Institution: Lancaster University

Unit of Assessment: B11 Computer Science & Informatics

a. Overview

Lancaster's research in this UoA is located in the *School of Computing & Communications*, which occupies the iconic InfoLab building at the south end of campus. The School comprises 48 academics (43.25FTE), 3 visiting professors, 2 teaching fellows (1.5FTE), 36 Research Associates (33.41FTE), 9 knowledge exchange (KE) staff (7.82FTE),14 administrators (11.75FTE), and 5 technicians (3.6FTE). We currently have 123 PhD students. Our annual research income, averaged over the REF period, is ~£3.8M.

Our research is organised into five core research groups: i) *communication systems*, ii) *computer networking*, iii) *distributed systems*, iv) *software engineering* and v) *human-computer interaction*. These are the organisational units around which we manage our contribution to the field, our publication and impact strategies, and our PhD admission and training activities. Although each group is a cohesive sub-unit, many important research areas (such as ubiquitous computing and cyber security) are collaborations that cut across the groups.

Lancaster University is a research-intensive institution. Departments are the primary building blocks and are organised into four Faculties. The School is a Department of the Faculty of Science and Technology (FST). The School participates in several interdisciplinary research centres at Lancaster that span Departments and Faculties. We are the founders and leaders of three such centres: i) the *HighWire* Centre for Doctoral Training (CDT) on Innovation in the Digital Economy (with the Management School and the Lancaster Institute of Contemporary Arts); ii) the *Security Lancaster* research centre (with Psychology, Engineering, Applied Social Science, Politics, Philosophy and Law); and iii) UCREL - the University Centre for Computer Corpus Research on Language (with Linguistics). In addition, we participate in the *Energy Lancaster* research centre (with Engineering, the Environment Centre, Chemistry and Physics).

b. Research strategy

Our research ethos rests on pillars of *real-world focus*, *systems-orientation*, and *cross-disciplinarity*; all with due attention to fundamental principles. This ethos has distinguished our research in computing and communication systems since the 1980s. We are motivated by problems involving real world stakeholders and data, using (e.g.) test-beds and experimental deployments to help us study systems in their wider social contexts. Our slogan is: *we build what we study and study what we build*.

Strategic development in the REF period. Since RAE2008, our overall research strategy has been embodied in the following 6 strategic elements:

1) *Nurture our key strengths-in-depth (as represented by our 5 core research groups)*. Computer Science is a diffuse field, and our fundamental strategy to ensure focus and cohesion has been (and continues to be) to concentrate in areas that reflect our established strengths, as long as these remain vital. As a result of the consistent application of this strategy, our five long-established core groups are well-balanced and spearheaded by world-leading figures in their fields, as evidenced by publications, citations, and esteem indicators.

2) Grow new strengths on the foundation of our core research groups. The core research groups are our foundation, but it is also central to our strategy to cultivate the agility to grow new areas opportunistically—especially where we see a confluence of intellectual and economic significance—either from within groups or (more typically) by growing cross-cutting linkages. We have a long record of success in this: e.g. in middleware, ubiquitous computing and natural language processing. Substantial examples initiated in the REF period include cyber security, social computing, digital economy, big data, and wireless sensor networks/internet of things.

3) *Maximize synergy by bringing together previously-separate academic departments*. During the REF period, we have merged the activities of the previously-separate Departments of Computing and of Communication Systems under the banner of the new School of Computing and Communications. This was a strategic move to increase synergy by bringing together academic

staff working in complementary areas. It especially emphasises the crossover between communication systems and computer networking, which has been further strengthened by a recent chair appointment that spans these areas.

4) *Maximise academic impact*. We aim to maximise our impact on the field by guiding staff to target the highest-impact venues for their research. All our staff have public citation profiles (http://scholar.google.com/citations), and we use the RAE2008 outputs in our UoA for impact benchmarking. This strategy has led to a marked improvement in impact: the median annual citation rate of our REF outputs is 6, up from 4.8 for our RAE2008 outputs. We consider this improvement to be significant, especially given that our RAE citation rates were already outstanding: 29.8% of our RAE outputs have >10 citations/year, a level reached by only 13.7% of all UK RAE outputs in our field (Google Scholar, Aug. 2012).

