.G., the largest EU manufacturer of powered motorcycles: **this enabled ELEGANT (H2020-957286, EUR4,983,250)**, developing secure vehicle-to-vehicle communications.

3.vi) Specialist Research Infrastructure

Cognitive Robotics Lab: a dedicated "Living Lab", for human-robot experiments, laid out as a living space. The lab has 9 robot platforms including iCub, Pepper (×3), Sawyer, Giraff, and Nao (×3), enabled by a GBP250,000 institutional investment.

Interaction Analysis/Modelling Suite: equipped for user evaluations, including Tobii eye-trackers, and galvanic skin-response equipment. This enabled collaborations with BBC, that in turn supported the *BBC Data Science Partnership*.

Internet of Things: An institutional investment (GBP45,000) supports IoT research, including Meshlium Scanners for estimation of crowd density, and Libelium Cymblots for monitoring environmental parameters.

3.vii) Shared Research Infrastructure

SpiNNaker is a unique neuromorphic computer, designed/built at Manchester, available through the *EU FET Flagship Human Brain Project*. This is available for use by any lab world-wide — and at the time of writing has run 5 million jobs for over 400 users worldwide.

FAIRDOM-SEEK (led by Goble) is a software platform for systems biologists to organise FAIR research outputs: the system is used worldwide by 140 major projects - including national programmes in patient data-sharing (Germany), and crop plant data-sharing (Belgium, France). Within this, FAIRDOMHub is a web-accessible registry for assets of biology projects: used by 204 projects, including the COVID *disease paths* international collaboration of 259 researchers.

Robotics: Several UoM projects (e.g. H2020 MoveCare) enable equipment-sharing between institutions, e.g. the Giraff telepresence robot, and the GBP30,000 Sawyer, used by students from Italy, and Waseda University (Japan).

An exa-scale HPC system is being constructed by the Unit (H2020 EuroEXA) that minimizes energy consumption, with a world-leading 100kW per-rack thermal density infrastructure. With 256 compute nodes (each consisting of a hybrid FPGA+CPU custom architecture) the system is one of the largest FPGA-accelerated clusters in the world, consisting 544 Xilinx Ultrascale+ FPGA devices. The system is currently used by 15 development teams across 7 European nations.

3.viii) Benefits In-Kind

Intellectual Property:

- ARM Ltd donate design specifications for the ARM Cortex-M4, valued by ARM at GBP1,500,000 annually - this enables the *SpiNNaker2* project. A previous similar in-period donation of the ARM968 architecture enabled the original *SpiNNaker*. ARM also donate GBP50,000 annually (unrestricted funds) to maintain our *ARM Centre of Excellence* status.
- BBC donated GBP380,000 plus industry-confidential data (e.g. interaction data for iPlayer). This supported 3 iCASE studentships and 5 internships.

Equipment:

- **Robotics:** including a GBP200,000 iCub robot, from Italian Research Council on indefinite loan to Cangelosi – this is used in e.g. the UKRI TAS Node on Trust, EP/V026682/1.
- **FPGA hardware** totalling GBP100,000, from Xilinx Inc., e.g. VCU118 kits (Koch/Kotselidis) enabling a novel secure FPGA Operating System (REF2: Vaishnav *et al* 2020).
- **Computing power:** A collaborative research agreement with AIST Japan enables access to the AIST Cloud Compute Facility providing over 400 GPUs.

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

4.i) Enabling Academic Collaboration

Our recruitment strategy (2.i, *implementing P1: Critical Mass/Complementarity*) leads to a **diverse pool of expertise**, with complementary interests – staff willing and able to “look outwards” to other disciplines/institutions (*P3: Ambition/Curiosity*).

This expertise is **sustained and recognised** - see Section 1.iv for how this is achieved.

Building on this solid base, Principle 2 (*Empowerment/Support*) leads us to provide the *funding and opportunities* to launch *new collaborations*, as our people see fit.

