

Institution: University of St Andrews



Unit of Assessment: UoA 11: Computer Science

Section 1. Unit context and structure, research and impact strategy

Unit Context and Structure

The School of Computer Science comprises 32 Category A academics. We have fostered, and are careful to preserve, a collegiate, collaborative school with a substantial emphasis on interdisciplinary research, benefitting from the other world-class schools in the arts and sciences at St Andrews. We are small and therefore agile enough to respond quickly to the constant changes in our discipline, such as the recent rapid rise of artificial intelligence and machine learning. We are large enough to achieve critical mass in the areas on which we have chosen to focus, organised into five internationally-recognised research groups investigating diverse theoretical and practical aspects of software and systems:

- **Artificial Intelligence.** Computational algebra; computational argumentation; decision-making and optimisation via constraint programming and propositional satisfiability; intelligent intrusion detection in cybersecurity; image processing; responsible and legal AI.
- **Computer Systems.** Cloud computing; data analytics, integration, and linkage; middleware; networking, distributed and autonomic systems; software engineering; wireless and sensor networks.
- **Health Informatics.** AI in precision therapeutics; computational models of cancer treatment and infectious diseases; software for medical devices and data analytics.
- **Human-computer Interaction.** Distributed learning environments; input and output technologies; intelligent interactive systems; natural language processing; pervasive and ubiquitous computing; privacy; visualization; virtual reality.
- **Programming Languages.** Compiler technology; functional programming; parallel/concurrent systems; generative programming; language design; type systems.

At REF2014, the School was organised into broad research themes containing several small, focused research groups. We reorganised into a larger group structure for inclusiveness and to foster collaboration. Our groups are valuable but not constraining: many academics are members of more than one group and/or carry out research involving several groups (e.g. co-supervision of PhD students).

Each group has a leader responsible for organising seminars and activities such as research away days, publicising the group, providing feedback on grant proposals, and mentoring PGR students and contract research staff. Group leaders manage a budget (5% of the School operational budget) to support group activities, conference travel, attendance at events to disseminate research and generate impact. The group membership decides the group leadership.

Our groups are heavily involved in interdisciplinary work beyond the School (Figure 1), see also Institution-Level Environment Statement, ILES, 2.5. Eight of our academics are members of the Centre for Interdisciplinary Research in Computational Algebra (CIRCA, Miguel is deputy director), established in 2000 to support collaboration between Computer Science and the School of Mathematics and Statistics. Eleven of our academics are members of the Institute for Data Intensive Research (IDIR), which gathers researchers from nine Schools across the University. The Mackenzie Institute for Early Diagnosis places data analytics at the core of several healthcare grand challenges and involves several members across the School. Dearle and Dobson are on its management board. Seven of our academics are members of the Centre for Research in Ecological and Environmental Modelling (CREEM), focusing on machine learning and sensor data analytics in the field. The School helped establish the engineering focus centre (E@ST), bringing our staff working on sensing, 3D prototyping, and machine learning together with colleagues developing new materials, medical and environmental devices.

Further active collaborations exist with academics in the Schools of Biology, Chemistry, Geography and Sustainable Development, History, Management, Medicine, Modern Languages, Physics and Astronomy, and Psychology. Externally, our staff collaborate with industry and academics worldwide (Figure 2, below).

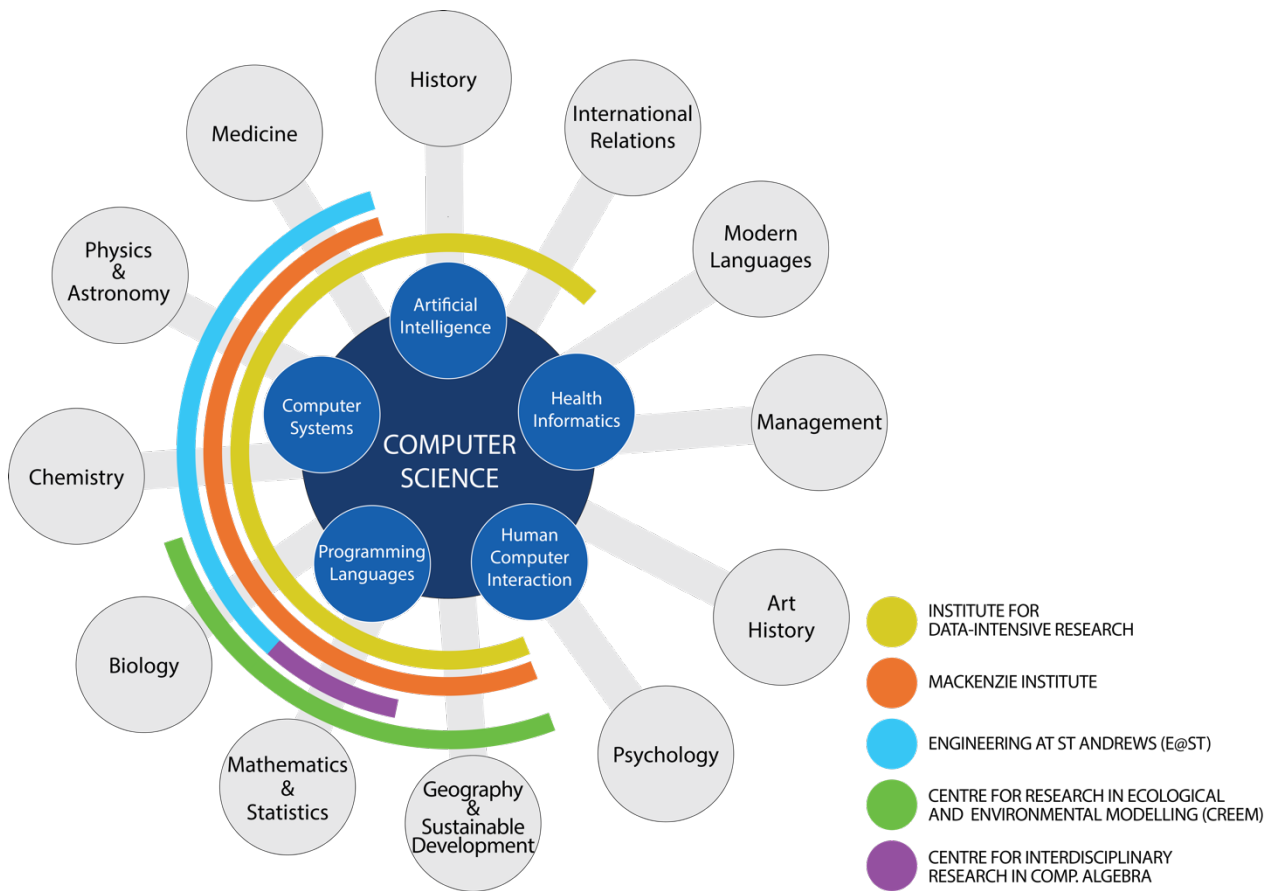


Figure 1 – Computer Science Group Structure and Wider Interactions within the University

The Research and Impact Committee (RIIC) oversees and promotes research and impact within the School, setting and reviewing research leave policy, encouraging research group activity and funding applications, making decisions on competitive research applications, and planning and documenting impact. The Director of Research convenes RIIC, which includes the group leaders, the Directors of Impact and Postgraduate Research, and representatives from contract research staff, postgraduate research students, and the Equality and Diversity Committee.

