Institution: University of the West of England, Bristol

Unit of Assessment: 11 Computer Science and Informatics

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

Structure

The Unit's research is organised into three groups: the Computer Science Research Centre (CSRC); the Creative Technologies Lab (CTL); and the Unconventional Computing Group (UCG). The Unit contributes to the discipline's foundations through to its application: from novel substrates for sensing and computation to novel human-computer interfaces for music composition. The membership and areas of interest of these groups are not mutually exclusive and there is significant collaborative research between them, together with other UWE, national and international partners. The groups are co-located in bespoke labs within the Department of Computer Science & Creative Technologies. Each group is led and managed by a senior colleague (Professor/Associate Professor) who also serves as its representative on the Faculty's Research and Knowledge Exchange (R&KE) Committee where issues such as UWE strategy implementation and research investment are addressed.

The Computer Science Research Centre (CSRC, lead: **Bull**) undertakes theoretical and applied research within the broad framework of ubiquitous computing, covering artificial intelligence, cyber security, data science, the internet of things, and smart cities. Its vision is that computer systems are "everyware", secure, and adaptable in nature. Current fields of research include bio-inspired approaches to machine learning, effective ways to integrate and exploit data, small device security, low power/cost graphene-based sensors, and mechanisms for citizen engagement with local democracy.

The Creative Technologies Lab (CTL, lead: **Mitchell)** is an interdisciplinary research group that spans and intersects computer science and the creative arts. The group's members share the vision that interfaces between people, technology and creativity will become seamless, giving rise to new levels of human perception, innovation and creative expression. Current research themes within the group include: graphics, visualisation and games; embodied and immersive interaction; sound and visual arts.

The Unconventional Computing Group (UCG, lead: **Adamatzky**) spans theoretical and experimental studies of novel principles of information processing in physical, chemical and biological systems. Its vision is that massively parallel unconventional computers which exploit the phenomena of non-linear dynamics intrinsic to a given system will enable computational capabilities beyond that of current technology. Current fields of research include cellular automata, nano-scale chemical computing, and slime mould computing.

The CSRC, formed in 2018 through the merger of two long-standing groups – the Centre for Complex Cooperative Systems and the Artificial Intelligence Group – acts as an enabler to the exploitation of fundamental and applied research in machine learning across the Unit's activities. CTL was formed in the same year to support the Department's expansion into the creative technologies, thereby forming a focus and identity for the research of the growing of number of staff working in the area. Growth was planned and subsequently achieved across the Unit during the REF period, as evidenced by this submission including the work of more than three times as many staff (9→29) as submitted in 2014 from the host department.

Objectives

UWE's research vision is to have an outstanding reputation for its user-led research applicable to real-world problems and to conduct world-class research in clearly identified areas of strength. The Unit's overall aim is to concentrate on maintaining the vitality of its existing groups while supporting promising trajectories within them that may emerge ultimately as new groups. Funding has been allocated in 3-year cycles allowing groups to plan ahead for investment in

staff, equipment, and research studentships. Following the stated objectives for the equivalent Unit in 2014, the overarching objectives for the period and next five years continue to be:

(i) maintain a vibrant, intellectually rigorous research culture, characterised by: adventurous, interdisciplinary collaborative research; working with national and international partners; strong support for individual initiative; encouragement for dissemination to students and the public; and, a mixed-economy of fundamental and applied research with impact.

(ii) extend and sustain the level of external funding from a portfolio of sponsors.

The Unit's overall aim is realised through appropriate local strategies for each of the contributing groups, monitored through regular reporting to the Faculty R&KE Committee, an annual group review, and the annual personal development reviews of group leaders. Many of the outcomes described below pertain directly to meeting these objectives over the assessment period.

UWE recently announced its 2030 strategy, the research component of which identifies a number of beacons that will be thematic priorities over the coming years. These are digital futures, health and well-being, sustainability by design, and creative industries. The core activities of the Unit are well-aligned to the first (CSRC, UCG) and last (CTL), with the potential for more interdisciplinary research within the other two. New, cross-UWE clusters are now forming under the beacons, with Unit members already active in those relating to digital health, cancer, transforming construction, healthy ageing, and conservation. Others, where the Unit will be able to play a key role, are expected to emerge in the next phase. These will bring new problems to be solved, requiring new fundamental research, new application domains, and open the Unit to new sources of external funding. Some of the impact-focused elements of these activities are connecting into the growing ecosystem of SMEs based in the University Enterprise Zone, detailed in the Institutional-level Environment Template

Impact

The Unit's approach to impact, in line with that of the University, reflects a long tradition of research focussed on real-world problems, often in collaboration with industry, with the explicit aim of achieving social and economic gains. The aim is to build long-term, multi-dimensional relationships with an ever-widening set of partners to achieve impact. These are initiated through a variety of approaches including individual academic and alumni networks, disciplinary communities and project collaboration. Consultancy agreements, student co-supervision, and partnership on small/medium sized funded projects assist with establishing trust, mutual respect, and an interchange of technical knowhow and appreciation of complementary competences. This model builds towards larger projects, potentially leading to the development of adopted/exploitable products or policy changes. The Unit has a strategy for impact that is:

1. To establish long-term research and development partnerships with national and international industries, organisations and academic leaders;
2. To supply training and mentoring for all research active staff to promote and enhance impact via external collaborations and audiences, reinforcing this through staff development;
3. To develop and facilitate pathways to impact for all substantial research projects;
4. To maximise tangible benefits and impact from collaborative research through entrepreneurship that generates income, patents and start-up opportunities; and,
5. To undertake public engagement activities for all substantial research projects in collaboration with UWE's Science Communication Unit.

