Institution: University of Ulster

Unit of Assessment: UoA 11: Computer Science and Informatics

a. Overview

Research in Computer Science and Informatics at Ulster is carried out within the Computer Science Research Institute (CSRI), established in 2004 within an institutional strategy to facilitate selectivity in research support. CSRI comprises 4 research groups: Information & Communication Engineering (ICE); Artificial Intelligence & Applications (AIA); Smart Environments Research Group (SERG); and the Intelligent Systems Research Centre (ISRC). The research groups are campus-based, comprising staff from 3 campus-based Schools within the Faculty of Computing and Engineering: SERG and AIA at Jordanstown campus; ISRC at Magee campus; and ICE at Coleraine campus, but with specific project-based and theme-based collaborations between the research groups. CSRI is managed by a Director, Scotney (Prof. of Informatics), with an Executive of group leaders: ICE: McClean (Prof. of Mathematics); AIA: Wang (Prof. of Computer Science); SERG: Nugent (Prof. of Biomedical Engineering); ISRC: McGinnity (Prof. of Intelligent Systems).

b. Research strategy

b.1 *Evaluation of Strategic Achievements*

Over the assessment period CSRI has nurtured strategic aims to enable sustained expansion, with particular focus on intelligent systems, assistive technologies, next generation networks and semantic analytics. Research group structures have been strategically refined and extended:

- **ICE** (5 staff) has developed from the ISE group reported in RAE2008, with focus on knowledge engineering and data analytics, applications in healthcare modelling and computer vision, and increasingly, performance management of next generation networks, systems and services.
- **AIA** (10 staff) is part of the Artificial Intelligence group reported in RAE2008, focusing on pattern recognition, reasoning, and semantic analytics, with applications in text mining, intelligent document analysis, ambient assisted living, and security-based scenario recognition.
- **SERG** (8 staff) has developed strongly from the AI group in RAE2008, with multi-disciplinary and collaborative research in sensor-based technologies, and applications in behavioural analysis, activity recognition, and assistive technologies for healthcare and independent living.
- **ISRC** (19 staff) is an expansion of the Intelligent Systems group reported in RAE2008, developed through new academic and research appointments and significant investment in new facilities and infrastructure, focussing on cognitive robotics, computational neuroscience, and biologically-inspired computation, with applications in robotic systems, neural modelling, and BCI.

The main strategic achievements across CSRI over the assessment period have been:

- Sustained increase in outputs in journals with high editorial standards; e.g., this submission has 49 papers in IEEE/ACM Transactions (compared with 40 in RAE2008, and 8 in RAE2001).
- An over 400% expansion in contract research staff time compared with RAE2008: 106 FTE (95 FTE in new posts), totalling 238 person-years, in this submission (cf. 17 FTE in RAE2008).
- Expansion of international academic collaborations through EU projects; research exchange arrangements in Europe, China, India and S. Korea; and leading UK-India research cooperation. 40% of the outputs in this submission have collaborating authors in other academic institutions.
- Significant expansion of collaborations with industry, through direct partnerships, large-scale project consortia, and industry-funded PhD studentships. Funding from industry and public corporations has doubled to £670K (from £330K in RAE2008).
- A 173% increase in annual expenditure on research awards compared with RAE2008. Total award expenditure was £18.55M, compared with £8.17M in RAE2008 and £5.5M in RAE2001.
- An almost 600% increase in total expenditure on awards from UK Research Councils, to £5.58M in this submission compared with £806,426 in RAE2008. A high level of EU funding (£2.52M), acknowledged in RAE2001 feedback and repeated in RAE2008, has been maintained.
- An approximate doubling in doctoral student graduations per annum to 86.5 in this submission from 57.3 in RAE2008 in an environment commended by QAA institutional audit.
- Completion of extensive new research facilities, with £12.6M of infrastructural investment to expand research in intelligent systems, computational neuroscience, sensor-based healthcare technologies, connected health, and telecommunications network performance management.
- Leadership of a major international research consortium (IU-ATC) in Next Generation Networks, Systems and Services, with funding of £18M over 5 years from EPSRC, India DST, and industry.
- Establishment of an industry-led Centre of Excellence in Connected Health Innovation, with total

investment of £5M over 5 years, for enhanced partnerships with industry and research users to deliver impact and stimulate regional economic development.

b.2 *Strategic Directions, Vision and Plans*

Research directions adopted by CSRI are strategically aligned with:

- The RCUK and EPSRC themes ICT, Healthcare Technologies (particularly Lifelong Health and Well-being) and the Digital Economy (focussing on Data, Information and Knowledge; Cloud Computing; Human-computer Interaction; and Pervasive/ubiquitous Computing);
- The EU FP7 ICT research programme (focussing on challenges in ICT for Health, Ageing Well and Inclusion; and Cognitive Systems and Robotics); and the FP7 Security research theme;
- The societal challenges of *Health, Demographic Change and Well-being*, and *Inclusive, Innovative and Secure Societies* identified in the EU Horizon 2020 Framework Programme.

CSRI's strategic plans build on developments achieved during the REF period to sustain and expand research income, infrastructure and activities of all 4 research groups to 2020 and beyond.

