Institution: City University London
Unit of Assessment: 11 Computer Science and Informatics

A. Overview

In the current REF period, we have built upon our long-standing research expertise in the fields of Software and Systems Engineering (SSE) and Information Science, while developing considerably our reputation and research output in the fields of Human-Centric Systems (HCS) and Information Analysis and Visualisation (IAV). Our School of Informatics has grown significantly since RAE 2008: 36 academic staff (32 FTE) are now submitted, an increase of more than 38%. Around one third of these staff have been recruited since 2010 as part of City University London's £35M academic recruitment drive undertaken in the last 3 years. Our submission incorporates two thirds of the academics of the former Department of Information Science who have been involved in computational/technical research.

Major challenges in computer science and informatics arise from (i) the pervasive operation of software systems in complex and heterogeneous socio-technical environments; and (ii) the need for such systems to operate in a secure and dependable way, whilst supporting diverse human-centric activities and utilising large bodies of evolving information often arising in rich media forms. In response to these challenges, we have developed novel, enduring and empirically validated concepts, theories and tools for adaptive and pervasive software systems development; rigorous methodologies for the assessment of system dependability, safety and security; human-centric system design and evaluation; and computational and visual analysis of large information sets.

Our research activities are focused in three areas:

(i) *Software and Systems Engineering (SSE)* – we have long-standing and world-leading expertise in the development of complex software systems and the assessment and verification of critical properties of such systems including dependability, safety and security.

(ii) *Human-Centric Systems (HCS)* – we have built expertise in the innovative design and evaluation of interactive and pervasive systems supporting human-centric activities, including health and social care; creativity in system design; and the development of novel interfaces and devices for such systems.

(iii) *Information Analysis and Visualisation (IAV)* – we have a more recent focus on and investment in the development and evaluation of algorithms, interfaces, workflows and theory to support the analysis, learning from and use of large collections of data including imagery, geographic data, video, audio and text.

The research is strongly interdisciplinary in character. Staff collaborate frequently with colleagues in a range of disciplines and application domains and, through industrial partners, in a variety of sectors. Examples include work on safety risk assessment, creativity in design and visualisation/geo-informatics. Our research has been applied to and/or influenced practice in industrial and government sectors including the nuclear, financial, software and rail industries, health services and local government.

Our existing strengths, together with our significant expansion through investment in academic staff with complementary capabilities, provide a solid basis for achieving our vision in the next five years. This is to establish the School on the world stage as a leading centre for problem-driven, interdisciplinary research in the three areas of focus.

B. Research strategy

B.1 Research aims and strategy for the assessment period

The aims of our research strategy within the REF period have been to:

(i) Produce world-leading research in our areas of focus and disseminate this through leading journals and conferences in these fields;

(ii) Apply the outcomes of our research to benefit society, enterprise and the public at large.

We have sought to do this by:

(i) Continuing to work in those areas listed in Section A where we have a critical mass of academics and demonstrated research excellence;

(ii) Building on these successes through the expansion of our research to address significant new challenges in: (a) cyber systems security (building on work in systems safety and reliability and software systems verification); (b) adaptive systems engineering (building on work in service

oriented systems); (c) creative system design (building on work in interactive systems design and requirements engineering); (d) data analysis and visualisation (building on work in geo-informatics and machine learning).

We have taken a selective approach to our response to key research challenges in the discipline, identifying areas of applied research where the School's existing strengths provide a basis for further success. Much of our work on cyber security during the current REF period, for example, has drawn on earlier successes in quantitative modelling of other aspects of dependability (safety, reliability). Our visualisation work has applied our established expertise in geographic information science to influence a broader community with interests in non-spatial contexts. This strategy has fitted closely with many of the identified priorities of research funding agencies, including RCUK and EU programmes on cyber security and EU ICT programmes on software systems and services, cognitive systems and technologies for digital content, health, creativity and learning.