As described in the Institutional-level Environment Template, UWE's Research, Business & Innovation team (RBI) is tasked with facilitating partnership and impact through a wide range of activities, including collaborative and contract research, knowledge and technology transfer, commercialisation, consultancy, enterprise, IP, professional development, and a range of different types of business and community engagement including innovation networks. The Unit has established a close working relationship with RBI to ensure continued impact from its

research. For example, RBI expertise supported all of the Impact Case Studies submitted by the Unit, providing support for intellectual property protection and licensing and spin-out advice. Other recent activity for the Unit includes supporting eight Knowledge Transfer Partnerships and obtaining a number of patents, including those relating to work emerging from an on-going collaboration with Airbus on process modelling (US9372667) and a number around memory allocation in parallel kernels (US0337587, US9244828, US9424099). The Airbus line of research continues one previously submitted as an Impact Case Study in 2014.

The Unit is submitting three impact case studies, two of which share their foundations with two of those submitted in 2014:

The CRISTAL-ISE study demonstrates the value of developing and exploiting long-term partnerships both with large European organisations (such as CERN, where the outcomes of research in the CSRC have been used to support the construction and running of the Electromagnetic Calorimeter of the CMS experiment at the Large Hadron Collider) and commercial organisations (e.g. Swiss company iCube and French company Agilium). This work was initiated in 1996 through CERN's Doctoral Scheme (4 PhD positions), grew with a Royal Academy of Engineering International Fellowship (1997-99), and then developed into a number of major EU projects (Health-e-Child, neuGRID, N4U, CRISTAL-ISE). This research has led to the establishment of a start-up company to further improve the reach of the impact.

The BETTER STATISTICS study began as a period of consultancy work won under tender (2006-07), which led to a CASE PhD Award with the Office for National Statistics (ONS) 2007-10, in collaboration with colleagues in UWE's Mathematics department. The CASE Award led to the adoption of the UWE methodology at ONS and additional ONS funding to integrate it into existing systems under licence from UWE. The work is on-going through consultancy and contract research agreements both with ONS and other similar European government agencies.

The MUSICAL GLOVES study shows the benefit of interdisciplinary research again initiated with consultancy funding, a variety of contracts, eventually leading to the establishment of a start-up company - MiMu - to commercialise the developed technology. Moreover, much wider impact through a variety of public engagement activities has emerged as a consequence of this research and subsequent technology development.

Not all of the impact activities in the Unit are industrially driven, as demonstrated by its public engagement work around computation in the natural world and creative technology. In the former case, since 2014, as part of two EU projects exploring the computational properties of slime mould – PhyCHIP and PhySense – members of the UCG have created eight art installations at locations across Europe, as well as participating in public outreach events such as Bristol Bright Night (2014) and "Lange Nacht der Forschung" at various venues in Austria (2015). Alongside appearing in a wide range of public science and general media articles, the work and members of the UCG feature in the award-winning documentary "The Creeping Garden" (Best Director, Fantastic Fest, Texas, 2014) which has been shown at many film, science, and art festivals around the world. The work also appears in two recent documentaries, Blob (2020) and Computing Garden (2020). The later stages of the PhySense project created an online citizen-science resource where participants could explore the biophysical response of cultured slime mould sensors to stimuli of their choice, with the ability to upload images and simple sensor readings to an open database. Unit members are regular contributors to the popular annual Cheltenham Science Festival, a long-standing education and outreach event co-founded by UWE – featuring the likes of Richard Dawkins, Brian Cox, Alice Roberts, and Robert Winston. The Unit increasingly collaborates with UWE's Science Communication Unit, an internationally renowned centre that has been advancing the science of public engagement for nearly twenty years.

Interdisciplinarity

The Unit places very high value on interdisciplinarity in its research strategy. All our groups are actively involved in interdisciplinary research, ranging from slime mould computing (UCG) to

application areas such as urban planning and policy modelling (CSRC). For example, building on the successful EPSRC Bridging the Gaps project "Health, Environment and Technology Research: HEAT@UWE" (EP/H000380/1, 2009-12) which supported interdisciplinary collaborations between colleagues across UWE, new collaborations have been formed and new externally-funded projects undertaken during this REF period, including 17 national and international external partners, e.g. EU FP7 project UrbanAPI (CSRC). This activity has markedly increased institutional expertise in interdisciplinary research. Outputs included a Best Practice Guide for Interdisciplinary Research report for the EPSRC, distributed nationally to all Bridging the Gaps project holders.

An example of on-going research initiated under the original HEAT mechanism is work by members of CTL, and colleagues in the Allied Health Professions department. This focuses on the use of gaming technology, specifically 3D avatars, in the treatment of people with persistent pain, in particular those with complex regional pain syndrome whose perception of parts of their body has been altered. An on-screen image of a 3D human figure can be manipulated to give an impression that accords with their perception. Users can resize and reposition any body parts that they feel are different and apply textures to represent perceived sensations such as burning, cold, hard 'stone like' feelings, or the feeling of body parts being insubstantial. The work has broadened in scope to create a more general, parameterised patient avatar under a project funded by the Nottingham University Hospitals NHS Trust. Other collaborations formed under HEAT have continued to secure prestigious funds during the period, including the EU H2020 project ClairCity around air quality with partners in Geography, and green energy technology projects discussed in Section 4 below, funded by the Leverhulme Trust and the EPSRC with partners in Engineering.