- **Funding:** University-level seed-funding is available to stimulate collaboration - e.g. School of Engineering collaborative grants, GBP50,000 maximum, multiple annual rounds, with light-touch review. Within the Unit, an equal distribution of flexible funding to groups (GBP120,000 in 2019/20) supports both serendipitous and planned cross-institutional visits.
- **Opportunities** within/beyond UoM are promoted widely, while local events enable meetings, e.g. the IDSAI “Advances in Data Science” seminars (43 since 2016) are highly cross-disciplinary, and cross-institutional in audience. In the Unit, our culture of collegiality and openness (*P4: Responsibility*) leads to exchange of opportunities among staff (example in 4.ii) and a light-touch visitor policy supports short-term visits.

Outcomes:

Collaborative projects: Across 52 EU projects, we partnered with 660 different organisations. We have 8 long-standing partners, each collaborating on 10+ EU projects: Barcelona Supercomputing Centre (23 projects); CNRS France (14); INRIA (10); CNR Italy (10); Fraunhofer (14); EMBL (14); CEA France (10); and Edinburgh (11).

For UKRI, we held 104 collaborative projects (with 46 UK academic institutions) where 44/104 involved another UoM Unit, showing local cross-disciplinary working. We hosted 195 visitors (35 different countries): **41/58 staff hosted an international visitor in the period.**

Collaborative outputs: We published over 1200 papers with co-authors from 66 countries: including 27 EU member states (34/44 European countries), and 19 outputs with African nations: South Africa (12 outputs), Egypt (3), Zambia (3), Namibia (1). Our top 5 collaborating nations: Germany (142 outputs), USA (115), China (91), France (78), Brazil (69).



Exemplar academic collaborations/networks/partnerships:**Local:**

- Authors from the Unit contributed to **Manchester's REF2 return for 7 other UoAs**, with a total of 17 outputs across Medicine, Public Health, Allied Health, Psychology, Biology, Physics, Business and Law.
- **Vigo** (collaboration between UoA11 and UoA5) led the CS elements of *BritainBreathing*, a nationwide Citizen Science project, to study seasonal allergies/asthma. The project works with the British Society for Immunology, **and is an impact case (UoA5)**.
- **UoM Institute for Data Science and Artificial Intelligence** has 974 members: 685 UoM academics/PDRAs, 137 PGRs, 106 businesses, 46 from other academic institutions. In the Unit, Ananiadou is Deputy Director, allocated 0.2FTE.
- **Thomas Ashton Institute** is a faculty-led initiative, with elements led by the Unit (Ananiadou, Jay) - a partnership with the UK Health/Safety Executive, focusing on understanding workplace injuries.

National:

- **The VADA Programme Grant** (GBP4,557,635, with Oxford/Edinburgh) developed end-to-end automation of a data preparation pipeline — results commercialised in a spin-out (VADA Ltd), applied (via KTP) to reduce the cost of on-boarding client data with a local SME, Peak.ai.
- **In Robotics and Autonomous Systems**, the RAIN hub (GBP12,203,190, EPSRC) develops nuclear robotics for extreme environments, stimulating collaboration between EEE and CS, including verification of systems (Fisher/Dixon), and ethics/transparency in human-robot interaction (Cangelosi/Dennis).

International:

- **EU FET Flagship Human Brain Project**. The Unit (Furber, Lester, Garside, Rhodes) plays a leading role, joining a consortium of over 100 universities to explore brain-inspired computing, and how *SpiNNaker* can accelerate brain research. Furber leads the HBP neuromorphic sub-project, and sits on the HBP Science Infrastructure Board.
- **ELIXIR**. In eScience (Goble) we have long-standing collaborations to develop infrastructure managing biological data, e.g. ELIXIR, the European inter-governmental Research Infrastructure for Life Sciences, where Goble leads the UK Node (18 organisations), enabling our participation in seven EU projects (46 organisations, 23 countries), including the US National Institutes of Health and seven pharmaceutical companies.
- **OpenPHACTS**: Goble/Pettifer/Stevens developed an entity-matching method, incorporated into the EU OpenPHACTS platform for pharmacological data. This prompted adoption of knowledge graphs by the pharma industry - the system (with our method at its core) has processed over 500m queries, from public/private organisations worldwide.
- **EuroEXA**: Goodacre is Technical Director for the 16-partner, EUR19,949,023 programme, delivering infrastructures for exascale technology - deployed by 15 international application teams in climate/weather, physics/energy, and life-science/bioinformatics.
- **Japan AIST**: We maintain a partnership with the Japanese National Institute of Advanced Industrial Science & Technology (AIST). Funding (donated by AIST) enables extended visits by Cangelosi/Ananiadou, and PGRs/PDRAs (total 50-person months). In 2017-20 this enabled 16 published articles.