The School is part of SICSA, the Scottish Informatics and Computer Science Alliance, a collaboration of Scottish Universities aiming to develop and extend Scotland’s position as a world leader in Informatics and Computer Science research and education. We benefit substantially from a collective voice with government and access to a larger community for collaboration, organised through research themes such as AI, cyber security and data science, each with an active programme of workshops and events. SICSA provides a broader experience for our PGR students through its Graduate Academy, which runs a highly successful annual PhD conference where students can present, network, and attend workshops and talks. Furthermore, SICSA runs DemoFest, an annual knowledge exchange event gathering researchers, industry practitioners and investors. The School was a founder member of SICSA and has been central to its governance and development (Section 4).

Research Objectives During the Assessment Period

The best research and greatest impact come from supporting our staff with the freedom and opportunity to pursue their interests. Different individuals and topics may require different patterns of collaboration, funding and dissemination, so we do not impose a single research group structure, or rigid expectations regarding funding and publication, instead supporting and

encouraging each researcher to generate knowledge however suits them. We review our strategic aims in support of this philosophy since REF2014:

- To foster a culture that provides the freedom to pursue individual research directions, and values and supports blue-sky research.

A salient example of a highly successful piece of basic research is *The Complexity of N-queens Completion* by Gent, Jefferson and Nightingale (Journal of Artificial Intelligence Research, 2017). This curiosity-driven work proves a foundational result about a variation of the famous chess puzzle once studied by Gauss. It received considerable media attention.

- To deepen and diversify our funding sources to fit our intellectual shape, provide continuity for our talented contract researchers, and enable us to respond quickly to opportunities requiring a rapid turnaround.

We have balanced substantial multi-year grants, such as the four-year EPSRC programme grant Science of Sensor System Software (EP/N007565/1, £900K at St Andrews held by Dobson), with smaller pieces of funding to address immediate practical problems, such as Harris-Birtill's work with Canon Medical (£46K) using deep learning in medical technology.

Our funding income has increased by 30% relative to the last REF period. In terms of diversity, we have increased our funding from the EU, such as the SERUMS project (£500K of €4.7M held by Bowles, coordinated from St Andrews), and other sources, such as Infineon Technologies (£194K Harris-Birtill). Miguel provides an example of an academic who has attracted both blue-skies funding (EP/P015638/1, £870K A Constraint Modelling Pipeline) and application-driven (Financial portfolio rebalancing with Butterfly Catcher Ltd funded via a Scottish Funding Council Innovation Voucher) in a single area – Constraint Programming in this instance.

- To grow and strengthen our research groups, exploring new areas and synergies across the university and externally as interest and opportunities arise.

Our Health Informatics Group was established in this period to exploit collaboration opportunities with the School of Medicine and beyond. It has been highly successful, growing to include seven of our academics with collaborations locally, nationally (e.g. NHS Scotland), and internationally (e.g. Zuyderland Medisch Centrum, The Netherlands).

We have appointed twelve academics across our research groups in this period, growing from 28 to 32 category A staff. Our strategy has been to strengthen our groups while gaining the opportunity to explore new directions. Akgün, for example, strengthened constraint programming and data linkage in the AI and systems groups, also bringing expertise in data mining. Arandelovic strengthened our expertise in machine learning while providing several new collaboration opportunities with medicine.

- To develop the careers and international profiles of our staff and students along their chosen mix of academic and industrial career paths.

The School granted Henderson a year-long sabbatical to study a law degree, experience he reinvested into his research, such as his work on the right to data portability, and teaching within his module on data ethics and privacy. The School was similarly supportive of Barker's two periods with Google as a Visiting Scientist. Voss spent the academic year 2018–19 in the Department of Philosophy at Harvard University supported by a Leverhulme International Fellowship. We made duty allocation and remote work arrangements to enable him to extend his stay into 2019–20.

Achieving Impact

Impact is an integral part of the School's research pathway. 5% of the School's operations budget is reserved for impact activities, and we specialise the University's support structures according to the needs of our diverse research base. At different technology-readiness levels we regularly leverage Impact Acceleration funding from EPSRC, Global Challenge Research funding to engage in large-scale interdisciplinary projects with global significance, and Innovation Vouchers for small-scale close-to-market engagements with Scottish SMEs. We use the School's funding

for activities we see as in the long-term interest but which cannot attract immediate external funding. We have found that many relationships take years to develop, so in 2018 the School established the biennial St Andrews ROCS (Research Open day in Computer Science) event, where prospective industrial partners are invited to the School to pitch their activities and hear about potential collaboration opportunities.

Our three impact case studies reflect how the various strands of our research lead to significantly different impacts. Bhatti's basic research in network protocols is leading to a sea change in how internet traffic is routed, gaining significant momentum as interest has built within the global communications technology community and the ILNP protocol moves towards standardisation. The School has supported Bhatti's attendance of IETF meetings as an essential part of advancing the standardisation process, without which such basic research cannot gain industrial traction.

The complexity of modern processors makes it imperative that functional units can be described and formally verified for individual correctness and overall consistency. Sarkar's conformance testing system is routinely used within large hardware companies (e.g. IBM) to test processors before release, and has identified subtle problems before production, saving significant costs. The approach is gaining wider impact through its use with ARM processor cores, found in almost all mobile devices. This work validates taking the long-term view of potentially impactful relationships, arising from long-standing academic and industrial partnerships that the School helped Sarkar to maintain and develop.

The School has devoted considerable staff and system resources for over twenty years to the development and support of the GAP open-source computer algebra system. Being open source has made GAP into a standard component in this area, in a way that would have been most unlikely for a commercial product. Consequently, it is used for research and teaching of topics in advanced mathematics across numerous universities and research institutions worldwide, and has been cited in thousands of research publications (https://bit.ly/gap_citations).

Supporting Interdisciplinary Research

As Figure 1 illustrates, interdisciplinary research is at the heart of what we do. We are located close to all other schools in the university, facilitating networking and events crucial to fostering and sustaining interdisciplinary collaboration. An illustrative example is the long-running CIRCA seminar series that brings together local and external mathematicians and computer scientists, supporting a fruitful stream of collaborative work. Centres such as CIRCA and IDIR were established directly to encourage interdisciplinary research; the School is active in their leadership and development.

In creating, and recruiting to strengthen, the Health Informatics research group the School has invested substantially in growing our collaboration with the School of Medicine, exploiting our expertise in artificial intelligence, data science and human-computer interaction. This has proven highly successful, for example resulting in Kelsey's high-profile collaboration with NHS Lothian on fertility preservation following cancer treatment.