Since the EPSRC funding finished, the Faculty – as original host to HEAT - has maintained the approach and arranges themed introduction meetings and/or workshops followed by the competitive allocation of small grants for new interdisciplinary collaborations. Recent awards involving Unit members include app development to encourage walking in a variety of different social groups with partners in Geography, cyber-security in space with partners in Engineering, and capturing and modelling traditional water stewardship in Asia with partners in Geography. A further source of funding which encourages cross-UWE pilot projects is available annually under the Vice Chancellor's Interdisciplinary Research Challenge Fund. The Unit has been a key partner in the majority of projects funded by the Vice Chancellor's Fund, with CSRC and/or CTL involved in over half of all projects to date (13 out of 20), including projects to develop chatbots for the cognitively impaired with partners in Allied Health, generative deep nets for video content creation with partners in Filmmaking, novel musical interfaces with partners in Fine Print, and modelling acoustics within virtual reality with partners in Architecture.

Open environment

As can be seen in the Institutional-level Environment Template, UWE was an early adopter of an open access repository including an ePrints data repository. The principles of - and possible pathways to - open access have been promoted by UWE's Library staff for a number of years through online material, workshops, and drop-in sessions. Moreover, all new staff and doctoral students attend training in open research as part of UWE's Researcher Skills Development Programme and, as of 2019, all research staff and students are expected to make their data open access through the institutional data repository. Unit staff are able to make use of UWE and Faculty funding for open access publication for both UKRI and other externally-funded research. Staff are also encouraged to use other appropriate means by which to share their research results and code (to aid uptake and reproducibility), such as arXiv and GitHub.

Integrity

UWE is committed to promoting excellent research which observes the highest possible standards of integrity, as detailed in the Institutional-level Environment Template and embodied in its Code of Good Research Conduct. Locally, alongside Faculty-wide and external representation, three Unit members form part of the Faculty's Research Ethics Committee which undertakes all student and staff research ethical approval procedures. All staff are required to

complete an on-line research ethics module. The previous chair of the Committee – covering the first half of the reporting period - came from the Unit. Where wider issues emerge, they can be escalated to the UWE Research Ethics Committee. The RBI team and other central services support members with all aspects of governance and integrity including data protection and management, legal frameworks and contractual requirements, IP issues, and external ethical approval procedures.

2. People

Staffing Strategy

The Unit's submission consists of outputs from a mix of staff with significant responsibility for research, including promising early career researchers through to experienced senior staff: 2 lecturers, 13 senior lecturers, 7 associate professors, and 7 professors. The Unit's overarching staffing strategy is to maintain breadth and depth both in terms of specialisms and demographics within a given research area identified as strategically important. In the current REF period, six senior lecturers were promoted to associate professor, as were two from associate professor to professor, one of whom was a UWE Wallscourt Professorship, representing targeted institutional investment into data science. To reinforce leadership and to provide succession planning, one associate professor post is maintained in areas where a professorial post exists. Recruitment of research assistants/fellows is largely based around externally funded projects, with selection panels chaired by the host group's lead to ensure an appropriate profile for group development, alongside the project requirements. Over 40 such positions have been created during the reporting period via a wide portfolio of projects. Several new-blood academic posts have been created to target mixed teaching and research positions with more emphasis upon the latter, one (in CSRC) in this Unit. These posts underpin established areas but with a view to moving into emerging topics, as identified at the Unit level. Target areas are typically identified to achieve synergy between teaching and research. The Unit has chosen to invest particularly in cyber security and the creative technologies over the reporting period, with four lecturers and one associate professor recruited in each area.

The Unit has also recruited five Graduate Tutors during the reporting period. These five-year posts support staff to pursue a part-time PhD alongside their teaching and learning experience, including support for lecture preparation and delivery. These roles are part of a Faculty initiative to support succession planning and promote promising academic careers. At the end of the five years, it is anticipated that such staff will be in a strong position to progress to academic posts and become fully active researchers.

Staff Development

All staff (research assistants to professors) undertake regular performance and development reviews which involve an annual meeting for each individual, as well as a number of catch-up meetings throughout the year. These meetings are carried out by the line manager, with the annual meeting the main focus for determining personal plans and development activities with respect to UWE, Faculty, Unit/group and individual priorities. For new staff, this process is replaced by a one-year probationary period which further includes the designation of a mentor, a two-year as-of-right research time allocation, as well as ensuring any immediate training needs identified at the point of recruitment are met. Staff are strongly encouraged to attend and give Department seminars, as well as to attend the regular development courses provided by RBI. These include transferable research skills (project management, communication skills, proposal writing) to complement specific technical skills required for their disciplines. The service also provides advice suitable to staff at all levels in the development of professional and business skills such as routes to impact, intellectual property rights, entrepreneurship, spin-out companies, and patent applications. Support to attend external training/events is also available. The University's Researcher Skills Development Programme is mapped to the Vitae Researcher Development Framework and its commitment to the Concordat to Support the Career Development of Researchers is evident in holding the HR Excellence in Research Award since 2012. In line with the Concordat, the Unit encourages its research assistants/fellows to enrol in

the University's Academic Development Programme which is accredited by the Higher Education Academy and obligatory for all new early career academic appointments. The programme is designed to build an understanding of the structures and mechanisms within which academics operate as researchers, administrators, managers and teachers. The effectiveness of this approach is demonstrated through two staff within the Unit who began their careers at UWE as postdoctoral researchers on fixed-term contracts and have now progressed to permanent roles as lecturers via a competitive appointment process.