- **ICE:** In healthcare management, modelling tools will be extended to patient pathways that include both community healthcare and acute hospital services, with sophisticated cost models and focus on stroke services. This work will be advanced through the EPSRC-funded MATCH consortium and new Cumberland Initiative, led by Brunel, to establish a national centre for developing solutions to grand challenges in healthcare service provision. Research in computer vision will address challenges in scenario recognition to create the secure societies envisaged in EU Horizon 2020, supported initially through FP7 project SAVASA. Through on-going leadership of the EPSRC-funded IU-ATC, new infrastructure to access the Project Kelvin high-speed trans-Atlantic interconnect, and planned Centre in Cloud Computing Technologies, we will continue to anticipate and drive the UK research agenda in Core Network Systems; cloud-aware communication protocols and adaptation; traffic profiling and autonomic network management.
- **AIA** has increasing emphasis on sematic analytics, with strategic plans to address EU Horizon 2020 challenges of *Innovative and Secure Societies*. We will fuse our work on spatio-temporal logic, neighbourhood similarity, text mining and video analytics (in collaboration with ICE) to develop methods and architectures for scenario recognition and information extraction/annotation that can be deployed in distributed systems and as software services. AIA will extend its collaborations with providers and users of security data to develop tools enabling rapid "triage" of large-scale video archives and real-time analysis of internet data. AIA will exploit a unique combination of research on NLP, document analysis and argumentation to develop engineering and manufacturing design decision support tools for the Aerospace and Defence industries. These goals are supported initially via FP7 SAVASA and the industry-funded Deepflow project.
- **SERG** will continue to drive novel assistive technologies to improve healthcare, well-being and independence associated with ageing and cognitive impairment, and to help prevention and management of long-term health conditions. Work in sensor-based behavioural analysis and activity recognition and prediction will promote community-orientated models for independent living and "ageing in place". We will extend engagement with healthcare professionals, clinicians, social care providers and end users to define a technology roadmap for next generation cognitive prosthetics. Building on projects with over £5.5M funding since 2008 from EPSRC, ESRC, EU, NI DEL, HPSS R&D Office, charities and industry, and focussing on data collection, annotation and analytics, SERG will develop mobile phone- and home-based technologies for self-monitoring and self-management, and evaluate factors influencing technology adoption. SERG will promote the "active ageing" paradigm, extending collaborations with designers/manufacturers to develop intelligent garments for healthcare self-monitoring. These strategic plans will be implemented via the infrastructure established with funding of £2.6M from NI DEL and InvestNI initiatives, and new InvestNI-funded facilities for evaluation of novel healthcare systems and devices.
- **ISRC:** Through collaboration with neuroscientists, biologists and clinicians, ISRC seeks greater understanding of biological signal processing and to translate that knowledge into computational systems. The Bio-inspired & Neuro-Engineering Team is developing large-scale neural systems on reconfigurable hardware that emulate vision, sound and haptics. The long-term focus of the Computational Neuroscience Team is on computational models of neuro-dynamics of ageing and neuro-degeneration that can assist clinical validation. The Nano-electronics Team is developing very large scale neural network architectures using low-power neuron cells with dense routing. With a world-leading robotics facility, the Cognitive Robotics Team is designing self-sustaining

robot ecologies and robots intrinsically motivated to learn and reuse skills. The BCI & Assistive Technologies Team targets communication and control for people severely paralysed or "locked-in", and enhanced motor restoration post-stroke. These goals will be advanced via continuation of work on FP7 projects Im-Clever and Rubicon, new FP7 projects Visualise and Si.elegans, a new £2.6M Functional Brain Mapping Facility, and ISRC's £14.5M state-of-the-art infrastructure.

Plans for embedding impact sustainably into CSRI's research strategy are being implemented via Centres of Excellence, funded through *InvestNI's* Competence Centre Programme. The newly established ***Connected Health Innovation Centre*** is a collaboration between SERG and Ulster's Engineering Research Institute to deliver connected health research at a scale that is industrially and clinically relevant. The first stages of the ***Capital Markets Engineering Centre***, that will enable translation of intelligent systems research in ISRC to market analytics and trading algorithms, have been established via funding of £537K from InvestNI and industry. Additionally, a ***Cloud Computing Technologies Centre*** proposal in ICE is well advanced, focused on "big data", security and resilience; content delivery networks; semantic models and network instrumentation.

c. People

c.1 *Staffing Strategy*

The demographic profile across CSRI is well-balanced, with 13 Professors, 13 Senior Lecturers/ Readers, and 16 Lecturers in this submission (overall median age 46). Whilst 7 academic staff in RAE2008 have left through retirement (3, including 2 professors), career change (1), or to other institutions (3), recruitment of 10 new staff (median age 32, and all aged 40 or below), including 6 ECRs with strong potential, has been a strategic priority: ISRC: Cecotti, Gardiner, Rano, Wong-Lin; SERG: Bond, Donnelly, Zhang; AIA: Browne, Hawe, Nibouche. A strongly supportive research environment has enabled staff to develop leadership in strategic areas, and professorial promotions since RAE2008 include Nugent (SERG Leader) and Wang (AIA Leader). Leadership within ISRC has been supported by 2 new senior international appointments: Agrawal for robotics, Kelso for computational neuroscience. Increasing the volume of contract research staff has been a key mechanism to expand our strategic centres of research focus. Since 2008 a total of 95 FTE new contract research posts have been created: 50 in ISRC to support computational neuro-science, neural engineering, and cognitive robotics; 21 in SERG supporting assistive technologies and activity recognition; 12 in ICE to support healthcare modelling, computer vision, and next generation networks; 12 in AIA supporting semantic analytics and intelligent document analysis.

c.2 *Career Development and Support*

Academic staff promotions since RAE2008, through rigorous competitive processes involving external assessment, include: to Professor (McDaid, Nugent, Prasad, Wang Hui); to Reader (Bi, Chen, Coleman, Coyle, Curran, Morrow); and to Senior Lecturer (Charles, Condell, Harkin, McCartney, Haiying Wang, Zheng). CSRI has also supported 3 existing staff not submitted in RAE2008 to achieve inclusion in this submission (Charles, Siddique, Haiying Wang); and Coyle, an ECR in RAE2008, to win an RAEng/Leverhulme Trust Senior Research Fellowship.