5) *Maximise real-world relevance through cross-disciplinarity*. Over the years we have initiated, led, contributed to, and benefited from interdisciplinary research with virtually all parts of the University. Since RAE2008 we have taken this to new levels, being at the helm of initiatives that develop genuinely novel and transformational ways of conducting research across disciplines. Prime examples of this are the £1.9M *Catalyst* project, one of only four projects funded by EPSRC's programme on "Promoting Cross Disciplinary Research"; and *HighWire*, a £5.9M EPSRC-funded interdisciplinary CDT on innovation in the digital economy.

6) *Maximize impact through knowledge exchange*. We have recently integrated a previously-separate IT-oriented knowledge exchange unit, called the Knowledge Business Centre (KBC), under the banner of the new School. This creates a unique environment in which business development and KE are integral to our operation. In particular, grant proposals benefit from the input of KE staff in identifying pathways to impact, and the KE staff are also formally involved in impact-related aspects of the execution of each new project. The senior KE role (Head of Business Partnerships and Enterprise) is part of the School's senior management team.

Research strategy at the group level. We now briefly discuss strategic development at the finer-grained level of the 5 core research groups.

1) *Communication Systems*. Communication Systems research has a long tradition at Lancaster but is newly integrated in this UoA. This is a natural development as the field has moved from roots in electrical engineering to embrace computer science and software-defined techniques. Currently, on the back of strategic new appointments (Ni, Musavian, Chatzigeorgiou), and in collaboration with the computer networking group, we are expanding into cutting-edge software-defined cognitive radio networks and green communications, network anomaly and fault detection, and autonomous systems in transport and other domains.

2) *Computer Networking*. We are long established as one of the leading computer networking research groups in the world, focusing traditionally on QoS/QoE, multimedia content networking, and programmable networks. In the REF period, we have developed strength in network resilience, which feeds strongly into our cyber security work (see below). Recent work on the design of the Future Internet applies virtualized routing concepts to core Internet mechanisms; and also extends to the internet of things, integrating embedded and mobile devices. One of our most notable areas of work in recent years has been the development and use of community testbeds or living labs.

3) *Distributed Systems*. Our vision here is to create component technologies, and associated underlying principles, that become part of the global distributed systems infrastructure. Historically our work was motivated by the need for application support in distributed multimedia and mobile systems, but in the REF period the emergence of new challenges in pervasive systems, very large scale systems and novel uses of virtualisation has prompted a switch of emphasis to work on highly complex distributed systems, and to demonstrating their potential in areas such as Wireless Sensor Networks, Smart Cities and Environmental Virtual Observatories.

4) *Software Engineering*. In the REF period, we have strengthened and broadened our already world-class coverage of SE research. Two appointments at the end of the RAE period (*Whittle*, *Lee*) are now fully integrated, and recent appointments (*Babar*, *Chopra*, *Mezini*) add further strength in empirical software engineering, cloud computing and software-as-a-service. We continue to spearhead key new areas in SE research, examples being requirements for adaptive

systems (see research vision papers at ICSE and RE); large-scale empirical research on the efficacy of model-driven engineering in industry (we produced the first large-scale industry-wide study of MDE practice); and the emerging area known as models@run.time.

5) *Human-Computer Interaction*. Lancaster is long established in HCI, but in the REF period we have made a real leap in our activity, evidenced by increased output at the top of our field (8 full papers this year in *CHI 2013*, the field's defining venue; only a handful of institutions world-wide contributed more). We maintain a strong focus on HCI for mobile and ubiquitous systems, with research in the wild (e.g., in rural communities) and advances in HCI-related systems and technologies (e.g., novel devices, modalities and techniques for interaction). We have also identified social computing as a key growth area, attracting over £4M in EPSRC funding.