Early Career Researchers
The Unit is committed in its support for early career researchers, in line with the Concordat to Support the Career Development of Researchers. This includes encouraging the involvement of Unit researchers in the Researchers' Forum, a university-wide activity designed to provide a space for research grade staff to meet and consider matters of common interest, including career development opportunities. Unit researchers are also encouraged to engage with the Concordat Implementation Working Group, comprising the Researchers' Forum Convener, research staff representatives, HR, the Graduate School and RBI.

New members of staff are able to apply for Vice-Chancellor's Early Career Researcher awards designed to support emerging researchers in priority areas. Staff in the Unit have won seven VCECR awards since 2014 in the areas of cybersecurity (cryptography, android malware, blockchain, IoT devices) and creative technologies (generative music composition, underwater imaging, VR). Approximately a third of people submitted by the Unit in this REF are in their first academic staff position, with around a quarter identified as early career. Both early career staff and postdoctoral researchers are encouraged to share their research activities and interests through giving seminars within their host group and the Unit's Department, as well as guest lecture slots within appropriate taught modules. Collaboration in joint publications and involvement in applications for funding is actively encouraged and supported by group and project leads.

One member of the Unit participated in the first round of a new Vice-Chancellor's Accelerator Programme for mid-career academics introduced in 2019, designed to develop their external bidding activities in particular, as described in the Institutional-level Environment Template. Three others have been involved in a similar scheme introduced within the Unit's host Faculty in 2020.

Research time
All academic staff have an allocation of 25 days a year to undertake research and scholarly activity. Support and guidance are provided for those who wish to use this time for research and impact (others may use it to develop their teaching). Additionally, academic staff are able to bid for up to 20% of their time annually to undertake research through a competitive Faculty-wide scheme. This time is typically taken throughout the year rather than in a concentrated period of research leave or a sabbatical. Professors and associate professors have additional as-of-right time allowances for research and research leadership. Staff successful in bidding also have externally-funded research time for the delivery of specific projects.

Research Exchanges
A key aspect of the Unit's staff development is to make use of the significant potential for academic enrichment through externally funded fellowships and visiting scholars. Visitors and wider virtual academic networks promote sustainable collaboration and encourage research 'without borders' thereby enabling, for example, involvement of the most appropriate international individuals in research challenges currently being faced. This is particularly encouraged around achieving impact with staff able to apply annually for workload allowances to undertake periods of residency within external organisations, as occurred in the cases of the data disclosure and gesture collaborations (see Impact Case Studies). Other notable examples during the period include:

Leverhulme Trust Visiting Professorship – (UCG, 2019-2020). Professor Eric Goles of the Universidad Adolfo Ibáñez, Chile spent six months at UWE working with members of the UCG on both automata network theory with respect to computational complexity and on the physical realisation of examples of different classes of such networks in a variety of media;

Royal Society International Exchange – Andriotis (CSRC, 2018) undertook a four month visit to the National Institute of Informatics (NII), Tokyo, Japan to consider how to embed privacy into social media streams, for example by the automatic detection and blurring of any faces not belonging to the main participant;

Great Britain Sasakawa Foundation Grant – Andriotis (CSRC, 2017) undertook a two month visit to the NII to consider aspects of the then new fine-grained access control of Android and how users engage with it;

King Hussain Cancer Care Hospital Visiting Professorship – Odeh (CSRC, 2019-present) is on an on-going secondment to a hospital in Jordan to aid the development of cancer care informatics in R&D and postgraduate education, working alongside key senior oncologists, cancer care professionals, as well as other visiting international scholars and physicians.

Staff Reward

A number of reward mechanisms are available to Unit members, including: Professorial Merit Pay, an annual scheme with the aim of recognising and retaining high-performing senior staff; the Exceptional Contribution Honorarium scheme, an annual process through which Department management teams can give recognition to individuals and/or groups of individuals who have made a significant impact to one or more aspects of the University, including research; and, Researcher of the Year, an annual scheme through which staff in each Department can nominate an individual who has performed exceptionally, e.g. through outstanding publications, prizes or impact. For example, the 2019/20 winner of the latter award was a member of CTL (Reed), in recognition of both his novel work on the emerging field of spatial audio for virtual reality and his being awarded an Immersion Fellowship by the South West Creative Technologies Network. The network is funded by Research England's Connecting Capabilities initiative.

