

Institution: University of Dundee (UoD)
Unit of Assessment: UoA11 Computer Science and Informatics
1. Unit context and structure, research and impact strategy

1.1 Unit Structure and Context

UoA11 research is structured as four *clusters* (each with a lead, underlined):

- Argument Technology (ARG-tech) (**Lawrence, Pease, Reed, Visser**) focuses on theoretical and practical aspects of argumentation and artificial intelligence.
- Computing Theory & Methodologies (CTM) (**Edwards, Fiadeiro, Janjic**) spans parallelism and data science, graph theory, and formal software system modelling and analysis.
- Computer Vision & Image Processing (CVIP) (**Magerand, Martin, McKenna, Trucco**) develops and applies visual data analysis and machine learning for biomedical, space exploration, and vision applications.
- Human-Centred Computing (HCC) (**Crabb, Rough, Waller**) research includes Augmentative & Alternative Communication (AAC) and User Experience (UX).

Together these form the *Computing Sciences* research theme, one of four overarching themes in the School of Science and Engineering which spans UoA10, UoA11 and UoA12. Researchers can affiliate with multiple clusters from across the University to facilitate inter-cluster working and build capacity beyond the core disciplines.

The Unit's vision to enable significant societal benefits through its research articulates clearly with the University's mission "to transform lives, locally and globally through the creation, sharing and application of knowledge". Unit staff have taken and will continue to take lead roles in research and impact aligned with the University's interdisciplinary themes, most obviously those of *Innovating Technology* and *Health and Wellbeing*. The Unit benefits from interdisciplinary collaborations across the University and beyond, embracing the institution's strategic priority of embedding interdisciplinarity to build a vibrant research culture that delivers impact.

1.2 Research Objectives and Plans during the Period

The Unit's vision at REF2014 was to be a world-leading centre of research excellence in its areas of specialisation, enabling societal benefits through research. REF2014 aims and plans were:

1. *To develop critical mass in focused specialisms, driven by strong connections to research users.*

It planned to grow sustainably, strengthening existing specialisms and cross-cluster synergies. The Unit strengthened its specialisms in ARG-tech, CVIP, and HCC through recruitment of early career Category A staff. Cross-cluster synergies were strengthened through joint EPSRC projects between HCC and ARG-tech (*BESiDE*, £1.3M, 2013-17), and between HCC and CVIP (*ACE-LP*, £1.0M, 2016-20). These clusters have strong connections to research users as exemplified by those projects' partners, and by user pools maintained by HCC (see 4.2). The CTM cluster was formed to consolidate research in that area. The Unit saw 15% growth in Category A FTE.

2. *To ensure stable research income from a diverse funding base.*

Total research income was £11.45M. This was from 39 different sources including EPSRC, NERC, BBSRC, EU, Space Agencies, BBC, Google, Microsoft, and CRUK (3.1). Mentoring helped achieve grant success, e.g. **Pease**'s EPSRC First Grant.

3. *To grow Postgraduate Researcher (PGR) numbers, increasing student staff ratio to 2:1 by boosting international recruitment of high-quality candidates, leveraging research networks, new agreements, and rolling recruitment.*

There are currently 22 PGR students with primary supervisors in Computing and another 10 co-supervised with other disciplines, a 2.3:1 ratio of supervisions to category A staff. PhD applications are now triaged and managed on a continual basis by Computing's PGR Lead. PhD funding was sought through industry with funding provided by Toshiba, NIDEK Technologies Srl, and Optos plc. during the period. Students were also funded by EPSRC, the Scottish Imaging Network (SINAPSE), and the Scottish Informatics & Computer Science Alliance (SICSA) research pool.

4. *To harness and build coherence through awareness raising and enhanced collaboration in areas of local strength where there are natural synergies, e.g. Health Informatics, Clinical Imaging, Life Sciences, Art & Design.*

CVIP raised awareness through involvement in the Academic Health Science Partnership between UoD and NHS Tayside, for example, leading to enhanced collaboration with the School of Medicine aligned to the UoD themes of *Health and Wellbeing* and *Innovating Technology*. In health informatics and imaging, CVIP has key roles (co-investigators, work package leaders, committee members) in large and strategic projects, e.g., Health Data Research UK (HDR-UK, £4M first-tranche funding, 2018), the £3.8M MRC/EPSRC PICTURES Programme Grant, the £7M NIHR Global Health Unit Dundee-Chennai INSPIRED project, UoD's Health Informatics Centre, and the Scottish National Safe Haven project. An example of synergy with Life Sciences is the £1.3M MRC project *Dynamics of Fundamental Cellular Processes by Live Cell and Tissue Imaging*.

5. *To seek new high-value international partnerships with leading research institutes reflecting the Unit's research strengths, to encourage visits and exchanges with leading labs, and further raise the Unit's profile by organising/hosting conferences.*

The Unit has been highly active in achieving these aims by (i) building collaborations with key partners including the Universities of Cambridge, Edinburgh, UCL, Duke, Göttingen, Harvard, and Twente, (ii) undertaking visits, e.g. to University of Konstanz (**Reed**, Senior Fellowship), University of Göttingen, Isaac Newton Institute for Mathematical Sciences (**Pease**), Chinese Academy of Sciences (**Trucco**), (iii) hosting research visits, e.g. from SICSA Distinguished Visiting Fellows, and (iv) hosting meetings and organising conferences, e.g. European Conference on Computer Vision general and poster Chairs (**Trucco**, **McKenna**), COMMA Co-Chair (**Reed**), ASSETS User Experience Chair (**Waller**), Future of Assistive Technology Conference Invited Chair (**Waller**), and Royal Society *Science+* meeting Chair (**Trucco**).

6. *To enhance monitoring, governance, and management of research and strategy.*

These aspects have undergone major reorganisation and are now coordinated by the School Research and Knowledge Exchange Committee, as described in 3.2. It oversees an Annual Research Review of all aspects of the Unit's research and impact.