To achieve our research aims, our strategy has been to:

- Invest in people. During the REF period we have appointed 11 new academic staff (4 in SSE, 3 in HCS and 4 in IAV) and funded 28 full PhD studentships and 16 fee-only PhD studentships, prioritising research areas identified for expansion.
- Establish collaborations with industry and other institutions outside academia as sources of real-world problems and as means of demonstrating the impact of our work.
- Seek external research funding and use it, along with internal investment, to provide a vibrant and sustainable research environment for our research staff and students and our academics.
- Strengthen our existing links and develop new ones with external and internal academic collaborators, especially in areas of interdisciplinary research.

B.2 Main changes from last RAE

Overall, our research agenda has remained in line with the general research directions set out in our submission to RAE 2008 (i.e., the development and evaluation of dependable socio-technical and interactive systems), although its focus has changed in some instances in response to external and internal factors (e.g., research on cyber security) and some research activities have been merged and re-oriented. Our research in programming languages, for example, now forms part of the SSE area, focusing mainly on security analysis of program information flows, while our research in intelligent systems and music informatics has been re-focused as part of the IAV area. Other research activities have been terminated (e.g., Bioinformatics). These changes reflect our strategy to reconfigure research within our selected areas of focus. The same strategy led us to integrate academics from the Department of Information Science who focus on computational aspects of information retrieval (CISR) and geo-informatics (giCentre) into Computer Science, to synergise with our experts in Machine Learning and develop the IAV area. The strategy also led us to invest in people to bridge gaps within the three research areas.

B.3 Key Research Achievements

In line with our strategy, some our key research achievements over the REF period, summarised below, have been based on collaborations with academic and industrial partners and research users, as indicated in Section E.

Software and Systems Engineering: We have built upon our long-standing record in the areas of systems reliability and safety, requirements engineering and service oriented systems engineering.

Research in the Centre for Software Reliability (CSR) has made significant advances in the ways that the dependability of critical software-based systems can be assessed to support quantitative safety cases. We have developed a theory of provably conservative and yet practically useable safety claims. This includes a novel way of reasoning about an important class of fault-tolerant system (such as nuclear protection systems) that overcomes problems of dependence between channel failures. This work has been reported in four papers published in the *IEEE Transactions on Software Engineering* journal in the last two years. Our research has received continuous funding from the nuclear industry for the past 17 years. Our results have been taken up by the Office for Nuclear Regulation (ONR) and have played a significant role in the licensing processes of new nuclear systems (details are set out in one of our impact case studies).

Our requirements engineering research was the first to reframe early requirements work as dependent on essential cognitive and collaborative creative acts (IEEE RE '10). We have developed a new theory of early requirements work as information search and idea discovery,

reported in the IEEE RE conference and the subject of a technical keynote address to IEEE RE '13. This reframing has led us to generate new forms of requirements techniques and tools, which were reported in IEEE RE conferences from IEEE RE '08 onwards. We have applied these forms to generate novel system concepts for automotive manufacturers, media organisations and air traffic control, e.g., new concepts of operation for multi-sector gate-to-gate planning across national boundaries with Eurocontrol. The industrial impact of this work has been recognised through the selection of our paper on reframing requirements discovery as complex collaborative creative work as one of the most important 25 papers in the first 25 years of the *IEEE Software* journal.

Our research in service oriented systems engineering has produced a novel platform for context-aware runtime systems adaptation, supporting service monitoring, discovery and replacement. We have developed new service interface, behaviour, quality and context matching algorithms and applied them in a proactive manner, which reduces significantly the overheads to runtime system performance, offering a realistic solution to the problem of runtime adaptation for the first time. This work has been reported in two papers in the *IEEE Transactions on Software Engineering* journal (2010 and 2013). The business potential and viability of our service discovery approach and the service query language underpinning it have been demonstrated by SAP and influenced the development of their next generation Certification-Aware Service Marketplace.

Human-Centric Systems: We have invented new forms of human-computer interaction and technologies supporting information-seeking and creativity support and deployed new technologies to change human behaviour in complex social systems in health and social care. Our new technologies are changing health and social care practices in the following ways:

- Interactive software tools that adapted computer-based gesture recognition and immersive world components in novel configurations to help people with severe aphasia learn communicative gestures were reported in the Participatory Design Conference (2012) and highlighted in the 2012 Annual Parliamentary Report on R&D in Assistive Technology (prepared by the Foundation for Assistive Technology (FAST) on behalf of the UK Department of Health). This led to the development of a proposal for new specialist clinical services for people with aphasia to Barts and the London Charity and the award of two interdisciplinary projects from The Stroke Association and the Tavistock Trust for Aphasia to exploit technology for improving the quality of life with aphasia in innovative ways.