Postgraduate Research Students

Within the Unit, there is a commitment to maintaining a vibrant and high quality population of research students. For example, as noted above, funds for bursaries have been provided to help enable a strategic approach to support areas of strength or development within groups, such as cybersecurity, data science, and IoT. All research students have a Director of Studies (DoS) supported by other academics as part of a supervisory team. The DoS is the academic lead with overall responsibility for supporting the student through their research degree. Each potential student is interviewed by a panel prior to enrolment, chaired by the Department's member of the Faculty Research Degrees Committee, a role taken by a member of the Unit throughout the reporting period. The member of staff identified as most likely to become the DoS, either from having set the topic of an advertised bursary or from the topic of the application, and those most likely to form the rest of the supervisory team (up to 3) will constitute the interview panel.

As detailed in the Institutional-level Environment Template, UWE has a university-wide Graduate School to provide a consistent and well-resourced support service, enable the sharing of good practice and support for cross-disciplinary research. The UWE Code of Practice for Postgraduate Research Study, closely aligned to the QAA Code of Practice, sets out the support with respect to postgraduate research degrees. The Graduate School offers general and personalised advice to research students about their training needs and each newly enrolled student has their training needs assessed with the supervisory team. A programme of research training workshops is provided to give both essential research skills and transferable skills. Topic-specific level M taught courses offered by the University can also be taken.

The Unit expects that all students will write and present a paper(s) for an external event(s),

ranging from a UK workshop to international conferences, closely mentored by the supervisory team, with further support via writing courses available in the Faculty and Graduate School. The Faculty runs an annual one-day conference at which students from all Departments present work in mixed sessions thereby encouraging cross-disciplinary discussions and the sharing of good practice, as well as aiding preparation for external events. Sessions are chaired by senior academics, with further questions and feedback provided by supervisory team members and other academics. Groups encourage their students to attend and/or give regular seminars, and to interact with visiting academics and project-based researchers. Each group maintains a lab space to support a lively, interactive community of research staff, students and visitors.

As part of the Unit's impact strategy, studentships are made available where 50% of the direct cost is contributed by an external partner, initiated by a lead academic as part of their networking activities. The set-up process is aided by RBI with respect to IP issues, confidentiality and collaboration agreements before the student is recruited. A representative from the partner organisation typically forms part of the interview panel and supervisory team thereafter. Current partners reflect a wide range of commercial organisations, including Airbus, local SMEs (e.g. Techmodal Ltd, Montvieux Ltd) and a start-up (Altered Carbon Ltd).

In line with UWE's regulations, student progress is formally monitored annually with separate forms from the student and supervisory team scrutinised by a Faculty Research Degrees Committee enabling, for example, the identification of good practice and students requiring extra support. Supervisory teams are expected to meet with the student regularly and maintain an agreed record of the outcomes. Students must produce a Progression Report before the end of the first 12 months (or equivalent for part-timers) of study, which is examined via viva voce by two members of staff not directly involved with the research/supervision. The outcome determines whether the student continues. Procedures exist for students to apply for leave or suspension from their studies at any time, with such applications to the Committee typically made with the support of the supervisory team. The Unit put in place extra social media and video conferencing groups with and without supervisory team member presence for all students in March 2020 in response to the closure of the University campus due to COVID. Results in the 2019 Postgraduate Research Experience Survey indicate the effectiveness of both the Graduate School and Unit's support processes described, with computer science students reporting 100% satisfaction in areas across their studies, from induction, to library support, to professional development, through to understanding the final submission process.

Equality, Diversity and Inclusivity

Inclusivity is one of UWE's five key values, in both its 2020 and 2030 strategies, and examples of associated mechanisms and activities through which this is achieved are described in the Institutional-level Environment Template. Staff in the Unit are involved in a number of them, including acting as mentors in the Women in Research Mentoring Scheme. The host Department is currently undertaking the subject specific Athena SWAN process for a 2022 submission.

Over the reporting period there has been an increased awareness of the need to recruit from all sections of the population. Monitoring data demonstrates that this has been effective for BAME representation - the 2014 REF submission for the Unit did not contain any BAME staff but now includes 38%. Although there is still a way to go, the gender balance has begun to improve, with female staff accounting for 7% of the submission compared to 0% in 2014.

Part-time staff have access to the same career pathways as full-time staff, with criteria for promotion being designed to take account of the impact of part-time working on productivity. Fixed-term contract staff are supported to develop and apply for promotion from research associate to research fellow and from research fellow to senior research fellow. As noted, two fixed-term research staff have moved into permanent academic positions during the reporting period.

A fund is available for students to attend conferences or workshops during their period of

registration. Through implementation of the Athena SWAN action plan, since 2018 caring costs have been included as an allowable expense for students attending conferences.

The Unit aims to ensure that no staff are disadvantaged in seeking support for research activities of any kind and group leads, supported by UWE's Equality, Diversity and Inclusivity team, are charged to make sure all of their staff are aware of appropriate opportunities and sources of help and advice. For example, the Department supports staff to attend external training, which includes specific women in leadership and BAME leadership programmes. Engagement with UWE's Learning and Development Centre, as detailed in the Institutional-level Environment Template, is also actively encouraged for staff at all career stages. Similarly, group leads are regularly made aware of support and initiatives emerging from UWE's Mental Wealth First strategy.

Within the Unit, staff have been identified as having significant responsibility for research, being independent researchers, and outputs have been selected, in strict accordance with the University's Code of Practice. This includes selecting outputs on the basis of their quality as determined through a thorough peer review process involving internal and external reviewers. As stated in the Code, there was no expectation about the number of outputs any one individual contributed to the submission. Where it was necessary to choose between a small number of outputs with the same quality score to reach the required total, account was taken of the distribution of outputs between individuals and across the subject areas of the submission.