Cluster-level plans stated at REF2014 were:

- *ARG-tech aimed to contribute to cultural wellbeing by developing critical literacy through research in debate and argument, partnering with organisations such as the BBC.*

As detailed in a REF Impact Case Study, the BBC commissioned ARG-tech to produce the *Evidence Toolkit*, challenging young people to spot "fake news" and illustrating how to recognise claims and evidence; founded upon the world's first public deployment of argument mining, into over 3000 schools, it has influenced UK and EU policy. Building on this foundation, ARG-tech

secured COVID-19 funding (ESRC, £94k to UoD) to tackle fake news around Coronavirus. It is now partnering with the Universities of Konstanz and Göttingen on argument technology-based interventions to augment and enhance deliberative democracy in partnership with Scottish and German governments.

- *CVIP aimed to emphasise biomedical image analysis with application to translational and stratified medicine, focusing on high-incidence conditions. Space research aimed to increase the number and value of missions to which its software is critical, as well as providing a near-Earth observation service consistently top-rated by NERC.*

Renewed emphasis on biomedical image analysis led to strengthened interdisciplinary collaborations in applied and translational research. Major projects investigating the role of retinal and brain image analysis focused on high-incidence conditions such as vascular dementia (EPSRC, £1.1M with UoD School of Medicine and University of Edinburgh), personalised medicine for diabetes (NIHR, with UoD School of Medicine and Dr Mohan's Speciality Diabetes Centres, India), and profiling diabetic cardiomyopathy (contribution to £10M CARDIATEAM, EU Innovative Medicines Initiative). Interdisciplinary initiatives included research on ophthalmology (NIDEK Co. Ltd. Technologies grant), digital pathology (EPSRC studentship, with UoD Pathology), HDR-UK (with UoD School of Medicine and University of Edinburgh), profiling lipoproteins linked to cardiovascular disease (with University of St Andrews) and screening pathologies in the food industry (BBSRC/Innovate UK with Newcastle University, Tulip Ltd., Hellenic Systems Ltd.). The European Space Agency (ESA) continues to fund (€1m since 2014) the Unit's research on its *Planet and Asteroid Natural Scene Generation Utility* (PANGU), a tool for testing and developing space navigation and guidance systems. Its impact is detailed in an Impact Case Study; it is critical to multiple missions including the ESA ExoMars Rover and Surface Platform Mission, the ESA-NASA Asteroid Impact and Deflection Assessment programme's HERACLES mission, and the ESA Phootprint mission. The Dundee Satellite Receiving Station provided its top-rated near-Earth observation service with NERC funding until 2019.

- *HCC aimed to expand and capitalise on its research in areas of high impact and national priority; its work on Augmentative and Alternative Communication (AAC) and Digital Social Inclusion impacting directly on social, cultural and physical wellbeing.*

HCC's reputation and high impact was nationally recognised with **Waller** receiving an OBE for services to people with complex communication needs. Its AAC research received EPSRC funding on the use of context to improve communication for users of voice output communication aids (£1M with CVIP, University of Cambridge, and others). Capitalising on the Social Inclusion in the Digital Economy hub with Newcastle University, HCC won further EPSRC funding, enabling research into understanding wellbeing within care home environments (BESiDE, £1.3M with Newcastle University, Balhousie Care Group, Heathfield Residential Home Ltd., Collective Architecture Ltd., and BUPA). The group's work aimed to impact accessibility through research into colour identification systems for people with colour vision deficiency (ColourSpecs: £100k with Norwegian University of Science and Technology); tools for accessible table discussion (Scottish Funding Council, with Ideas for Ears); and accessible interaction techniques (Carnegie Trust, with BBC R&D and Rochester Institute of Technology).

1.3 Research and Impact Objectives for the Next Five Years

The Unit will continue to compete effectively by focusing on excelling at research in its specific areas of strength. Each of the Unit's specialisms, as well as being internationally leading, should be positioned to contribute in unique and important ways to collaborative research projects in its

area. Cluster research plans will continue to support vitality and sustainability of multiple areas of impact (3.1), including PANGU space technology (CVIP) and argument technology in the public sphere (ARG-tech), as detailed in the Impact Case Studies.

ARG-tech will apply its techniques to real-world applications of argumentation and AI in domains such as healthcare, academic collaboration, intelligence & defence, law, and democracy. It will deliver new foundational results in philosophy and linguistics (theoretical and computational), and forge new deployments for both professional and general audiences.

CTM will address foundational, methodological, and architectural aspects of modern computing systems, whose complexity arises from high levels of distribution and connectivity that can change over time, bringing them closer to the dynamical systems found in, say, biological or social systems. It will develop tools and methodologies for structured, formalised high-level programming of massively parallel hardware, while addressing the pressing issues of performance versus energy consumption (green computing) and application security for modern hardware systems.

HCC will leverage its track record in designing for diverse users and situations to understand and address challenges that exist when people use technology to actively participate in society. Work will focus on enabling digital participation with a focus on complex human limitation and equally complex environmental considerations. HCC will increase multidisciplinary collaborations, combining skills from researchers in computing, psychology, design, medicine, and business.

CVIP will collaborate to leverage big data from Scotland's national medical imaging archive to develop new AI tools for disease diagnosis and risk prediction. CVIP will increase intra-School collaboration with colleagues in Mathematical Sciences and Engineering & Physical Sciences. Its space technology research will continue to focus on surface modelling and simulation for vision-based guidance and navigation.

1.4 Facilitating Impact and Interdisciplinary Research

The Unit runs a seminar series with external speakers and encourages research visitors (4.1). It is an active member of the Scottish Informatics & Computer Science Alliance (SICSA), a research pool funded by the Scottish Funding Council comprising 14 computing 'departments' across Scotland. It thus benefits from SICSA's research themes, funding support, graduate academy training activities and knowledge exchange events. For example, staff are encouraged to present at the annual SICSA DemoFest, showcasing the best Computing research from Scotland's Universities to private and public sector organisations. Most of the Unit's research involves interdisciplinarity; researchers can affiliate with multiple research clusters in a way that is not tied to discipline.

Strategic research retreats for staff and students, supported through the School's Research Fund, provide opportunities to engage in strategy refinement. For example, CVIP ran annual summer workshops at a country hotel and winter workshops away from the Computing building over the entire REF period, at which all cluster staff and students presented research and planned joint working. ARG-tech's annual retreat focuses on creative thinking around new problems; the 2017 edition led to successful application to Dstl/DASA for Dialogical Fingerprinting (£94k) in 2019. PhD students and post-docs get involved in impact activities including award-winning public engagement (see Black in 4.2) and industrial liaison (see Gemechu in 2.2), and a strategic aim is to increase this further. The Unit encourages and facilitates public engagement as described in 4.2.