Research strategy at the level of cross-cutting research areas. As noted, our research is strongly characterised by working across conventional sub-field divisions, enabling us to develop distinct areas of leadership that draw on cross-cutting and interdisciplinary expertise. We now briefly expand on strategic directions in a sample of these cross-cutting areas: ubiquitous computing, cyber security, and natural language processing:

1) *Ubiquitous Computing*. We are well-recognized internationally as a hub of Ubicomp research, with a track record of widely-impacting contributions since the 90s. Our leadership in this field is an early example of the success of our "grow from core strengths" strategy: it originally grew from work in distributed systems and HCI, but now pervades all of our research without requiring the establishment a distinct core group. In the REF period we have developed global leadership in the new area of open display networks, including a new dedicated symposium (*Pervasive Displays*) and leadership of a European FET consortium. In addition, we are now growing another new area: that of sustainability; we have started to carry out EPSRC- and ESRC-funded interdisciplinary research on energy demand, and ubiquitous computing systems that support sustainable lifestyles.

2) *Cyber Security*. We are one of only eight EPSRC-GCHQ Academic Centres of Excellence in Cyber Security Research across the UK, and the only such centre in the North of England and Scotland. This builds on our track record in key areas including network resilience; networked and embedded systems security; huge-scale data analysis; and studies of user behaviour and human factors relevant to cyber security issues. We are currently developing several research strands that are critical in addressing present-day cyber security problems: responding to unanticipated cyber-threats; ensuring the resilience of networked systems; coping with the fluid nature of identity; and instilling a cyber-security culture across organisations.

3) *Natural Language Processing*. Lancaster's University Centre for Computer Corpus Research on Language (UCREL) is an interdisciplinary cross-faculty research centre that focuses on applied corpus-based linguistics and natural language processing. It has a track record that goes back over 40 years. In the School, we apply the UCREL work strategically for new methods in software engineering, social computing and cyber security. In the REF period this has led for instance to new research on online child protection (which is the subject of one of our Impact Case Studies). Further expansion is already underway in the digital humanities.

Future strategic planning. Our general strategy going forward is to continue to pursue the strategic elements described above, and, in addition, to:

- *Boost the strategic role of the research groups*. Our 5 core research groups are already cohesive units following the School's strategy, but going forward we plan for them to define more explicitly their own sub-strategies. These will include: targeting larger grants such as programme grants and CDTs; being strategic about where and when to publish (such a move has already paid off in the HCI group); identifying impact cases from the start and involving our KE staff in their ongoing development; and applying an ongoing impact assessment strategy to collect and disseminate impact more broadly.
- *Resource key growth areas with a view to increasing our leadership in these areas*. This is especially the case for our newest and most rapidly-developing growth areas: i.e. cyber security and social computing/big data. Efforts towards these goals are already well underway, as evidenced above. We will continue to grow these areas by targeting large (+£1M) EPSRC grants and making further strategic staff appointments.

- *Push forward on cross-disciplinarity and real-world application*. We aim to transcend our currently-project-based approach to cross-disciplinarity by moving our emphasis more towards cross-departmental research centres that provide a long-term focus for large-scale real-world challenges. This is already exemplified by our initiation and leadership of Security Lancaster, a new university-wide research centre on cyber security.
- *Exploit the new role of Head of Business Partnerships and Enterprise*. There is significant potential to further leverage the contribution of our KE team and company co-location facilities. We plan, for example, to bring more research-oriented companies into our company co-location wing in InfoLab (we have a KPI that each such company should partner on at least one major research grant proposal), and to better exploit structural funds (e.g. ERDF) to support research-centred activity.

Governance. The School sits within the University's well-established governance structure. The Head of School is ultimately responsible for operational and strategic management. Responsibility for research management is delegated to a Director of Research; for research training to a Director of PhD studies; and for business relationships to the Head of Business Partnerships and Enterprise. These Directors represent the School on Faculty committees for research, postgraduate studies, and business and enterprise.

A Strategy Committee composed of senior academics advises the Head of School on overall direction, including research strategy; and an Industrial Advisory Board provides external input to the School's strategy. A Research Committee oversees operational management of research and research training activity, including grant preparation, ethics procedures, PhD research training, and seminars and visitors. All research proposals are subject to internal review within the School prior to submission, and to financial and ethics approval by the University's Research Support Office (RSO). Any projects with potential ethics concerns are reviewed by the University's Ethics Committee. The University is a member of the UK Research Integrity Office which advises on research ethics.

c. People, including:

i. Staffing strategy and staff development

Since RAE2008, our staffing strategy has comprised the following four strategic elements:

