

Institution: University of Aberdeen

Unit of Assessment: 11 (Computer Science and Informatics)

1. Unit context and structure, research and impact strategy

1.1 Context and structure

Computing Science is a vibrant, dynamic and outwardly looking Unit. It is staffed by international researchers and enjoys a culture of cross- and interdisciplinary research and collaboration with industry, government and the third sector. The Unit has a track record of projects from diverse funding bodies. It is one of four disciplines in the School of Natural and Computing Sciences, together with Physics, Mathematics and Chemistry. Research in Computing Science is organised under two cross-disciplinary themes: “**Trust, Identity, Privacy and Security**” (**TIPS**) and “**Human Inspired and Understandable Computing**” (**HIUC**). **TIPS** focuses on the specification and verification of the features of autonomous systems and human-agent teams, data sharing and core areas of cybersecurity. **HIUC** covers the theory and applications of machine learning, automated reasoning and formal argumentation, explainable artificial intelligence (XAI) and natural language generation (NLG).

In 2014, Computing Science research had three themes: “Agents, Reasoning and Knowledge” (ARK), “Natural Language Generation” (NLG) and “Systems Modelling” (SM). The themes were re-aligned strategically into the two themes, described earlier, pre-empting (but also fine-tuning them to) international and national focus on cybersecurity and (explainable/accountable) AI. This change was further motivated by: (a) the increased interdisciplinarity of our research (for example, with the medical school, where we contribute to the GBP15M Innovate UK Industrial Centre for AI Research in Digital Diagnostics, iCAIRD); (b) our successful involvement in funding programmes like the Digital Economy TIPS programme; and (c) the need to capitalise on our long-standing expertise in topics such as explainable AI using NLG, reasoning and formal argumentation techniques. The themes have a fluid and flexible nature, enabling staff to collaborate across and within them.

Oren (Head of Department) leads the Unit, representing Computing Science within the School and University. Edwards (Head of School) is a researcher in Computing, overseeing school-wide policies, budget, strategy and planning. The Director of Research (Vasconcelos) represents the Unit in research-related issues and forums and is responsible for: disciplinary research training and yearly research “away days”; the dissemination of calls-for-proposals and Unit-specific research-related information; and the organisation of research seminars and other research events (e.g., annual “research jamborees”, explained in section 2.3).

The 2014-2020 period saw a reduction in staffing. The University recruited seven new lecturers/senior lecturers (four in **HIUC** and three in **TIPS**) and created a new research sub-group with complementary specialisms within cybersecurity (four FTEs). The recruitment is part of the University-wide strategy “Aberdeen 2040”, placing AI and Data as a central interdisciplinary challenge for the next 20 years and includes plans for a further increase in staff numbers (see REF5a). The 20-year strategy/vision for the discipline is to enhance academic interdisciplinary collaborations (e.g., medicine, law, geography, biology, transport and arts), and partnerships with industry, government and other stakeholders, as reflected in research grants and publications (see items 3 and 4 of this document)

1.2 Research strategy

Our two cross-disciplinary themes reflect core research strengths that are of international importance. Cross-theme collaboration has been exploited in various recent calls-for-proposals. We adapted the research vision laid out for REF2014, factoring in our staff changes and new research challenges.

Since REF2014, we strengthened our themes by recruiting staff with complementary research foci to bring in new ideas and approaches; this is evidenced by the strengthening of our machine learning and cybersecurity expertise, as we recognised these are essential to our research vision. While we carry out theoretical and applied research within each theme, we have also built successful cross-theme collaborations and interdisciplinary research; these have attracted funding and generated impact (e.g., Supporting Security Policy with Effective Digital Intervention (SSPEDI), EPSRC, “Human Dimensions of Cyber Security” call, EP/P011829/1, combining Cybersecurity, Human-Computer Interaction and Policy-based Reasoning). We have engaged with industry, government and other stakeholders; these include food (Food Sentiment Observatory, ESRC, ES/P011004/1) and transport (PORTIS, “PORT-Cities: Integrating Sustainability”, EU 690713,). Engagement with industry has taken place via consultancy (Vasconcelos), secondment (Reiter, Sripada, Pan) and projects co-funded by companies and industry sector funding bodies (e.g., Selex Galileo, IBM-UK, Microsoft Research, OGTC and Oil and Gas Innovation Centre (OGIC)).

Computing Science is close to the Institute of Pure and Applied Mathematics, sharing resources (e.g., joint seminar speakers, software licences, special hardware such as GPUs) and engaging in collaboration (e.g., joint supervision of PhD students and joint grant applications). Staff are encouraged to collaborate across themes. Computing has pathways in place for collaboration with other disciplines and stakeholders ranging from informal (e.g., stakeholders are invited to attend events where we showcase UG, MSc and PhD research projects), to more structured but informal (e.g., an MSc summer research project co-supervised by colleagues from other disciplines), to more formal (e.g., a summer internship or MSc research project exploring an AI solution to a problem provided by a stakeholder, with intellectual property provisions and non-disclosure agreements in place).

Our institution is part of the UK Reproducibility Network. Reflecting national and international expectations, we adopt, with central support, an open and reproducible approach to research, whereby data, software, experimental setups and results are made available to the scientific community and the general public. We ensure research integrity (including ethical review, management of data and supervision), supported centrally and in compliance with the UUK Concordat (2019) (see REF5a). The institutional engagement with these initiatives has provided clear internal processes to follow (for research integrity, the ethical review of experiments is a well-defined and positive exercise, leading to improvements in process(es) and product(s)), and we have access to tailored IT provisions for making research outcomes available to different segments of the public (i.e., data “safe havens” to provide controlled access to datasets and a trusted computational environment to support research using sensitive data sets, long-term storage of documents and data and so on). We adhere to the “Code of Conduct” of the British Computer Society (BCS) and the “Code of Ethics and Professional Conduct” of the Association for Computing Machinery (ACM).