The School's Associate Dean for Industrial Engagement provides leadership on engagement with industrial partners and organisations, supporting its ambition to be a preferred partner in the economic and social progress of the city, the region, and beyond. This includes creating and growing partnerships, developing opportunities for industry-led research and consultancy, and encouraging pathways for impact and commercialisation. The Unit works closely with UoD's Research and Innovation Services which provides advice on routes to impact, exploitation options, and industry engagement and commercialisation.

The Unit convenes an Industrial Advisory Board whose roles include provision of a network of contacts, assisting with research collaborations, and advising on commercialisation and impact activities. Chaired by Drew Bryce (Bluebox Aviation Systems Ltd.), it has members from IBM, NCR, ScotlandIS, Edesix, Contact Engine, and Circle IT. The Unit also engages with companies involved in the School's Graduate Apprenticeship work-based degree programmes, which include a degree in software development.

1.5 Open Research Environment

Significant progress towards an open research environment has been made, leveraging UoD's Library and Learning Centre (LLC) and Discovery Repository to ensure open access compliance. Standard practice for the Unit is to deposit all research publications, including those not in scope of REF policy, in this repository. Staff serve on editorial boards of open access journals (4.4).

LLC advises on data management planning and compliance with funders' open data policies. Datasets arising from the Unit's research have been published (with DOIs) as open data, sometimes where this was not a requirement, e.g. *50 Salads* for evaluation of activity recognition algorithms, *Recorded Observation in Care Homes* from the BESiDE project, plant-soil data from the *Grow Observatory* European citizen science project. HCC made workshop material and software associated with ACM CHI publications available (CC BY-SA 4.0). All data published by the Unit has been published using CC-BY licenses, facilitating re-use.

ARG-tech's open infrastructure for hosting and managing argumentation datasets (AIFdb, www.aifdb.org) has been used to develop corpora by teams in France, Germany, Poland, Spain, Portugal, the Netherlands, Russia and the US. As a result it supports the world's largest collection of argumentation datasets. With metadata and permalink guarantees in place, the infrastructure aims to mint its own DOIs. ARG-tech software includes the openly accessible Argument Mining Framework (amf.arg.tech), argument translation and evaluation web services (ws.arg.tech), and the world's most widely used argument analysis tools: OVA (ova.arg.tech) with over 100,000 users in 80 countries (Google analytics). Most components are released LGPL or CC-BY-SA, with derivatives then developed, e.g. of OVA at University of Trier and of AIFdb at Dstl.

1.6 Research integrity

The School has a Research Integrity Lead, supported by a Deputy. They are responsible for promoting a culture of research integrity in the School and provide (i) an independent point of contact for staff and research students outside their immediate research environment, (ii) impartial advice on responsible conduct of research, and (iii) advice on making misconduct allegations. Research staff and students are provided with online video-based training in Responsible and Ethical Practice in Research and Publication which is mandatory for research students and new supervisors. Additional workshops from an external trainer are provided by UoD's Organisational and Professional Development (OPD) unit. Ethical review and approval of non-clinical research involving human participants proposed by staff and students is overseen by the School Research

Ethics Committee. It reports to the University Research Ethics Committee, which provides oversight, monitoring and guidance.

2. People

2.1 Staffing strategy and staff development

In addition to the 13.5 FTE returned staff, UoA11's wider research community includes research assistants, research students, technical support, and staff who engage with research to inform teaching.

Computing is committed to recruiting researchers with outstanding research track records and potential for achievement at the highest level. The Unit recruited from high profile international institutions such as ETH Zurich, Chapel Hill North Carolina, and CTU Prague. Appointment of **Magerand** (2019) to CVIP, **Crabb** (2018) and **Rough** (2020) to HCC, and **Lawrence** (2019) and **Visser** (2019) to ARG-tech, helped maintain or build capacity in those clusters. **Janjic** (2019) was recruited to strengthen capacity in data science, working across clusters, especially around parallelism and medical big data. **Fiadeiro** (2019), who researches formal software system modelling and analysis, was appointed as Dean of the School of Science & Engineering.

Demographic profile is well balanced after healthy recent intake of early career academics, thereby supporting succession planning. Five professors (distributed across clusters, one of whom is Dean), two senior lecturers, and seven lecturers make up the Category A staff, all of whom are on permanent contracts. The age profile is 20-29: 7%, 30-39: 36%, 40-49: 21%, 50-59: 29%, >60: 7%.

Strategy for recruitment and growth is aligned with clusters, allowing for cross-discipline appointments. New teaching programmes will enable expansion following this REF period. HCC has already grown by a further 2 FTE since the REF census date with the appointment of a Senior Lecturer and a Lecturer (both on Teaching & Research contracts) in Assistive Technology. A new appointment (1 FTE) in networks and sensors is also being made.

The Associate Dean for Research sits on all shortlisting and appointment panels for roles that include significant research responsibilities. The appointment process usually runs over two days to ensure candidates interact with staff in relevant clusters and become familiar with the research structure before interview.

All research active academic staff undergo an Annual Research Review, in addition to the annual Objective Setting and Review process. These supportive processes prompt reflection and guidance regarding research goals, achievements and challenges. Given multiple new academic staff, mentoring and development are critical for the Unit. Early Career Researchers (ECRs) are provided with a tailored programme of support to prepare them for leadership and are assigned a mentor (a senior academic in an aligned research area) whom they meet regularly. They are also enrolled on postgraduate training for teaching and learning in Higher Education. The Unit is committed to the Concordat to Support the Career Development of Researchers. Its staff benefit from UoD's researcher development programme including courses mapped to the Vitae Researcher Development Framework.