4.ii) Developing Relationships with Research Users

Fostering our interfaces for impact (1.iii) provides a base of long-standing industrial partners. These are exploited by ECR academics, who regularly partner with established staff as mentors to “bring them on-board” (*Principle 4: Responsibility*, our open and collegiate culture). New partnerships are also enabled by *sabbatical/secondment policies (2.iv)*, for example, Kotselidis extended a sabbatical at KTM A.G. Ltd into a part-time industrial appointment (**3.v**), enabling the H2020 ELEGANT project (EUR4,983,250) on secure vehicle communications.

We provide examples where the virtuous circle (1.ii) has enriched our environment: materially (via inward investment) and intellectually (driving new cross-theme research directions), e.g.:

AstraZeneca. Senior staff member, Brass, introduced an AstraZeneca contact to a then junior staff member (Brown), leading to a fruitful reciprocal research collaboration. This was supported by Unit-funded visits, and 2 PhD co-supervisions (2014-15), leading to an AstraZeneca investment of GBP400,000 (2016) to support Brown (A.I. theme) and Jay (Human Centred Computing). Outcomes: Methods for statistical biomarker selection, with a user-informed and co-designed visualisation, now being integrated into AstraZeneca workflows.

BBC Research & Development. In 2017, UoM started a 5-year Partnership with BBC R&D. The Unit funded initial interactions – enabling a funded project (EP/M017133/1), and a PGR internship. This stimulated *institutional investment* of GBP22,000 (2016, matched by BBC) to create a university-wide network fostering interdisciplinary data science. We authored a White Paper, ‘*Challenges/Opportunities in Data Science*’ (now a standard BBC reference), and embedded PDRAs into BBC labs. This led to a BBC investment of GBP380,000, enabling 5 internships and 3 iCASEs.

ARM Ltd. A long-term relationship enables access to ARM IP. Exemplar outputs include the *SpiNNaker* architecture, and a 28nm System-on-Chip architecture (*EuroEXA*). In 2018 we were awarded the *ARM Centre of Excellence* status, providing a recurring donation (GBP50,000 p.a.) to support activities. This supports ECRs in establishing career directions (e.g. Pop, Cordeiro, Pavlidis).

4.iii) Wider contributions to the Economy and Society

Translational research in text mining of MP enquiries. As a Parliamentary Fellow, Batista has contributed to Government efficiency – the research is being deployed in the House of Commons Library to accelerate searching 600,000 historical MP enquiries.

We helped define the national curriculum. Furber chaired the Royal Society advisory committee “*After the reboot*” (2017), advising government on the CS curriculum. Supporting this, the Unit hosted the North-West Regional Centre for the ‘Computing at School’ initiative, providing professional development opportunities for teachers.

Responding to demand from local SMEs for skills in A.I. and Data Science, we co-lead the GBP6,000,000 ERDF “AI Foundry” project providing A.I. expertise to 170+ Manchester SMEs, helping them develop new products/services.

A collaboration between Vigo and Salford NHS authority increased usability of NHS software. A medication safety dashboard, deployed in 43 GP surgeries (local population: 250,000) was analysed by Vigo, resulting in changes to the layout/interaction protocols.

We enhance the economic efficiency of academic networks via the *EasyChair* conference management system, designed/maintained by the Unit (Voronkov) – with over 3,000,000 registered users, and serving over 83,000 conferences worldwide.

We contribute to national digital skills training via the Institute of Coding (Embury/Jay). We develop tools for teaching software engineering based on industry input, informed via empirical software engineering research on historical student code collections.

4.iv) Engaging with Diverse Communities via our Research

We partner with several NHS organisations (e.g. Christie Cancer Hospital), to deploy research: e.g. local Christie clinicians use the work of Embury/Brass on ‘data journeys’ (see REF2) to assess patient data-flow.