Our research strategy, aligned with our institutional 20-year vision Aberdeen 2040 (see REF5a), enables us to exploit the funding landscape and create impact. Our themes (with their cross-disciplinarity, fluidity and flexibility) align with “AI and Data”, a UK Industrial Strategy grand challenge. Our themes align with the UKRI Industrial Strategy Challenge Fund’s “Digital Security by Design” priority, especially in connection with the safe/secure adoption of AI and the Internet-of-Things technologies. Additionally, our themes align with EPSRC’s Delivery Plan (i.e., “Trustworthy and accountable data, AI and autonomy for a successful society”) and EPSRC’s Digital Economy “Trust, Identity, Privacy and Security” priority area. Our culture of collaboration across machine learning, NLG and reasoning and cybersecurity gives us a differential reflected in our rich portfolio of funding bodies and partners/collaborators. Social, economic and scientific impact is a result of our fundamental and applied research and our strong culture of interdisciplinary research and engagement with government bodies, companies, the general public and other stakeholders, aiming at sustainable, co-designed research agendas.

Computing Science’s current/future research plans address our cross-disciplinary collaborations, especially connecting AI/cybersecurity (motivated by initiatives such as UKRI’s “Digital Security

by Design” and the rising importance of the Internet-of-Things) and reasoning/machine learning/NLG (motivated by world-wide interest in “AI and Data” as well as explainable and accountable AI). We plan to recruit another five FTEs with track records in complementary specialisms, including data mining, symbolic AI (knowledge representation and reasoning) and human-computer interaction, to diversify and strengthen the themes and consolidate cross-discipline collaborations. We facilitate and encourage cross-discipline collaborations through events (e.g., workshops, specialised research seminars and research “away days”) to develop fundamental and applied research outputs and grant applications. Our recruitment will look for candidates with clear evidence of interdisciplinary research and engagement with stakeholders (industry, government or third sector).

1.3 Impact strategy

Our impact strategy has three axes: i) cross-theme collaboration; ii) interdisciplinary research; and iii) engaging with stakeholders. The cross-theme aspect gives us a differential (e.g., combining cybersecurity with persuasion techniques or NLG with formal argumentation), and the combination of approaches resonates positively with different research communities (as evidenced by our funded grants and research outputs). The second axis concerns interdisciplinary research with a broad range of disciplines (e.g., Biology, Healthcare, Law, Music and Physics), creating synergies and multiplying the impact. Finally, in our third axis, by working with industry, government, the third sector and the public, we conduct and evaluate/validate our research with real-life, high-impact/high-visibility problems and issues.

In addition, Computing Science encourages the exploitation of the commercial potential of our research, supported by the University’s Impact and Knowledge Exchange team in the setup of spin-out companies and protection of intellectual property. One of our impact case studies highlights the journey of a spin-out company that grew to become one of the world leaders in commercial automatic text generation, Arria NLG. Our second impact case study showcases the commercial exploitation of fundamental computing science research on creating customised reports based on medical data, combining the expertise of healthcare professionals and computer scientists.

Our projects establish novel cross-disciplinary collaborations with stakeholders across multiple segments of society. For example: “Trusted Things & Communities” (TrustLens, Digital Economy, EP/N028074/1) combines fundamental research on trust, risk and the Internet-of-Things with issues relating to governance and policy, engaging with Aberdeen City Council and local communities to shape future technologies and their use by society; and Collaborative Intelligent Spaces (CISpaces, U.S. Army Research Laboratory and the UK Ministry of Defence, W911NF-06-3-0001) combines data analytics with formal argumentation techniques to support the process of sensemaking, complementing human expertise in the generation of intelligence products and engaging stakeholders including expert intelligence analysts from DSTL, ARL and NATO experts.

We have developed and exploited approaches to increase impact and visibility. This includes the *co-design of research* and *early involvement with stakeholders*, increasing their influence on and interest in the outcomes and, ultimately, the impact, as evidenced by the EPSRC-funded projects “Supporting Security Policy with Effective Digital Intervention” (SSPEDI, EP/P011829/1), with the National Grid and Aberdeen City Council, and “Trusted Things & Communities” (TrustLens, EP/N028074/1), with local communities.

We also *engage with the general public while solving real-world problems*, extending and adapting fundamental research. These problems come from biology, oil and gas industries, transport engineering and medical and health sciences, and *staff share best practices and personal contacts to engage with experts and professionals* from these domains.

Our research exploiting NLG to engage the general public in “citizen/crowd science” to help in (interdisciplinary) nature conservation projects illustrates this well. “BeeWatch” invited citizens to

submit photographs of bumblebees and enabled the identification of species using an online key. This research was a collaboration with the Bumblebee Conservation Trust (BBCT), funded by the Digital Economy Hub (EP/G066051/1), featured on the BBC news website and in the programme “Beechgrove Garden”. “Blogging Birds” is a collaboration between computing science, environmental scientists and the Royal Society for the Protection of Birds (RSPB), harnessing data mining and NLG to create personalised “blogs” of red kites being re-introduced in England and Scotland and attracting attention from the general public and the media.

Impact is increased through adoption and championing of open-source software, open access publications, open experimental data and data sharing solutions and documents explaining our research to the general public. A report published by the Software Sustainability Institute in 2017, analysing ResearchFish data, showed that Aberdeen was second in the UK in publishing software outcomes from EPSRC-funded projects.

