Institution: Newcastle University

Unit of Assessment: UoA 11 Computer Science and Informatics

a. Overview

Newcastle University's UoA 11 is based in the School of Computing Science within the Faculty of Science, Agriculture and Engineering. Our research aims to advance computing science in areas that are relevant to industrial and societal needs. Researchers in the unit work within groups that reflect established and sustainable areas of strength. The current groups are: *Biology, Neurosciences and Computing (BNC)* (Wipat, Krasnogor, Kaiser, Zuliani *ECR*), *Concurrent Asynchronous Systems (CAS)* (Koutny, Khomenko, Pietkiewicz-Koutny, Steggles), *Dependability* (Romanovsky, Fitzgerald, Harrison, Jones, Freitas *ECR*, Hao *ECR*, Yan), *Digital Interaction (DI)* (Olivier, Wright, Balaam *ECR*, Kirk, Ploetz *ECR*), and *Systems* (van Moorsel, Mitrani, Shrivastava, Watson, Ezhilchelvan, Gross, Missier *ECR*, Thomas). In order to build collaborative relationships with other disciplines and with industry, government and user groups, we have established several specialist units: the Digital Institute, and Centres for Cybercrime and Computer Security, Software Reliability, e-Science, and Synthetic Biology and Bioexploitation.

b. Research strategy

Our **vision** is to be a world-leading centre for fundamental and rigorous computing science research that is stimulated, informed and evaluated by application in areas of importance to industry and society. Our **strategic approach** is to provide sustainable research group structures that give staff and students a strong disciplinary identity, but equally to empower researchers to work with other disciplines and sub-disciplines at their own initiative as opportunities for novel research endeavour arise. We do this by focusing investments (academic posts, studentships and facilities) on the disciplinary areas represented by groups, while also providing resources such as investigator-controlled research initiative funds (25% of overhead) to active staff. Longer-term support for external collaboration, dissemination and impact is facilitated by cross- and multidisciplinary research centres and Digital Institute to bring together researchers from diverse disciplines and serve as distinctive points of contact with industry, government and user groups.

Current position with reference to RAE 2008

Strong growth in our research base is an indicator of our thriving research environment: since 2008, research associate numbers have more than doubled to over 60, PhD completions have similarly increased from 28 to 64 over the review period, and the unit's current grant portfolio is 114% greater by value, with annual grant income exceeding £100K per academic staff member.

The potential of computing science to help address challenges in social inclusion, wellbeing and ageing has motivated research in systems, human-computer interaction and ubiquitous computing, including our winning the *RCUK Digital Economy Hub on Social Inclusion (SiDE)*. This has so far delivered eight 'best paper' awards, five prizes for excellence and impact, four start-up companies, and has enabled the UoA's researchers to attract over £6M in additional funding for 33 new projects (approximately £32M) linked to the SiDE research agenda. To reflect the growing importance of this area we established a new *Digital Interaction (DI)* group, recruited at senior and junior levels to gain critical mass, and invested in the *Culture Lab* facility, which has created a unique research space, helping us to create one of the leading groups worldwide, establish collaborations like the *BBC User Experience Research Partnership*, and win the new *Centre for Doctoral Training (CDT) in Digital Civics* in 2013.

Responding to the challenges of cybercrime and security (a nascent theme in 2008) researchers in the Dependability, Systems and DI groups focused collaboration on technical areas of social and business relevance such as e-voting and support for human factors in security decision-making. We hired faculty with industry experience (IBM and Thales), created the *Centre for Cybercrime and Computer Security (CCCS)* to focus interaction with industry, government and law enforcement, and consolidated staff and students in high-quality space. As a result, we gained recognition as a *GCHQ Academic Centre of Excellence in Cyber Security Research (ACE-CSR)* in 2013.

New computing challenges posed in biology and neurosciences led us to establish a group in *Biology*, *Neurosciences and Computing*. We invested in new posts at all academic levels, bringing in Krasnogor (Chair) and his team to create one of the largest computational synthetic biology groups in the UK, creating dedicated laboratory space, and jointly with colleagues in cell biology

developing the new *Centre for Synthetic Biology and Bioexploitation (CSBB)*.

We sustained growth in established areas following investment in staff and facilities. Advances in distributed systems and cloud research were recognised by the co-location of the Red Hat Research Centre (one of only two worldwide) with the unit in Newcastle, and a £1M investment by the Department of Culture, Media and Sport (matched by the University) to create a £2M Cloud Innovation Centre focused on industry engagement and jointly managed with Newcastle City Council. We invested in academic staff to strengthen the Dependability group, and undertook ground-breaking projects in formal methods, from semantic foundations to industry application [ICS2], the group's importance being recognised by two platform grants. The *Modelling and Reasoning* group built on the strategic recruitment that had been achieved by RAE2008 and, recognising the potential for asynchronous computing, developed into the *Concurrent Asynchronous Systems* group, with significant success in transferring foundational results to industrial asynchronous circuit synthesis [ICS4].

Strategic plans. We will continue to invest in staff and resources in a way that allows researchers the freedom to work at their own initiative, sometimes speculatively and across disciplinary boundaries. In order to further develop our vision of collaborative research in areas relevant to industry and societal needs, we will relocate the entire unit in 2017 to a new £50M purpose-built facility *Science Central*, co-located with laboratories in smart grid, transport, devices and digital technologies, including space for businesses. This will provide facilities that will attract new staff, and allow the unit to develop its pivotal role in the University's research programme on the societal challenge of sustainability, particularly growing cloud computing and developing new initiatives in cyber-physical systems. A significant priority is the development of our doctoral training offering through the new CDT in Digital Civics.