- Research into the complexity of patient handovers in clinical settings reported in CSCW (2011) led to a novel design combination of interactive technologies that enhanced situational awareness. This was licensed to a leading London hospital for use in its children's acute transport service. It also led to new guiding principles for patient handover produced by the Clinical Safety Team of the UK Department of Health.

- Software that combines novel data capture and analysis algorithms on low specification mobile phones to record and analyse registration and verbal autopsy data about deaths in developing countries, which was reported in CHI '13, has been adopted by the World Health Organization. It is currently deployed in South Africa, Malawi, Nepal and India.

- New forms of creativity and reflective learning support in residential dementia care based on similarity-matching computational creativity algorithms (ACM Creativity & Cognition '13, CACM '13), demonstrated to lead to improvements in care quality in pilot residential homes.

Our research revealed how computer aids affected in detail clinicians' decisions in breast screening (*International Journal of Computer Assisted Radiology and Surgery*) and led to a statistical methodology (*Journal of Medical Decision Making*) for detecting when a computer decision aid increases risk for some patients when used by certain types of clinicians.

Information Analysis and Visualisation: Our research in information visualisation has produced new techniques for visualising and interacting with complex data sets to reveal structure and for designing novel and effective visualisation solutions. Visualisation techniques include: spatial tree maps for representing geography and multiple hierarchies concurrently; OD maps - a scalable technique to show flows between large numbers of origins and destinations geographically; and sketchy rendering to produce hand-drawn interfaces to data designed to promote engagement. Design contributions include: a user-centred approach to visualisation; a language to describe and discover visualisation possibilities; and the application of techniques to deliberately stimulate creative thinking in visualisation design. The work is reported in a series of 21 papers in *IEEE Transactions on Visualisation and Computer Graphics* and has resulted in two Honourable

Mentions at IEEE InfoVis, two Best Paper awards and an Honourable Mention at IEEE VAST and award-winning entries to open data challenges from IEEE, Nokia and Google. Our research has been transferred into diverse application domains such as assessing risk in the insurance industry (Willis); establishing situational awareness in areas of conflict (UK Ministry of Defence); and visualising energy data (E.ON).

Our research in data analysis - machine learning, computational intelligence, computer vision - has resulted in: new techniques for neural symbolic computation that have been used for real time adaptation of the conditions in driving simulators in response to drivers and instructors; and object recognition with application to computer-aided detection of cancers and other diseases, enabling non-invasive detection through image and video processing. The work is reported in *Machine Learning*, *IEEE Transactions on Neural Networks and Learning Systems*, *Medical Image Analysis*, and *NeuroInformatics*.

B.4 Future vision and strategic plans

In line with our vision (see Section A), our strategy for the next REF period is to strengthen research in areas where we have demonstrated leadership and expand it into complementary areas. To achieve this we plan to:

- Respond to the increasing demand for very high systems dependability - particularly safety and security. Since 2008 we have made striking advances, but important and difficult problems remain. We will address: dependability assessment of design-diverse fault-tolerant systems; quantitative safety cases based on disparate evidence (e.g., from testing and proof); probabilistic measures of security; quantitative risk cases for complex infrastructures; 'holistic' dependability cases involving computers, humans and organisations; and new models of security assessment and certification for cloud and service oriented systems.

- Expand our research in service oriented systems engineering to address challenges related to the provision of autonomic software services on shared and federated computational infrastructures (e.g., cloud), with a focus on supporting scalable and fault tolerant data analytics.

- Produce novel pervasive communication technologies and telexistence paradigms to enable a presence of all five senses, as well as non-verbal and emotional communication through digital networks and the physical world of humans and devices. This will address the challenge of making more meaningful exchanges in the physical and virtual world, drawing upon expertise in HCI and pervasive systems.

- Provide scientists, engineers and society with interactive graphical interfaces to larger and more complex data sets and sophisticated analytical functionality through which they can be processed and interpreted. This will address the big data challenge by drawing upon expertise in information retrieval, machine learning, signal processing, visualisation and visual analytics.