We encourage staff, PhD students and PDRAs to follow the Software Sustainability Institute best practice guide; software is made openly available on web sites such as GitHub, Zenodo and BitBucket (e.g., nu-BDI, SimpleNLG and CISpaces). Data sets (e.g., supporting research on NLG, formal argumentation, the Internet-of-Things, machine learning and data provenance) are made available in the University’s research repository (with over 30 datasets) and external web sites (e.g., GitHub and GoogleDocs). Datasets are publicised through the institutional research pages. Open Access publication of research papers is encouraged. In 2014 31% of all our published outputs were open access and in 2020 the percentage was 59%. The University has a Research Data Management policy requiring a data management plan that sets out resource provisions for hosting data, software and documents on our servers, in addition to making resources available on public Web sites. Many colleagues engage with the general public or academic communities via “blogs” (e.g., Reiter and his “open source for NLG”) increasing the reach and impact of our research.

The Unit continues to support the vitality and sustainability of our research impact by encouraging best practice in science communication and stakeholder engagement. For example, staff receive training in communication through media outlets supported by the University’s Communication team and the Public Engagement with Research Unit (PERU) (REF5a). Staff regularly present their research at events to the general public such as the Edinburgh International Science Festival, British Science Festival and TechFest.

2. People

2.1 Staffing strategy

Our staffing strategy reflects major international research drives for AI, cybersecurity and trusted systems.

Our Unit has experienced notable staff movement (from 18 FTEs in 2013 to 8.7 FTEs early in 2020). However, we hired seven new staff members and at census date 15.5 FTEs are in post. Within the REF period, ten colleagues were promoted (three to Chairs, four to Readers and four to Senior Lecturers – see following section), evidencing investment in staff.

Our ongoing recruitment is part of a University-wide strategy, placing “AI and Data” as one of our five interdisciplinary challenges for the next 20 years (as described in “Aberdeen 2040”, see REF5a). In line with our strategy, we recruited four FTEs with complementary research portfolios on AI and three FTEs on cybersecurity. The new recruits strengthen our **HIUC** (Leontidis, Yi, Yun, Zhong) and **TIPS** (Akram, Li, Sharma) themes, bringing their expertise (both in fundamental research and applications to real-world problems) as well as collaboration networks (from academia and industry). The discipline, through both research themes, has strong academic interdisciplinary collaborations (e.g., medicine, law, geography, biology, transport and arts), as well as partnerships with industry, government and other stakeholders, as reflected by several research grants and publications (see items 3 and 4 of this document).

HIUC was boosted by the following appointments: Leontidis, Yi and Zhong contributing to fundamental research on machine learning and its application to various important domains, such as nuclear energy (Leontidis), smart farming and driving assistance (Yi) and energy grids (Zhong). Yun contributes expertise on formal argumentation to support accountable and explainable/scrutable AI.

TIPS benefits from: Akram's research on core cybersecurity issues as well as "security for machine learning" and "machine learning for cybersecurity" (also creating cross-theme connections with **HIUC**); Sharma's research on cybersecurity, with a focus on the Internet-of-Things and smart cities (including 5G networks); and Li's work on identity, authentication and electronic signatures. Together with Collinson, **TIPS** has four FTEs with a solid track record in complementary cybersecurity topics, forming a new cybersecurity research sub-group and supported by GBP100K of institutional funding for a dedicated cybersecurity research and teaching lab. The flexible nature of the research themes facilitates strategic and opportunistic cross-collaborations, benefitting researchers through the exchange of ideas, approaches, techniques, collaborators from other disciplines, use-case partners and contacts with industry.

We have attracted staff whose research is of international quality (evidenced by their publications, collaborations and grants), both as early-career researchers (Li, Sharma, Yi, Yun, Zhong) and mid-career researchers (with a track record of funded research and high-quality outputs; Akram and Leontidis). Our strategy is to sustain an international team, with current staff from the UK, USA, EU, China, Brazil, India, South Africa, Singapore and South Korea, providing a rich network of world-wide contacts and collaborations. Hiring decisions explicitly consider the interdisciplinary reach of candidates and how novel and relevant the application domains are.

Our organisation model for research is lean (staff interact directly with the team director of research, head of Unit or head of School), flexible (with research themes allowing the easy flow of staff among them) and agile (with the ability to create cross-theme and interdisciplinary teams in response to research drives and target calls).

Our staffing strategy addresses diversity, equality and inclusion issues in Computer Science. All interview panel members complete training on diversity and equality, including unconscious bias training, and panels include a fair representation of the wider academic community (including colleagues with protected characteristics). Many of our recent grants have more gender-balanced teams of PDRAs (the numbers are for staff based in Aberdeen): TrustLens (EP/N028074/1), 50% female; SSPEDI (EP/P011829/1), 40% female; RAInS (EP/R033846/1), 50% female.

2.2 Staff support and development

The Concordat to Support the Career Development of Researchers (see REF5a) shapes our staff policies and procedures, enabling them to take advantage of workshops and training sessions as part of our yearly 10-day training allocation to support impact development, stakeholder involvement, grant finance management and so on. These skills contribute to staff professional development and increase our research sustainability, relevance and impact. The University of Aberdeen received the HR Excellence in Research Award in 2010 and successfully retained it for its researcher development programme. All ECRs have reduced teaching and administration loads to help accelerate their research and are assigned senior colleagues as mentors, with progress being reviewed annually.

The Researcher Development Unit (see REF5a) offers many opportunities, including workshops and training for ECRs, research staff and post-graduate research students. The induction programme is attended by all new researchers, followed by longer-term support at the university level and through School and Unit-based provisions. Units across Scotland collaborate through the Scottish Computer Science and Informatics Alliance (SICSA) (a consortium of 14 Scottish Universities, promoting excellence in University-led research, education and knowledge

exchange in Informatics and Computer Science) in providing discipline-specific staff development opportunities.