1) *Foster critical-mass in the 5 research groups while growing strength key new areas*. This mirrors our primary research strategy of growing new areas on the foundation of stable strengths-in-depth. During the REF period, we have moved from an academic staff complement of 34 (33.25FTE) to our present 48 (43.25FTE). We have appointed 16 new staff, predominantly to newly-created posts. 3 of these strengthen the interface of communication systems and computer networking (*Chatzigeorgiou*, *Musavian*) and provide new leadership in this area (*Ni*); 2 expand distributed systems research into wireless sensor networks and cloud computing (*Porter, Wang*); 3 expand our core software engineering activity (*Chopra*) and provide leadership in empirical SE and language engineering (*Babar*, *Mezini*); 4 expand HCI activity into (e.g.) graphics (*Alexander, Karnik, Kim, Lau*); and 4 bolster cross-cutting research in cyber security (*Baron, Such*), social computing (*Rowe*), and big data (*Zhao*). All these appointments are complementary to our existing expertise, bringing new and distinct research agendas while sustaining coherence.

2) *Maintain an optimal balance of leadership and new blood*. We have taken care to maintain a balance in overall staffing profile such that around 25% of our staff are within the first few years of their career. We see this as crucial in maintaining the vitality of our research environment. As a consequence, 13 of the 16 new appointments we have made in the REF period have been early career appointments. This makes it important for us to develop these staff into future research leaders, which we do through the staff development measures discussed below. Fostering early career staff also plays to our strengths, as we have an international reputation in building research careers, based on a record of developing new staff on a fast track to attain positions of senior leadership (in our own institution, nationally and internationally). For example, several staff who were first-time lecturers with us in the RAE2008 period now hold chair positions; Laurent Mathy internally and since 2011 also at Liège, Belgium, Gerd Kortuem at the Open University, and Enrico Rukzio at Ulm University, Germany. Others have made significant moves as well, e.g. Alessandro

Garcia to Professor in Brazil.

3) *Maintain diversity, and improve gender balance*. The School is a highly diverse and international environment, and we have long recognised the need to recruit from as wide a pool as possible. This is reflected in the fact that our new recruits in the REF period include 11 nationalities, with 8 coming from posts abroad. We do, however, recognise a long-standing concern in under-representation of women at all levels. Among our PhD students, 26% are female, a modest improvement since the RAE2008 (24.6%). The number of women among our academic staff has increased from only 2 (1.25 FTE) at the start of the REF period to 6, but remains at only 12.5%. We regard it as vital for the quality of our environment to more strongly promote gender equality. The University has taken steps to support women in their career development, and this is reflected in the award of Athena SWAN Bronze certification in 2008 (and renewed in 2011). We are now preparing the School for its own award, in 2014.

4) *Foster vitality by hosting high-profile visitors*. These include formal Visiting Chair positions (Prof. Paddy Farrell in communication systems; Prof. James Sterbenz in computer networking; and Prof. Alistair Sutcliffe in software engineering) and senior academics on sabbaticals (e.g., Plattner of ETHZ in computer networking; Cheng of Michigan State in distributed systems/software engineering; and Hussmann of LMU Munich at the intersection of HCI and software engineering).

Going forward, our focus will shift from the recent phase of aggressive recruitment towards integrating and nurturing our significant complement of new early career staff: for example, we aim for 75% of our early career staff to make Senior Lecturer over the next REF period. In terms of gender, we aim for Athena SWAN Bronze certification and to have further increased our complement of female academics. Where staffing opportunities arise we will continue to apply our existing policies as detailed above. In addition we look to target one-off appointments of high-profile, world leading, academics to (e.g.) seed new areas.