Progressing Toward a Culture of Open Research

The School has an established culture of openness regarding our software and research materials (ILES, 2.4). Researchers routinely make software and resources available on GitHub and Figshare – examples of long-lived open source projects include GAP and Conjure. Miller and colleagues share their work recording historic artefacts and sites on publicly available platforms such as Sketchfab and Roundme. Henderson co-founded the CRAWDAD wireless network data archive, which hosts hundreds of datasets used in thousands of research papers worldwide. He sits on the University research data advisory group and has published on data archiving and research reproducibility. Gent co-founded and Miguel, Jefferson and Akgün continued to edit CSPLib, the world's major repository of constraint programming benchmarks.

Konovalov is a trainer for Software Carpentry and delivers training across the University in software and data skills for all disciplines. He is also a Fellow of the Software Sustainability Institute and the editor of the Journal of Open Research Software, and recently initiated the Code4REF project (<https://code4ref.github.io/>) to encourage researchers to record software outputs in University information systems and help the recognition of software as a primary

research output. We hosted a 2014 summer school on Experimental Methodology in Computational Science Research with speakers from the Universities of Cork and Edinburgh, Microsoft Research, and the Software Sustainability Institute.

Supporting a Culture of Research Integrity

The School recognises the fundamental importance of research integrity. The School Ethics Committee (SEC) has grown to eight academics and one administrator, meeting monthly to discuss staff and student ethics applications. Henderson convenes the SEC, sits on the University ethics committee and is active in the university ethics management project working group to redevelop processes, exercising his research expertise e.g. in data protection and the use of social media. He has also published in various applied research ethics venues. All students must consider research ethics as part of their final projects, and a new data ethics module for undergraduate, MSc and EngD students includes a strand on research ethics. The University provides research integrity training for staff.

Research Objectives: The Next Five Years

We believe that St Andrews provides the best environment to research and study computer science. Our objective over the next five years is to maintain and strengthen that position.

Computer Science is a dynamic subject. While there are broadly-agreed foundations it is important to ensure that research retains relevance and importance. We maintain an on-going process of refining the number, membership, and focus of our research groups, assessing existing groups and proposals for new groups from the twin standpoints of marrying blue-skies and applied research. Previously, this has led to our strengthening our AI group with hires beyond the core competencies of constraints and computational mathematics, adding argumentation (Toniolo) and image processing (Arandelovic); and to focusing the increasing work in medical informatics into its own Health Informatics Group. The formation of a Research Software group is under way following the appointment of Konovalov. It will focus on interdisciplinary computational research in all areas (from digital humanities and medical informatics to astrophysics and discrete mathematics), development of underpinning research software, training in computational science (e.g. drop-in sessions, training workshops), studies in research software and campaigning for the recognition of the roles of research software and its developers in research. The group is especially interested in reproducibility of computational experiments, which is particularly timely given the increasing appreciation of the importance of reproducibility in Computer Science research.

The School is continually deepening and refining its approaches to research and training. During this period the School identified a need for a research administrator and industrial liaison to provide focus for our dissemination activities. We have integrated this goal within the E@ST initiative through the appointment of a coordinator experienced in industrial liaison, who will work across the range of engineering activities including those within the School. This change leverages St Andrews' small size to find and pursue opportunities benefitting several Schools.

The University plans a major investment in a new STEM building to house both Computer Science and the School of Mathematics and Statistics. A single state-of-the-art facility will promote synergy and collaboration within the School, and we will obtain the benefit of strengthening our existing collaborations with Mathematics and Statistics, for example via the cross-disciplinary CIRCA, CREEM and IDIR centres.

Section 2. People

Staffing Strategy and Staff Development

Our strategy is to recruit, develop, and retain high-quality academic and contract staff engaged with our ethos of community and collegiality (ILES, 3).

Staff Development

Early-career staff are allocated reduced teaching and administrative loads in their first three years and a start-up budget of at least £5K, supplemented when specialised equipment is required. All staff have personal overheads funds derived from grant income. Early-career staff are encouraged to collaborate with established staff in acquiring first research grants. Brady and Brown, for

example, have successfully obtained first grant funding in this period. New staff are mentored both locally and within the institutional structures, including as part of joint mentoring programmes with other institutions. Probationary staff are assessed bi-annually over their 2–5 year probation by a committee comprising the mentor and two other staff (one full professor). All staff engage in an annual confidential review meeting with the Head of School or their PI to discuss career goals and agree a plan of action.

The University is committed to supporting the further development of women. The School has supported the attendance of Balasubramaniam, Bowles, Duncan, and Ye at the Aurora programme, and of Bowles at the University's Elizabeth Garrett programme.

We understand the importance of fellowships to career development, particularly of contract research staff within the framework of the Concordat to Support the Career Development of Researchers, and encourage and support fellowship applications at all career stages. Proposals are shepherded by senior staff, and mock interviews are arranged internally and with colleagues from other disciplines. In this period Jefferson has held a Royal Society University Research Fellowship; Barker a Royal Society Industry Fellowship; Voss a Leverhulme International Academic Fellowship; and Dang a Leverhulme Early Career Fellowship. Kelsey is a Fellow of the Royal Society of Medicine, recognising his influential interdisciplinary work. Dobson has been elected to Scotland's national academy as a Fellow of the Royal Society of Edinburgh.

The University's Centre for Educational Enhancement and Development (CEED), Organisational and Staff Development Services (OSDS), and Careers Centre provide varied staff development courses, such as mandatory training in supervising postgraduate students. Grants are allocated for attendance at external staff development events. Our staff, such as Bain, Henderson, Konovalov and Torpey provide training for CEED and OSDS on topics such as software carpentry and data organisation.

The School actively manages staff careers. The Career Support Officer leads an annual review to assess staff members' state of readiness for promotion. Staff are then mentored in preparing promotion applications. This has led to successes in this period: Barker, Kelsey, Miguel to Professor; Arandelovic, Jefferson, Kelsey, Sarkar to Reader; Balasubramaniam, Bowles, Duncan, Nacenta, Ye to Senior Lecturer; Letham, Lewis, Terzic to Lecturer; and Janjic to Senior Research Fellow.

We enrich our environment by programmes of outside speakers. Since 1969 the School has run a bi-annual Distinguished Lecture Series of world-leading researchers giving a day-long series of lectures. In this period these have included: Luca Cardelli (Microsoft Research and Oxford), Carl Hewitt (MIT), Jane Hillston (Edinburgh), Maria Klawe (Harvey Mudd College), Julie McCann (Imperial), Timothy Roscoe (ETH Zürich). The School hosts a term-time weekly seminar series where diverse external speakers present to a general Computer Science audience. Recent speakers include: Ankush Jhalani (Bloomberg), Daniel Katz (Illinois), and Marina Romanchikova (National Physical Laboratory). The School also supports group-centric seminar series.

At our weekly Grant-writing Club researchers at all levels share experience (e.g. successful proposals, proposal reviews, funding panel experiences), critique work in progress, and present ideas. The dissemination of this experience benefits the whole School, and the feedback gained from a broad range of viewpoints benefits individual researchers. Miguel's Constraint Modelling Pipeline grant, for example, benefited greatly from discussion at this meeting.