Batista works with Amnesty International human rights investigators (ESRC ES/R00899X/1) on hate-speech detection.

Jay/Vigo engaged with the Manchester Museum to develop a citizen-science app for digitisation of a fossil collection (800+ downloads), also resulting in a CHI workshop paper.

Parsia leads our LegalTech Initiative engaging with a consortium of local law firms—the initiative won “Alliance of the Year” at the 2019 British LegalTech Awards.

Public engagement: Jay presented programmes (BBC, ITV) about robots and society. Reger/Cordeiro have duties (0.2FTE) for Public Engagement/Liaison supporting events such our presence at British Science Week, and *BlueDot Festival*.

Pupil work placements: The Unit welcomes young people (age 15-17) for research-based placements—in the period we hosted 10 (plus 4 cancelled due to COVID). For example, 3 pupils in 2019 created a dataset, used by Batista in a proposal.

4.v) Contribution to Sustainability of the Discipline

REF2021 Guidelines: Jay led the Software Sustainability Institute team (9 authors, 36 reviewers: including UKRI and the Society of Research Software Engineering) to create REF2021 software output guidelines.

The Software Sustainability Institute facilitates the advancement of research software through training, advocacy, policy, and research. As Research Director, Jay leads the SSI’s Open Evidence Bank and research strategy.

Training: Our staff taught in 17 events over the period, e.g. Estonian Summer School in ML (Brown) 2019; European Summer School on Logic, Language and Intelligence (Sattler/Parsia) 2014-2019. The Unit hosted events, e.g. *SpiNNaker* workshops 2016-19: 146 people (18 countries), supporting international activity in neuromorphic computing.

Responsiveness to national and international priorities:

- **Mental health:** In recognition of a national need, *NewMind* (with Taylor as academic lead) built a community around technology for mental health, and (via its road-map) fed into the cross-council mental health initiative.
- **Open Data in Research:** We are a founding contributor (via Goble) to the influential FAIR (Findable, Accessible, Interoperable, Reusable) principles for data management. Goble maintains leadership roles in various FAIR advocacy organisations.
- **Hardware Security:** Goodacre led a bid from 26 businesses across 8 sectors, and 8 universities, for the ISCF *Digital Security by Design* programme. This resulted in a GBP200,000,000 programme — GBP70,000,000 from government, and GBP130,000,000 industrial co-investment (e.g. Microsoft, Google) — with Goodacre as the Director. To date, 12 projects across 15 Universities have received GBP20,000,000 in funding.

Unit-level environment template (REF5b)

- **SmartCities:** CityVerve (GBP10,000,000, 2016-18) was a landmark DCMS/InnovateUK project, led by the Unit for the University (Taylor), partnering with 20 organisations, delivering a more connected Manchester – sub-projects included data collection/analysis on COPD symptoms in the Manchester Corridor (Jay).
- **Trustworthy Autonomous Systems:** Fisher was academic lead for the development of a Strategic Priorities Fund bid, leading to a UKRI programme totalling GBP33,000,000.

Exemplars of interdisciplinary research:

In collaboration with the **Institute of Neuroscience/Medicine** at Julich Research Centre, Furber *et al.* used *SpiNNaker* to implement a cortex model in biological real-time (Rhodes *et al.*, 2019), out-performing HPC/GPU implementations (see impact case). **Working with AstraZeneca**, and closing the virtuous circle, Brown extended a theoretical foundation for feature selection (see REF2014) to cover prognostic/predictive biomarker selection in personalised medicine (REF2: Sechidis *et al.* 2018). **In Medical Imaging**, Cootes/Lindner developed methods in Computer Vision, and commercialised *BoneFinder*, identifying skeletal structures in 2D medical images.

4.vi) Indicators of Wider Influence

Journal Editorships (65 total), including **5** Editor-in-Chiefs, e.g. Computer Journal (Furber, 2016-20); J. Biomedical Semantics (2009-19); **29** Associate/Guest Editors, e.g. Machine Learning Journal (Brown), J. Logic & Computation (Fisher); and **31** Editorial Board Members.