Senior staff provide mock panels and pre-reviewing of proposal drafts/rebuttals. Staff who have held fellowships mentor new applicants during fellowship proposal drafting. Staff are regularly briefed on appropriate funding opportunities using *RESEARCHconnect*. Individual staff research activities, such as travel and networking, are supported at School level by a Research Fund

approved by the Research Committee, with priority given to ECRs. All staff align their research interests with at least one research cluster, and thereby become incorporated in group activities (e.g., reading groups, postgraduate supervision, group funding applications). The Workload Allocation Model protects research time; newly appointed academic staff on teaching and research contracts are allocated reduced teaching workloads. Cluster Lead roles are recognised in the model, as is PGR supervision, time on external research projects and impact generating activities such as consultancy and service work, meaning that the teaching and non-research project-supervision load is balanced across all staff taking into account these research commitments. These come on top of a baseline research allocation to support generation of new avenues of research and strong contribution to the wider academic community.

UoD sabbatical leave may be granted to staff who have served three years or more, at the rate of one semester per three years of service. Staff are encouraged to fund research sabbaticals through external funding. **Reed** secured £40k funding as part of DFG's Cluster of Excellence in the Politics of Inequality for a 5-month visiting senior fellowship at University of Konstanz. McKillop (Research Assistant) spent a month at University of Göttingen furthering collaboration with political scientist Gold; post-doc Snaith made extended visits to Roessingh Research & Development in the Netherlands.

2.2 Research students

All PhD students are provided with computer equipment and individual desk space in the most relevant lab. Privileges they share with staff include 24-hour access and a shared staff common room. They are welcome at Computing staff meetings. PhD students are expected to contribute to regular cluster and project meetings and encouraged to interact in a spirit of collaboration and sharing with other students and researchers. They often assist with supervision of MSc and undergraduate projects related to their research.

UoD procedures and practices for postgraduate research are supplemented by the School's own Postgraduate Research Guide. All doctoral students are allocated two supervisors with further supervision from collaborating academics in the case of interdisciplinary research. Each student meets twice a year with two members of academic staff other than their supervisors as part of the Thesis Monitoring Committee programme to discuss achievements, goals, and individual development plans. This provides an opportunity to raise concerns (e.g. regarding supervision or access to resources) and contributes to a documented portfolio of progress. Students can also seek guidance from the Computing PGR Lead and the School's PGR Director (who is a member of the board of the UoD Doctoral Academy). Students transfer formally to the PhD programme after their first year, having satisfied an examining committee based on a report (including plan), presentation, mandatory research integrity training, and oral examination.

All research students are encouraged to present at high quality international and national conferences, and to attend relevant summer schools. Financial support for this is provided by the School's Research Fund and the Discipline of Computing's budget. Students benefit from the environment provided by SICSA with its seminars, masterclasses, conferences and funding opportunities, e.g. there have been 36 UoD PhD student attendees at SICSA PhD Conferences (2014-19), a student representative on its organising committee, and SICSA summer school sponsorship and bursary support. OPD's Researcher Development Programme provides training suitable for Computing PhD students including workshops covering PhD Launchpad (year 1), Making Progress in Your PhD (year 2), Finish Up, Move on (year 3), Career Options, Researcher Wellbeing and Mental Health, EDI, and research ethics. Bespoke training (e.g. in statistics) and

graduate school events provide further opportunities for development. Research clusters run regular journal clubs, at which staff and students meet to review research together.

The School supports an annual two-day Computing PhD Symposium organised and chaired by PhD students with two senior academics acting as advisors. It features student-edited proceedings and student-selected keynotes/panels on, e.g. open data, publishing, and 'life after the viva'. All students are required to participate each year by reviewing extended abstracts and giving a talk on their research. Annual prizes are given to reward the best first-year student presentation and the best overall PhD student.

The quality of PhD education is evidenced by external awards to students, e.g. Best Student Paper Awards at European Conference on Argumentation (**Visser**, 2015) and Computational Models of Argument (Duthie, 2016), EPSRC UK ICT Pioneers Finalist (Stein, 2014). PhD students are encouraged to participate in public engagement activities and spend time as research interns or visiting researchers in companies or labs elsewhere to broaden their experience, e.g. Duthie and McKillop visited University of Konstanz; Akbar was research intern at Toshiba Medical Visualization Systems; Gemechu was appointed Industrial Fellow in Residence, funded by Contact Engine. The quality of PhD training provided by staff is evidenced by their invited contributions to doctoral training and summer schools (4.3).

The Unit strives to balance retaining talented local graduates and attracting students from elsewhere. UoD receives an EPSRC Doctoral Training Award used to competitively fund studentships in the School, in some cases with staff securing matched funding externally. Studentships are also funded by industry and other organisations (1.2).

2.3 Equality, Diversity and Inclusion (EDI)

The School is committed to the Athena SWAN charter principles, holds an Athena SWAN Bronze Award (since 2018) and is working towards a Silver Award application in 2022. Its Athena SWAN self-assessment committee, led by Computing academic Murray, focuses on actions that maintain and enhance inclusive culture and collegiate working practices. School and University-level EDI and Athena SWAN action plans guide ongoing improvements in support of all staff and students; these are informed by the University's biennial staff survey.

Staff in the Unit can access a range of University work-life balance policies including coverage for those with changed circumstances, compassionate leave, parental leave (including shared), adoption/fostering leave, carer's leave, and fertility treatment leave. Computing's Discipline Lead maintains regular contact with staff during their leave. Discussions related to return to work, including requests for reductions in FTE, are held prior to return in line with UoD's Flexible Working Policy. The Unit can be flexible in transitioning staff to/from part-time working; job sharing and flexible/phased retirement are also supported. During lockdown, staff and research students were supported to work effectively from home, and computational resources were fully accessible to support remote working on research. Voluntary declaration of any mitigating circumstances is part of the standard academic promotions process.

The Unit appoints staff and recruits research students on merit alone and is committed to equality and diversity. Staff appointing and shortlisting panels are gender balanced. Online training in equality and diversity is mandatory for staff and includes modules on *Diversity in the Workplace*, *Disability*, *Diversity in Learning and Teaching*, *Stress in the Workplace*, and *A Manager's Guide to Stress*. Additionally, a *Recruitment and Selection* module is taken by staff involved in those activities. Unconscious bias training sessions are available to all in the School. A full-time

counsellor for mental-health issues has recently been appointed and has supported staff and students with caring responsibilities and other needs during the Covid-19 pandemic. Harassment advisers are available for staff and students.