Staffing and Recruitment

Applicants' publication, funding and engagement profiles are benchmarked against what would be expected of someone on a trajectory towards a world-leading career, moderated by career stage and pathway. In this period we have focused on recruiting early-career staff who, in developing at St Andrews, become invested in the School, helping to maintain and strengthen our collegiate community.

We have recruited eight new academics to strengthen all five of our research groups. We have balanced appointing the best external candidates (Arandelovic, Clarke, Fayed, Toniolo) with recruiting locally from contract research positions, allowing the School to retain those of our best researchers seeking an academic career path (Akgün, Brown, Harris-Birtill, Hinrichs, Konovalov,

Dang), while diversifying our research interests. We have balanced traditional Computer Science backgrounds with other disciplines (Harris-Birtill in Physics, Konovalov in Mathematics, Clarke in design, Brown with start-up experience).

Our contract researcher community is key to our success in attracting external funding. 23 such staff have been employed in this period, recruited to the same rigorous standards as our academics. Testament to their quality is that academic appointments from among our contract research staff were made in the face of strong international competition.

The School has successfully recruited non-UK academics (Canadian, Croatian, German, Italian, Serbian, Turkish, Ukrainian, Vietnamese) and contract researchers (Bosnian, Chinese, German, Hungarian, Italian, Mexican, Serbian, Spanish, Turkish). 40% of our academic and 20% of our contract research appointments have been women. This improves significantly over the previous REF period and is significantly above the national average, reflecting our commitment to gender balance in Computer Science.

Leave

All staff are given regular research leave from teaching and administration of one semester every four years. We allocate research leave outside this schedule for staff working on strategically significant proposals or projects, or who are identified as benefitting from additional focused research time. Henderson, for example, was granted a contiguous year of research leave to study a law degree and change the focus of his research.

Stimulating and Facilitating Exchanges Between Academia and Industry

We gain valuable experience from seconding our staff to industry, for their own development, to establish new partnerships, and to return experience to the School. The School is flexible in agreeing a work pattern to accommodate such projects. Examples include Barker's two periods working with Google, producing a high-profile piece of research analysing the performance of the Google Borg cluster, and Fayed's current position at Cloudflare. The St Andrews ROCS event was established exactly to stimulate such exchanges.

Recognising and Rewarding Research and Impact

Staff and students can apply to a travel budget (11% of the School operational budget), to attend a conference, workshop or other such opportunity in the absence of their own funds. This budget is derived from academics' overheads accounts, so all staff contribute and benefit. 10% of this budget supports speculative travel activities, for example attending the 2019 Data Science Initiative Summer School in Paris, and the 2018 Summer School on Deep Learning in Genoa.

We have had considerable success with the Scottish Funding Council Innovation Voucher scheme (19, worth £105K) to establish new collaborations with SMEs. This activity is incentivised by making the entire award available to the staff member involved to spend on research and impact activities. Workload adjustments are made for, for example, those involved in writing up impact case studies. Impact features strongly in promotion cases: Sarkar, for example, was promoted directly to Reader in 2018, substantially due to his work on formally verified hardware concurrency, now deployed commercially in all ARM-based devices.

Students

Our students are highly valued and fully integrated members of our School. We maintain an open, approachable culture where students are actively encouraged to interact with staff. This is supported by our physical estate, with research students' offices interleaved with those of staff and a single common area for students and staff. Staff are encouraged to propose research-led undergraduate and MSc projects, an important resource particularly for those exploring new ideas or whose work is not yet supported by external funding or PhD students. The School runs an Undergraduate Research Assistant Scheme with 7% of the operations budget, supplemented by University funds.

Recruitment of Doctoral Research Students

Prospective students are encouraged to correspond directly with potential supervisors, supported by administrative mechanisms to help identify supervisors where needed. Applications are the

same for internal and external applicants, and include a proposal of the student's devising to gauge technical thinking. Students selected for interview are given a relevant paper as the basis for a technical discussion. This advantages students by balancing the initial on-paper evaluation, and provides an opportunity to boost otherwise weak proposals. Candidates are interviewed by a proposed supervisor and Director of PG studies, who agree a recommendation.

Monitoring and Support Mechanisms, Skills Development

Our culture prioritises community, emphasising the value of shared learning and experience through three mechanisms. First, all students undergo an annual review process in the same week, allowing the sharing of support and advice in a potentially stressful experience. The format is lightweight and responsive: a 45-minute oral review conducted by two independent members of staff. Students and supervisors submit written comments on their training and supervision beforehand, and students generate short research reports. Secondly, the School hosts a bi-monthly PGR seminar series at which every student, once during their tenure, delivers a 40-minute technical talk based on related work, rather than their own. Attendance is mandatory (facilitating consistent UKVI engagement monitoring). Finally, the School sponsors an annual residential 2-night retreat, where the students organise the programme of research and leisure activities.

Equality and Diversity

We value our diverse research community, and recognise the need to support staff from any group (gender, ethnicity or sexuality, for instance) still underrepresented among computer science researchers. Many senior staff roles have been filled by women and BAME staff across the period, including Director of Teaching, Director of Impact, research group leaders, EDI and taught-programme coordinators. Within this period 40% of academic staff recruited were women and 60% were non-UK nationals. We continued our longstanding policy of recruiting over 50% of new staff externally, providing a constant stream of new thinking.

Following our action plan from our Bronze Athena/SWAN award of 2017 we have introduced mechanisms to monitor staff recruitment and development, and support measures to counteract historical, unconscious or institutional biases. These include checks and adjustments in our recruitment processes, such as the language used in job advertisements; on duty allocation; before, during or after parental leave; and ahead of the annual promotion round. In planning our Distinguished Lecture Series and School seminars diversity is explicitly considered. A new role of Career Support Officer monitors these initiatives.

Constructing our REF Submission

We have carefully considered equality and diversity in constructing this submission. Following the institutional code of practice outputs were selected purely based on an assessment of quality, following two blind reviews per output proposed. Check-in meetings with a diverse panel were held with each member of staff to be returned. Outputs were selected by attributing their best-reviewed paper to each staff member, and then filling the required basket of outputs based solely on quality according to the reviews. No expectation was placed upon any staff member to provide a particular number of outputs, beyond the minimum. This is reflected in our output profile, which does not disproportionately favour any subset of the School. The university has stated that attribution of REF outputs will play no role in promotion.

Study Leave

Following institutional practice all staff with open contracts on all career tracks are entitled to a semester of research or impact paid leave every 4 years. Eligible staff are reminded annually of the option to apply for research leave, with mentors and research group leaders also encouraging staff to consider research leave at appropriate times. This process is monitored by the Career Support Officer. The Head of School has supported every application made in this period.

Flexible and Remote Working

Staff need for flexible working is considered when duty and timetabling preferences are sought annually. The diverse School Management Group also considers staff requests to balance personal and family commitments even without a formal flexible working agreement. For example,

some staff have been assigned teaching in a block or scheduled to allow days free from teaching commitments, or scheduled all teaching in one semester.

