| **Institution: The Open University** |
| **Unit of Assessment: Computer Science and Informatics** |
| **a. Overview** |

Computing research at The Open University (OU) is people-centred: committed to integrating technology effectively into human activity. We address problems that matter to a society where computing is becoming ubiquitous and pervasive. Thus, the Centre for Research in Computing (CRC) has three broad objectives: to *empower* – by placing people at the centre of all our work; to be *situated* – by attending to the interplay between context and technology; and to *challenge* – changing perspectives by continually and creatively disrupting boundaries. Recognising that real problems demand multiple perspectives and interdisciplinarity, we reshape disciplinary boundaries to gain fresh insights, and thereby develop radical, people-centred solutions to complex problems. Our approach reflects the OU's mission, to harness technological innovation to empower people everywhere, openly and at scale.

The CRC was created in 2001 to embody the OU's strategic, long-term commitment to excellence in computing research. Its collaborative infrastructure brings together the distinctive strengths of two units: the Knowledge Media Institute (KMi) and the Department of Computing and Communications. We build on three themes, which operate as intellectual centres of gravity, consistent with the research strategy described in the 2008 RAE:

- Human-centred computing (HCC)
- Knowledge media (KM)
- Software engineering and design (SEAD)

Each constitutes a coherent, sustainable core of expertise with external recognition, as well as a body of work with cumulative impact. These are not bounded areas; researchers work freely within and across themes: sharing projects, a joint PhD programme, a seminar series, and physical space. This dynamic infrastructure reinforces our ability to work rigorously across disciplines and innovate in terms of models, principles, techniques and systems. Adopting our three objectives to *empower*, be *situated* and *challenge* is our strategy for taking these three themes forward.

| **b. Research Strategy** |

In pursuing our research strategy, we have, since 2008:

- exploited our three themes, building on our existing strengths, and expanding into areas that address, extend, and continually challenge our vision for people-centred and ubiquitous computing;
- developed inter-disciplinary and cross-boundary collaborations that enrich our key themes; and
- driven the research forward via a comprehensive research infrastructure.

This strategy has been implemented through strategic recruitment and research management; ongoing research training and support across the CRC; targeted bidding for funding; investment in research infrastructure, both social and physical; active engagement with practitioners and users (through collaboration, consultancy, part-time PhD students, visiting Research Fellowships); communication of our research in both peer-reviewed venues and through less conventional modalities such as social media; expansion of our doctoral research programme; and the cultivation of an international, collaborative research culture.

Since 2008, we have advanced our international standing. Returned staff has increased from 24 to 32 (33%); and our research income has increased from £7m to £11m (57%). CRC researchers have led major research projects distributed across all three themes and with diverse funding: £7.35m funded internationally (e.g., SOA4All - Service-Oriented Architecture for All, EU, Domingue); £3.45m funded nationally (e.g., MaTREx - Making Tacit Knowledge in Requirements Explicit, EPSRC, Nuseibeh); and £220k from industry (e.g., DSDM Consortium, Sharp).

The STELLAR project - Sustaining Technology Enhanced Learning at a Large Scale - exemplifies our leadership of large, interdisciplinary, international communities, which is an element of our strategy. The OU was both the scientific lead (Scott) and the coordinating partner for STELLAR, a

€5m EU FP7 Network of Excellence in Technology Enhanced Learning (TEL), with 15 partners in a cross-disciplinary consortium of researchers in computing, education, pedagogy, and psychology. STELLAR provided a vision and strategy for EU research in TEL and continues to shape this domain actively through the TEL Europe community (http://www.teleurope.eu/).

Within and across our three themes, research leaders coordinate and orchestrate groups and grow capacity. Our collective direction is shaped, within a culture of research autonomy, by the CRC research leaders, who meet regularly to review both the CRC's overall strategy and each unit's and group's contribution. The research management is strategic; the group structure is dynamic. This fluidity enables responsiveness, cross-fertilisation and change within our overall strategy. As a consequence, new cross-cutting research activities have emerged, for example using natural language processing techniques to address challenges in requirements engineering (de Roeck); using ethnographic methods to elicit and contrast interaction design and software engineering practice in order to improve collaboration (Sharp); applying a domain ontology method to extract concept maps for adaptive e-learning (Song); and integrating large scale data mining with semantic technologies to support the process of making sense of scholarly data (Motta). Our three themes are described below, each framed in terms of a key challenge, indicative accomplishments since 2008 and the strategic direction for the future.