We have an annual staff development programme for all researchers aimed at progress and future plans and wider career and professional development. The Unit shares indirect cost contributions from successful research grants between a strategic fund and investigators' discretionary accounts. The investigators' fund incentivises grant applications, while the strategic fund supports new staff and research students. These funds enable travel, general research support (i.e., pilot studies, experiments and software development) and new collaborative initiatives with other disciplines/institutions. ECRs receive an initial discretionary allowance for each year of probation (to support academic visits, attendance at conferences, etc.) and 50% of a PhD studentship (50% externally funded).

Staff retention is extremely important, especially in light of recent staff movement. The Unit provides a mentoring program that pairs new staff with experienced colleagues acting as a "first port of call" to help with teaching, research and administrative processes and to help new staff manage their career path. Mentoring takes place in an informal and friendly fashion with regular meetings. There is a healthy team spirit, where colleagues help and support one another. Some of our recently appointed staff have had flexible work arrangements in place due to COVID-19 disruptions, working away from Aberdeen.

The Unit, in line with institutional policy, values a healthy work-life balance and encourages staff to keep to core-working hours. The institution offers staff membership to a state-of-the-art sports centre within walking distance of the Department. The institution also offers preferential rates for private healthcare. Staff and research students are regularly reminded of our institutional on-line resources on mental and physical well-being and training sessions on mindfulness and stress management, among others.

Our annual review exercise enables staff to discuss their performance and achievements with an experienced and trained colleague and to set goals for the following year. The review feeds into the annual promotion exercise, for which we share best practice and offer structured meetings to help with the preparation of promotion applications. Within the reported period the Unit had three staff promoted to Professor (Oren, Masthoff, Vasconcelos), three to Reader (Pan, Lin, Siddharthan) and four to Senior Lecturer (Pang, Guerin, Collinson, Sripada). Staff secondments further our research sustainability; during the REF period, Sripada and Reiter were seconded to Arria, and Pan was seconded to the Edinburgh Huawei Research Lab.

2.3 Research students

One of the Unit's strategic goals is to increase PGR student numbers while enhancing their already high quality. PhD students are supported by the University "Elphinstone" PhD scholarships, by EPSRC Doctoral Training Partnerships (EP/N509814/1 and EP/R512412/1) and the various Scottish Funding Council (SFC) research pooling initiatives. More traditional modes of studentship funding (Industrial CASE awards, DTA studentships) are available, and we have had fully funded industrial studentships (e.g., by Arria NLG plc, Selex Galileo Ltd., IBM-UK) and students supported by EU H2020 "Fostering new skills by means of excellent initial training of researchers" (e.g., "Interactive Natural Language Technology for Explainable Artificial Intelligence" – NL4XAI, 860621 and "Personal Health Interfaces Leveraging Human-Machine Natural Interactions – PHILHUMANS, 812882). Some international students have received governmental funding (e.g., China, Nigeria, Indonesia, Saudi Arabia and Turkey). A strategic partnership with Curtin University (Australia) includes the funding of joint PhD studentships. We have PhD students visiting us from other UK institutions (e.g., Edinburgh, Southampton, Warwick), Europe (e.g., Spain, France, Netherlands) and the rest of the world (e.g., Brazil, China).

The School encourages industrial collaborations by offering matching funds for studentships when industrial funding is secured for the balance; successful examples of this model include

Arria NLG, Selex Galileo, and IBM-UK. All staff supervise research students. The recruitment of PhD students is undertaken through the institution's Postgraduate Research School, responsible for recruitment, admission, progression and career development of all postgraduate research students (see REF5a).

PhD students are allocated two supervisors. In exceptional cases, students may have three supervisors, especially when the topic is interdisciplinary (colleagues from e.g., Biology, Transport Engineering, Petroleum Engineering, Geography, Business, Medicine and Physics). Supervisors are required to undertake mandatory supervision training.

Progression of PhD students is monitored through a system of six-monthly reviews, a progress report and oral examination after nine months and 21 months conducted independently by two members of staff not involved in the supervision, providing support to discuss all aspects of the PhD programme. Training for postgraduate research students is provided by the Postgraduate Research School, combining courses from the University's generic skills programme with discipline-specific courses. At the beginning of their PhD, all students complete an initial skills audit to create their personalised Training and Development Roadmap. All students are required to present their work at research group seminars. At the annual "research jamboree", a poster is presented by all PGR students in years one and two while final year PhD students give a presentation. PhD students also benefit from the learning activities (lectures and tutorials) of modules of the MSc in Artificial Intelligence programme, providing a structured way for those who need to brush up their AI skills or learn about new topics. PhD students are expected to attend Computing Science seminars, as these give opportunities for students to broaden their knowledge and learn how to organise and present research. We encourage and financially support PhD students to attend the annual PhD Conference organised by SICSA, the Scottish Informatics and Computer Science Alliance; our PhD students helped organise the 2016-2019 editions of the event. We are also the Unit outside the Scottish central belt with the highest number of participants in all years the event has taken place).

The Unit organises an annual "research jamboree" event where PGR students give short presentations and/or present posters. We invite representatives from public and private sector bodies, as well as colleagues from other Units, with a view to showcasing our research and giving PhD students the opportunity to talk about their research to disparate audiences (offering them a similar experience to that of a conference). The jamboree also provides opportunities to build or expand networks of contacts. Computing has three reading groups on Computational Linguistics, Machine Learning and Formal Argumentation, with regular meetings gathering staff and research students interested in the topics (the reading group on Formal Argumentation also attracts international staff and PGR students to their meetings, giving our PhD students access to international leaders in the field).

Supervisors are trained to be aware of issues relating to protected characteristics (e.g., rearranging furniture, adjusting personal space for PhD students on the autistic spectrum and rearranging times of meetings to accommodate religious holidays and observances). Ours is a diverse and vibrant population of PhD students; of the 45 PhD students who graduated within the reporting period, more than 80% came from outside the UK.