Career Pathways for Part-time and Fixed-term Staff

The School has a strong track record of accommodating staff wishing to work part time, and of guiding fixed-term staff into permanent positions. Connor and Salamon are examples of academic and contract research staff currently working part time; Harris-Birtill, Sarkar, Terzić and Toniolo provide examples of staff who have moved from fixed-term to open contracts.

We provide continuity of employment by naming our contract researchers on follow-up funding applications and, where appropriate, moving researchers between grants. Examples of such movement to provide continuity include Barwell, Brown and Hoffmann. Furthermore, the University covers short gaps in funding, which supported Morrison for three months. Contract research staff are actively encouraged and supported in applying for open posts (see above).

Facilitating Those with Caring Responsibilities, Ill Health, or Disability

The school travel fund (see above) is used to support all staff in attending conferences, courses, and training, administered by the School Manager and the Director of Research. We allow staff and students to specify travel that fits their individual circumstances.

One member of the School is legally blind. The School has invested in assistive technology and human assistance as required, for example for explaining diagrams and accompaniment to conferences. We also took the opportunity to ensure that all the School's facilities, information, and services were accessible to all.

Funding Applications, Promotion and Reward, Recruitment

A group including the Career Support Officer, Equality and Diversity Convener, Director of Research, Director of Teaching and Staff Welfare Officers meet before the annual promotion round to consider all staff eligible for promotion. The aim is to ensure systematic consideration of all eligible staff. One-to-one meetings are organised either to encourage individuals to apply for promotion in the current academic year, or to suggest actions to strengthen their case for promotion.

Leadership roles are advertised to all eligible staff, who are encouraged to consider applying. Appointments to these roles are made by the School Management Group.

Returning from Periods of Leave

A phased return in terms of workload is arranged for staff who return from parental leave or absences due to illness. Staff returning from such leave meet with Head of School or a delegate to discuss their requirements. Supervisors of research students returning from similar circumstances or Leaves of Absence discuss plans and strategies for pragmatic re-engagement.

Staff with Protected Characteristics

We follow recommendations from the University Occupational Health unit and Student Services on providing support and resources required for staff and students with disabilities. Arrangements for events organised for research students consider protected known characteristics of the cohort. Staff and students are encouraged to approach relevant role holders, such as the Head of School, Staff Welfare Officers, Equality and Diversity Convener or Student Welfare Officers, to discuss support required in relation to a protected characteristic.

Staff have access to University staff networks such as the Staff BAME Network and Women in Science St Andrews (WISSA) to meet, network and collaborate with others.

Wellbeing

The School has student and staff welfare officers, allocated to one male and one female staff member. They act as an optional first point of contact for discussing problems or concerns for those who do not wish to speak to academic co-ordinators or line managers, and signpost individuals to appropriate further help and guidance, often within the Human Resources or Occupational Health units.

Mentors help new staff to settle into school life and offer guidance on career, research and teaching matters. Supervisors monitor the wellbeing of research students. Students are allocated a second supervisor as additional support and research groups provide a further support framework. Annual review meetings provide an opportunity for research students to discuss their wellbeing with two independent staff members.

Section 3. Income, infrastructure and facilities

Income and Research Funding

The School's total grant income has risen by 30% to around £9M in this REF period, compared with REF2014. We have increased the diversity of our funding sources, with 53% from funding councils, 27% EU funding, and the remaining 20% from other sources. Grants have been awarded to staff members across all our research groups, with sustained success throughout the period.

Strategy for Research Income

The School seeks to diversify its research income and to widen the participation of staff in grant-writing. The former is aided by a dedicated University-funded business development manager (BDM) tasked with identifying and communicating future and alternative funding sources, and by the central Research Funding Support teams who manage contract negotiations and subsequent awards (ILES, 4.1). The latter is supported by a programme of mentoring grant-writers co-ordinated through our grant-writing club, which the BDM attends. This strategy effectively manages the risks of preparing proposals for new *versus* established venues and keeps us deeply engaged with emerging funding strands such as EPSRC's new investments in mathematical sciences, while opening up new opportunities for collaboration.

We have been increasingly successful in working across St Andrews to pursue cross-disciplinary opportunities. Example include CIRCA (computational algebra) and the Mackenzie Institute (early diagnostic medicine). The School has recently joined CREEM (ecological modelling), contributing expertise in sensing and sensor data analytics. We have also developed collaborations crossing the academic and government/NGO sectors, most notably in applying virtual reality techniques to cultural heritage, which has led to a substantial number of awards for working with small (and otherwise under-served) agencies and sites across the UK and beyond.

Notable funding obtained

Major long-term funding includes:

- Automated Conflict Resolution in Clinical Pathways (Bowles, 2014).
£334K EPSRC.
- CoDiMa (CCP in the area of Computational Discrete Mathematics) (Linton, 2014).
£293K EPSRC.
- OpenDreamKit (Linton, 2015).
£630K EU.
- C3 Scalable Shared Memory via Consistency-directed Cache Coherence (Sarkar, 2015).
£213K EPSRC.
- Science of Sensor System Software (Dobson, 2015).
£911K EPSRC.
- A Constraint Modelling Pipeline (Miguel, 2016).
£870K EPSRC.
- Modelling and Optimisation with Graphs (Jefferson, 2017).
£266K EPSRC.
- Connected Culture and Natural Heritage in the Northern Environment (Miller, 2017).
£139K EU.
- Adaptive Brokerage for the Cloud (Barker, 2017).
£380K EPSRC.
- Teamplay (Brown, 2017).
£374K EU.

- Stochastic models to enable tailoring of medications to patients with multiple morbidities (Bowles, 2018).
£157K MRC.
- Millimetre Wave Radar-On-Chip (Harris-Birtill, 2018).
£193K EU.
- SERUMS (Bowles, 2018).
£505K EU.
- A Learning, Optimising Compiler for Computational Group Theory (Jefferson, 2018).
£202K Royal Society.
- Programming as Conversation: Type-Driven Development in Action (Brady, 2019).
£367K EPSRC.
- Keep Learning (Miguel, 2020, joint with Napier).
£464K at St Andrews, EPSRC.

In addition, we have obtained over £200K in short-term and small-scale funding for collaboration with SMEs and charity sites.

Management Structures for Research

The Head of School leads the School's research management team and centres around a Director of Research with responsibility for research strategy and operations, aided by a Director of Impact responsible for non-academic applications of research, a Director of Post-graduate Research responsible for our PhD and EngD programmes, and a Director of Infrastructure responsible for developing and maintaining our computing and storage infrastructures. An independent Ethics committee is charged with ethical approval of all projects, liaising with the institutional ethics bodies. This committee has grown in significance alongside the growth in projects tackling digital medicine and novel interfaces.

Communication is vital in keeping staff informed of opportunities and in gaining feedback to management on decisions. The Head of School maintains a monthly journal circulated to staff, while the Director of Research circulates a weekly research update of funding and consultancy opportunities. Twice-yearly staff councils provide opportunities for feedback. The School maintains a staff handbook to codify processes in research and other areas of operation, and various social media feeds to celebrate successes as a means to encourage additional activities. The School has a universal "open door" culture providing easy access to senior management.