Staff from the Unit organised and hosted the SICSA *Women in Computing Research* event (**Pease**, Komendantskaya, 2016). **Pease** is joint leader for the SICSA theme *Supporting and Recruiting Women in Computing*. Strong female role models in the Unit during the period include Computing's Discipline Lead (**Waller**, OBE) who was born with cerebral palsy, and the President of the ACM (Hanson, FRSE).

2.4 Preparation of the REF Submission

In preparing this submission, the Unit's Planning Group was guided by the University's REF 2021 Code of Practice, framing its decision-making process in the context of the principles of equality, diversity, and inclusion. The Planning Group made decisions on outputs and attributions in a manner that aimed to maximise the overall quality profile, based on a thorough process of internal and external evaluation. All staff were invited to propose potential Impact Case Studies. The submitted Impact Case Studies reflect the Planning Group's view of the strongest demonstrable research impacts in the reporting period. All Planning Group members completed EDI and Information Security training modules, and REF-specific training in Equality & Diversity including Unconscious Bias training, prior to the decision-making process.

3. Income, infrastructure and facilities

3.1 Research Funding

The Unit attracted £11.45M in research funding over the period. In addition to published outputs, this funding led to significant impact, including enabling aspects of the Impact Case Studies. Specifically, research underpinning the PANGU case study was supported by the European Space Agency (ESA) *PANGU-4: Planet and Asteroid Natural Scene Generation Utility Tool Enhancement* project (Grant to UoD £494k. **Martin**, Parkes). The EPSRC-funded project *Argument Mining* (£680k. Sole investigator: **Reed**) underpinned the Argument Technology case study. Further funding for ARG-tech included £671k from Dstl (Mar 2019-Mar 2021) on applications of argument technology to intelligence analysis. Academics in the HCC and CVIP clusters led further major EPSRC-funded projects:

- *ACE-LP: Augmenting Communication using Environmental Data-driven Language Prediction*. £1M. **Waller** (PI), **McKenna**, Zhang. Partners: University of Cambridge (Kristensson), Arria NLG Ltd, Edesix Ltd, Scope, Capability Scotland, Communication Matters, National Museum of Scotland, Ninewells Hospital & Medical School, Sensory Software International Ltd, Tobii Dynavox. (Ranked number one at the 'User Interaction with ICT' prioritisation panel).
- *Multi-modal retinal biomarkers for vascular dementia*. £923k, Unit income £313k. **Trucco** (PI), **McKenna**. Collaborators: UoD School of Medicine (Doney), Edinburgh Centre for Clinical Brain Sciences and Centre for Cognitive Ageing & Cognitive Epidemiology (Deary, Dhillon, Doubal, MacGillivray, Wardlaw).
- *BESiDE: Built Environment for Social Inclusion in the Digital Economy*. £1.3M. Hanson (PI), **Reed**. Collaborators: UoD Art & Design (Lim, White), UoD School of Medicine (McMurdo), Newcastle University (Watson). Partners: Balhousie Care Group, BUPA, Collective Architecture Ltd, Healthfield Residential Home Ltd.

Grants obtained as part of major international consortia included:

- *COUCH: Council of Coaches*. EU H2020. Grant to UoD: £416k. **Pease**. Collaborators: UoD School of Medicine (Conway, Wake). Partners: University of Twente, Roessingh Research & Development BV, Danish Board of Technology Foundation, University Pierre and Marie Curie, Polytechnic University of Valencia, Innovation Sprint.
- *INSPIRED: India-Scotland Partnership for Precision Medicine in Diabetes*. NIHR Global Health Research Unit (£7M, PI: Colin Palmer, School of Medicine). **Trucco** leads the *Retinome* package. Income to Unit: £852k.

Sustainable research income generation will target interdisciplinary, challenge-based research in areas where the Unit is well placed to lead or provide critical input. For example, CVIP will leverage opportunities provided by the scale and nature of medical data resources available through collaborations in Tayside (e.g. GoDarts: Genetics of Diabetes Audit and Research; SHARE: Scottish Health Research Register) and strong links nationally (UK Biobank) and internationally (e.g. 0.5M patients in India via INSPIRED), building on extensive collaborative networks and long experience of interdisciplinary biomedical research to target research questions that require large-scale data and high quality consortia. As a current example, **Trucco** is computing investigator on the UoD-led PICTURES programme (2019-2024), a £3.8M consortium with the Universities of Edinburgh and Abertay, NHS Scotland, and industry, funded through MRC/EPSRC as part of HDR-UK. ARG-tech will grow funding based on its reputation for techniques in argument mining (surveyed by **Lawrence** and **Reed** in *Computational Linguistics*, 2020) and its applications including intelligence analysis.

A key target for 2021-23 is to secure funding for ECRs; submission of a New Investigator Award proposal is a minimum expectation for ECRs (**Pease** won her EPSRC First Grant during the period), and applications for externally-funded personal Fellowship support are strongly encouraged. Internal peer review of proposals and responses to reviewers, as well as mock interview panels, involving fellowship holders, and Research Council panel and college members, together with proposal development support from Research & Innovation Services, will help ensure bids of the highest quality. There will be a focus on fellowship funding at all levels including UKRI and charitable sources.

The Unit will take opportunities with colleagues and collaborating institutions, working with the Doctoral Academy, to bid for large scale Doctoral Training initiatives. It will harness its Industrial Advisory Board in planning how to better marshal and leverage its many successful commercial collaborations, to win service and industrial research funds, and to enhance its impact.

3.2 Organisational and Operational Infrastructure

Human Infrastructure

Research clusters deliver the strategic research directions of the School. They inform staff recruitment, coordinate ECR mentoring and training, organise seminars, and coordinate peer-review of grant applications and mock-interviews for fellowship applications, drawing on expertise across UoD. They also serve as interfaces with other schools in the University for inter- or multi-disciplinary research.