The Postgraduate Research School offers a portfolio of training and development activities. To ensure sustainability, our Unit has "pathways" to support academic careers; one such pathway sees UG and PGT (MSc) students working on projects with a substantial research element, enabling a smooth transition to the PhD programme (at least seven of the PhD students who graduated in the period followed this pathway). Another pathway (with support from supervisors and careers services) sees PhD students becoming PDRAs with us (more than eight PhD students followed this pathway) or in other institutions. A third pathway supports the transition of PDRAs into academic careers in our own Unit (e.g., Pang, Kollingbaum) or at other institutions (at least four PDRAs are now academic members of staff in other HEIs). Some of our PhD students have now become established researchers in industry (e.g., IBM-UK Research, BT Research, Amazon-Alexa, Google and Trivago). Our careers service team supports PhD

students in applying for jobs/positions, with the support of supervisors, in writing CVs and cover letters and in practising for their interviews.

2.4 Equality and diversity

Our School has an active Equality, Diversity and Inclusion Committee (EDIC), which received the Athena SWAN Bronze in 2016. EDIC has introduced carer support for conferences, return to work sabbaticals (for maternity or long-term illness) and active promotion support and encouragement. The School's EDIC has created a neutral language guide that supports female and LGBT staff. It is also currently working towards creating more networks and increasing the range of PGR bursaries and scholarships available for women and other under-represented groups.

Equality and Diversity training is mandatory for all staff and provides fundamental awareness of the legislative framework and its practical implementation. This training also highlights the University's Equality, Diversity and Inclusion Policy (see REF5a). Staff are encouraged to attend unconscious bias training. Staff and PGR students can join a range of groups such as the senior female network group, LGBT staff network group, the disability network group and the staff race equality network.

Hiring committees must have gender representation and all members must have completed equality and diversity training. Supervisors of PhD students are trained on protected characteristics, and we share best practice (Unit-specific) on provisions to accommodate these (see previous examples). As a Unit, we strongly support our institution's zero-tolerance policy on any form of discrimination. We provide our staff and students with additional communication channels to raise their concerns in a supportive, constructive and positive environment. Staff and research students are encouraged to report any disabilities or protected characteristics, which are handled sensitively, but also with a duty of care. Where appropriate, other support units and services are made aware of these, so that they can provide help or guidance.

We provide flexible working hours (as well as arrangements for working from home) for staff and students who have to care for members of their families, who have health issues that might prevent them from leaving home or that might impact their ability to work normal hours. Specific past cases include: a researcher who became a carer and was able to work from home with reduced/special hours some days of the week; another researcher who had to look after his children was allowed to work flexible hours from home; and a research fellow who developed mental health issues was able to work from home, with close support from his line manager. Our Unit is child-friendly, and we accommodate the needs of our staff and students with young families, for instance, by avoiding meetings outside the school day and by allowing PGR students to work flexible hours (especially during School holidays).

Our institution's policies underpin the institution's Mental Health and Wellbeing Strategy by setting out how the University will proactively support staff and students to maintain good mental health and wellbeing. Our School has its own Wellbeing coordinator, who acts as a point-of-contact between our staff and other University services/units that support physical, mental, workplace and personal wellbeing, as well as wellbeing at home.

We provide extra support to our female students, pairing them with a mentor with a view towards introducing them early on to our pathways for academic careers. Our post specifications use gender-neutral language and include text explicitly inviting the application of individuals from across all equality protected characteristics.

3. Income, infrastructure and facilities

3.1 Income

Our Unit attracted a total of over GBP13M of research funding, averaging just over GBP1.85M/year. We have a diverse portfolio of research grants funded by the EPSRC, EU, ESRC, Innovate UK, Cancer Research, GCRF and NERC, among others. The success of the Unit has had a strong influence on the institutional strategy, as our research themes align well with priorities of governments, funding bodies and the general public, with immense potential for societal and financial impact. Accordingly, a new director for the “Data and Artificial Intelligence Interdisciplinary Challenge” has been appointed, reflecting the strategy “Aberdeen 2040” and highlighting the institution’s commitment to the area (see REF5a).

Research income was negatively affected by staff turnover over the reporting period and uncertainty associated with EU funding. However, there has since been a major recruitment drive toward strategic staffing and staff development as reported in Section 2.1. The Unit has the building blocks to regain its previous strength in terms of staff numbers and increased income. The quality of our AI and data-related research has ensured that the Unit remains competitive, as evidenced by our portfolio of awards and research outputs.

Some of the major awards in the period featuring cross-theme and/or interdisciplinary research are (figures indicate the value to our Unit) RAINS (GBP789K, EPSRC EP/R033846/1, **Edwards**), SSPEDI (GBP756K, EPSRC EP/P011829/1, **Collinson, Oren, Vasconcelos**), Trusted Things & Communities (GBP783K, EPSRC, EP/N028074/1, **Edwards**), Social Media Enhancement (GBP505K, ESRC ES/M001628/1, **Edwards**), NL4XAI (GBP239K, EU 860621, **Reiter**), PORTIS (GBP330K, EU 690713, **Kollingbaum**), PHILHUMANS (GBP263K, EU 812882, **Reiter**), and Smart Routing (GBP236K, Innovate UK 102615, **Edwards**). We also secured funding for doctoral training (GBP488K, EPSRC EP/N509814/1; GBP105K, EPSRC EP/R512412/1; GBP10K, NL4XAI, EU 860621; GBP65K, PHILHUMANS, EU 812882). These and other grants showcase our cross-theme efforts (e.g., SSPEDI combines HCI and policy-based reasoning) and interdisciplinary research with Engineering (PORTIS), Geography and Environment (RAINS and Trusted Things & Communities), Psychology (SSPEDI) and Sociology (Trusted Things & Communities). Other research is in partnership with and co-funded by companies from the Oil & Gas sector (Asset Reliability, Innovate UK KTP11653, **Sripada**; Data Quality for Oil & Gas E&P, The Data Lab and OGTC, **Vasconcelos**; Glycol Controlled Injection, OGIC, **Vasconcelos**).