Each research group has a group leader and a budget, renewed annually, to support seminars and other team-building activities.

Operational Investments and Funding

The school has an operational budget of £1.3M per annum of which £793K is discretionary and from which the school ring-fences £285K for PGR scholarships, £150K for equipment, and £80K for casual salaries. Of the remainder, we allocate:

- 11% to a travel pot available to all staff and research students for research related travel, managed by a committee that considers requests for funding;
- 10% to staff research accounts for staff to fund their own activities;
- 5% to research groups to spend on research group activities for example invited speakers, research group away days;
- 7% to school funded internships, which last year provided internships for 19 students with a further 2 internships from non-operational budgets.

The strategic goal of this funding is to ensure that the School has the opportunity to pursue research ideas ahead of grant funding, and in areas where funding opportunities are sparse. This ensures equality of opportunity for students and researchers in *all* the research we conduct.

Equality and Diversity

As the School has diversified its staffing and research portfolio over the REF period, the School management group has championed diverting resources from other areas of the School's budget, allocating funding to prime and support the new activities so that new staff are facilitated in developing their careers and independent collaborations. This has involved a move away from traditional computing infrastructure to create novel facilities in emerging technologies. One example is our new work in physical computing, complementing our existing sensor and HCI activities, which is requiring investment in a range of prototyping and 3D fabrication equipment. Another is the increased emphasis on medical data analytics, which has significant specialist requirements for (especially) storage.

Operational Infrastructure and Facilities

The School's research group structure has enabled us to plan the development of infrastructure that will be of significant shared value, rather than devoting private facilities to individual projects. In addition to specialised equipment we have:

- Increased physical and virtualised compute capacity accessible to researchers across the School. New facilities include a 24-node compute cluster, GPU-equipped workstations and additional VM hosting capacity.
- Installed faster, higher-capacity network storage.
- Developed capacity to provision dedicated single-host and cluster-based virtualised computing, networking, and storage configurations for repeatable experiments.
- Allocated funding to commercial cloud computing credits.
- Redeveloped of our HCI laboratory through moving to venue with 50% more floor space allowing for more area to be dedicated to experimental setups.

The School occupies two dedicated adjacent buildings, within which it is free to develop the space for teaching and research uses. Our dedicated server room caters for production and experimental systems and hosts a range of modern, enterprise-grade servers for compute, hosting and storage. These facilities have been provided by investment from the University and from a variety of research grants. They are supported by a highly-qualified team of three technicians (including one with extensive hardware development experience) and two systems administrators.

In this period our buildings have seen significant investment in network infrastructure for client and server networks (covering offices, server room and research and teaching laboratories) providing higher data rates and increased redundancy. Furthermore, our student laboratories have been redeveloped to move their focus from lecture venues to spaces aimed at supporting group-based and individual development work to better support research-driven teaching and PGR research.

The School operates a five-year equipment replacement cycle with an annual £150K budget, allowing us to regularly update our compute and storage provisioning. This approach ensures that the School's hardware and software systems are up-to-date and can adapt quickly to follow developing technology trends and to meet changing requirements. Staff's personal machines are upgraded from the central budget, to ensure that capabilities are not limited by grant income.

The School has had significant investment in its estate from the University during the REF period, with over £510K spent on improvement work (additional to maintenance). This included major lab refurbishment, work to create additional research space, new network infrastructure for client and server networks (covering offices, server room and research and teaching laboratories) to provide higher data rates and increased redundancy. Student laboratories have been redeveloped to move their focus from lecture venues to spaces aimed at supporting group-based and individual development work to better support research-driven teaching and PGR research activities. General improvements to the environment have included providing baby-change facilities, installing a plumbed coffee machine, and sparkling water facilities to reduce carbon footprint.

Shared and Collaborative Use of Research Infrastructure

The High-Performance Computing service provided by Cirrus, one of the EPSRC Tier-2 National HPC Facilities, has been extensively used by several research projects in the AI group. All of this work is computationally heavy and powerful computational resources are essential. The projects

include a series of studies about automated generation of synthetic benchmark instances, building portfolios of streamliners for constraint programming, a proposal of a new and efficient constraint-based local search algorithm, and various studies of solving Patience games.

Specialist Research Infrastructure and Facilities

In addition to our general infrastructure the School has made a number of highly specialised investments in support of specific strands of the research strategy. The School has in-house facilities, supported by extensive expertise, for fabricating experimental electronic devices and physical components through 3D printers and CNC systems. These include:

- 3D printing and fabrication facilities for physical computing, complementing facilities available at institutional level by targeting rapid small-scale prototyping ahead of larger commitments.
- Funding training for a drone piloting licence that allows the Virtual Worlds group to carry out drone-based photography and video capture, in-house.

Benefits in Kind

In addition to these investments, the School has benefited significantly from in-kind contributions from industry. Notable examples include:

- An 84" Microsoft Surface Hub.
- Google Soli radar devices.
- Nvidia GPU grant program awards.

Library resources

The University's recently-refurbished main library is well-supplied with physical and electronic resources. Operating both centrally and from a mathematical sciences annex in the neighbouring Physics building, the Library provides electronic and physical subscriptions to all the major journals in computer science and adjacent areas, as well as providing subscription-based access to several book series in e-book form. Reciprocal arrangements with over 20 other university libraries further extend the resources that are directly available to support research. The University's strategic plan favours the provision of resources in digital form, which enormously increases accessibility while reducing both storage requirements and carbon footprint.

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



Figure 2 – Computer Science: Map of Academic (blue/circle) and Industrial (red/"i") Collaborators

Research Collaborations, Networks and Partnerships

We have a large base of cross-School, cross-institutional, and international collaborations. The research grant portfolio includes membership and leadership of Scottish, UK and EU project consortia as well as membership of international and US-based activities, including:

- Co-management of the CRAWDAD international wireless data archive (Henderson);
- Leadership within the IETF in developing future IPv6 standards (Bhatti);
- Chair of the IFIP Working Group 2.11 Program Generation and member of Working Group 2.16 Language Design (Brady),
- Providing expertise to the RISC-V ISA specification group (Sarkar),
- Contributing to the ISO C++ standardisation effort (Jefferson); and
- Management of the CSPLib benchmark library for Constraint Programming (Akgün, Jefferson).

National collaborations are enhanced by our leading role in the Scottish Informatics and Computer Science Alliance (see Section 1), creating a collaborative research culture across Scottish institutions. We have provided two Directors (Hammond 2016–18, Quigley 2019–20); Graduate Academy Director (Miguel 2014-16, Sarkar 2018–); co-theme leader of the Human-Computer Interaction theme (Nacenta 2014-18); and leader of the Cybersecurity Nexus (Duncan 2019-). Hammond, Quigley and Miguel served on the advisory board of the Data Lab Innovation Centre *ex officio*.