Human-centred computing (HCC)
Alani, Holland, Laney, **Mancini**, Minocha, Price, **Scott**, **van der Linden** (Returned researchers are listed under the theme which is their primary affiliation, and leaders are indicated in bold).

The computer has escaped the box, into the wild; technology is infiltrating all aspects of social life, redefining our concept of interaction. This highlights an increasing need for research into the complex and increasingly coupled relationships between people and computing, and the co-evolution of computing technologies and human societies. The challenge is to integrate new technology seamlessly into human activity in a way that serves as well as delights. We address this challenge with a methodological focus on understanding technology in context 'in the wild', working in HCI, interaction and user experience design, music computing, technology-enhanced learning, immersive environments, and animal-computer interaction (see our 'enhanced senses' and 'virtual collaboration' impact case studies).

Key accomplishments:
- Our research on **new forms of interface** – such as tangible interaction, whole-body interaction and sensor-based interactions – has shown that integrating these technologies into activities such as music, sport, education, and theatre empowers users and blurs boundaries (van der Linden, Holland, Laney, Minocha, Petre). The 4Decades 'serious game' has demonstrated how multi-user, multi-surface systems encourage critical debate and support multi-stakeholder consensus-building in complex domains such as global climate economics (Laney). Our work on haptic technologies such as the Haptic Lotus (van der Linden) has revealed how shared multi-modal experiences can dissolve the boundaries between blind and sighted people.
- Our research in **music computing** (Laney, Holland) has created more accurate models of musical structure, perception and cognition, leading to the development of new tools – for example, tools that for the first time allow expert performers to navigate the infinite class of arbitrary well-formed scales, with timbral overtones to match. We are introducing new forms of interface into music: our haptic bracelets (Holland) allow beginners to learn intricate multi-limb drum patterns through computer-mediated haptic interaction alone, and our MusicJacket (van der Linden) uses vibro-tactile feedback to train the motor skills of young violin students. These technologies have been deployed in school and therapeutic settings.
- Our research on **animal-computer interaction (ACI)** pioneers the investigation of the triangle between animals, people and technology (Mancini, van der Linden). Increasingly, animals interact directly with technology in the context of service to human owners, animal husbandry and efforts to improve animal welfare. Our ACI Manifesto [Mancini, *ACM Interactions* 18(4), 2011] is galvanising a growing research community, and has led to collaborations with NGOs (e.g., Medical Detection Dogs, Dogs for the Disabled, Dogs Trust, Woburn Safari Park) and industry (e.g., Retrieva Tracking) to develop new interfaces to empower animals.

Environment template (REF5)

We have established a research environment for HCC research that will carry our research into the future. As part of our collaboration with E.ON on the Milton-Keynes-based 'Thinking Energy' trial, we have set up a test bed spanning more than 50 homes for 'Internet of Things' research. Through a new collaboration with the Technology Strategy Board (TSB) Future Cities Catapult, we are investigating the intersection between wearable technologies for blind people, smart city technologies and guide dogs. We are forging close relationships with the TSB Transport Systems Catapult to investigate how big data and personalisation can engender a new relationship between people and public services.

Knowledge media (KM)

d'Aquin, de Liddo, de Roeck, **Domingue**, **Dooley**, Fernandez, Mikroyannidis, **Motta**, Pedrinaci, Piwek, **Power**, **Rüger**, **Song**, Willis, Zdrahal

Richer web content, the popularity of social networks, internet-enabled devices and the Internet of Things all contribute to society's growing data deluge. The challenge is harnessing computing technology to bring information meaningfully to users when they need it – to generate meaning in context, in a way that serves business needs, societal infrastructure, communities and individuals. Our research in semantics and ontologies, linked data, natural language generation and information retrieval (IR) addresses problems associated with understanding, managing and using online, networked resources at scale. Resources may be human language texts, rich interactive media, web services/web APIs and online users engaged in collaborative activities (see our 'enabling exploration' and 'tackling socio-technical dilemmas' impact case studies).