Ulster's institutional Strategy for Research and Innovation (R&I) 2009-15, revised and extended in 2012, includes mechanisms to support career development at all stages. The PVC (R&I) devolves an annual budget to the CSRI Director, based on QR income, overheads recovered from external funding, and applications to external funders. This devolved budget averages £175K per annum (increased from £125K in RAE2008), and is used strategically to support staff to develop their research profile by attending conferences/workshops, travelling to develop research partnerships, hosting or organising events, and participating in scientific committees and other professional work. The University provides additional funding for strategic career development through competitive initiatives supported, in part, by DEL NI, InvestNI and other bodies. For example, 5 staff received Innovation Leaders awards from HSC R&D Office, totalling £49,400; 8 different staff members have obtained a total of 10 InvestNI Networking awards (totalling £5,925); and 7 University-funded strategic research development awards have been obtained, totalling £47,659 and involving 8 staff.

Within CSRI the Director, supported by the group leaders, holds individual meetings annually with staff to help develop personal research plans and targets. Senior researchers also support staff in developing grant applications by reviewing their draft proposals. CSRI holds workshops annually to increase staff awareness of research initiatives, state-of-the-art in strategically important research areas, policies and procedures. Staff are kept up-to-date by email and research group meetings on initiatives and funding opportunities, and staff also participate in regular seminar programmes

organised by each research group. Additionally, Research Office and Staff Development provide a Researcher Development Training Programme of events to support staff in awareness of funding opportunities, developing proposals, supervisory skills, and compliance with research governance.

All newly appointed staff undertake an induction and development programme, and are supported by Heads of School through reduced teaching and administrative loads. All new staff complete a Postgraduate Certificate in Higher Education Practice: in 2010 a compulsory module on Supporting Research Practice was introduced to provide a framework in which staff develop a proposal and receive guidance and feedback from staff with track records of successful applications and Review Panel experience; an early success is Donnelly's EPSRC First Grant. For PhD supervision, ECRs are paired with staff with a record of successful supervision. For international collaboration, support is provided to attend partner search events and meetings with potential consortium partners.

For structured career development of professorial staff, in 2008 the University introduced a process for Professorial Progression that encourages research leadership: annually, RI Director, Head of School and Dean set and review both short- and longer-term targets for individuals to achieve developmental criteria-based progression within a salary Band and promotion to a higher Band.

c.3 *Concordat to Support the Career Development of Researchers*

The importance of recruitment, selection, retention and career development for Contract Research Staff (CRS) are recognised via the Concordat, with annual opportunities for advancement, regular training and development provision for CRS and supervisors, and opportunities to publish, develop grant proposals (CRS are encouraged to enrol on the Supporting Research Practice module) and participate in teaching activities. Conditions for CRS are championed by the University's Coordinator for CRS Concordat, and the University's Research Concordat Steering Group, chaired by the PVC (R&I), monitors the implementation of institutional policy related to CRS and reviews the University's progress in meeting the recommendations of the Research Careers Initiative. The University participated in the 2011 Careers in Research On-line Survey (CROS), and in 2013 Ulster received the European Commission's "HR Excellence in Research" award, acknowledging alignment with the European Charter for Researchers and Code of Conduct for their Recruitment.

c.4 *International Staff Appointments, Recruitment and Visiting Scholars*

CSRI has a pervasive international culture: 19 (45%) of the staff in this submission, and 5 of the 10 recruited since 2008, are non-UK/Irish. For CRS, 55% are non-UK/Irish. CSRI sustains a programme of Visiting Professors, appointed for 4-year periods to enhance leadership and collaboration in strategic areas: Eric Adams (Game Design and Production Consultant, USA); Nader Azarmi (Director, Etisalat BT Innovation Centre); Roy Harper (Consultant, Ulster Hospital); Gregory O'Hare (Prof, UCD); Noel Sharkey (Prof, AI & Robotics, Sheffield University); Daniel Yeung (Prof, South China University of Technology); Sean Gaines (Director, International Projects, Vicomtech, Spain). Prof. Sharkey, an EPSRC Senior Media Fellow, was appointed with a remit to help staff enhance their activities in public engagement. CSRI hosted RK Sinha (Birla IT, India) as a Leverhulme Visiting Fellow, and funds a continuous programme of international visiting scholars that has enabled staff to collaborate with over 80 researchers via intensive visits to Ulster (from Australia/ NZ(2), Canada(2), China(7), India(5), Japan(4), S. Korea(8), Malaysia(2), Singapore(3), UAE(1), USA(9), UK(11), rest of Europe(27)), and CSRI strongly encourages staff to develop sustainable collaborations with research institutions internationally through visiting appointments or funded exchanges. Staff with international Visiting Professor appointments are Nugent, Parr, Hui Wang, Zheng; Visiting Scholar positions are held by Coyle, Liu, Nugent, Prasad, Haiying Wang.

c.5 *Supporting Equalities and Diversity*

CSRI operates within University policies and procedures for equality and diversity. The Equality and Diversity Services department develops and promulgates policy and good practice in relation to both staff and students, and provides training and advice on interpretation and implementation of policies and codes of practice. The University's Equality Scheme addresses gender, marital status, age, race, religious belief, political belief, disability, sexual orientation, and responsibility for dependants. Ulster is a member of the Athena Swan Charter to promote equality for women in STEM subjects, and applied for bronze status in November 2013. CSRI supports equality of opportunity through open communications to staff about strategic initiatives, funding opportunities and training, and via a maximum teaching load policy of 180 hours per annum. The Faculty operates a formal review policy for membership of CSRI, with annual meetings (involving Director,