Section 3. Income, infrastructure and facilities

Research income

The Unit's strategy is for groups to maintain a wide portfolio of external funding. The total amount of funding over the reporting period of around £7M has been achieved with support from RBI, including a weekly funding and networking opportunities update, bid writing workshops, a peer review process, a mentoring scheme and maintenance of a research expertise directory for both internal and external collaborators. Cross-group collaboration in responding to funding opportunities is frequent; for example, the current EU H2020 project EvoNano which is a collaboration between UCG and CSRC (2018-2021, £356k to UWE) looking at nanoparticle design via AI techniques for cancer treatment. Members of the Unit are part of a Faculty Industrial Strategy Working Group which was formed to aid the engagement of the Unit's groups with emerging Government initiatives. This has proven to be particularly significant for the early career members of the Unit where funding has been obtained across the range of size and scope of projects, from Grants4Growth, to Defence Science & Technology Laboratory, to KTPs, through to Innovate UK projects.

More specifically in relation to research grants and related infrastructure and facilities:

The Computer Science Research Centre has lab space with bespoke network and server resources, a variety of 3D printers, and embedded systems facilities both for the production of novel hardware and for cyber security research on small devices. The research portfolio ranges from large-scale, international multi-partner projects involving academic and commercial partners, to smaller industrial strategy projects. Notable examples include a series of EU grants concerning various aspects of smart cities, EPSRC and Leverhulme Trust funding for green energy through AI projects, and Innovate UK projects on assistive robotics. The value to UWE over the period is:

- EU H2020: 3 grants, £0.6M
- RCUK: 2 grants, £0.4M
- Government (KTP, Innovate UK, TSB, etc.): 23 grants, £2.5M
- Charities: 1 grant, £0.1M
- Industry: 9 grants, £0.2M

The Creative Technologies Lab has dedicated multimedia research labs and facilities, including sound-treated audio/video studios, dedicated compute servers, and immersive and motion tracking systems. The portfolio ranges from one international and a number of UK multi-partner interdisciplinary projects involving academic and commercial partners, to smaller commissions. Notable examples include an AHRC funded fellowship exploring gestural composition through the Bristol and Bath Creative R&D network and an AHRC Knowledge Exchange Hub (South West) project exploring real-time, online collaboration between musicians. The value to UWE over the period is:

- RCUK: 2 grants, £38k
- Government: 3 grants, £170k
- Charities: 1 grant, £99k
- Industry: 3 grants, £30k

The Unconventional Computing Group supports cross-university collaboration centred in this Unit with newly created dedicated lab space representing an investment of ~£150k to enable the creation of computing devices from a wide range of novel materials, from living substrates to nanoscale components. The research portfolio includes EU, EPSRC and Leverhulme Trust funding for projects exploring chemical, slime mould, and fungal computing and sensing. The value to UWE over the period is:

- EU H2020: 4 grants, £2M
- RCUK: 1 grant, £0.7M
- Charities: 3 grants, £0.4M

In addition to the Unit's own infrastructure and facilities, staff in the Unit benefit from a strong working relationship with the Centre for Data Intensive Science at the University of Chicago established under a previous EU project (neuGRID) through which it has access to the Open Science Data Cloud (OSDC). The OSDC provides the scientific community with resources for storing, sharing, and analysing terabyte and petabyte-scale scientific datasets. For example, this enables access to complementary public datasets, the building and sharing of customised virtual machines, and a wide variety of data analysis tools.

As part of the Athena SWAN submissions being undertaken by Departments across the Faculty, the issue of gender and equal access to research infrastructure and support has been investigated through a staff survey. The results show staff find the environment very supportive, with no significant difference between genders.

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

Collaborations

As noted, one of the primary vehicles by which members of the Unit undertake research collaboration is through joint projects, ranging in scale from consultancy through to multi-national EU projects. The Unit has been involved in seven EU projects during the period, representing a collaborative network of over 50 partners in 20 countries. For example, a series of EU funded projects developed with colleagues in urban planning at UWE have served as the foundation for two British Council funded collaborations (CSRC, 2016 and 2019) with Taylor's University, Malaysia exploring smart sustainable cities within developing countries. The funding enabled CSRC staff to spend time at the collaborating institution, organising workshops at international events, as well as generating research outputs.

Other examples of international collaborations of varying scale include: a British Council funded project (CSRC, 2018) to provide timely crop-related information to farmers in Egypt in collaboration with Fayoum University; two EU Cooperation in Science and Technology (COST Action) short-term scientific mission (STSM) grants to enable members of the CTL (2018 & 2019) to visit partners at the Institut des Matériaux Jean Rouxel, France to consider the

exploration of game engines in modelling composite materials; and, a COST Action involving the UCG and the Institute of Medicine, Croatia to consider self-propulsive nano-particles for cancer treatment as a consequence of their involvement in the EvoNano EU project (UCG & CSRC, 2018-2021).