Key accomplishments:

- Our **natural language generation** research takes information in one form and presents it, through automatic generation, in another form that is clearer and more accessible. CODA - Coherent Dialogue Automatically Generated from Text (EPSRC, Piwek) generates coherent dialogue from text, e.g., as an engaging alternative to information leaflets. SWAT - Semantic Web Authoring Tool (EPSRC, Power) creates English text from ontology notations which are otherwise opaque to many users. AgINFRA - Agricultural Scientific Data Infrastructure and ViBRANT - Virtual Biodiversity Research Network (both EU, Morse) convert historical agricultural and biodiversity literature into digital resources, interpreting scanned physical texts into meaningful taxonomic information by combining automatic extraction and human expertise to support curation. Our research is used in industry: our ontology verbaliser (Power) enabled the Bioinformatics Institute to rectify errors in their ontology, and our monologue-to-dialogue technology was used to produce information videos for the Papworth Trust.

- Our **information retrieval** research has moved the boundary of what we can do with search by providing automatic annotation and full multimedia searching on audio-visual content independent of its nature and structure (Pharos - Platform for Search of Audiovisual Resources across Online Spaces, EU, Rüger). This work has been taken up by Orange Ltd. and France Telecom for multimedia access. Renaissance (EPSRC, Song) has shifted the IR paradigm toward a unified theory of information retrieval based on a Quantum Theory framework intended to address the challenges of context-sensitive and multimodal search.

- Our **semantics and ontologies** research has advanced the state of the art in the use of ontologies for large-scale semantic applications in distributed organisations. We led the €14M EU FP6 integrated project NeOn – Lifecycle Support for Networked Ontologies (EU, Motta), which brought together 13 partners in semantic technology research and produced a powerful toolkit, which is one of the top three solutions for ontology engineering currently available.

Ongoing knowledge media research is enabling a whole new range of services for ubiquitous technology, e.g., CARRE - Shared Decision Support for Cardio-Renal Disease (EU, Domingue), which will bring linked data to the Internet of Things for **healthcare**. We are prioritising work which presents a 'future internet' vision of learning services; our **linked data** work has already resulted in the first university linked data portal (http://data.open.ac.uk) to make data repositories from a higher educationally institution available within the Linked Open Data cloud. This service has become the basis for a range of new applications and apps, from institutionally-focused apps (e.g., DiscOU, d'Aquin, http://discou.info) to new international educational services (e.g., FORGE - Forging Online Education through FIRE, EU, Domingue).

Software engineering and design (SEAD)
Bandara, Hall, **Nuseibeh**, **Petre**, **Sharp**, Tun, Wermelinger, Yu, **Zisman**

The nature of software is changing: divorced from any specific hardware or individual provider, software is turning into an adaptive fabric, embodying new principles of construction and organisation, and underpinning society. This requires fundamentally new approaches to designing, engineering and reasoning about software that accommodate complexity and uncertainty. We address this challenge through research in requirements engineering, security and privacy, software design and development, adaptation and evolution, and traceability.

Key accomplishments:
- Our engagement with diverse research disciplines, including psychology, interaction design, engineering, machine learning and natural language processing, has produced new ways of thinking about wicked software engineering problems (Nuseibeh, Bandara, Hall). In MaTREx - Making Tacit Knowledge in Requirements Explicit (EPSRC, Nuseibeh), we extended natural language processing techniques to develop novel ways of handling ambiguity in **software requirements**, a key contribution for accommodating uncertainty in requirements elicitation. We have demonstrated that new approaches which bridge the gap between software and traditional engineering disciplines and between software requirements and business requirements achieve significant savings for industry (Hall).
- We have helped software engineers to build systems that give end users greater confidence in their data, by developing techniques for eliciting and analysing **security and privacy requirements** (Nuseibeh, Bandara, Tun). The PRiMMA project - Privacy Rights Management for Mobile Applications (EPSRC, Nuseibeh) produced novel approaches to understanding, and new technical solutions for managing, users' **privacy requirements**. Its award-winning ContraVision method for eliciting users' privacy concerns in relation to futuristic technologies has been adopted by international researchers studying collaborative health and wellness-management technologies. Our use of security requirements for risk assessments (Nuseibeh) was applied in a collaboration with National Air Traffic Services (NATS) and Rome Airport on a study for Eurocontrol on the feasibility of replacing ground radar with GPS on planes (resulting in a co-authored publication in *IEEE Computer,* http://dx.doi.org/10.1109/MC.2009.299).
- Our work in the field with practitioner communities on **empirical studies of software development** (Petre, Sharp), challenges preconceptions and provides actionable insights about representations and practices. For example, research clarifying the role played by the physical nature of supporting artefacts plays a role in the collaborative environment of agile software development has prompted practitioners to re-think their approach and expectations for distributed working. Sharp's work explicating the gap between agile theory and **agile practice** led to the creation of the DSDM Agile Research Network (agileresearchnetwork.org), which tackles practitioner-identified problems through research.