Dean and Heads of School) to appraise individual staff research performance against criteria.

c.6 *Research Students: Recruitment, Training and Support Mechanisms*

A sustainably growing number of doctoral students has been established: PhD completions show an upward trend from 14.67 in 2008-09 to 19.67 in 2012-13, averaging 17.3 per annum, almost doubled from 9.5 completions p.a. in RAE2008. A majority of studentships are supported by either the University's Vice Chancellor's Research Studentship programme or by DEL (30 and 60, respectively, since RAE2008). (DEL awards are treated by HEFCE as equivalent to RCUK awards, for which NI universities are ineligible to apply, and are provided in lieu of these.) Additional studentships are funded via increased partnerships with industry: BT (4), SAP (2), Intel, Seagate Technologies, Core Systems, IN2, 360 Production, Bath Institute of Medical Engineering, NYSE Technologies, Citi, 1st Derivatives, Fidessa, Singularity; and external grant awards EPSRC (4), ESRC, DEL Cross-Border (2), InvestNI (5), DARD). Opportunities have also been developed for students to have shared industrial supervision and to experience industrial research, with 4 students undertaking internships at BT labs, Martlesham.

Research students are managed through the Faculty Research Graduate School (RGS), in association with the University's Research Office (RO). RO is responsible for research student registration and maintaining records, including both periodic data returns, such as to HEFCE and REF, and of individual student progress. RGS is responsible for recruitment, quality assurance and maintenance of standards, within procedures established by RO. RGS has a robust recruitment process to allocate research studentships through open competition and interview. Almost all students recruited have a First Class Honours degree, and many also have a Masters qualification.

In all four research groups infrastructural funding has been used to create state-of-the-art working environments for PhD students. All full-time PhD students have dedicated individual office space and lab facilities. RGS provides approx. £1,000 per student per annum to purchase networked PCs for new students and for student training and development, including attending conferences. The Staff Development unit works with RGS to develop and deliver a Doctoral Innovation Programme, offering ILM Level 5 Project Management certification and HEA Associate membership, together with more specific Faculty-based training in areas such as scientific writing. Training is also provided for supervisors in the assessment of student training needs. In its Institutional Audit report, March 2010, QAA commended Ulster on its "framework for the management and development of research degree programmes". QAA considered "the balance between PhD students being associated with Research Institutes and the way that their administration is located in the Faculty RGSs but monitored centrally by RO was thoughtful and productive"; felt assured that induction processes were "well-designed and effectively implemented"; and "found evidence that (PhD) student representation on (RGS and RO) committees was both valued and effective".

c.7 *Research Students: Progress Monitoring*

The Head of RGS and RI Director jointly review confidential annual reports from students and supervisors, highlighting any resource or progress issues. Student progress is monitored through annual assessment procedures: in Year 1, a 100-day viva and report; within 10 months, a more substantial viva and report, including a paper for conference submission, to secure confirmation of PhD registration; Year 2 students present posters at the annual Faculty Research Dinner; and early in Year 3 students make oral presentations at the annual RGS conference and receive feedback from a panel of senior researchers. There are corresponding assessment time-points for part-time students. Students are strongly encouraged to publish and use peer review feedback and input from supervisors to achieve appropriate postgraduate standards and timely completion. At the annual Faculty Research Dinner, CSRI awards four prizes for PhD students: best PhD thesis; best published paper; best confirmation report (sponsored by McGraw-Hill); and best poster.

d. Income, infrastructure and facilities

d.1 *Provision and Operation of Infrastructure and Facilities*

ISRC is housed in a dedicated building that provides 2,446m^2 of fully refurbished workspace, accommodating approx. 50 academic, contract research, and support staff, together with approx. 30 PhD students. The Cognitive Robotics Lab includes a 100m^2 powered floor, enabling long timescale experimentation, a Vicon camera system for accurate tracking, 2 RoboSavvy 1.3m-high humanoid robots, 2 Schunk 7DoF manipulators on Scitos G5 bases, 2 additional Scitos G5 robots, a Willow Garage PR2 robot, a Shadow Robotics 5-finger robot hand, 10 Pioneer P3-DX robots,

and a collection of Khephera, Koala and Robotino robots, with video and audio accessories. The BCI Lab is equipped with a modular sound & RF shielded EEG room and resourced with a range of BCI systems, including g.tec 64 channel g.BSamp system, 40 channel NuAmps Express NeuroScan system, 8/16 EEG/EMG/ECG channel mobile units and a 4 EEG channel wireless mobile unit. These are supported with several sets of head-gear along with passive and active wet EEG electrodes as well as dry electrodes. The g.tec BCI systems are also equipped with physiological sensors and processing systems for measuring respiration, heart-rate, galvanic skin response and oxygen saturation. The lab also has an Arrington Eye-tracker and a computerised smart wheelchair system. The experimental equipment is complemented by 2 x 34 Node HPC Clusters (totalling 408 Cores & 816GB RAM, and 544 Cores & 2.18 TB RAM, respectively), enabling rapid, large-scale, high-precision computation. Recently, the Computational Neuroscience Team has secured funding from InvestNI for a £2.3M Magneto-encephalography (MEG) imaging system, ordered 25th October 2013, the only MEG system on the island of Ireland.