Staff development. Career development is fostered through a lively and stimulating research environment that benefits both from concentration in groups, and from agile collaboration across areas. We pride ourselves on a collegiate culture and atmosphere of support, both in the School and across the University. Clear processes are in place to support the development of academic and research staff: All new academic staff participate in induction courses and take the Certificate in Academic Practice (CAP). A staff appraisal and review scheme is in operation across the University, coupled with staff development and training programmes. A clear framework guides academic promotion, with heavy emphasis on research performance. A sabbatical scheme supports the development of established staff. In the REF period, 17 staff were granted sabbaticals for a total of 176 months, representing an investment by the University in the development of staff and their personal research agendas amounting to £1.14M, in terms of the cost of employment. New members of staff in the School receive light teaching loads for the period of their probation (typically 3 years), during which time they focus on achieving a clear, agreed set of targets, including targets for research. The targets are designed to firmly establish each staff member in their academic career and are defined within a formal probationary agreement. To help ensure that these targets are achieved, new staff are allocated a senior academic in their research area as mentor: a role which is recognised and rewarded as a key responsibility. The Director of Research and members of the Research Committee provide additional mentoring, and support new staff in developing research leadership.

The University fully implements the Concordat to support the career development of researchers through a clear action plan; and Lancaster's commitment to the Concordat has received European recognition with an HR Excellence in Research award. At the School level we implement specific schemes supporting researchers, for example operating a Graduate Academy that provides training on consultancy projects with industry, and helps researchers build networks in the private sector. We also support postdoctoral researchers in developing their own proposals for independent research. For example, 5 PDRAs won Marie Curie postdoctoral fellowships in the REF period, and 2 won funding awards resulting from EPSRC sandpit participation).

ii. Research students

The School has long-standing PhD programmes in Computer Science and in Communication Systems, and leads a CDT (HighWire) in Digital Innovation. We have a vibrant PhD student

community with currently 123 students, of whom 53 are from the UK, 21 from EU countries and 49 from overseas, overall representing 33 different nationalities. Over the REF period, the average number of PhD degrees awarded per year was 23.6, up from 9.6 in RAE2008. The number of degrees per staff member rose to 3.17 (RAE2008: 2.17). Our PhD graduate destinations have included top international addresses such as Harvard and Microsoft in the US, academic posts overseas, a wide range of posts in UK academia and industry, and foundation of start-ups.

Our PhD programmes have evolved since RAE2008 to include improved support and progress monitoring, and enhanced access to research training. Research guidance is provided by a principal supervisor assigned to each student, and this is supplemented by periodic progress monitoring by a panel of experienced staff and staff with cognate research interests. Monitoring comprises a set of defined checkpoints, commencing with an initial assessment of the student's skills and knowledge, from which training needs can be identified; and followed by a series of progress panels until the student is ready to submit.

A wide range of research training courses is provided for PhD students, coordinated by the Faculty's Graduate School, while through HighWire we have introduced a new taught component on research methods, ethics, interdisciplinary perspectives and critical analysis. Research students are actively encouraged to attend conferences, summer schools and doctoral colloquia internationally, and we dedicate research training and travel funds to support this. All students engage with research users as part of their training (as this is in the nature of our research), and the above-mentioned Graduate Academy helps graduate, doctoral and postdoctoral students gain vocational experience through short-term consultancy projects with industry.

Responsibility for PhD student development lies with the Director of Postgraduate Studies, who oversees recruitment, admissions, progress monitoring, training and supervision arrangements, assisted by research group representatives from the Research Committee. Research groups play a key role in admissions, and in running seminars and reading groups for PhD students. Our strategy is to create distinctive opportunities based around the groups with opportunities to work across discipline and sub-discipline boundaries.

We recruit internationally on the basis of our world-wide reputation in each of our research areas. We have a number of formal international partnerships (e.g. Erasmus exchanges with ETH Zurich, LMU Munich, and others) and many other long-standing collaborations through which we attract and exchange students. In the REF period, we have hosted over 30 visiting research students including from the US, Japan, Malaysia, Korea, Brazil and several European countries. We have further increased the international impact of our doctoral training through leading and participating in 3 FP7 Marie Curie Initial Training Networks (DESIRE, IMPULSE, iCARENET).