To engage with the demands of complexity and uncertainty, we have expanded the scope of our research to include work on **adaptive, service-oriented systems** (Zisman, Bandara, Yu), for example developing techniques for automated service discovery that can handle uncertainty by using soft constraints. This complements our work on the practical use of **model-driven software engineering** (Petre), and its applications to adaptive service-oriented systems and adaptive user interfaces (Zisman, Bandara). Our ongoing research is supported by diverse organisations including the European Research Council (Adaptive Security and Privacy, ERC), the Qatar National Research Fund (Adaptive Information Security), and EPSRC (Privacy Dynamics).

Future CRC research
Our recently awarded MK:Smart project (led by Motta: £8m HEFCE Catalyst grant plus £8m partner co-funding) exemplifies one of our most important planned trajectories for the next 3 to 5 years. The project is a national demonstrator for how urban analytics can deploy big data feeds to support sustainable economic growth and citizen and business innovation. Our collaboration with the Transport Systems Catapult will provide an arena in which to co-design a digital infrastructure for novel mobility solutions. These substantial interdisciplinary initiatives with major public and industrial stakeholders will enable us to address our vision of people-centred ubiquitous computing in a large urban arena, providing the infrastructure for research at scale and addressing the challenges of urbanisation around the world. This larger, richer context of complex, socio-technical

ecosystems changes the scope and impact of our research, both in terms of knowledge discovery and knowledge transfer. We are actively developing further large-scale collaborations with stakeholders in business and industry to provide technologically-advanced solutions – making this a focal element of our ongoing strategy.

The text above sets out plans for each theme in the next five years, such as adaptive systems, animal-computer interaction and big data. We are well-positioned to deliver these, having secured significant new funding in the last six months (£28.4m funding for 13 projects; £5.4m OU share). We shall continue to build on the mechanisms, articulated at the start of this section, that we have deployed successfully since 2008.

---

c. People, including:

> **I.   Staffing strategy and staff development**

The profile submitted to this REF is: Professor (11), Reader (1), Senior Lecturer (12), Senior Research Fellow (1), Research Fellow (7). Our staffing strategy supports our research strategy and commitment by prioritising appointments of academics who can: (1) build research excellence within our key themes, (2) expand our research into related emerging areas, and (3) complement existing expertise. Since the 2008 RAE census date, four new academics have been recruited: three research leaders (one each in ubiquitous computing, software engineering, and knowledge media) and one early career researcher (ubiquitous computing). We have also developed and promoted tenured staff: four to Professorship; one to Readership; and four to Senior Lectureship. Four contract researchers have been promoted to Research Fellow to pursue independent research. Of the staff submitted to the 2008 RAE, two retired, two moved abroad and two took appointments at other UK universities. Despite the economic climate we have maintained both leadership and critical mass in each of our key areas. In the next few years, we plan to improve our age profile by recruiting more early career researchers.

The interdisciplinary nature of our research means that individual researchers may move across disciplines, sometimes focusing on aspects of computing technology, sometimes on integrating that technology into other disciplines. As a result, some of our research and researchers are submitted under the disciplines to which we contribute (e.g., Buckingham Shum's research on technology-enhanced learning and learning analytics is submitted under Education).