SERG and AIA share a large-scale Intelligent Environment (approx. 630m^2) to support research, deployment and evaluation of Connected Health solutions, data acquisition and semantic analysis of user environments. This facility includes 3 dedicated smart labs (including a smart kitchen and living room), 2 conference rooms, 16 personal offices, and a demonstration area to support local community engagement. The whole Intelligent Environment is equipped with over 400 sensor nodes and devices supporting experimentation and evaluations via continuous data collection and analysis for activity recognition and behavioural monitoring for activities of daily living. The smart labs are supported with a Tomorrow Options gait analysis platform, a KNX home-based automation installation, an RFID infrastructure, a range of image analysis platforms and an Orthokey video-based activity annotation tool. The environment also has a wide range of mobile and gestured controlled interfaces, including a Microsoft Surface. A newly refurbished robotics and wearable technologies lab, with Pioneer P3-DX and Robot Sputnik3 platforms, supports research to develop autonomous robots for use in home-based settings. A TC2NX-16 full body scanner is available to acquire anthropometric measurements for research in wearable technologies. Two 16-channel data acquisition devices support BCI research, and a Leica ScanStation is available for rapid development of 3D environmental models. Development facilities also include a range of mobile platform development environments and devices (Android, iOS (iPhone & iPad), Blackberry, Symbian, Windows Mobile), and a large suite of software products, including Labview, MATLAB, 3ds Max and Adobe CS5, supports all of the hardware facilities and installations.

ICE facilities are housed in the NETCOM Hub, which provides state-of-the-art fixed and wireless network test equipment. For research requiring set-up and dynamic automation of realistic network user scenarios, this includes an Agilent Wireless Communications Test Set, Wireless Connectivity Test Set, Vector Signal Generator, UMTS Interactive Function Test Software, Signal Studio for 802.11 WLAN, Signal Analyser, and Vector Signal Analysis Software. A PacketStorm IP Network Emulator provides WAN emulation and network bandwidth simulation. Additional hardware includes Cisco and Netgear switches and routers, and 4 analog/digital mixed signal oscilloscopes. A cloud computing test-bed has been established for research on VM optimisation, with extensive virtualisation software. A test-bed of Libelium Waspmotes supports wireless sensor cloud computing research. Collaborative research with clinicians and medical physicists is supported by a 4D stereophotogrammetry camera system from Dimensional Imaging. An extensive software suite, including Opnet, Analyze, Matlab and Hugin Expert, supports research across the group.

CSRI has a full-time clerical post to assist the Director, and the Faculty provides one administrative and one clerical post to support staff in all aspects of research management. ISRC has a full-time business manager and a further clerical post, along with a full-time manager and secretary in the technology & innovation EPI Centre. 4 Technical Planning Managers and 9 Technical Services Engineers within the Faculty support individual staff/student equipment and laboratory facilities.

d.2 ***Investments in Infrastructure and Facilities***

Within the last 5 years extensive new research facilities have been completed, with over £12.6M of infrastructural investment to support expansion of research in intelligent systems, computational neuroscience, connected health and sensor-based healthcare technologies, and network performance management. A further £8.5M external funding to develop new infrastructure has already been secured in 2013 to expand and sustain all of these areas over the next 5-year period.

ISRC's Cognitive Robotics, BCI and hardware lab facilities have been established with funding through to mid-2013 totalling £14.5M: from InvestNI's Centres of Excellence programme and the Integrated Development Fund (£7.2M) and the University's input to new academic posts and infrastructure (£7.3M). Funding of £1.5M (Nov 2008-Mar 2011) from the NI DEL Cross-border R&D programme enabled development of the Computational Neuroscience Team, a collaboration with neuroscientists at Trinity College Dublin's Institute of Neuroscience. New R&D investment of £2.6M (Apr 2013-Mar 2018) from InvestNI will now establish the NI Functional Brain Mapping Facility, including a MEG imaging system. This will be one of fewer than 10 such facilities currently installed in the UK, enabling research in neurological modelling to develop pharmaceutical treatments for neurological degenerative diseases. Further investment of £237K by InvestNI in a £548K Capital Markets Collaborative Networks project builds on initial investment of £300K by five leading capital markets companies, and is the next stage in a planned Capital Markets Engineering Centre, exploiting computational intelligence-based approaches for market analytics.

The SERG and AIA Intelligent Environment is a dedicated research environment developed with funding of £624K (Feb 2009-Mar 2011) from the NI DEL Research Capital Investment Fund (RCIF) to support Deployment of Sensing Technology in Connected Health Care. Complementary funding of £2.0M (Nov 2008-Mar 2011), shared with Ulster's Engineering Research Institute (ERI), from the NI DEL Cross-border R&D programme enabled development of the Centre of Excellence in Point-of-Care Sensors, a collaboration with Dublin City University's Biomedical Diagnostics Institute. Through the Nestling Technologies Initiative, investment of £421K provided a real-life test bed of 16 intelligent homes for technologies supporting independence and well-being for older people. New InvestNI R&D funding of £483K (Apr 2013-Sep 2016) will establish a Self-management Platform for Connected Health to provide University-based and community-based test-bed and demonstrator facilities for novel pre-market systems and devices developed through R&D activity. Further new investment of £5.0M (Jun 2013-May 2018, joint with ERI) from InvestNI's Competence Centre programme will establish the Connected Health Innovation Centre, with an industry-led transformational research programme in e-health, tele-monitoring, and home-based care.