Strategically, Computing Science is well provisioned to exploit the funding landscape, as both HIUC and TIPS themes align with “AI and Data”, one of the grand challenges of the Industrial Strategy of the Department for Business, Energy and Industrial Strategy. Our TIPS theme aligns well with the UKRI Industrial Strategy Challenge Fund’s “Digital Security by Design”, especially in connection with the safe/secure adoption of AI and the Internet-of-Things. Finally, explainable, ethical and accountable AI has attracted much interest and funding (e.g., Knowledge Transfer Network’s recent CivTech Sprint Challenge on Explainable AI, with Police Scotland). By enabling collaboration among our staff across machine learning, NLG and reasoning and cybersecurity, we have a competitive differential.

Our research strategy harnesses our culture of collaboration with other disciplines, industrial and use-case partners and other stakeholders. We will consolidate and expand our collaborations, especially with medical and health sciences, engineering, biology and the arts, and our engagement with different sectors of industry (e.g., energy, decommissioning, food distribution and food security) and government bodies (e.g., Aberdeen City Council, NHS Scotland and the British Office in Taipei through Edward’s participation in the recent Taiwan-UK AI Cooperation). Our research strategy delivers impact, through the combination of strands of our research themes, to provide solutions to problems from other disciplines, industry and governmental bodies and by disseminating research results to scientific and professional communities and the general public.

3.2 Infrastructure

Our Unit shares best practice in attracting funding, with regular workshops and information sessions on grant writing. The institution's Research and Innovation (R&I) unit provides support for business development, project finance planning and financial reporting and offers legal services (including those related to intellectual property issues and non-disclosure agreements when collaborating with companies), in addition to meeting the requirements for ethical, open and reproducible research. A clear internal application process via a Web portal is also available and all applications are reviewed internally by two independent assessors (see REF5a).

R&I provides advice on identifying and nurturing impact, facilitating interactions with external organisations, identifying intellectual property opportunities and exploiting innovative ideas. The Public Engagement with Research Unit (PERU) provides advice on public engagement activities and on funding for them. The Researcher Development Unit (RDU) offers training on public engagement and offers many online tools from the National Co-ordinating Centre for Public Engagement to help develop ideas. Aberdeen Grants Academy (GA) supports our researchers in all stages of the research grant cycle, from conception of ideas, through development of funding applications to research delivery and realising the impact of our research. IT Services provide support in costing, procuring, purchasing and installing special hardware and software licences, as well as data storage solutions for research (including long-term archiving). The Unit also offers training on IT security awareness and a range of other services such as networking and bespoke research computing lab provision.

The institution offers technical support and computational resources to ensure our research is open and reproducible. The Aberdeen University Research Archive (AURA) provides access to the full text of research outputs and theses are held in our Digital Resources collections. Following our University policy for Research Data Management, IT Services provide technical support and computational resources (e.g., secure storage space, web servers and remote data bases) for staff.

Our centrally managed and recently upgraded High-Performance Computing (HPC) services are remotely available to all research students and staff, offering access to a supercomputing cluster and software suite. Additional resources (e.g., access to EPSRC's Archer and EPCC's Cirrus, as well as a cloud computing infrastructure) can also be procured. Secure data storage services are available for research, catering to very large data collections, offering different degrees of security and privacy. Training and support are available for both HPC and data storage services. The institution offers a suite of licenced software including MATLAB, SPSS, NVivo and SNAP, among others. Our library services provide access to a wealth of computing-specific and mathematics-specific digital resources, including books and papers, as well as data collections. ABVenture Zone, our incubator for start-ups and spin-out companies, offers a range of support services for staff and students who wish to exploit their research commercially.

The University of Aberdeen Research Governance Handbook provides a framework for research ethics and governance at the University. The University of Aberdeen provides mandatory Research Governance and Ethics training to all staff and PhD students involved in research. Computing disseminates the handbook to staff so that researchers are well informed of the ethical, legal, institutional and funder requirements. Staff use the UK Research Integrity Office's Code of Practice for Research checklist, which incorporates the key points of good practice at all stages of a research project.

3.3 Facilities

Our academic staff have individual offices and PDRAs and PhD students share offices in groups of four to six people. We are all on the same floor of our building. We have four dedicated computing labs that can be used as seminar/meeting rooms and to host research experiments; these labs have audio-visual resources (e.g., interactive white boards, high-definition screens and loudspeakers or projectors). The space provisions encourage interaction and collaboration.

Staff and PhD students are provided with a computer (desktop or laptop, with their choice of operating system) and are allowed to manage their own software (subject to the institution's cybersecurity policies). The University of Aberdeen recently awarded a GBP100K investment fund to establish a dedicated cybersecurity laboratory, consisting of specialised hardware and software, with provisions for Internet-of-Things and industrial control systems. This lab helps catalyse Aberdeen's cybersecurity research.

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

4.1 Collaboration with the research base

Our Unit has developed and sustained a strong culture of collaboration and interdisciplinary research with many disciplines. Some of our external academic collaborators in funded research grants are the Universities of Trieste and Trento, University of Edinburgh, Eindhoven University, Delft University of Technology, University of Utrecht, University of Utah, Monash University, University of Santiago de Compostela and University of Malta. Exemplars of our government and third sector grant collaborators are NHS Scotland, Aberdeen City Council, Aberdeenshire Council, Birmingham City Council, National Railway Company of Belgium, Law Commission, Transport Systems Catapult and National Grid. Some of our industrial partners are Arria NLG, Orange (France), Accenture (Spain), IBM-UK, BAE Systems and Phillips Research North America.