Our strong and supportive research culture attracts researchers from around the world. The CRC community includes over 25 different nationalities. Our senior academics span China, Brazil, the USA and many European countries, bringing global research links and cultural understanding. A third of our professoriat is female. The OU holds an Athena SWAN Bronze Award for promoting gender equality, "demonstrating a clear commitment to change and a solid foundation for eliminating gender bias". The Computing and Communications Department plans to apply for bronze status in the next three years.

The OU is committed to equal opportunities for all staff in pursuing their research. All academic staff are guaranteed dedicated research time, and all are encouraged to apply for external and internal funding. Coordinated support for external engagement and developing grant applications is available at University, Faculty, and CRC levels to help individuals develop and pursue their research agenda. Applications for externally-funded research fellowships are encouraged, allowing researchers to be released from teaching and administrative duties. Successes include two Royal Society Wolfson Research Merit Awards (Nuseibeh, Petre), a Visiting Research Fellowship at Stanford University (Alani), Visiting Professorships at the University of Paris 13 and the Italian National Research Council (Motta), and an internship at Google Zurich (Fernandez).

All staff engage in ongoing career development and appraisal, coupled with tailored workload planning that tracks career goals and performance against development objectives. A CRC-wide research development programme includes external seminar series, research and reading groups, and an annual 'Research Fiesta' (a forum for intellectual debate and for refining medium- to long-term research goals). The CRC invests a substantial amount in research annually, split between studentships, flexible support for research activity (including 'seed money' for new projects and collaborations, and development for early-career staff), equipment, and infrastructure.

The OU is a signatory to the Concordat to Support the Career Development of Researchers and works actively to implement all seven principles. Our robust implementation of the Concordat has been recognised with the European Commission HR Excellence in Research Award. Transferring the experience of senior staff to career-young academics is regarded as critical. New appointments are assigned personal academic mentors and probationary supervisors, and have reduced teaching loads for the first two years of their appointment. We seek to move contract researchers into permanent positions (e.g., Pedrinaci and d'Aquin) through mentoring and internal development processes.

The CRC fosters international research through collaboration; it welcomes some 50 visitors each year. Some visitors spend a short time giving seminars and engaging with our colleagues (e.g., Robyn Lutz, NASA). Others stay longer (e.g., the academics from Tianjin University in China visiting Song and Yu as part of an EU Marie Curie project). Our influential community of long-term visitors includes Visiting Professors Michael Jackson and Cory Doctorow, and Visiting Senior Research Fellow David Bush (NATS), who play strategic roles as research collaborators, advisors and domain specialists.

c. II.   Research students

The University infrastructure for PhD research exceeds the requirements of UK Research Council and Quality Assurance Agency specifications. Our programme is given coherence by structured six-monthly progress reporting, and a University-wide Virtual Research Environment (VRE). The VRE provides access in one place to a range of skills, news, careers, supervision, library, social media and administrative resources, and hence ensures comparability of experience to all OU research students regardless of their physical location or part-time or full-time status. All students have (at least) two supervisors and a third-party monitor who takes a pastoral role.

The CRC currently has 81 students, a 45% increase over the last 5 years. Since 2008, 47 PhD students (including PT and FT) completed their degrees successfully. 76% of full-time students complete in 5 years (based on 2008/9 entries). More than 95% of our students publish in refereed outlets before submission, with 4 Best Paper awards since 2008. Full-time students receive an annual bursary to cover travel and research expenses. The success of this vibrant PhD programme is due to a comprehensive PhD support infrastructure and training programme that operates throughout the students' PhD studies, including a strong focus on community building and peer-to-peer learning, weekly research skills seminars, regular on-line seminars for part-time students, an annual student conference attended by the whole research community, funding to attend conferences, external courses and summer schools, and dedicated on-line resources including the OU's VRE. Students attend research groups and seminars alongside academic staff, and engage with research visitors. This doctoral programme is at the forefront of quality and innovation, as reflected by our collaboration with Vitae, and by invitations to lead doctoral activities within European networks of excellence and to lead doctoral symposia at major international conferences, such as SIGCSE (Computer Science Education), ECTEL (European Conference on Technology Enhanced Learning) and ICSE (International Conference on Software Engineering). We have also applied the OU's leadership in innovative educational models to international PhD Summer Schools. These include the SSSW and ESWC summer schools in the Semantic Web area, as well as JTELSS in Technology-Enhanced Learning. PhD students regularly take up positions in academia (e.g., Calgary, Nottingham, Inria, Université Catholique de Louvain), private companies (e.g., Yahoo, Nokia, BBC, Fujitsu, Google, IBM, T-Systems, General Motors, Nature) and non-profit organisations (e.g., the Open Data Institute).