ICE's NETCOM Hub for Next Generation Internet and Computational Modelling for the Digital Economy was established via NI DEL RCIF investment of £530K (Feb 2009-Mar 2011), further refurbished in 2012, and augmented through the equipment budget of IU-ATC (Jun 2009-Jun 2014). New InvestNI R&D funding of £457K (Aug 2013-Aug 2016) will connect NETCOM to the Hibernia Network landing station adjacent to Coleraine campus, giving access to the Project Kelvin high-speed interconnect to N. America. NETCOM will then be the "Research Lab with fastest connections (to USA) in Western Europe", in a unique position to leverage UK-USA and NI-RoI-USA joint research programmes. Further new investment of £5M is being sought from InvestNI's Competence Centre programme to establish a Cloud Computing Technologies Centre, with an industry-led research programme in partnership with BT, Microsoft, and IBM, to be submitted 2014.

d.3 *Research Funding Portfolio*

In addition to the £21M already invested in, or secured for, development of CSRI infrastructure described in Section d.2, a further £14M of competitive research funding has been newly obtained in the assessment period, including £5.6M from RCUK and £3.1M from EU FP7.

In ISRC, cognitive robotics research has been supported by £1.2M, including two FP7 awards, IM-CLeVeR (£505K), developing methodology for designing robots that can be intrinsically motivated to learn new skills, and RUBICON (£385K), developing and validating self-sustaining learning ecologies of robots; a UKIERI award (£145K) for Intelligent Assistive Robotics; and a Leverhulme award (£130K) for autonomous mobile robots. Computational neuroscience research has attracted £1.8M, including two FP7 awards, Si elegans (£1.1M), developing a hardware-based framework that accurately mimics C.elegans in real time, and VISUALISE (£416K), on Visual Modelling using Ganglion Cells; an EPSRC award (EP/F055579/1: £252K) to develop a Biologically Plausible Spiking Neuron in Hardware; an eFUTURES award (£32K) for Hardware/software Models of Brain-like Self-Repair; and a British Council award (£39K) on Brain-inspired Interconnects for Nano-electronics. BCI research has been advanced through an EPSRC award (EP/H012958/1: £102K) for Autonomous Multiclass BCIs; an RAE/Leverhulme Senior Research Fellowship (£43K) for adaptive BCIs for assistance and rehabilitation; and a Leverhulme Trust Visiting Fellowship (£29K).

In SERG, research in technologies for healthcare self-management and "active ageing" has been

supported by £1.1M of new funding awards, including EPSRC award SMART (EP/F001959/1: £568K), developing a personalised self-management system; an ESRC New Dynamics of Ageing award (RES-353-25-0004: £194K & Studentship: £51K), developing technology-enabled garments for self-monitoring of safe exercise and well-being; an NIH award (£51K) for a self-management platform; and £187K from EU INTERREG IVB for the Pro-Fit project, developing sport "field-labs". Research in next generation cognitive prosthetics has been supported by awards totalling £1.1M, including EPSRC TSB award NOCTURNAL (£113K), developing assistive night-time technologies; EU AAL Joint Programme awards: PIA (£101K), to support Instrumental Activities of Daily Living, and MobileSage (£40K), for personalised and location-sensitive assistive services; EU award MyHealth@Age (£197K), developing technologies to enhance personal safety and social contact; EU Leonardo Da Vinci award STAR (£38K), for Skills Training for Carers of People with Dementia; EU FP7 award BRAIN (£306K), developing BCIs into practical assistive tools for users with impaired communication; and 2 awards jointly with ICE for research on healthcare technology assessment: EPSRC award MATCH-Plus (EP/G012393/1: £172K, via Brunel), assessing impact of user needs data in design and use of cell phone-based cognitive prosthetics, and an Alzheimer's Association award TAUT (£128K), for development and evaluation of technology adoption models. Research in home-based intervention technologies for autistic children is supported by an EPSRC award (EP/K014420/1: £99K) to develop automated behavioural analysis and interpretation; an EU FP7 award MICHAELANGELO (£202K), developing a model for remote management, treatment and rehabilitation; and an HSC R&D award (£248K) to study heart rate variability bio-feedback.

In the AIA Group, funding awards exceeding £900K support research in semantic analytics and reasoning, including an EU FP7 award (£327K), SAVASA, jointly with ICE, developing scenario recognition and annotation for video archive search and analysis; 2 awards co-funded by SAP and InvestNI: DEEPFLOW (£249K), to develop engineering and manufacturing design support tools, and STRATOSPHERE (£120K) on Stream Data Decomposition for Profiling Smart Structures; and a Templeton Foundation award (£122K) on Explaining Away in Science and Religion.

In ICE, funding of over £2.4M supports research and leadership of international cooperation in telecommunication network resource and performance management. This includes leadership of the EPSRC-funded India-UK Advanced Technology Centre (IU-ATC) in Next Generation Networks Systems and Services (EP/G051674/1: £492K & Phase 2 EP/J016748/1: £596K); an EPSRC INTERACT award (EP/F030118/1: £119K) to establish the IU-ATC consortium; a UKIERI award (£148K) to establish an Indo-UK Virtual Research Graduate School; EPSRC award SUAAVE (EP/F06358X/1: £671K), Sensing Unmanned Autonomous Aerial Vehicles; EPSRC award Digital Economy IT as a Utility Network+ (EP/K003569/1: £39K), to enhance access to, and trust in, IT facilities; and 4 EPSRC/British Telecom CASE Awards (totalling £371K). Research in healthcare process modelling is supported by EPSRC award MATCH (Phase 2, EP/F063822/1: £1.5M, via Brunel), shared with ERI, modelling economic and quality-of-life outcomes.