Our successful international collaborations are underpinned by substantial projects including:

- RePhrase (H2020, 2015), coordinated by St Andrews. 9 partners from Israel, Austria, Spain, Italy, Hungary, and the UK. The project created tools and techniques for software development in parallel programming, including a new C++17 standard for parallelism.
- OpenDreamKit (H2020, 2015), coordinated by the Université of Paris-Sud. 19 partners from France, Germany, Poland, Norway, the Netherlands, and the UK. The project resulted in new libraries, tools, standards, and demonstrators for modern computational mathematics teaching and research.
- Teamplay (H2020, 2018), coordinated by Inria. 11 partners from Germany, Greece, Denmark, France, Spain, the Netherlands, and the UK. The project is developing new programming language techniques to reason about non-functional properties such as time, energy and security.
- Serums (H2020, 2019) coordinated by St Andrews. 10 partners from Israel, Austria, Spain, Cyprus, the Netherlands, Belgium, and the UK. Serums focuses on future healthcare provision, enhancing personal care and maximising treatment quality, while ensuring patient trust in the security and privacy of their data.

Relationships with Beneficiaries

We maintain fruitful long-term relationships with users and beneficiaries of our work.

Digitising Scotland is digitising 24 million Scottish records of births, marriages and deaths dating from 1856. With colleagues at The University of Edinburgh, Queens University Belfast, The Australian National University and the National Records of Scotland we are performing record linkage on this dataset using new metric search techniques whose accuracy is calibrated against ground truth information from a Swedish dataset.

With Marine Scotland Science and CREEM we are developing machine learning techniques to automatically process decades of images of salmon scales to understand salmon behaviour over long periods. We collaborate with the Scottish Oceans Institute in the re-identification of skate, and the sizing/sexing of lobsters from images, essential techniques for estimating wild population sizes. This collaboration has leveraged MSc and PhD studentships, and led to funding applications.

Researchers at the Potsdam Institute for Climate Impact Research use Brady's Idris language for formalising models of decision procedures applied. This has led to two co-authored papers as well

as improved tooling, libraries and automated reasoning support.

Adobe Ltd support internships, undergraduate scholarships and doctoral scholarships for our students. Several former PhD students have moved to Adobe Labs and continue to work with us. Technology developed in St Andrews for managing and interacting with cloud-scale data is being used on an experimental basis within Adobe.

Our computational mathematics research is based on strong relationships with the community of researchers and teachers in mathematics, physics, and chemistry. Konovalov disseminates expertise in managing large-scale open-source software projects with communities through his work as a Fellow of the Software Sustainability Institute and with the Society of Research Software Engineering. His PLOS Computational Biology paper “Ten Simple Rules for taking advantage of Git and GitHub” was among the top 50 most downloaded papers across all PLOS journals in 2016.

Our sensor analytics work is used for monitoring industrial pollution, and for improving the sensitivity of commercial devices for detecting microbial resistance. We focus on making it easier to design such experiments, and to interpret and respond to the results, which makes data far more valuable to end-users.

Our work in complex networks interacts with clinicians studying microbial resistance and similar processes. We are improving our ability to simulate how disease pathogens evolve through an infection process and how co-infection with multiple diseases affects disease dynamics. We are also developing techniques to help understand how small-scale features of human contact networks can affect the large-scale behaviour of epidemics.

Through collaborative research projects in virtual museums including EU LAC Museums, CINE Northern Peripheries and Arctic Programme, and CUPIDO North Sea Region Cultural Heritage, we contributed significantly to the preservation and accessibility of cultural heritage. Examples include:

- **Virtual Time Machine Exhibits:** *Illicit Still Experience*, Tomintoul and Glenlivet Discovery Centre. *Lords of the Isles*, Finlaggan Heritage Centre. *Picts and Pixels Exhibition*, Perth Museum. *Skriduklauster Monastery*, Iceland. *Medieval Abernethy*, Abernethy Museum. *The Curing Yard*, Timespan Museum and Archives. *St Andrews Cathedral 1318*, Historic Environment Scotland.
- **Virtual Time Binoculars Mobile Apps:** *Edinburgh 1544*, *Bennachie Colony*, *Finlaggan*, *Seat of the Lords of the Isles*, *St Andrews Cathedral*, *UIST 360*.
- **Virtual Museum Infrastructure:** *World War One Roll of Honour*, Royal Scots Museum. *Digital Doors Open*, Scottish Civic Trust. *SLEAT the South of Skye*, SLEAT Development Trust, *Tay Landscape Partnership*.

Nederhof is a member of the International Association of Egyptologists, the primary body for this discipline. Collaborating with the global Egyptological community, he developed extensions included in the Unicode 12 international standard to enable the representation of hieroglyphic text.

Our Health Informatics Group work with medical professionals with different specialisations (diabetes, cardiovascular, rheumatoid arthritis and other autoimmune diseases) to investigate precision therapeutics as part of Health Data Research UK, and with Rhode Island Hospital, US, and Aberdeen Royal Infirmary on radiation oncology. We have worked with clinical oncologists at the Western General Hospital, Edinburgh, to develop a new version of NHS Predict, a toxicity predictor for breast cancer considering co-morbidities.

We provide expertise to Copenhagen University Hospital investigating cryopreservation of ovarian tissue as a fertility preservation technique. Accurate prediction of attributes (unmeasurable *in vivo*) is needed to quantify differences in the populations investigated, and we apply AI and statistical learning to quantify the confidence in results based on small samples. We work with The Wolfson Fertility Centre on individualised approaches to assisted conception, adapting our tools and techniques for fertility after cancer to the wider problem of helping subfertile couples.

Our tool CISpaces (Collaborative Intelligence Spaces) was developed alongside expert analysts in the UK and US intelligence communities to support analysis of potentially conflicting evidence to form plausible hypotheses. Analysts provided requirements for the tool, realistic scenarios, and

evaluated the quality of support that the system provides. CISpaces is supported by the US Army Research Lab and the UK DSTL, and was selected by the UK and US government partners as one of three scientific highlights from the NIS ITA programme. A second version of CISpaces, supported by the UK DSTL in the follow-on Defence and Security Accelerator programme, is available to professional analysts in the UK Joint Forces Intelligence Group and as an open-source tool (cispaces.org).

Contribution to the Sustainability of the Discipline

We have established an Engineering Doctorate (EngD) programme, unique in the UK in being completely funded by industry through partnerships in directly-impactful research. The School provides a programme director (Bhatti) and administrative support. Current industry sponsors include Canon Medical, Aggreko, NHS Scotland, and Deutsche Asset Management. Topics include image analysis, data science, artificial intelligence, systems engineering, and financial systems. Student intake is international, with current students from the UK, Chile, Indonesia, and the USA.

Konovalov is a Fellow of the Software Sustainability Institute (SSI) and a member of the Carpentries (<https://carpentries.org/>), a global volunteer organisation for teaching foundational computational and data skills to researchers. As a certified Instructor and Trainer Konovalov has co-run 10 Software Carpentry workshops training over 250 researchers, and has trained 20 Carpentries instructors.