Research students are integral to our research activity. They play a key role in contributing to the vibrancy of the School (e.g. with the seminar and workshop events they organise), to the high quality of our research output, and to our international reputation. 24 of our REF outputs are first-authored by one of our PhD students, and several more by visiting students. Since 2010, six of our students have won Dean's awards, recognising them as best-in-their-year across all science and technology subjects at Lancaster. Many develop into outstanding ambassadors for our research and an increasing number are invited to prestigious internships (e.g., at Microsoft Research labs in Redmond, Beijing and Cambridge, Nokia Research, and Google Research).

d. Income, infrastructure and facilities

Strategic investment. The University is committed to the long-term strategic importance of Computing and Communications as one of its flagship centres for research, training and impact. Lancaster's commitment to growth in our field is demonstrated by its funding of 10 new academic posts in the School of during the REF period, on top of replacing all leaving staff. This has been complemented by investment in PhD studentships, plus corresponding seed-corn grants, totalling £3.7M.

The £15M investment in our InfoLab building prior to REF was followed by an £8.7M investment in HighWire during the REF period: the University matched the £5.9M RCUK contribution to HighWire with £2.8M for buildings, a new staff post and additional studentships. Another key investment of £7.1M was made in a new building adjacent to InfoLab to house the University's Information

System Services (ISS). ISS provides critical infrastructure to research in the School, and plays a key role as research partner in the operation of testbeds and community projects. Over £1M of HEIF money and over £3M of ERDF funds have been invested to operate the extensive KE and business development facilities that are embedded in our research environment.

We have also seen substantial new investment in facilities and equipment that benefit our research. The University invested £1.2M in a High-end Computing (HEC) facility, of strategic importance to our research, which increasingly involves "big data", especially in our new growth areas of cyber security and social computing. A £1M equipment donation from industry was invested in a wireless broadband research laboratory that benefits our growing communication systems activity. Over £500k was invested by the University in capital equipment to foster new research directions in the School (e.g. OpenFlow in computer networking, digital fabrication in HCI) and in particular the research of new early career staff.

Building and infrastructure. As mentioned above, the School has, since 2005, occupied a purpose-built home in the 6779m^2 InfoLab building. InfoLab was designed to our express requirements for a state-of-the-art research space, bringing together under one roof everything that feeds into successful research, and supported by a configurable, easily expandable ICT infrastructure. To support the collaborative ethos on which our research thrives, InfoLab co-locates laboratories, staff and student offices of varying sizes and configurations including mixing spaces; meeting and seminar rooms; video conferencing rooms; a large reception area; shared kitchens; and a café/restaurant. The building's configuration allows us to creatively locate academic, research and KE staff, and research students, in teams; while the kitchens and mixing spaces foster informal intellectual exchange and esprit de corps. InfoLab houses our own systems support team and also a research support team that provides financial-administrative support dedicated to the School's pre- and post-award project management. An entire wing of the building is dedicated to KE including our company co-location space (which currently hosts 17 companies), fostering regular formal and informal mixing between School staff and staff from the hosted companies.

We have extensive research lab space in InfoLab. A large open floor experimental systems lab (XSLab) is flexibly allocated to support research with experimental hardware/software systems across all areas. Adjacent space includes hardware and embedded systems labs, and a lab that houses a range of digital fabrication tools (laser cutter, 3D printers). Flexible space is available for controlled user studies and we have extensive facilities to support these, e.g., with eye- and body-motion tracking systems. In the REF period we have also created new laboratories for specific research areas, including the Aeroflex Wireless Broadband Laboratory, established with industry support; and two labs for our cyber security research, one of which is designated as a "dirty lab" for simulation and investigation of cyber attacks in a contained setting.

The computational resources required for research are provided jointly by ISS and the School's systems support team. The network infrastructure is central to our operation, and incorporates OpenFlow-enabled equipment, allowing researchers flexibility in network experimentation and protocol development. Virtualisation technology is heavily used within the School to host experimental services and research projects. We have our own dedicated virtualisation cluster in the School as well as access to VMware clusters that ISS host in each of their two data centres. This benefits many areas of research including cyber security, natural language processing, ubiquitous computing and media distribution. Real-world testbeds play a central role in our research. A significant development in the REF period is RuralConnect, a living laboratory that takes research out of the traditional laboratory environment and deploys it into rural communities. RuralConnect is recognised by the EU as a member of the European Networks of Living Labs, and has facilitated "research in the wild" across computer networking, distributed systems and HCI.