Additional PhD studentships are provided by 6 industrially sponsored NI DEL CAST awards (total: £175K), and awards for 5 studentships in Capital Markets Engineering (total: £360K). PhD student training is enhanced by 2 awards from the RoI HEA Programme for Research in Third-Level Institutions: Telecommunications Graduate Initiative (£45K), and Digital Arts & Humanities (£41K).

d.4 *Consultancies and Professional Services*

Total income through consultancies by Computer Science staff during the REF period totals £1.3M. This includes £1.0M from 57 FUSION projects (total value £2.6M) started since 2008 (funded by InterTrade Ireland for knowledge/technology transfer to SMEs in RoI). Additional funding awards enabling consultancies and service partnerships include: 9 Knowledge Technology Partnerships (total £894K); 6 InvestNI Proof-of-concept awards (total £599K: drug dosage monitoring devices, secure digital watermarking, brainwave-controlled devices, surveillance via gait identification, delivery of streaming music, and autonomic computing environments); an EU Interreg IIIA award (£186K) for the Electronics Production and Innovation Technology Centre; EU FP7 award MaPEeR (£121K), supporting SMEs; Enterprise Ireland awards (£197K; £263K): Total Energy Management for Production Operations; and 5 HSC R&D "Innovation Leaders" awards (total £99K).

e. Collaboration and contribution to the discipline or research base

e.1 *Research Collaborations*

Research throughout CSRI is predominantly interdisciplinary and collaborative with national and

international partners in academia, research institutions, industry, and user-facing professions. Through 12 EU-funded projects (discussed in Section d.3), formal collaborations across Europe have been established with 39 universities or research institutions and with 42 industry/professions partners. These collaborations are substantially interdisciplinary, involving cognitive and neuro-scientists, clinicians, therapists and healthcare professionals, and legal-ethical practitioners.

Collaborations with UK academic and industrial partners are supported substantially by major RCUK-funded projects: SUAAVE (Oxford, UCL; BAE Systems, Boeing, BT Labs, Home Office Scientific Development Branch, Thales); IU-ATC, Phases 1 and 2 (Bristol, Cambridge, Lancaster, Queen Mary London, St Andrews, Southampton, Surrey, UCL; BT Labs, Toshiba, InfoSys, MIDAS, Sasken, Tejas, Wipro); MATCH and MATCH-Plus (Brunel, Birmingham, Nottingham); RIGHT (Brunel, Cambridge, Cardiff, Southampton); SMART (Bath, Sheffield, Sheffield Hallam; British Pain Society, BT Labs, Philips, Teler Ltd, Stroke Association); Design for Ageing Well (Brighton, Newport, Salford, Westminster); and Spiking Neuron in Hardware (Liverpool). Again, inter-disciplinary research pervades these partnerships, including engineers, economists, healthcare managers, therapists and other professionals, social scientists, and textile and garment designers.

CSRI exploits Ulster's geographical location to engage strongly in all-Ireland research initiatives and networks. Interdisciplinary Cross-border Research Centres in Intelligent Point-of-Care Sensors (collaboration with Dublin City University's Biomedical Diagnostics Institute), and Computational Neuroscience (with Trinity College Dublin's Institute of Neuroscience) have been developed with joint DEL(NI)-HEA(RoI) funding. The Nestling Technologies Initiative supported collaborative infrastructure with Dundalk Institute of Technology for smart home technology assessment.

Beyond Europe, the TAUT project has established collaboration with psychologists at Utah State University and epidemiologists at University of Utah. MoUs for research collaboration, including staff and student exchanges, have been established with Kyung Hee University, S. Korea, since 2011, and Southwest Jiaotong University, China, in 2013 for a joint Centre in Advanced Machine Intelligence. Two collaborations with the Chinese Academy of Science's Opto-electronics Academy commenced in 2013, supported by ESA's Dragon3 programme for training young scientists. CSRI is a founding member of the IEEE InterCloud Test-bed Project (commenced October 2013), which includes 21 cloud and network service providers, cloud-enabling companies, and academic and industry research institutions from US, the Asia-Pacific region, and Europe, and will contribute to developing standard methodologies for cloud-to-cloud interworking.

Partnerships have enabled CSRI to focus on leading edge industry-relevant research, with access to data and end-users for research evaluation. Collaboration with BT has shaped our strategies for cloud computing research and low-cost energy-efficient technologies. International research has led to new partnerships within UK: e.g. a crop-imaging system developed in IU-ATC initiated collaboration with DARD NI on monitoring forest disease. CSRI's international collaborations in assistive healthcare technologies have established platforms for large-scale industry-standard evaluation, and tool and device development. Collaborations have also provided the frameworks to secure significant future infrastructural developments, such as the NI Functional Brain Mapping Facility and access to the Project Kelvin high-speed interconnect to North America.

e.2 *Contributions to the Discipline*

CSRI is leading transformation of internationalisation of the discipline. Parr is overall UK academic lead for IU-ATC, the first and largest international ICT project between UK and India, involving 7 research-leading IITs, an Indo-UK Virtual Graduate School, and over 200 researchers. The 2012 RCUK Impact Review (page 4) and "Excellence with Impact" website highlight that "The UK is now third on the Indian Government's preferred list of partner research collaborators, from previously not being on the list, due to the IU-ATC". The 2012 RCUK Digital Economy Impact Review Panel report cites IU-ATC as a major example of impact, with significant impacts on Knowledge Economy and Influencing Policy (Economy and Society), and "significant success in gaining further R&D investment, as well as generating international engagement". CSRI's leadership of IU-ATC is influencing future UK-India research models: Parr was an invited plenary panel member, UKTI-India meeting with UK Minister for Universities and Science and UKTI CEO, June 2013, and at the Indian Global Business Summit, June 2013. He was also Panel Chair for EPSRC UK-India Partnerships in Advanced Manufacturing and chaired the British Council UKIERI funding panel.