We collaborate with medical and health sciences, drawing from the critical mass and excellence of our Institute of Applied Health Sciences. An example of an ongoing collaboration is the GBP15M Industrial Centre for AI Research in Digital Diagnostics (iCAIRD), one of five successful bids to the UK Government Industrial Strategy Challenge Fund (ISCF), focusing on the application of artificial intelligence to digital diagnostics to enable clinicians, health planners and industry to work together. Other projects use specific computing techniques to study and address real-life medical issues: "Proving the Utility of Fast Field Cycling MRI in stroke and small vessel disease" (PUFFINS, Scottish Government Chief Scientist Office, TCS/19/44), in which machine learning is used to increase the benefit of MRI technologies; PAtient-centred Care for Fibromyalgia: New pathway Design (PACFiND, Versus Arthritis, Ref. 21958), where data mining is carried out to improve healthcare services for patients with fibromyalgia; "Graph-Based Data Federation for Healthcare Data Science" (UKRI ISCF), which integrates healthcare data from different sources; and "Early-life origins of brain resilience to mental illness and cognitive impairment across the life-course" (Medical Research Council, Ref. MC-PC-MR/R019541/1), which explores "big data" management, data analytics and machine learning to support population studies.

We collaborate with Physics in the project "A Systems Approach to Sustainable Sanitation Challenges in Urbanising China" (SASSI, NERC, Ref. NE/S012354/1), studying complex human-environment interactions in sanitation systems, and in the pilot project "Provenance of Food Delivery through IoT" (PROOFD IT, funded by the Internet of Food Things grant), investigating Internet-of-Things techniques to track food delivery. We collaborate with Transport Engineering, Geography and Environment Sciences in the project PORTIS, funded by the EU (Ref. 690713), using AI techniques to simulate government policies and determining how these impact on travel choices in port cities, in Smart Routing (Innovate UK, Ref. 102615), which aims to improve public transport by enabling people to combine their journey data and preferences with real-time transport information (privacy-preserving journey planning robust to network problems), in the Transport Systems Catapult, as a member of the University Partner Programme, and in the project Social Media Enhancement, funded by the ESRC (ES/P011004/1), developing tools combining argument mining, qualitative modelling and dataset annotation to advance the state of the art in social media analytics and data management. We collaborate with Biology through projects like BeeWatch, funded by the Digital Economy Hub, in partnership with the Bumblebee Conservation Trust (BBCT), exploiting NLG and "citizen/crowd science" to engage the general public in nature conservation projects (specifically the monitoring of bumblebees in the UK), and "Blogging Birds", in partnership with the Royal Society for the Protection of Birds (RSPB),

harnessing data mining and NLG to create personalised “blogs” of red kites being re-introduced in England and Scotland and reaching out to thousands of members of the public who were able to follow the “daily lives” of birds.

Our Unit has strong ongoing collaborations with universities and research centres in the UK, Europe and the rest of the world through informal collaborations such as co-authorship of scientific papers, reciprocal visits and hosting of PhD students. These institutions include the Universities of Warwick, Glasgow, Southampton, Oxford, Manchester, Bath, University College London, the City University of New York (CUNY), the AI Research Centre in Spain (IIIA-CSIC), Polytechnic of Warsaw, the University of Tokyo, Pontifical Catholic University in Rio Grande do Sul (PUC-RS, Brazil), the University of São Paulo and the University of Otago.

4.2 Contribution to the research base

Our research output has been presented and published at international conferences and in journals, attesting to the quality of our research and its theoretical/scientific contributions and its value when applied to solve real-life problems.

Our research outputs have contributed to conferences such as IJCAI, AAI, NeurIPS (formerly known as NIPS), AAMAS, ISWC and ICRA, among others and journals such as the AI Journal, ACM Transactions, Springer’s Cognitive Computation, Autonomous Agents and Multi-Agent Systems, and others. Our staff serve in various international communities in different ways. For example, a number of staff contribute towards Journal Editorships – Vasconcelos (Associate Editor, Knowledge and Information Systems, Springer), Akram (Guest Editor, Special Issue of Future Generation Computer Systems, Elsevier; Associate Editor, Human-Centric Computing & Information Sciences, Springer), Leontidis (Editorial Board, Computers in Biology and Medicine, Elsevier, 2018-2019), Sharma (Associate Editor, Human-Centric and Inf. Sciences, Elsevier), and Zhong (Associate Editor, Neural Processing Letters, Springer). The following staff are members of (Senior) Programme Committees – Oren (IJCAI 2015-2021; AAMAS 2016-2021; ECAI 2016-2020), Vasconcelos (IJCAI 2017-2020; AAMAS 2014-2020; AAI 2018-2020; ECAI 2018-2020) and Leontidis (NIPS, NeurIPS 2018-2020; AAI 2019-2020; IJCAI 2020; ICML 2018-2019). Membership in Professional Bodies is exemplified by the following: IFIP Working Group on Pervasive Systems Security (Akram), ACL-SIGGEN (Reiter, Chair), IEEE (Leontidis, Vasconcelos, Akram, Sharma), ACM (Oren, Vasconcelos, Akram, Sharma), AISB (Vasconcelos) and BCS (Leontidis).

A portion of the staff are members of advisory boards of funding bodies: Leontidis (Full College Member, EPSRC; Panel member of UKRI Future Leaders Fellowship Scheme), Oren (Full College Member, EPSRC, 2016-ongoing) and Edwards (Member of ESRC Peer Review College, 2015, 2017-ongoing; Member of Steering Committee for the Innovate UK – EPSRC – KTN – Digital Catapult, 2014-2016). Our staff have been involved in the organisation of a number of conferences including Digital Heritage Conference 2019 (Leontidis, Organiser), INLG 2017 (Reiter, General Chair), 25th Int’l Conf. on Conceptual Structures (Yun, Programme Chair), 9th Int’l Conf. on Information Security Theory & Practice (Akram, Chair), IEEE Conf. on Trust, Security & Privacy in Computing and Communication (TrustCom 2018 & 2019, Akram, Track Chair), AAMAS 2014 Doctoral Consortium (Vasconcelos, Co-organiser), COMMA 2014 (Oren, Chair) and PRIMA-2018 (Oren, Co-Chair).