Regional collaborations have flourished during the current REF period, including those building on our earlier highly successful European Regional Development Fund (ERDF) Innovation and Knowledge Network programmes – iNets (~£4M). Led by UWE, the iNets provided direct funding, advice, support and networking for small/medium enterprises and organisations across the southwest in microelectronics, environment, and bio-medicine. These spawned regional collaborations that have flourished in the current REF period. For example, a collaboration with a national charity for the disabled based in Bath, Designability, was funded via Innovate UK (CSRC, 2016-18). Members of the Unit have used HCI and AI techniques to help develop a multi-purpose robotic arm for assisted living. Along with Designability, the team have been invited to join the Lloyds Register Foundation's Assuring Autonomy International Programme based at the University of York which has commercial, charity and academic partners from across the globe. Unit members are developing safety standards and processes for the deployment of assistive robotics in healthcare, and these will form part of the Foundation's 'Book of Knowledge' which the Foundation intends to become the definitive reference for the regulation of autonomous systems.

Engagement

The Unit has a long history of engagement with – and impact upon - communities outside of academia. For example, since 2011 members of the CTL have been involved in a range of immersive and virtual reality interactive art-science installations including "Danceroom Spectroscopy", "Transmission" and "Figuring". In these projects, participants' movements are captured and embedded within rigorous molecular/epidemiological simulations and rendered in real-time to produce engaging audio-visual effects. Building on events at the London 2012 Cultural Olympiad and the 2013 World Science Festival in New York, exhibitions, performances, workshops and outreach have continued at the 2015 Bhutan International Festival, and for three months at 'We the Curious' science centre, Bristol in 2018. This work has won five awards including a UK National Research Engagement Award 2014 (Established Project category) and an Honourable Mention at Prix Ars Electronica (Hybrid Arts) 2014. The projects, in collaboration with partners from the universities of Bristol and Bath Spa, as well as numerous independent artists and performers, have been supported by the Arts Council England, the EPSRC, the Royal Society, and the Royal Society of Chemistry. Most recently, the work has been supported by the Leverhulme Trust, Royal Society and an Academies Apex award to support excellence in cross-disciplinary research (CTL, 2018-20).

Between 2016 and 2019, in a new partnership with Knowle West Media Centre (KWMC), members of CSRC developed 'UWE Sense', a low-powered portable sensor system designed to measure pollution experienced by residents. The KWMC is a local charity which works with people from diverse backgrounds to develop new and creative models for achieving positive social change. KWMC's co-design process, called the Bristol Approach, has been applied to develop sensor in-closures with school students from east Bristol and Ladybird sensors that can be hooked on a backpack or connected to a bike. The device was launched with women cyclists in Bristol (September 2018), with initial trials running for a month. The trial provided evidence of poor air quality which were reported to Bristol's DIY Tech Fair (October 2018).

UWE Sense is a general platform for low-power, low-cost sensors, with a Bluetooth 5 control system, and support for a wide variety of sensors, e.g. NO_x, and includes a UWE-Sense/Bristol Approach Android/iOS application that gathers data from the sensors and communicates with the Data Unity cloud services. The team has now created a second generation UWE Sense platform utilising a graphene-based gas sensor that is deployed as part of Bristol City Council's Legible City project – a live map infrastructure across the city centre. The data from this smart city application is also being used to inform city planning around air quality management. The graphene gas sensor technology has been developed in partnership with local SME Altered

Carbon Ltd, including a co-funded PhD as noted above. As a result of this evolving collaboration with the SME, physical computing now forms a recognised theme within the Internet of Things thread of the Unit's main research centre – CSRC.

With the aim of forming new relationships to open up new funding and impact opportunities, the Unit ran the first of a planned annual day-long showcase event in 2019 to be held at various venues in the city centre. Selected staff and students presented their work to an open audience, including invited guests from existing collaborators but also targeted external organisations. The initial event was based at a local arts centre and included a talk and live music performance by two-time Grammy award winner Imogen Heap through the Unit's involvement in MiMu's digital gloves, as detailed in the associated impact case study. In particular, and as planned, staff reported making many new local connections during the event. As a consequence of COVID, a virtual event was held in 2020 and physical events will resume as soon as conditions allow.

The Unit works with diverse communities through its outreach and public engagement activities. For example, the aforementioned three-month Danceroom Spectroscopy exhibition in 2018 was held at We The Curious, a local – and internationally renowned - public science venue which specialises in promoting and providing free access for underprivileged groups, including refugees and asylum seekers. Moreover, members have worked with children and young adults with a variety of disabilities. For example, members of CTL have an on-going collaboration with the UK's only disabled-led, regional youth orchestra (South West Open Youth Orchestra) and Open Up Music, which aims to make orchestras accessible to young disabled children, to perform pieces specifically composed for instruments designed for disabled musicians. These instruments are capable of capturing different types and degrees of physical movement. In collaboration with King's College London, members of CTL are also studying the impact of drumming on brain development in autistic children. In a collaboration led by Exeter University, through AHRC funding (CSRC, 2016-20), members have applied HCI techniques to explore the effects of early years powered mobility devices/chairs and telepresence robots on the physical and cognitive development in young children.

Wider Contribution

Examples of our strategy to promote on-going, inter-disciplinary research with wider scope, include work initiated under the HEAT mechanism discussed above, including the SAM App project. SAM is a mobile application being developed to enable personalised anxiety monitoring and management, and represents a collaboration between members of the CSRC and colleagues in the Psychology department. It is being supported by UWE as a future resource for both students and the wider public, with more fundamental research having been supported by HEFCE (CSRC, 2018-19). The app has been downloaded well over one million times in 218 countries, reaching the top 100 health apps in 106 countries on Apple and the top 100 health and fitness apps in 15 countries on Android. It has been covered in a variety of media, such as the BBC World Service, Teen Vogue, and the British Psychological Society.