Parr is a Member of EPSRC ICT Strategic Advisory Team (SAT) and active in 3 SAT Sub-groups:

International, Impact with Industry, and National Internet Test-bed; and Vice-chair, IEEE ETC Sub-comm. on Cloud Coms & Networking. CSRI is active in international advisory boards: McGinnity: CHIST-ERA ERANET, Kunshan Industrial Technology Research Institute, and DUKE WISeNet project; Nugent: EU CHIRON project, Social Care Institute of Excellence, and the Textile Institute.

CSRI staff lead professional bodies and international organisations: Scotney is President, Irish Pattern Recognition & Classification Society; McClean: Treasurer, Irish Statistics Association; Hui Wang: Inaugural Chair, IEEE SMC Society UK & RoI Chapter; Coyle: Chair, IEEE CIS UKRI Chapter, and Chair of 3 IEEE CIS sub-committees. CSRI staff are active on executive committees: Scotney: IAPR Governing Board; Hui Wang: IEEE SMC Society Board of Governors; Chen: iiWAS Executive Steering Committee; Donnelly: ESEM Council Board; McCartney: Royal Irish Academy Mathematical Sciences Committee, and Council of the British Society for History of Mathematics.

Coyle, Curran, McGinnity and Parr are members of EPSRC Peer Review College. Black (Danish Council for Independent Research; New Zealand Ministry), Curran (Cyprus National Foundation; FP7 Marie Curie Actions), Nugent (Alzheimer Society Canada), and Parr (UAE ICT Fund) have been active in project evaluation internationally. Black (Institution of Engineers Ireland) and McClean (Operational Research Society) are Accreditation Committee members. Black is Trustee, Action on Hearing Loss; Curran is an IEEE Technical Expert for internet and security matters.

In the REF period Visiting Professorial appointments have been held internationally by Nugent: Lulea Technical University, and University of Florence; Parr: Etilisat-BT Innovation Centre, and Trinity College Dublin; Hui Wang: Jilin University, and Tsinghua University; and Zheng: Fuzhou University, and Fujian Polytechnic of IT. Visiting Scientist/Scholar positions have been held by Coyle: IIT Kanpur; Liu: Southwest Jiaotong University, and University of Jaen; Nugent: Kyung Hee University; Prasad: IIT Kanpur; and Haiying Wang: CRP-Santé, Luxembourg. Research excellence has also been recognised by elections to Fellowship: Black: European Alliance for Medical and Biological Engineering, McClean: Operational Research Society, and Curran and Wilkie: BCS.

CSRI has organised/hosted 12 international conferences: IMVIP2008; HSCM 2008; CASI2010; CinC2010; S-Cube2010; KSEM2010; AICS2011; UKIERI Workshop on BCI & Assistive Robotics 2011; ICOST2012; UK-Ireland IEEE SMC Workshop 2013; Intelligent Systems Summit 2013, and will host IEEE BIBM2014. In total, 12 staff have been (or designated to be) Programme Chair/co-chair at 19 international conferences: Bi (KSEM 2010), Charles (IDEAL2010), Chen (SAGAware2011 & 2012, UCAMI2013, MoMM2013), Donnelly (ICOST2012), McClean (HSCM2008, CASI2010), McGinnity (AICS2011), Morrow (IMVIP2008, S-Cube2010), Nugent (CinC2010, pHealth2011, ICOST2012, IWAAL2013), Parr (S-Cube2010), Scotney (IMVIP2008, KSEM2010), Haiying Wang (ICNC'09, '11, & '13), and Zheng (IEEE BIBM2014). Additionally, CSRI staff have chaired/co-chaired workshops at SAI2013 (Bi), WI-IAT '10 (Chen), AI-2010, IEEE SSCI 2011 & 2013 (Coyle), ESSDERC/ ESSCIRC2008 & 2009 (Harkin, McDaid), SMCEW2011 (Nugent), BIBM2010, 2011, 2012 & 2013 and Pervasive Health 2011 (Zheng).

Invited Keynote Lectures at international conferences include: Nugent: ADI2009; McGinnity: ICCE 2010; Scotney: ICMLC2010; McClean: INFORMS2011 and MSMPRF2011; Black: ICOST2012; Maguire: IEEE CIS2012; McDaid: INCF2012; Curran: ISSC2013; and Hui Wang: ICMLC2013. In addition, CSRI staff have presented over 70 invited lectures at universities and scientific meetings in UK, Europe, Australia, China, India, Japan, Korea, and USA during the assessment period.

CSRI staff are engaged extensively in journal editorship (12 Editor/Associate Editor roles, with a further 34 Editorial Board memberships), and are particularly active in promoting the development of new research areas through leadership of journal Special Issues. 18 staff have been Guest Editor for 34 journal Special Issues, including IEEE T-CIAIG (Coyle), IEEE T-ITB (Curran), IEEE T-ASE (Nugent), and IEEE JSAC (Parr). Journal editorship roles include: Assistant Editor, Int. J. Pervasive Computing & Communications; Assc. Editor-in-Chief, Progress in Intelligent Computing & Apps. (Chen); Founding Editor-in-Chief, Int. J. Ambient Computing & Intelligence (Curran); Assc. Editor, J. New Mathematics & Natural Computation (Maguire); Editorial Board, IEEE J. Biomedical & Health Informatics (Nugent); Editor-in-Chief, Int. J. Automation & Control Eng.; Editor, Paladyn J. Behavioural Robotics; Assc. Editor, Engineering Letters (Siddique); Assc. Editor, IEEE Trans. SMC Part B; Assc. Editor, Int. J. Machine Learning & Cybernetics (Hui Wang); Exec. Editor, Int. J. Computers in Healthcare; Managing Editor, Int. J. Computational Biology & Drug Design (Zheng).