Students are recruited through normal channels, including advertising and professional networks. We also use conferences, summer schools, collaborations and internships to identify and form relationships with potential candidates. In the REF period, we have hosted 49 PhD students from 21 countries, including Brazil, Czech Republic, France, Germany, Japan, Nepal, Sweden and the USA for 3-6 months each as part of their studies abroad. Some have chosen to remain at the OU (e.g., Bourgeois, Kreitmayer, Xambo).

d. Income, infrastructure and facilities

D.1. Facilities
Computing excellence underpins the mission of the OU, which was founded to exploit computing

and communications technology for education. The University's commitment to computing research is clearly evident in the purpose-built facilities for each of the collaborating units. The KMi labs on the penthouse floor of the award-winning Berrill Building host innovative collaborative and webcast facilities. The £17m Jenny Lee Building, part-funded by the Science Research Investment Fund and opened in 2008, houses Computing and Communications and features state-of-the-art labs supporting research in usability, ubiquitous and ambient technologies. Its reconfigurable working environment allows the CRC to investigate how people interact with, and through, technology-enabled environments.

Since the 2008 RAE, the University has invested strategically in additional labs to support expanding research areas:

- A **Security and Privacy Lab** (established in 2011) that supports experimentation with security in the context of mobile and ubiquitous technologies.
- The **Music Computing Lab** (2008), with further funding from AHRC- and EU-funded projects, offers specialised musical, haptic, gesture-sensing, and sound processing systems to complement custom-built research prototypes and musical software. It shares an anechoic chamber with Acoustics and a recording studio with Music.
- The world's first **Animal-Computer Interaction Lab** (2012) provides a growing repertoire of monitoring equipment and bio-sensing technology with which to test interaction prototypes with animals in an animal- and owner-friendly setting.
- The **Ubicomp Lab**, with its focus on augmenting and extending everyday, learning and work activities, has been expanded and now features eye-tracking, motion capture technologies and interactive surfaces, as well as a workshop for developing prototype interfaces.

D.2. Infrastructure
Computing research at the OU has access to: a **network of 77 servers** (including a Datacore 87tb SAN, that allows us to spin up a server in minutes, test a new concept service, and kill it just as quickly); **3 campus data centres**, supported by a significant cloud service off campus; **the IMPACT Cluster**, a parallel computing facility with 754 CPUs used to support STEM research; and **a VMware vSphere cluster** (with 96 processors running 130 virtual machines) that provides high availability and dynamic resource scheduling.

Since 2011 the OU has invested £320k in expanding the IMPACT cluster and plans to continue this level of investment in the future. The two clusters have been used in HCC and SEAD research to process natural language corpora and software repositories, and to perform big data analytics for urban data mining, including phone, transport and energy usage.

The CRC's home Faculty also funds the Electronics and Audio Visual Production unit, which provides electronic and mechanical design, development and repair. This unit has built bespoke equipment used in our ACI, ubiquitous computing and music computing research.

The CRC's technical expertise and computing facilities are also used strategically to support world-leading technology and learning outreach for the OU. For example, CRC researchers provide the live publishing platform that implements support for our iTunes U and other streaming and webcast services (see our impact narrative).

The OU's research support infrastructure is coordinated across central and local services. Central research services comprise five teams: (1) grants and contracts, (2) innovation and enterprise, (3) governance and communications, (4) academic staff development, and (5) the postgraduate research degrees office. These complement and support the dedicated research administration teams and technical and project officers in each of the CRC's contributing units by sharing information and expertise; supporting cross-disciplinary activity; running research development workshops; coordinating European funding and other large grant opportunities; and providing expertise in knowledge exchange, intellectual property, and commercialisation. Hence, the CRC is part of a coordination network that leverages resources and expertise across the University, while providing tailored support.