Our strategy is to drive the development of our research along these directions through challenges arising in energy, health and assisted living, transport, social media and security and to seek to impact these areas through our outcomes. This expansion will build on our existing strengths and expertise acquired through our recent academic staff appointments (see Section C). Our plan is to expand further this core research capability through the acquisition of research funding and the corresponding recruitment of PhD students. The alignment of our research directions with new funding programmes and priorities (e.g. EU Horizon 2020, RCUK Global Uncertainties, Healthcare and ICT programmes) and the opportunities for developing joint bids with our industry, user and academic partners will be a key enabler for achieving this plan.

B.5 Research development and assessment processes

The sustainability of our research is supported by financial and reporting policies that enable decentralised decision-making by groups of researchers within the scope of the overall School research strategy. Groups and principal investigators (PIs) have direct control over portions of overhead and directly allocated research income in order to develop their research activities. They receive 20% of overheads plus one-third of the funded PI time that is charged on projects for use in support of research. This has enabled research staff bridging, research dissemination, collaborations with external parties and the development of new areas (e.g., support for short-term internal projects investigating the feasibility of new research directions).

The achievement of research objectives and the adequacy of the resources available for them are monitored regularly within the School and the University. The alignment of research objectives of

individual members of staff with the School's strategy and the attainment of these objectives is assessed in annual appraisals. There is a University Annual Research Quality Monitoring process which reviews the quality of research publications. School-level objectives are monitored by the Associate Dean for Research and the School's Research and Executive Committees. The Research Committee has responsibility for establishing research objectives and priorities for the School, reviewing progress against them, setting policies for the allocation of research funding (e.g., research studentships) and overseeing School-wide research activities. The Executive Committee is responsible for executive decisions on strategy, research income targets and expenditure and for aligning research with the educational activities of the School.

C. People, including:

C.1 Staffing strategy and staff development

Staffing strategy: Two main forces have shaped our staffing strategy over the REF period. The first is the University's Strategic Plan 2012-2016, which features major investment in academic excellence to secure City's position as a leading global university. The second is the research strategy of the School, which has been to strengthen further our research in areas of traditional strength and develop new research directions in carefully selected areas where existing strengths and the expertise of new academics will enable us to reach the critical mass required to achieve excellent outcomes. We have accordingly made the following 11 new appointments since 2008:

(i) Software and Systems Engineering: one professor in Security and Dependability (K. Jones) and three lecturers in the areas of Cyber Security (Komninos), Enterprise Systems (Comuzzi) and Cloud Computing (Kalyvianaki)

(ii) Human-Centric Systems: one professor (Cheok) and one lecturer (Bird) in Pervasive Computing and one senior lecturer in Human Computer Interaction (O'Sullivan)

(iii) Information Analysis and Visualisation: two part-time professors in information analytics (G. Andrienko and N. Andrienko), one senior lecturer in image processing (Slabaugh) and one lecturer in data science and visual analytics (Turkay).

These appointments include replacements for four members of academic staff who left. In the same period, four of our research staff have been promoted to academic posts: three in the area of dependability and security (Gashi, Povyakalo and Stankovic) and one in visual analytics (Slingsby). Based on the same standards used for external appointments, these promotions demonstrate the ability of our environment to support the development of our staff to the required level of research excellence (relevant support mechanisms are discussed below). Our investment in academic staff has been complemented by investment in PhD students within the strategic areas of our research (see Section B.1). Following the new appointments, we continue to have a balanced mix of international and UK staff (20 UK and 16 international members of staff) and all staff included in our submission, bar one part-time semi-retired member, are on continuing contracts.