Exemplars of participation on grant/awards committees: EPSRC peer review college (9 staff); staff acted for national awards committees, e.g. RAEng Chair Sift/Interview Panels (Goble, 2015-17), RS Newton Awards (2015-present), and EPSRC UKRI Innovation Fellowships Interview Panel (Dixon, 2018). Unit staff also contributed expertise for international agencies, including FNRs (Olivier), Polish National Science Centre (Pratt-Hartmann), Canada Research Fellowships (Harper), Heidelberg Laureates (Goble), Netherlands Organisation for Research (Dixon).

Fellowships (14 total): 2x RAEng Research Fellows, (Pop, 2015; Petoumenos, 2018); ERC Advanced (Furber, 2013-18); RAEng Emerging Technologies Chair (Fisher, 2019); RAEng Industrial Chair (Lujan, 2019-24); RAEng Industrial Fellowship (Embury); renewal of Royal Society URF (Lujan, 2013-16); Royal Society Wolfson Merit (Lujan, 2019); SSI Fellowship (Jay, 2016); Royal Society Newton International Fellowship (Palomar-Perez, 2016); AstraZeneca Data Science Fellowships (Brown, Jay 2016-18); UK Parliamentary Fellowship (Battista, 2018-20); Rutherford Fellowship HDRUK (Lindner, 2015-20).

Prizes:

- **Best Paper awards at international venues** (27 total), e.g. ECML 2014, PACT (2016, 2017), CGO (2017, 2019), VEE 2019, SWSA 2019 Ten-Year Award, and FG 2015 Test-of-Time Award.
- **Elected Fellowships/National-level awards:** FREng (Goble/Furber/Taylor); FRS (Furber); FBCS (Fisher/Cangelosi/Goble/Harper); Distinguished FBCS (Furber); FIET (Fisher, Furber); CBE (Goble, Furber); OBE (Taylor); BCS Lovelace Medal 2014, RS Mullard Award 2016, Science Council 100 Leading UK scientists 2014 (Furber); nomination by the President of Poland to a Professorship of Mathematics (University of Warsaw, Pratt-Hartmann).
- **Discipline-specific awards:** ELLIS Fellow (Kaski); IEEE (Furber); FIAPR (Cootes/Taylor); Herbrand Award (Voronkov); Member of Academia Europaea (Paton/Furber/Sattler); 4 Turing Fellowships (Ananiadou/Cangelosi/Jay/Nenadic); honorary doctorates: Goble (Maastricht), Furber (QUB), Ananiadou (Thessaloniki).

Memberships of national/international councils: BBSRC council (Goble); Athena Swan panel (Clinch, 2016-21); Italian REF panel "*Valutazione Qualità Ricerca*" (Cangelosi); RAEng Membership Panel 9,10 (Taylor, Goble); EPSRC ICT Strategic Advisory Team (Fisher); Chair of EPSRC Healthcare Technologies SAT (Taylor, 2014-17); Director of *N8 Centre of Excellence in Computationally Intensive Research* (Taylor, until 2018); Chair of the Royal Society Sectional Committee 0 for CS (Furber); President of *Extending Database Technology* Association (Paton, 2016-20); National Engineering Policy Centre's *Safety & Ethics of Autonomous Systems* committee (Fisher); Management Board for UKRI/Turing A.I. for Science & Government programme (Taylor); Research/Innovation Council of Finland (Kaski).

Invited Talks: 262 total, including 78 keynotes e.g.: Jisc Digifest 2015 (Goble), IJCNN 2015 (Furber), IDA 2015, PAKDD 2020 (Kaski), FV 2017 (Dixon).

Conference chairing: Unit staff held over 150 organisational roles in conferences/workshops in the period. Noting only senior roles: General Chair (**35** times, e.g. Goodacre, HiPEAC 2018), Programme Chair (**31** times, e.g. Nenadic/HealTAC 2019), Area/Track Chairs (**16** times).

Other: 5 staff (Taylor/Goble/Cootes/Stevens/Sattler), are in the *UK Top 100 scientists for CS & Electronics* (Guide2Research, 2020), and 2 (Goble/Stevens) in the WoS/Clarivate *Highly Cited* list.