D.3. Funding portfolio
Our external funding strategy has, since 2008, focused successfully on diversification and sustainability, both in terms of income and in terms of access to relevant communities, by:

- Diversifying funding sources; our current portfolio includes support from, e.g., RCUK, EU, TSB, HEFCE, Leverhulme, Microsoft, Google, DogsTrust.
- Increasing the number of large grants, e.g., our ERC €2.5m Advanced Grant on Adaptive Security and Privacy, our £1m Wolfson Foundation grant for the Open Science Lab (with the Science Faculty), and our $1m grant from the Qatar National Research Fund.
- Increasing interdisciplinary grants, e.g., a Leverhulme grant for HCI education research with Botswana, the EU ViBRANT project on biological literature, and an AHRC project (with the Health and Social Care Faculty) on Older People and Technological Inclusion.
- Building further long-term relationships with industry, currently including Microsoft, SAP, Yahoo, E.ON, NATS, and Diamond Light Source.
- Increasing in-kind contributions, e.g., E.ON is giving access to live energy data from 75 households, and lending internet-enabled domestic appliances valued at £200K, to design new user interfaces for energy-aware, smart-grid connected appliances.
- Securing consultancies and providing professional services, see below.
- Exploiting synergies with teaching and outreach, e.g., staging an immersive experience with haptic technology at the Battersea Arts Centre with Extant, a theatre company for and by blind people; demonstrating the SenseBoard at the London Urban Prototyping Festival; hosting AS/A-level students as Nuffield summer interns; participating in Code Club and the Computing at Schools networks; and building Internet of Things capacity in schools as a partner in the TSB-funded Intel Connected City Research Lab.

We will carry this strategy forward, responding to the changing funding landscape and our own development by increasing the emphasis: (a) on major collaborations and larger grants; and (b) on industry collaborations leading to funding and in-kind contributions.

e. Collaboration and contribution to the discipline or research base

The CRC has a rich history of collaboration with external partners from academic, business, not-for-profit and government/policy domains. We have engaged in more than 40 collaborative research projects since 2008, ranging from short engagements with a single partner to projects of over 5 years duration with up to 20 partners. The profile of consortium partners includes highly respected higher education institutions (e.g., Imperial College London, University of California Irvine), national research institutes (e.g., NASA and Diamond Light Source) and government bodies (e.g., Milton Keynes and Sunderland Councils), and corporations and SMEs (e.g., Google, Microsoft, Telefonica, Yahoo!, Verizon, BBC, SAP, BT, IBM, SUN, Santander, BP, Rolls-Royce, Philips, RAI, ATOS). The OU has a Memorandum of Understanding with Japan's National Institute of Informatics (NII), which has resulted in mutual visits, regular joint workshops, 3-month research internships by our PhD students at NII, and co-authored papers. 51 outputs in this submission have international co-authors (46%), and 5 (4.5%) have industrial co-authors.

Our **leadership in the academic community** is evident in:
(1) the coordination of international collaborations such as EU projects (e.g, STELLAR, FORGE);
(2) advisory roles (e.g., EPSRC's ICT Strategic Advisory Team, Nuseibeh; BCS Council, Hall);
(3) chairing over 20 of the leading conferences in our areas (e.g., PC Co-Chair: IEEE/WIC/ACM Web Intelligence 2010 and 2013, Rüger; Chair: International Semantic Web Conference 2009, Motta; European Chair: International Conference on Signal Processing, Dooley); and bringing the 32nd European Conference on Information Retrieval to the OU in 2010 (Chair: Rüger);
(4) leading or participating in steering committees (e.g., Chair ICSE Steering Committee, Nuseibeh; Knowledge Engineering and Knowledge Management - EKAW, Motta; President 2007-10, European Association of TEL, Scott; Chair ESWC Steering Committee, Domingue);
(5) 13 leading editorial roles (Editor-in-Chief of *TSE*, Nuseibeh, Editor-in-Chief of *IJHCS*, Motta, Associate Editor of *IEEE Transactions on Systems, Man and Cybernetics*, Part C, Zdrahal, Associate Editor-in-Chief of *IEEE Software*, Sharp) and membership of 24 editorial boards;
(6) contributions to standards and working groups (e.g., Chair, IFIP Working Group 2.9 (Requirements Engineering), Nuseibeh).