Support for staff development: All new academic and research staff are assigned a mentor to advise them on general academic matters and personal professional development. Mentors are typically senior academic staff from the same research area. Early career staff are encouraged to develop their research through co-supervision of research students and assistants and the development of joint research proposals with experienced staff. Our academic and research staff also have access to the Research and Enterprise Development programme of the University that covers areas such as academic writing, supervision of research students and leadership development of principal investigators. Staff may apply for sabbatical leave for a period of time up to a maximum of one-seventh of service at the University, providing an intensive opportunity to progress research. Sabbatical applications are approved at School level and Senate. Within the REF period, twelve academic staff took sabbaticals, in which they were released from their administrative and teaching duties to enable them to achieve specific, pre-agreed research goals. Notable outcomes of these sabbaticals include successful grant applications (e.g., EU F7 IP Social Sensor) and publications included in our submission. Staff development is supported and monitored through annual appraisals (see Section B5). Individual research (and other) objectives are set in line with the overall research strategy of the School and necessary measures of support are agreed (e.g., training), monitoring progress and adjustment. As of March 2012, the University has also adopted a plan for the implementation of the Concordat to support the career development of researchers. We have already adopted measures to achieve consistency between the terms and conditions of employment of academic and research staff (e.g., parity in annual

leave entitlements, continuing contracts as the norm); enhance training opportunities for research staff; and promote equality and diversity (e.g., monitoring to tackle inequality and discrimination). Forthcoming measures include the adoption of consistent principles across the University for bridging funding for research staff and the alignment of probation, appraisal and promotion processes with the equality principles underpinning our REF Code of Practice.

C.2 Research students

Overview: Our research degrees programme has undergone significant expansion and enhancement since RAE 2008, resulting in a vibrant community of research students. 71 are currently enrolled on the programme (60 full-time, 11 part-time). Of these, 21 were admitted to the programme in 2011/12 and a further 20 in 2012/13. We have awarded 48 PhDs since 1st August 2008, comparing favourably with the 21 awarded during the last RAE period. These improvements are the result of investment in studentships, systematic efforts to support and monitor student progression and enrichment of the student experience (see below). The programme underwent a successful Periodic Review in 2012. Students rated highly the quality of their supervision in the 2013 Postgraduate Research Experience Survey: 93.1% confirmed that their supervisors had the skills and subject knowledge to support their research (sector average: 90.6%) and 89.7% confirmed their overall satisfaction with the programme (sector average: 81.7%).

Recruitment: Research students enter the programme through application for a University studentship; studentships funded by other sources such as research grant income; or direct application if they have funding from other sources. Since 2011, we have offered 37 full PhD studentships and 16 fee-only studentships. 28 of the full studentships have been funded by the University's Doctoral Studentship Scheme, 3 have been funded directly by industry (Mentor Graphics, Adelard and the Cloud Security Alliance) and 6 have been funded by EU research grants (S-CUBE, OPTIMIS, ASSERT4SOA and CUMULUS). Applications for studentships are assessed by a panel consisting of the School's Associate Dean for Research, the Assistant Dean for Research Students and Senior Tutors for Research (STRs), according to rigorous admission criteria regarding academic qualifications and fit with our strategic research areas. Applications for direct admission are assessed by an STR and at least one member of academic staff, according to the same admission criteria, and must be approved by the School's Board of Studies.

Supervision and progression monitoring: All research students are assigned a supervisory team of two research active academic staff, one of whom must be an experienced supervisor with a successful PhD supervision record. As of November 2013, 24 members of the submitted staff (including six of our newly recruited academic staff) are contributing to the PhD programme as first or second supervisors with a maximum supervision load of six. Students are expected to qualify within the maximum period of candidature (four years for full-time students and seven years for part-time). Student monitoring is accomplished through: (1) monthly updates of student progress sent to STRs; (2) reviewing of progression data by our Research Degrees Committee and Board of Studies; and (3) requiring students who fail to submit their thesis within the maximum candidature period (where no extenuating circumstances apply) to pay full fees. Research students are expected to maintain written records of meetings with their supervisors through an online Research and Progress (RaP) record system.

Training and Support: Research students attend a University and a School induction upon admission. Specific training and development needs of each student are assessed by the STR during admission and subsequently by supervisors. Training provision includes: (i) the University's Research and Enterprise Development Programme; (ii) the biannual University Researcher Development Days and annual Research Symposium for doctoral students where students present their work through posters and papers and compete for prizes; (iii) the Impact and Commercialisation PhD skills programme run by the Enterprise Office; (iv) modules on specialist Masters courses and the MA in Academic Practice; and (v) dedicated workshops, seminars and reading groups provided by the School. Further development of the training programme is in progress through the City Graduate School, formed in August 2012. A community of research students is fostered through initiatives including welcome receptions, monthly "coffee and cakes" mornings run by the research students and funded by the School, School workshops where research students present work to their peers, reading groups and a resource centre on Moodle.