Management structures in which the Unit operates were reorganised in 2015 with formation of the School of Science and Engineering. Management and monitoring of research and impact, and sharing of best practice, are now coordinated by the School Research & Knowledge Exchange Committee whose membership includes the Computing Research Lead and PGR Lead. It is

chaired by the Associate Dean for Research who is a member of the University Research & Knowledge Exchange Committee as well as other groups convened by the Vice-Principal (Research) for defining or monitoring implementation of University-wide strategic objectives. The Associate Dean meets staff individually for monitoring, planning, and scoping of opportunities as part of the Annual Research Review process. Together with target setting at Objective Setting and Review meetings, and research cluster meetings, this helps keep ambition levels high for the Unit's research activities, environment, outputs, and impact.

The School Research Administrative Lead coordinates a team supporting the research-driven culture. This includes (i) collating and analysing data relevant to Annual Research Reviews and other research activity; (ii) supporting adherence to Open Access and Open Data policies; (iii) disseminating research funding opportunities using RESEARCHconnect; (iv) ensuring effective support is in place for costing research proposals (pre-award); and (v) liaising with Research Finance Services over creation of grant administration structures and cost centres (post-award).

Physical and Digital Infrastructure

The Queen Mother Building (QMB) was purpose-built for Computing and designed to be fully accessible. Space in QMB is organised to co-locate cluster members, achieving a working environment, in which cognate researchers, from PhD students to professorial staff, are in close physical proximity, facilitating collaboration. QMB was designed to allow a fourth floor to be added, a cost-effective option for expansion that would maintain co-location and cohesion.

The QMB received further investment during the period. It has been part of a university-wide £7M network upgrade project delivering a gigabit network to the desktop. Additionally, a dedicated firewall solution that caters for Computing's requirements has been implemented to satisfy Cyber Essentials requirements. Furthermore, the server infrastructure has seen hardware upgrades with some storage being transferred from traditional magnetic HDD to SSD technology at a cost of around £8k. Overall maintenance and improvement of services such as web and database hosting for the research portfolio, and new investment into GPU-driven processing, cost approximately £50k. The Unit's research is currently aided by a School support team of 3 FTE administrative and 1 FTE specialist support staff who work closely with centralised IT support (UoDIT).

Computing operates a hardware/software investment cycle to ensure staff have up-to-date resources. Software requirements are also gathered on a continuous basis to support research. All research students and staff have access to a wide range of software including Visual Studio Enterprise, MATLAB (with over 40 toolboxes), CUDA and Python in-house. Computing has invested in shared GPU servers and desktops that have greatly facilitated deep learning research by staff and students in CVIP and ARG-tech with support from Nvidia and from research funds. The loan of a Nvidia DGX server and storage solution was an example of Nvidia's support. Staff can also access the University's centrally supported High-Performance Computing facilities.

The QMB User Testing Lab has been renovated, providing state-of-the-art AV recording and eye-tracking capabilities within an HCI testing environment, and HCC has set up dedicated prototyping space for Virtual/Augmented Reality research with equipment such as HTC Vive Pro, Microsoft HoloLens, and Sony Xperia Touch (c. £50k investment). QMB houses the User Centre, a unique resource hosting user groups who meet regularly to learn about technology and take part in research (4.2).

The Unit benefits from investment across UoD to support its interdisciplinary strengths. Dundee Interdisciplinary and Innovation Forum events included Artificial Intelligence, Health Informatics,

and Health and Wellbeing: Ageing Society. The University's Health Informatics Centre (HIC) has an ISO27001 certified environment, part of a federated Scottish network of Safe Havens, and develops a Research Data Management Platform to manage, anonymise, and extract images linked to health data, to support over 1.5 Petabytes of routinely collected radiological imaging data. CVIP is collaborating in this effort and will continue to work with HIC to leverage this infrastructure to develop algorithms for diagnostics, risk prediction, and discovery. CVIP's research on digital pathology benefits from the Tayside Biorepository secure tissue bank.

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

4.1 Support for and Effectiveness of Research Collaborations and Networks

Unit staff collaborated productively with UK Universities (e.g. Cambridge, Edinburgh, Newcastle, UCL), overseas universities (e.g. Duke, Göttingen, Harvard, Twente) and companies and NGOs. Funded industrial collaborations in the REF period include those with the BBC, Roessingh R&D BV, OPTOS plc UK, NIDEK Technologies Srl (Italy/Japan), Hellenic Systems Ltd., and Tulip Ltd. Exemplars of effective research collaborations and networks not detailed elsewhere in this document include the following:

ARG-tech's network includes Contact Engine (**Reed** appointed to Scientific Advisory Board), Ombudsman Services, Juralio Ltd. (**Reed** served as interim CTO), IBM, and the UN. **Pease** has long-term connections and collaborations with the Universities of Edinburgh, Heriot-Watt, Queen Mary London, Saarbrücken, Genoa, Cambridge and Oxford, and with Dundee colleagues in Medicine (Conway) and Art & Design (Moncur). Further ARG-tech collaborations include the Universities of Amsterdam, Utrecht, Southampton, Cardiff, Liverpool, Rutgers, CMU, and MIT.

CTM, through the European H2020 SERUMS (*Securing Medical Data in Smart Patient-Centric Healthcare System*) project (**Janjic**), collaborates with University of St Andrews, Universite Catholique de Louvain (Belgium), University of Cyprus, IBM, Accenture, Sopra-Steria (UK), Software Competence Center Hagenberg (Austria) and two large hospital centres, Zuyderland Medisch Centrum (Netherlands) and Fundacio Clinic per a la Recerca Biomedica (Spain). This consortium aims to put patients at the centre of future healthcare provision, enhancing personal care and quality of treatment, while ensuring trust in security and privacy of confidential data.

CVIP involvement with the Academic Health Science Partnership, established between UoD and NHS Tayside in 2014 to promote translation of University healthcare technologies, has enhanced collaboration with NHS clinicians; **McKenna** and **Trucco** have funded collaboration with dermatology on deep learning for skin lesion diagnosis; in HDR-UK (with UoD Medicine) **Trucco** leads the *Advanced machine learning for image analysis* theme with University of Edinburgh focusing on MRI and clinical risk and outcome associations. The **VAMPIRE** retinal image analysis programme (led by **Trucco** in long-term partnership with McGillivray at University of Edinburgh) has built an extensive network of interdisciplinary collaborators and clinical centres nationally (Queen's University, Belfast Ophthalmic Reading Centre and Centre for Public Health; Ulster University; UCL/Moorfields Eye Hospital) and internationally (Duke University; Tufts School of Medicine; Harvard Medical School; Centre Hospitalier Universitaire de Grenoble; Universidad del Valle, Colombia; Dr Mohan's Diabetes Speciality Hospitals; Madras Diabetes Research Centre) who apply VAMPIRE software and contribute directly or indirectly to the image analysis research.