Research funding portfolio. Our funding strategy over the REF period has been to grow income from research councils, UK government bodies and industry while sustaining our strong position in Europe (in RAE2008, we reported the highest EU income per staff-FTE in the UK in our UoA). Our total income per year averaged £3.76M over the REF period (in RAE2008 it peaked at £2.7M). 182 new grants were won over the REF period, and the annual cumulative value of new grants rose to £5.3M in 12/13. Funding from research councils has steadily increased over the audit period, and accounts for 38% of our income and over 40% of our new grants (74). Income from Europe remains our largest funding element (44%), and we have diversified from standard collaborative

grants to significant income from the "People" programme (Marie Curie networks and fellowships). Direct income from industry has doubled over RAE2008 and now represents more than 10% of our portfolio. Income from central government bodies (TSB etc.) has increased similarly and is growing into a significant component of our funding mix (6.7%). With marked increases in grant awards in 12/13 we are set for a strong start into the next assessment period.

We have three strategic priorities to sustain research income growth. First, we will focus on larger grants and centre bids. For example, the average contribution from research council grants to our research was under £150k; we aim to increase this very significantly. Second, we aim to increase the number of PIs. A third of our submitted staff are ECR and it is a key priority for us to support and promote our early career staff as leaders of significant grant activity. Third, we aim to further broaden our funding, for which the European Research Council is one specific priority.

Consultancies and services. A wing of InfoLab is dedicated to KE, and we are founding board members of the TSB's national ICT KTN. InfoLab has become a recognised part of the business support landscape in the Northwest region. We have strong links to public support agencies, e.g. Local Enterprise Partnerships, and we provide a range of professional services to the business community. We have facilities for co-location of start-up companies, and over the REF period have hosted over 40 companies, with 17 currently in residence with us; our Graduate Academy trains research students on consultancy projects (deliver assistance to companies in conjunction with increasing student employability); and we organise a wide range of KE events in InfoLab and across the region. Our KE activity is audited, with recognised impact in terms of business assistance and job creation. The School has direct income from consultancy and services of ~£200k/year (12/13: £211,602).

e. Collaboration and contribution to the discipline or research base

Collaboration. This is completely ingrained and hard-wired into our research ethos, with a long history of collaboration across discipline and sub-discipline boundaries; with other universities and research organizations; and with industry both within the UK and internationally.

Leadership in interdisciplinary collaboration. In the REF period, our staff have been at the helm of new flagship projects with colleagues from other departments at Lancaster (e.g. HighWire, Security Lancaster, Catalyst). Other key areas in which we collaborate with other disciplines include virtual observatories, energy demand and sustainability, digital humanities, and corpus linguistics. It is indicative of our interdisciplinary orientation that we have attracted grant income from diverse research councils, including ESRC, AHRC and NERC in addition to EPSRC.

International collaboration. Academic collaboration in the School has a strong international orientation, strikingly evident in the fact that 52 of our submitted outputs are internationally co-authored (43%). Half of our research income is directly associated with international collaboration and we have started 41 new European collaborative projects in the REF period. We have hosted over 80 extended research visits (4 weeks and longer) from abroad, including senior academics on sabbatical leave (from the US, Australia and Central Europe), academics and researchers seconded from collaborating institutions (e.g., new partnerships developed in Brazil, and in Asia), and over 30 students on 'internships'.

Collaboration with industry and user communities. Practically all of our research involves collaboration with industry and/or user communities. 52 of 182 new grants in the REF period are publicly-funded collaborative projects with non-academic partners, and 34 projects are directly funded by industry; the majority of other grants are from research councils with in-kind contribution from industry. We have collaborated with ~150 non-academic partners over the REF period, with exemplars ranging from multi-nationals (e.g., Microsoft, IBM) and major national partners (e.g., BT, BBC, BAE) to SMEs and local user communities (e.g., in RuralConnect, and around our Centre of Excellence in cyber security). This close engagement with research users is key to us, as our research is motivated by its potential impact on important real-life problems. Instead of first doing research, followed by a separate attempt to get end-users interested, we proactively seek collaboration to inform our research from the start. As an exemplar, the Environmental Virtual Observatories project was co-designed with the community at its core including stakeholders like DEFRA, water companies, the Environment Agency.