Members of the CRC have received 23 best paper awards (e.g., Most Influential Paper from 2001, Mobile HCI 2011, Holland) and 13 other awards (e.g., Mozilla/MacArthur Foundation Design Challenge Winner 2010, Cohere). One student and one early career researcher (Heath, d'Aquin)

were named among "AI's 10 to Watch" by *IEEE Intelligent Systems* in 2011. We delivered 51 keynotes at international conferences (e.g., INLG 2010, Power; MODELS 2011, Petre) and 18 invited tutorials or lecture series at international venues. We have engaged in 16 international summer schools (e.g., Director: ESWC 2011/2012/2013 summer school, Domingue). Six researchers have held Visiting Chairs at other universities (e.g., University of Waikato Hamilton, NZ, Rüger; University of Paris 13, Motta; Imperial College London, Nuseibeh), and Nuseibeh was seconded as Chief Scientist to Lero, providing leadership of the Irish national software engineering research centre's research across 6 universities.

Our research embraces **users**, whether technical stakeholders (e.g., the software developers who informed our empirical studies of design – Petre), domain specialists (e.g., the Hallé Orchestra, in a KTP collaboration to investigate the use of social media for online engagement with audiences - Scott), or end users (e.g., the violin students who participated in the development of the MusicJacket - van der Linden). We work actively with users during the formulation of research questions, through research and development, and subsequently to deploy our technologies into real contexts. For example, in Vital for Doctors, d'Aquin collaborated with the Heart of England NHS Trust to contextualise OU Linked Data and Learning Analytics technology in a demonstrator for the training of doctors. Minocha's work on Older People Online engaged organisations such as Age UK and the University of the Third Age in a series of workshops to engage users and inform policy.

Our interest in users and their contexts, and our strategic commitment to ubiquitous computing, lead naturally to **interdisciplinary research** – such as our work in ACI and music computing. Examples of interdisciplinarity cut across our themes. For example, Living Human Digital Library (EU, Domingue) in collaboration with the Rizzoli Orthopedic Institute combines medical and computing research skills in interactive digital library services to access collections of complex biomedical data on the musculoskeletal apparatus. e-Dance (AHRC, Buckingham Shum) is a research collaboration with choreographic practitioners as part of a national programme to exploit e-science technologies in the arts and humanities. The OU extended its Memetic toolkit for recording, replaying and annotating dance sessions in the Access Grid to create tools for choreographers to rehearse and perform distributed compositions. ViBRANT and AgINFRA (EU, Morse) are good examples of interdisciplinary research applications in biology and agriculture.

Our **collaboration with industry** is effected through research projects, knowledge and technology transfer, and consultancy – with collaborators acting both as research partners and as informants. Examples of research projects include the PRiMMA project (EU, Nuseibeh), a research collaboration with National Air Traffic Services (NATS) helping to improve security requirements and to understand software system failures. In eGov4U (EU, Minocha), the OU worked with city councils in the UK, Iceland, Ireland, and Malta to develop citizen-centric public service provision to increase engagement among socially disadvantaged citizens. Examples of technology transfer include FlashMeeting for Schools, a not-for-profit collaboration in which The East of England Broadband Network (E2BN) hosted national and international school video communications using KMi FlashMeeting technology, with analysis of engagement and impact. The DiscOU technology (d'Aquin) is founded on an ongoing collaboration with the BBC in the semantics area and uses the OU's linked data technology for the real-time semantic discovery of OU Open Educational Resources in the context of BBC programme data. Examples of consultancy include Sharp's work with the DSDM Consortium Board: addressing significant issues within agile software development, eliciting a detailed understanding of the problems identified by industry practitioners, and developing modifications to practice which will supplement the method, with direct impact on industry practice.

CRC research has informed the **research agenda of industry and public bodies**. Examples include a UNESCO funded Bioethics feasibility study on the elaboration and implementation of eLearning modules for UNESCO's Bioethics capacity building activities that informed the research agenda for UNESCO in Technology Enhanced Learning (Zdrahal & Scott). Funded by a Vitae Innovate research contract, we carried out empirical research into social media usage in academia that resulted in the *Vitae Handbook of Social Media for Researchers and Supervisors*, distilling best practices including ethical, professional and legal issues and listing resources for practical use (Minocha, Petre).