HCC collaborates in W3C where **Crabb** leads on developing Mixed Reality Web Guidelines for WCAG3.0. **Crabb** is a member of the BBC UX Research Partnership, established between BBC R&D, UoD, UCL, and the Universities of Bath, Newcastle, Nottingham, and Swansea. Work on

implementation of accessible services has resulted in changes within the iPlayer platform, creating international digital impact, as well as in joint publications and BBC White Papers.

External collaborations are fostered by encouraging incoming visitors as seminar speakers, visiting scholars and distinguished visitors funded through external programmes such as SICSA and by internal strategic funding. SICSA sponsored the UoD-organised and hosted SICSA Medical Image Analysis Workshop in 2015 (**McKenna, Trucco, Zhang**) to build a network of researchers in medical image analysis, further bolstered through the SINAPSE Scottish Imaging network (Image Analysis Deputy Lead: Zhang), and helping to raise CVIP's profile nationally and strengthen collaboration, particularly with the University of Edinburgh.

The Unit has had a continuous flow of international research visitors including exchanges based on exchange/travel grants or project grants. It hosted three Distinguished Visiting Fellows (competitively awarded through SICSA): Moens (KU Leuven), Carpendale (University of Calgary) and Johann (Appalachian State University). The Unit's seminar series funds visitors largely from the UK and Western Europe for short stays, and occasionally longer visits from further afield. ARG-tech alone hosted 34 research visitors over the period, nearly all international. Outgoing international visiting positions included **Trucco's** adjunct professorship at the Chinese Academy of Sciences, Ningbo (2016-19) and **Reed's** appointments as Visiting Professor, Polish Academy of Sciences (Dec 2016-Dec 2017) and Senior Research Fellow, University of Konstanz, DFG Cluster of Excellence (Jan-Jun 2020).

4.2 Relationships with Research Users, Beneficiaries and Audiences to Develop Impact

End users are involved in most of the Unit's research from grant application through to impact. Projects typically have advisory groups, ensuring relevance to users and beneficiaries, and more lasting impact, e.g. the *ACE-LP* (EPSRC) advisory group drawn from people who use AAC, clinicians, charities representing disabled people, and industrial experts. Its central hypothesis was that communication rate and experience of people who use Voice Output Communication Aids can be improved by leveraging automatically perceived contextual data to inform a probabilistic language module. In addition to engaging in research, industry research partners actively took part in HCC public engagement with national museums, e.g. *More than just computer speech* (National Museums Scotland, <https://vimeo.com/358837456>) and *Technology Taster Day* (V&A Dundee, <https://vimeo.com/359049317>).

The Unit has a Public Engagement Officer, and the School Deputy Director for Public Engagement is from the Unit (Black). All clusters are involved in public engagement. In 2015, Computing, in collaboration with Leisure & Culture Dundee and Life Sciences, created a public engagement venue: *Outer Space|Inner Space* (<https://aac.dundee.ac.uk/osis/>) at the iconic Mills Observatory. Computing events hosted there include *Ways of Vision* (Flatla) and *Alien Surfaces* (**Martin**). *Outer Space|Inner Space* created the brands *Science Saturdays* and *Wednesday Wonders*, offering activities for an established, interested audience of all ages. This will continue to allow the Unit to share its work without the need to organise suitable accessible venues. Staff gave outreach talks, e.g., at Edinburgh International Science Festival (**Pease** 2017); Café Science on Computational Creativity (**Pease** 2016) and Voices from Care Homes (McIntyre, Postdoc, 2015); TedX Dundee (**Trucco** 2015); and Dundee Women's Festival (**Waller** 2020).

HCC maintains the *User Centre*, a collaborative network drawn from "hard to reach" population groups, meeting weekly in the QMB, run by users, and with Crabb as academic contact. It includes a pool of older computer users from which researchers can recruit participants for user studies; the *Straight-Talking Group*, an active group of adults with complex physical disabilities who use AAC

systems; and the *Tap and Talk Aphasia Group* which works with former NHS stroke patients investigating mainstream iPad apps from an accessibility perspective. User pools are augmented by users accessed through clinical partners. They have been involved in multiple projects in UoD and elsewhere (e.g. Napier, Robert Gordon, and Newcastle Universities).

UoD recognises excellence in public engagement through its Stephen Fry awards; commendations for work that excelled at engaging audiences with research were awarded to ARG-tech (**Reed** et al., 2018, 2019) for “argumentation technology and the BBC”, for *Outer Space|Inner Space* (2017), and for engaged researcher of the year (Black, HCC 2019). As an example of media coverage, the *ACE-LP* EPSRC project featured on BBC Click with a live computer vision and AAC demo and interview in front of a V&A audience (2020).

Staff contribute to policy debate and provide commentary on industry research. For example, **Reed** was invited speaker at the Holyrood Communications' Effective Digital Communication event (2018), contributed to Scientific Briefing on “Fake News” at the Parliamentary & Scientific Committee, Palace of Westminster (2019), and to an All-Party Parliamentary Group on AI (2020). **McKenna** and **Trucco** have both participated in scoping events for Toshiba/Canon as invited experts (2015, 2019). **Reed** was invited as sole academic commentator at IBM's Project Debater launch (San Francisco, 2018).

STAR-Dundee, a 2002 spin-out from the Unit, continues to work with UoD and won Design and Innovation Business of the Year at the Courier Business Awards 2017. The Enterprise in Education award was won by My Diabetes My Way, Scotland's interactive website and mobile app for people with diabetes, impact arising from user-centred design and health informatics research supervised by **Waller** in collaboration with the School of Medicine. It allows all 310k people with diabetes in Scotland to support self-management and access clinical records, is evidenced to improve clinical outcomes and quality of life with cost savings of £230 for £33 invested (independently validated) and was embedded in the Scottish Diabetes Improvement Plan and eHealth Strategy. It led to a 2017 spin-out (MyWay Digital Health) now employing 25 staff.