We actively encourage our research students to write papers (14, i.e., 11%, of our REF outputs have research student contributors) and to participate in international conferences. This has led to

participation in top tier international conferences such as IJCAI, ICSOC, ICWS and IEEE InfoVis. The School provides all research students with an allowance of £1,500 towards conference participation costs during their studies. Additional support is available via research grants, the City Graduate School, Livery Companies and Future Fund. Eleven of our research students have won awards in international events. All full-time research students are engaged in teaching, normally as laboratory tutors.

D. Income, infrastructure and facilities

Infrastructure and facilities: The School has integrated research and teaching facilities as well as rooms for visitors. This space is organised into physically adjacent office and open plan areas so that academic and research staff and research students working in the same research area can be in close physical proximity. The space is on the main University campus, enjoying access to central research facilities such as libraries and providing opportunities to forge links with researchers in other Schools. Our researchers have access to specialist and dedicated research and technical support, in addition to those provided by the University. We also operate an Interaction Lab (IL), which provides infrastructure for human-centric research activities and a controlled experimental environment for conducting empirical research. The IL contains equipment for eye tracking, mobile user testing and novel interaction devices (e.g. gestural and brain-computer interfaces) alongside more traditional usability testing. This facility has supported several EU- and EPSRC-funded research projects (e.g., MIRROR, COLLAGE, EVA, GReAT, GeST) in domains such as dementia care, aphasia therapy and emergency management. In October 2013, we established a specialised Cloud-computing Lab (CCL) to support our activity in this area on cloud security certification (EU projects CUMULUS and ASSERT4SOA) and autonomic service provision on shared infrastructures. The CCL will also support our plan for expanding further in this area in 2014-19 following the recruitment of new academics. As of September 2012, further space was acquired to enable the accommodation of newly recruited academic staff.

The University has made a substantial financial investment of £165M to support the expansion of infrastructure, estate and research, which has enhanced the School's capacity for research activity. As of September 2012, further space was acquired to enable the accommodation of newly recruited academic staff. £1.5M has recently been invested in library collections including e-journals. Our academic dissemination of research benefits from the University's digital repository, City Research Online, which provides open access to publications and research data.

Three School-based research administrators manage administrative aspects of research projects and support research and academic staff and research student recruitment and administration. They liaise closely with the University's Research Office, which has responsibility for formal grant reporting and contracting processes. All staff members and research students also have access to a technical support team.

Income and funding strategy: The total research income of the School in the REF period is £6,714,737, i.e., an average income of approximately £42,000 per annum per submitted FTE staff for the period. The main sources of our income are EU funding (£3,369,424), UK Research Councils, British Academy and Royal Society (£1,456,090), UK Government, Health and Local Authorities (£869,681), UK charities (£207,532) and direct industry funding (£705,493). Over the same period our academic staff have also offered consultancy services to several industries, professional bodies and public sector organisations, including, for example, BAE Systems, National Rail, Citi (IQContent), Social Care Institute Eurocontrol and UK Civil Aviation Authority, generating a total income of £687,029. The distribution of our research funding reflects our strategy. EU and UK Research Council funding programmes are our key targets. EU funding is targeted for research requiring collaboration with external academic partners, cross-national inputs and inputs from diverse industrial partners and groups. EU funding is strategically important for us as it provides funding for PhD students (see Section C.2) and gives them direct access to external industrial and academic expertise. Our collaborations with several industrial and academic partners in Europe (see Section E) and the recognition of our expertise and ability to deliver high quality research outputs have contributed to our success in this area. UK Research Council funding is targeted for more fundamental research and direct industry/service user funding (e.g., charities, health and local/government authorities) for research involving transfer of results to specific domains and professional practice. The acquisition of external funding is an objective for all research-active staff and is monitored annually through staff appraisals. To support staff, the

University organises regular seminars on grant proposal preparation and provides administrative support in preparing grant proposals and contracts and other related formal agreements (e.g., research consortium agreements for exploitation of joint research). The School provides further support by covering costs of proposal preparation activities by staff.