Support for research collaboration. Our in-house research support team, in addition to the University's central Research Support Office, is a key factor in our ability to manage a large and diverse portfolio of collaborative grants; and our in-house KE team supports academic staff in identifying and building relationships with potential research users, in planning and organising impact-oriented activities, and in grant development and execution. Other key facilities are centralised in the University, including an International Office which assists in the development of long-term research partnerships with overseas institutions (a recent example is a substantial partnership with the University of Sao Paolo).

Contribution to the discipline and research base. We contribute substantially to a range of research fields through the leadership of our staff in their international peer communities. The following are indicative examplars:

Editorial positions on journals. Our staff play leading roles (Editor in Chief EIC, or Associate Editor AE) on at least 27 journals, serve on the editorial boards of many other journals, have edited 32 journal special issues, and are editors of book series in networking, software engineering, and HCI. Exemplars include Angelov: EIC *Evolving Systems,* AE *IEEE Trans SMCB,* AE *IEEE Trans Fuzzy Systems;* Blair: EIC *Internet Systems and Applications*; Davies: EIC *IEEE Pervasive*; Mihaylova: EIC *Open Transportation Journal,* AE *Signal Processing*, AE *IEEE Trans AES*; Gellersen: Editor *Personal and Ubiquitous Computing*; Mauthe: Co-Editor *Multimedia Systems*; Ni: Editor *Security and Communication Networks*; Hutchison: Editorial Board *Springer LNCS*.

Programme chairing of international conferences. Our staff have served as PC chairs/co-chairs of major events in over 50 instances. Exemplars include Friday: *Pervasive'09*; Gellersen: *UbiComp'09*, *CHI'13 (Systems SC)*; Mezini: *ESEC/FSE'13*, *ECOOP'11*, *AOSD'08*; Roedig: *EWSN'09*; Rukzio: *Mobile HCI'13*; Sawyer: *RE 2012*; Whittle: *MODELS 2011*.

Leadership in international conference organisation. Staff have chaired and hosted major international conferences (e.g., Rashid: *ECOOP'11*; Davies: *MobiSys'12*; both hosted at Lancaster); initiated new conference series (e.g., Davies: *PerDis*; Hutchison: *e-Energy*); and are members of conference steering committees in 39 instances (e.g., Blair: *Middleware* [SC chair]; Gellersen: *Pervasive* [SC chair 2007-9]; Coulson: *Euro-Par*; Friday and Gellersen: *Ubicomp*; Davies: *MobiSys* and *HotMobile* [SC chair]; Mezini and Rashid: *AOSD*; Whittle: *MODELS*). Many of our ECR staff are demonstrating early leadership, for instance through workshop organisation at major conferences (e.g., Alexander at Mobile HCI and CHI; Lau at UbiComp; Porter at Middleware; Rowe at WWW).

Keynotes at international conferences. Our staff have given over 60 invited presentations at international conferences, exemplars include Blair: *ACM Mobility 2009* and *ACM ComPAS'13*; Davies: *12th International Conference on Mobile and Ubiquitous Multimedia (MUM'13);* Hutchison: *Global Future Internet Summit,* Korea 2013; Rashid: *Chinese National Conference on Computer Software and Applications,* China 2009.

Programme committee membership. In the audit period, our staff have served on technical programme committees in over 600 instances. We have a strong presence on the PCs of leading conferences in the field; exemplars including *UbiComp* (4 staff on most recent PC) and *CHI* (6 staff on current PC).

PhD examining. In the audit period, our staff have examined at least 64 PhDs abroad, and 52 in the UK.

Grant selection panels. Several of our staff are on the EPSRC college and frequently review proposals and serve on prioritisation panels, e.g. Coulson chaired two EPSRC funding panels in the REF period. Staff have served on grant selection panels internationally, e.g. Gellersen for Academy of Finland and Science Foundation Ireland; Coulson for IWT, Belgium.

Other exemplars of specific leadership. Other miscellaneous positions of esteem and leadership include, e.g., Rashid: *Chair of the Dahl-Nygaard Prize Committee awarded for Outstanding Service to Object-Orientation Research 2013*; Mihaylova: *Governing Board of Directors of the International Society of Information Fusion*; Whittle: *Committee of BCS Distinguished Thesis Competition*.