Consultancy is an important part of the Unit's research activity as it provides a means to deliver impact and establish commercial relationships. Examples are **Reed's** work as CTO for Juralio Ltd (2013) and as a member of Contact Engine Ltd.'s AI Board (2018-) whose CEO is an Honorary Professor in ARG-tech.

4.3 Contributions to Sustainability of the Discipline

Apart from all the research activities already mentioned that help to build and sustain the discipline, staff contribute by engaging with external PhD training. Nationally, for example, Computing hosted the SICSA PhD Conference 2017, the HCI Camp one-week summer school 2019 (Co-Chair: **Crabb**), and the first Summer School on Argumentation (SSA-2014) with **Pease** contributing an invited talk. Internationally, **Pease** co-chaired the ICCC-2017 Doctoral Symposium and was an invited ICCC-2018 PhD panellist. **Reed** gave invited tutorials at the International Graduate School on Argument & Rhetoric (IGSAR-2014), and the Swiss Universities Doctoral Programme *Language & Cognition* PhD Workshop on Linguistic & Corpus Perspectives on Argumentative Discourse (Fribourg 2019), an invited lecture at the Argupolis doctoral programme (Lugano 2014) and taught a course (with Budzynska) at ESSLLI-2017 European Summer School. **Pease** was invited speaker at the Summer School on Creative Cognition (Budapest 2017). **Trucco** gave an invited 3-day course on retinal image analysis at Universidad del Valle, Colombia (2015) and was invited lecturer at the Computer Vision summer school, Lappeenranta University (2018). **Reed** gave argument

mining tutorials at ACL-2016 and ACL-2019. UoD is an active contributor to the SICSA pool, having provided its Director of Education and committee members throughout the period.

4.4 Selected indicators of influence, contributions to and recognition by research base

Fellowships, Honours

OBE for services to people with Complex Communication Needs, 2016 New Year's Hons. (**Waller**)
 Fellow, International Association for Pattern Recognition (FIAPR) 2016 (**Trucco**)
 Elected member of Academia Europaea 2017 (**Fiadeiro**)
 Honorary Fellowship, Royal College of Speech and Language Therapists, 2017 (**Waller**)
 Visiting Fellow, Isaac Newton Institute for Mathematical Sciences, Big Proof 2017 (**Pease**)
 Distinguished Fellow, British Machine Vision Association (BMVA) 2020 (**Trucco**)

Editorial Board Memberships, Programme Chairs (Open Access journals in *italics*)

Argument & Computation (**Reed**, -2015, Coordinating Editor), ACM TACCESS (**Waller**), *Applicable Analysis & Discrete Mathematics* (**Edwards**), Applied Intelligence (**McKenna**), Argumentation and Advocacy (**Reed**, -2016), *Electronic Proceedings Theoretical Computer Science* (**Fiadeiro**), *Informal Logic* (**Reed**, -2017), Information Processing Letters (**Fiadeiro**), *J. Computational Creativity* (**Pease**), *J. Imaging* (**McKenna**), *J. Modelling in Ophthalmology* (**Trucco**), *J. Public Deliberation* (**Reed**, -2016), Machine Vision & Applications (**McKenna**), SN Computer Science (**Fiadeiro**). *Selected Guest Editorships*: Computerized Medical Imaging and Graphics, 2017 (**Trucco**), *J. Diabetes Science & Technology*, 2016 (**Trucco**), *Philosophy & Technology*, 2017 (**Reed**), *Science of Computer Programming*, 2014, 2015 (**Fiadeiro**). *Programme co-chairs*: Brazilian Symposium on Formal Methods (SBMF-2017) (**Fiadeiro**), European Computer Science Summit (ECSS-2017) (**Fiadeiro**), Int Conf on Computational Creativity (ICCC-2017) (**Pease**).

Research Council Membership, Grant Committees

EPSRC College (Full: **Fiadeiro**, **McKenna**, **Reed**, **Trucco**, Hanson, Newell; Associate: **Waller**); Committee 25, French Research Council/ANR (**Fiadeiro**); Carnegie Trust Assessors (**McKenna**, **Reed**, **Trucco**); BBSRC TRDF Panels 2014/2016/2018 (**McKenna**); Academy of Finland Review Panel, Japan-Finland Call 2015 (**McKenna**).

International Prizes (Selected)

Best Paper Awards CHI-2015 (Flatla) CHI-2016 (Flatla), CHI-2020 (**Waller**)
 Winner, Endoscopic Vision Challenge Sub-challenges on Polyp Localisation and Early Barret's Cancer Detection, MICCAI-2015 (Zhang, **Trucco**, **McKenna**)
 Winner, Performance Evaluation of Indirect Immunofluorescence Image Analysis Systems (both tasks), I³A@ICPR-2014 (**McKenna**, Zhang)
 Winner, White Matter Hyperintensities Segmentation Challenge, MICCAI-2017 (Zhang)

International Keynotes and Invited Talks (Selected)

International Conference on Agents and AI, Lisbon 2015 (**Reed**)
 Cultures of Mathematics, New Delhi 2015 (**Pease**)
 MICCAI Workshop Keynotes: CARE-2015, OMIA-2016, LABEL-2017 (**Trucco**)
 Big Data, Reasoning and Decision Making (BraD-2017), Zhejiang University (**Reed**)
 Public Policy and Good Governance (CPG) Conference on Governing the Future (German-Southeast Asian Center of Excellence) Bangkok 2019 (**Reed**)
 Body of Knowledge: Art and Embodied Cognition, Melbourne 2019 (**Waller**)
 Image-based Systems Biology (IbSB), Jena 2014 (**McKenna**)
 AAAS Symposium Massively Collaborative Global Research in Maths & Science 2016 (**Pease**)
 DFG funding programme launch (Schwerpunktprogram) RATIO, Bielefeld 2018 (**Reed**)

CVPR Workshop on Medical Computer Vision & Health Informatics, 2019 (**Trucco**)

Invited Winter Lecture, Int J Language and Communication Disorders 2017 (**Waller**)

Schloss Dagstuhl Workshops: Present & Future of Formal Argumentation, Debating Technologies, 2015 (**Reed**).