E. Collaboration and contribution to the discipline or research base

E1. Collaborations: Collaborations with external organisations and individual researchers form a key component of our research strategy. Our main objectives are to: contribute to national and international initiatives for setting research priorities for our disciplines; advise governmental and professional bodies and other institutions on policy; apply the results of our research to industry and wider society; develop joint research with industry and academia in areas of common interest; and participate in professional activities (e.g., reviewing for funding institutions). The School encourages and supports staff participation in collaborative activity by providing time and financial resources (e.g., related travel expenses) and recognising their positive impact on staff development and the overall visibility of the institution. Significant contributions and activities within the REF period are summarised below.

Academic collaborations: We have been involved in EU networks of excellence, coordination and cooperation in science and technology (COST) actions including, for example, S-CUBE, NeSSOS, AMBER, VisMaster and MOVE. These have either provided significant funding for joint research with colleagues in the UK and overseas or enabled us to host and participate in short-term research exchanges (e.g., COST "scientific missions"). They have also enabled us to participate in and influence the development of agendas for future research and funding in our areas of interest (e.g., participation in the EU/ENISA Network and Information Security (NIS) Platform WG). In addition, we have bilateral collaborations with some of the world-leading institutions in our research areas. Key collaborators of SSE include SRI International on dependability modelling, the University of York on system reliability, the Fraunhofer (SIT) on secure service oriented systems adaptation and the University of Oxford on data type parametricity. Key collaborations in IAV are with INRIA, KTH, Fraunhofer (IAIS), Imperial College London and Duke University, USA.

Collaborations with industry and research users: Collaboration with industry and research users is central to our strategic aim of pursuing problem-driven interdisciplinary research and is significant in all areas. In SSE we have long-standing collaborations with EDF, SSM (Swedish Regulator), ISTEC (German assessor), CINIF and Adelard on assessing the reliability of nuclear protection and producing assurance cases for safety-related systems. Additional collaborations have commenced in the REF period on security certification of service oriented and cloud systems with significant industrial partners in the UK and overseas including SAP, INFINEON and the Cloud Security Alliance. Other collaborations involve research users, notably the UK Office for Nuclear Regulation and the US Nuclear Regulatory Commission. These focus on advising on public policy and regulations on nuclear safety. We have also collaborated with NATS and EuroControl on requirements processes for air traffic management and provided consultancy on risk assessment to the UK Civil Aviation Authority. In HCS, research on computer-based aphasia therapy has benefited from collaboration with Barts and the London Charity. Other notable collaborations involve the World Health Organization (use of mobile phones to record and analyse registration and verbal autopsy data about deaths in third-world countries), London's Great Ormond Street Hospital (digital system to improve patient handovers) and the UK Registered Nursing Home Association (use of digital creativity and reflective learning support to improve dementia care). In IAV, our work on visualisation has been transferred into diverse application domains through close collaboration with influential partners in industry (MicroSoft, Yahoo! IBM, Willis, E.ON, Toyota, Continental, Alcatel-Lucent), service (NHS, British Library, BBC, Deutsche Welle) and government (Transport for London , Defence Science and Technology Library/Ministry of Defence, Department for Communities and Local Government).

Interdisciplinary activities: We have participated actively in the establishment of two University interdisciplinary research centres: the *Centre for Cyber Security Sciences* and *City Collaborative Transport Hub*. These provide access to expertise from other disciplines that is significant to some of our research (e.g., legal aspects of security, socio-economic aspects of risk assessment) and application areas (e.g., transport management applications of our research on visual analytics). Experts in other disciplines from these centres and other parts of the University are also involved in the supervision of 14 of our current research students.

E2. Participation in Professional Activities and Leadership: Participation in professional activities within our disciplines provides important services and contributions to our community and plays an indispensable role in the recognition of the University and the professional development of our staff. Our staff are therefore expected to seek out and take up relevant opportunities. Significant examples are summarised below.