School staff contribute extensively to summer schools and other tutorial programmes. Highlights include Brady's engagement at the Oregon Programming Languages Summer School 2017 and other events in the UK; Henderson's tutorial at the CRISP surveillance summer school and the Estonian cybersecurity summer school; Akgün's several tutorials on constraint programming at the leading international conferences; Nacenta and Hinrich's workshops on experimental methodology and visualisation aimed at building the user communities; and long-term engagements with the Scottish Programming Language and Verification summer schools and the Erasmus Mundus Dependable Software Systems programme.

Engagement with Diverse Communities and Publics

Outreach is conducted by every member of the School through live events, the national press, social and traditional media (ILES, 2.8). The School maintains a strong annual presence at SICSA DemoFest showcase where we present and demonstrate our work to academia and industry. Dearle helped establish the University's Digital Health Science initiative, which hosts seminars attended by academics and NHS members. Bowles has presented her research at Café Scientifique, organised by and open to the general public. Gent and Miguel have written articles on Artificial Intelligence for the national press, and Gent's work on n-queens completion was featured very widely. His advances in understanding patience games was featured by Major Nelson, the most popular Xbox gaming podcast, in their 700th episode. Brady's book, "Type Driven Development with Idris", has exceeded 5,500 sales. Dobson's work on epidemic modelling gave rise to a general-audience book and an associated web site making all the experimental code available to "citizen scientists".

Our virtual museum infrastructure has empowered 30 museums in 21 countries across the world to understand, explore and digitally preserve their heritage. This includes reconstructions of 25 subjects, 370 digital artefacts, 109 virtual tours, 73 videos and 18 mobile apps. Our virtual reality exhibits have been installed in 17 museums in Scotland with a combined annual footfall in excess of 320k people, stimulating local economies by enhancing visitor experience. We have reached millions of people through pieces in social and traditional media, including The Guardian, the BBC, Google Maps and Facebook.

The School has a very active outreach programme for schools, with a view to spreading the excitement of computer science to a broader range of social groups. This includes several week-long residential summer programmes where students attend research-based lectures, labs, and other activities organised by members of the School. Examples include events with the Sutton Trust as part of the University's agenda for widening participation; Science Summer Schools organised as part of the University Summer Access Experience courses; and First Chances,

where local school pupils are supported in their literacy, numeracy and IT skills throughout the academic year, culminating in a residential summer school. Throughout the year the School hosts day visits from local schools themed around topics such as the development of computing technology or the connection between Computer Science and video games. Dearle and Balasubramaniam run in-class sessions and an after-school club at a local primary school. Codefirst:girls is very popular, with many instructors from our student body: the School provides space, competition judges and prizes, and St Andrews was the first university to include this course on student transcripts. We supported the creation of a RoboGals chapter in St Andrews, providing advice, guidance and equipment. As part of the interdisciplinary module Communication and Teaching in Science our undergraduate students visit local schools to design and teach lessons in their subject.

Personal Leadership, Recognition, and Awards

The leadership of our staff members is widely recognised. Dobson has been elected a Fellow of the Royal Society of Edinburgh. Kelsey has been elected a Fellow of the Royal Society of Medicine and a member of the International Society for Fertility Preservation, and is a Board Member of the Managed Services Network for Children and Young People with Cancer, NHS Scotland. Jefferson holds a Royal Society University Research Fellowship. Dang has been awarded a Leverhulme Early Career Research Fellowship (2020-2023). Barker held a Royal Society Industry Fellowship (2014-16). Voss was granted a Leverhulme International Academic Fellowship (2018-19), and has been awarded a Technology and Human Rights Fellowship (2020) from the Carr Centre for Human Rights Policy and Harvard. Bowles was selected for the Farr Institute's Future Leaders in Health Data Science programme. Several staff have held leadership roles in SICSA (see above). Quigley served as SIGCHI Vice President for Conferences (2015–20), is an ACM Distinguished Speaker, and served on the board of ScotlandIS, which represents Scotland's digital technologies industry.

Sarkar received the ACM SIGPLAN Most Influential ICFP paper award, presented in 2017 (for 2007). Henderson received best paper awards at: WSDM 2017 Workshop on Mining Online Health Reports, 6th International Workshop on Hot Topics in Peer-to-peer computing, Online Social Networking (HotPOST 2014). Nacenta received a Best Paper Honourable Mention Award at the ACM SIGCHI Conference. Brady was awarded best paper at Trends in Functional Programming 2014. Quigley was awarded best paper at the 12th ACM International Working Conference on Advanced Visual Interfaces, 2014. Dang was awarded best paper in the GECCO 2017 Evolutionary Combinatorial Optimization and Metaheuristics track.

Several of our staff, such as Bowles, Dobson, Henderson and Sarkar, are members of the EPSRC College. Sarkar was an invited reviewer for ANR France in 2018. Barker is an Independent Expert for the European Commission. Dobson has been elected to the steering committee of ASOS, the main conference venue for self-adaptive and autonomic systems research. Barker was a Google Visiting Scientist in 2016, and a Google Senior Visiting Scientist in 2019.

Our staff are frequently asked to give invited or keynote talks. For example, Kelsey spoke at the 4th Biennial World Congress of the International Society for Fertility Preservation, 2015, and the 61st Annual Meeting of the Canadian Fertility and Andrology Society, 2015. Brady's invitations include IFL 2017, PLACES 2017, TYPES 2017, ML Workshop 2017, BCTCS 2017, SPLASH-I 2016, Scala 2014, LFMTTP 2014. Toniolo was invited to address the first Conference on "Bridging the Gap between Formal Argumentation and Actual Human Reasoning", Bochum, 2018. Quigley's frequent keynote invitations include: Mensch-und Computer Conference, Germany 2019; the 5th International HCI and UX Conference 2019; and the IEEE Working Conference on Software Visualisation, 2018. Ye gave a keynote talk at an international workshop at PerCom 2019. Dobson delivered the keynote at the Conference on Design and Architectures for Signal and Image Processing (2018).

An important aspect of leadership are editorial activities in the high-profile international journals across all our areas of interest, which have included computer algebra (Linton: Applicable Algebra in Engineering; Konovalov: Journal of Software for Algebra and Geometry), computing systems (Linton: Communication and Computing; Barker: IEEE Transactions on Services Computing, Journal of Cluster Computing), machine learning (Arandelovic: Information, Pattern Recognition), human-computer interaction (Quigley: Proceedings of the ACM on Interactive, Mobile, Wearable

Unit-level environment template (REF5b)

and Ubiquitous Technologies; Nederhof: Transactions of the Association for Computational Linguistics), and software technology (Brady: Journal of Functional Programming; Konovalov: Journal of Open Research Software; Henderson: IEEE Technology and Society). Special issues guest-edited have included topics in machine learning for cultural heritage (Arandelovic: Sci), wireless technologies (Bhatti: IEEE Communications Magazine), high-performance computing (Brown: International Journal of Parallel Programming, International Journal of High Performance Computing), natural language technology (Nederhof: Journal of Language and Modelling), human-computer interaction (Quigley: ACM Transactions on Interactive Intelligent Systems, User Modelling and User-adapted Interaction), and sensing (Ye: Information, Sensors). Henderson has served on the editorial board of ACM Books.