Over the REF cycle, staff members served in the External Examination of PhD Theses – Oren (8), Vasconcelos (3), Edwards (2), Zhong (1) and Reiter (3). Staff also contributed to a number of Keynote/Invited Presentations and Tutorials, including “Computational Argumentation in the Context of Human-Agent Interaction” (Oren, Keynote, ECAI 2020 and AAMAS 2019), “Introduction to Formal Argumentation Theory” (Oren, EASSS-18), “Normative Multi-Agent Systems” (Vasconcelos, Tutorial, PUC-RS, Brazil, 2014), “Retinal Vascular Geometry: Novel Biomarkers of Progression from Diabetes to Diabetic Retinopathy” (Leontidis, Keynote, British Association of Retinal Screening Conference, 2016), “AI, Health & The Future of Accountable Intelligent Systems” (Edwards, UK-Taiwan AI in Healthcare Workshop, 2019), “Making Trust

Transparent: Realising a Citizen-Centred Internet of Things” (Edwards, UK-Japan IoT Workshop, British Embassy, Japan, 2017), “Trusted Things & Communities: Understanding and Enabling a Trusted IoT Ecosystem” (Edwards, Royal Society of Edinburgh-Taiwan Ministry of Science & Technology Joint Workshop on Internet of Things, 2016), “Social Media, Linked Data & The Context Question” (Edwards, UK-India Social Media Workshop, UK Science & Innovation Network, 2014) and “Evaluating Natural Language Generation Systems” (Reiter, NAACL, 2016).

4.3 Contribution to the economy and society

Our research has contributed to various segments of the economy and society. Research on NLG yielded SimpleNLG, an open-source software system for natural language surface realisation, which is a reference implementation with thousands of adopters/users world-wide. The application of NLG (combined with data mining and process automation) to real-world problems has been very successful, leading to the creation of the company Arria, initially a spin-out SME that has grown significantly over the past six to seven years to become a world leader in the commercialisation of NLG technologies, creating jobs and contributing to the high-tech economy. NLG research has provided technologies to turn physiological data from vital sign sensors into readable reports specifically designed to be handed over to emergency services, which is now being exploited commercially by MIME Technologies to develop industry-leading medical emergency solutions for high-altitude and offshore environments.

Our research in automated reasoning contributed to the open standard RuleML language used to specify queries and inferences in Web ontologies, mappings between Web ontologies and the dynamic Web behaviours of workflows, services and agents. Research on machine learning has provided algorithms, datasets and reproducible experiments to address problems like improving energy efficiency for food retailers, thus saving money and the environment. Research has also addressed anomaly detection in nuclear reactors via deep learning, increasing EU security.

Our research has contributed to public engagement and understanding of research through projects like BeeWatch, which – through citizen science – made the general public important players/stakeholders in the monitoring of wildlife in the UK, and “Blogging Birds”, which asked the general public to follow the “daily lives” of birds. The Achieving Self-directed Integrated Cancer Aftercare (ASICA) project gathered computing staff and healthcare specialists to develop software for the education of skin cancer survivors. The software instructed on how to carry out self-examinations and enabled users to send images of skin abnormalities directly to specialists. The solution benefitted patients (e.g., people from remote communities were no longer required to travel to meet health workers, and patients become empowered as they initiate and control the process), specialists (e.g., images can be assessed without the need of a face-to-face consultation) and health services.

Our research projects, across our themes, have helped build human capacity for the UK, training PDRAs to conduct ethical, open and reproducible research, while focusing on fundamental research (e.g., algorithms, computational models or formalisms) or applied issues (applying fundamental research to specific domains or to solve real-life problems, which includes learning about different domains). They have been coached to disseminate results and engage with stakeholders and the general public and have developed a valuable set of transferrable skills such as communication, teamwork, critical analysis, experimental design and evidence-based thinking, helping them to advance their careers in academia or in industry.

Our staff contribute to various governmental initiatives such as Opportunity North East Digital & Entrepreneurship (Edwards) to grow a digital economy in the North East of Scotland, the Aberdeen City Deal (Edwards, Coghill) to support various strategic projects (e.g., agri-food and nutrition, bio-therapies and transport) and the Digital Catapult (Innovate UK, EPSRC and KTN; Edwards). We also contribute to the National Decommissioning Centre (Leontidis, Vasconcelos, Oren, Yi and Kollingbaum), a multi-disciplinary (Engineering, Geosciences, Physics and Computing), GBP38m partnership between the OGTC and the University of Aberdeen and part

of the Aberdeen City Region Deal, capitalising on our expertise in AI to devise technologies and solutions for the decommissioning of offshore infrastructure.

Reiter is chief scientist with Arria NLG (global leader in natural language generation) and has been seconded twice to the company in the reporting period; Reiter was also an advisor to MIME Technologies (which seeks to provide inflight and off-shore first-aid support). Vasconcelos works closely with local energy companies, adapting and extending AI techniques to solve real-life problems (e.g., intelligent injection of glycol for BlueGentoo and improving data quality for HyperDAP).

Our pathways (UG/MSc students to PhD students; PhD students to PDRAs; PDRAs to academics and researchers) contribute to bridging the AI and digital research skills gap, benefitting the economy and society. Additionally, we run a successful research-led MSc in AI programme, providing essential skills to the UK economy. We also help deliver the MSc in Data Science programme and the MSc in Health Data Science. We expect these programmes to have a combined intake of 100-120 students, who will be trained on state-of-the-art and state-of-the-practice AI research.