Fellowships and senior memberships of learned societies: Fellowships amongst our staff include the Royal Statistical Society (1), IEEE CS (1), the ACM (1), the BCS (3), IET (2) and the Institute of Mathematics and its Applications (1). We also have two senior members of IEEE CS.

Journal editorial boards: Eight of our researchers have served as editors, associate editors or area editors in international journals. These include editor-in-chief roles in Neural Comp. & Artif. Intel., ACM Computers in Entertainment, Edutainment and Lovotics; associate editor roles in IEEE Trans. In Soft. Eng., IEEE Trans. In Vis. and Comp. Graphics, J. of Logic & Computation, J. of Applied Logic, Int. J. of Soft. Eng. & Know. Eng., Int. J. on AI Tools, Info. Visualisation, Virtual Reality, and Int. J. of Virtual Reality, Advances in HCI, IEEE Security & Privacy, and IEEE Sign. Proc. Magazine; and area editor roles in IEEE Software. Fourteen of our researchers have also served on the editorial boards of a total of twenty-nine international journals.

Government Committees and Advisory Board memberships: Our researchers serve on the Information Assurance Advisory Council, CESG Academic Advisory Group and Academic Liaison Panel, UKCRC, NATO TTCP Supply Chain Risk Management/Assurance Cases (UK Academic lead), Engineering Infrastructure and Interdependencies Expert Group (treasury DBIS) and Council of University of Piraeus.

Leadership roles in industry, commerce, professional and subject bodies/associations: These include participation in the IEEE John von Neumann Medal Committee (2007–09), UK Computing Research Committee (2010–), IEEE Harlan D Mills Award Selection Committee (2010–), Technical Advisory Board of Mentor Graphics and Steering Committee of Governance, Compliance and Risk Stack of Cloud Security Alliance (2011–) and chairmanships of the BCS Information Retrieval Specialist Group (2011–) and BSI Standards Comm. on Information and Documentation (2003–).

Engagement with national and international funding bodies: Five of our researchers are members of the Research Council Review Colleges (4/EPSRC; 1/ESRC). Another five have been reviewers for national and international funding institutions, including BBSRC, MRC, AHRC, JISC, Leverhulme Trust, NSF (US), NSERC (Canada), SRI (Ireland), NOW (Netherlands), SNSF (Switzerland), FIVU (Denmark), ISF (Israel) and GSRT (Greece).

Engagement in international conferences: Four of our researchers have been members of steering committees of international conferences including IEEE Requirements Engineering Conference (2010–), Mobile HCI (2011–12); TEFSE (2008–). Over the same period, nine of our researchers have served as chairs of international conferences/workshops, including InfoVis (2012 & 2013) and ACE (2009), and twenty-four in the organising or programme committees of several international conferences, including top-ranked conferences such as ICSE, IJCAI, AAAI, ICSOC, ICWS, IJCNN, IEEE DSN, ICML, GIScience, IEEE InfoVis, and IEEE VAST.

Invited keynotes and lectures: Eight of our researchers have given keynote presentations in 15 international conferences/workshops including IEEE ICPC 2010; IEEE ICALT 2012; IEEE GIC 2010; ACM CHI DIS 2008; DESERT 2012; ISMAR 2011; MobileHCI 2011; 30th Anniv. Safety and Reliability Society Conf. 2010; Geoinformatica 2012; GeoComputation 2011; Geomorphometry 2009; AutoCarto 2008; and DCDS 2013. There has also been an invited lecture at the Annual Onassis Foundation Lectures in Computer Science (2010).

Awards and prizes: We have won several awards at high quality international events including: the most influential paper award at RE 08, one of 25 most influential papers published in 25 years of IEEE Software (2009) and best paper awards in IEEE RE 2011, MobiSec 2011, SecurWare 2009, NCA 2009 and IEEE VAST Best Paper 2011 & 2012. Additional prizes include best technology paper in British HCI 2009, Honourable Mention CHI 2012, 1st Prize in Nokia Ubimedia Awards 2011 and Certificate of Honour 2010, IEEE Infovis Honourable Mentions 2009 & 2010, IEEE VAST Honourable Mention 2010, IEEE VAST Challenge Awards 2009 & 2010, GIS Research UK best paper 2008, 2009 & 2010, and Google KML in Research Prize 2009.