A further example has arisen from the series of EU projects in CSRC mentioned above, where Unit research has created new insights for organizations involved in civic planning and administration, and enabled a fruitful exchange of knowledge between diverse stakeholders including urban planners, transport planners, IT experts, GIS experts and citizens. The approach first manages requirements through collaborative digital tools such as the open source content management system, Redmine, and then produces a set of evaluation criteria designed on stakeholders' functional and non-functional requirements (based on ISO25010). For example, WeLoveTheCity is a social innovation company based in Rotterdam, specialising in participatory planning and design. WeLoveTheCity used CSRC research to develop their understanding of technology strengths and limitations in participatory urban planning, and successfully applied this knowledge in citizen participatory events, known as 'smartathons'.

The collaborative culture fostered by the methodology also helps technology providers more clearly understand user needs and develop software that addresses these needs. For example, the Sustainable Buildings and Cities Unit of the Centre for Energy of the Austrian Institute of

Technology (AIT), Vienna, is a commercial research and technology organisation, which partners with both public authorities and industry. AIT made use of the CSRC method to identify a set of requirements for its 'mobility explorer' product used by local government in Vienna, Vitoria-Gasteiz, and Bologna. The product uses telecom data to identify and visualise population distributions and mobility patterns in a city, thereby enabling transport planners to see where people spend their time, where they come from to work in the city, their mode of travel, etc.

Research within the Unit has addressed a number of key national/international priorities, including those of climate change and an ageing society. In the former case, 3D printing has been used to exploit the capabilities of AI directly in physical space, i.e. without the requirement for sufficient understanding to build accurate models/simulations. Through funding from Leverhulme Trust (CSRC, 2014-16) and EPSRC (CSRC, 2016-18, the approach has been applied to the design of arrays of novel vertical axis wind turbines and microbial fuel cells, in collaboration with colleagues in Engineering and Microbiology respectively. The wind turbine work was undertaken in conjunction with a local green energy SME and efforts towards its exploitation are on-going. Similarly, smart home technologies for the elderly are being developed using AI and HCI techniques. For example, in collaboration with the ExtraCare Charitable Trust, who own 16 residential care homes nationally, digital assistants and sensor networks have been developed in situ (CSRC, 2017-19). The work has also led to contributions to national charity Skills for Care's 2018 scoping report on the emerging use of AI in social care.

Contributions to the discipline

The Unit can be seen to have contributed to the sustainability of the discipline over the period in a number of ways, ranging from Editor-in-Chief roles, including for journals founded by members (as detailed below), editing a book series entitled "Emergence, Complexity and Computation" (Springer, Adamatzky), to undertaking international conference hosting and organising roles (also detailed below).

Indicators of the influence of the Unit's members, such as contributions to and recognition by the research base during the reporting period, include:

Editorships: Founding Editor-in-Chief *Cellular Automata*, Old City Publishing Ltd. (Adamatzky), *Evolutionary Intelligence*, Springer (Bull), *Unconventional Computing*, Old City Publishing Ltd. (Adamatzky); Editor-in-Chief *Parallel, Emergent and Distributed Systems*, Taylor & Francis (Adamatzky), *Parallel Processing Letters*, World Scientific (Adamatzky); and, Unit staff serve on the editorial boards of over twenty journals, including Evolutionary Computation (MIT), Soft Computing (Springer), Memetic Computing (Springer), Information Sciences (Elsevier), Nano Communication Networks (Elsevier), BioSystems (Elsevier), and Frontiers in Robotics & AI.

Reviewing: REF2014 Sub-panel member Computer Science & Informatics, EPSRC College members (5), EPSRC Panel membership during the period (4), EU FP7 and Horizon 2020 project reviewing, UKRI AI CDT Panel, NCSC / EPSRC PhD Studentship Scheme for ACE-CSRs Panels, and international Government body reviewing (Australia, Belgium, Canada, New Zealand, Poland, USA).

Committees: IEEE Emergent Technologies Technical Committee, IEEE SMC Society Technical Committee on Soft Computing, IEEE Computational Intelligence Society Technologies Task Force on Unconventional Computing (Committee Chair), IEEE Computational Intelligence Society Technologies Task Force on Bio-inspired, Self-organising Collective Systems (Committee Chair), the IEEE Computational Intelligence Society Technologies Task Force on Memetic Computing, BSI AMT/010 Robotics committee, and the AMT/010/01 Ethics for Robots and Autonomous Systems committee.

Events: Unit members regularly review for a large number of conferences, have undertaken Chair roles for six conferences during the period, including IEEE and ACM events, and have given many invited talks. Of note, as part of on-going work at CERN, and as described above and in the CRISTAL-ISE impact case study, McClatchey (CSRC) was invited to speak at its 60th

Anniversary event in 2014, as well as contributing a chapter to the associated book. More recently, in 2020, Caleb-Solly (CSRC) served as a witness for the House of Lords' Science and Technology Committee as part of its inquiry into Ageing: Science, Technology and Healthy Living which is considering how technology can help ageing people live more independently and more healthily.