Research achievements and goals

Here we highlight advances made and new goals for the technical areas that we identified in RAE2008 and subsequently.

Biology, Neurosciences and Computing

Achievements. We addressed strategic objectives set in 2008 in a range of key outputs. Firstly, we have developed new computational approaches to semantic data integration which have been integral to successful studies in ageing in yeast and humans [Wipat:2], the BBSRC CISBAN and Ondex projects, and knowledge derivation for biology and neuroscience [Wipat:2-4, Kaiser:1]. A strong focus of our research effort has been in the interaction graph-based analysis of complex biological systems as exemplified by [Wipat:1-3, Kaiser:2-4], including metabolic networks [Wipat:2]. Work on the network analysis of the brain has revealed principles for the development and plasticity of networks in order to understand or treat clinical cases of developmental brain disorders or lesions [Kaiser:1-4].

Goals. Our key strategic goal is to establish the BNC group as the premier computational biology research group in a UK university. For this we will build on our leading position in integrative bioinformatics [Wipat, Bacardit (new appointment), Krasnogor], neuroinformatics [Kaiser], synthetic biology [Wipat, Krasnogor, Zuliani] and complex systems [Krasnogor, Wipat, Kaiser, Zuliani] by expanding in biodata and biotext mining, biocomputing, bioimage analysis, intelligent and automated design of biological systems, and high-performance scientific computing. We will advance on our fundamental approaches to noisy and complex datasets (ACM Humies awards 2007/10/12 (Bronze/Gold/Silver); best contact map predictor CASP'09/10) [Krasnogor:1-4].

Concurrent Asynchronous Systems

Achievements. In addition to the breakthroughs in asynchronous circuit synthesis arising from Khomenko's Fellowship DAVAC [Khomenko:3] that contributed to [ICS4], we have laid foundations for practical synthesis of GALS (globally asynchronous locally synchronous) systems [Pietkiewicz-Koutny:1-4]. We have also delivered theories and internationally leading tools for effective modelling and analysis of concurrent systems based, in particular, on non-sequential semantics expressed through Petri net unfoldings, including: resolution of encoding conflicts in asynchronous circuits [Khomenko:1,4]; behavioural property verification for systems supporting features such as mobility and security [Khomenko:2, Koutny:2-4, Steggles:4]; models of causal relationships in biologically inspired membrane systems [Koutny:1]; and abstraction methods for synchronous and asynchronous multi-valued regulatory networks [Steggles:1-2].

Goals. We will continue (initially within UNCOVER) to develop theories and tools for effective modelling, analysis and synthesis of concurrent asynchronous systems, extending our existing solutions to deal with complex evolving systems using techniques based on structured partial order semantics [Khomenko, Koutny, Pietkiewicz-Koutny]. We plan to develop practical verification methodologies (based on Petri net unfolding) and synthesis tools (based on step firing policies) for GALS systems and bio-inspired reaction systems [Khomenko, Pietkiewicz-Koutny, Steggles]. We will also deliver efficient verification tools based on rewriting logic for the analysis of security properties of distributed systems supporting mobility and timing constraints [Koutny, Steggles].

Dependability

Achievements. We have pursued the development of foundations, methods and tools for fault avoidance and tolerance that can be successfully deployed in industry. Our internationally leading role in this field was evidenced by leadership of two FP7 Integrated Projects on formal methods – DEPLOY ("a remarkable four-year experiment", Sir Tony Hoare), and COMPASS – and by significant industry applications [ICS2]. The group advanced the design of cooperative [Romanovsky:1,3], embedded [Fitzgerald:1,4], and concurrent systems [Jones:1-3], and systems balancing reliability, performance and energy consumption [Romanovsky:2,4]. These are embodied in reusable techniques (e.g. [Fitzgerald:2], [Harrison:1-3]), a new architecture for extraction of strategies from interactive proofs [Jones:4], and tool composition methods for model-checking. The group has responded to internationally recognised 'grand challenge' problems in formal verification, producing significant reference models, e.g. of the Xenon hypervisor [Freitas:1], a cardiac pacemaker [Fitzgerald:3] and Mondex smartcards [Freitas:2].

Goals. Our most pressing challenges are in delivering dependability technology for both avoiding and tolerating defects in distributed, reconfigurable systems. We will establish a laboratory for cyber-physical systems at Science Central, developing collaborative modelling, co-simulation and verification technology, building on work in DESTECS and COMPASS [Fitzgerald, Romanovsky], and targeting energy and transport applications. Using our experience in formal proof, we will target next generation tools that are readily integrated with industry processes [Freitas, Fitzgerald, Romanovsky]. We will develop new ways of reasoning about concurrency (especially software) at various levels of abstraction using the rely-guarantee approach [Jones]. We will (initially in PRiME) lay foundations for adaptive, scalable control of many-core systems to addressing interplay of reliability, energy consumption and performance [Romanovsky].

Security

Achievements. This new strand of work concentrated on technical challenges in cybercrime and security, and its quality was recognised by the granting of GCHQ ACE-CSR status in 2013. Hao had significant outputs [Hao:1-2], and gained associated funding through ERC grant SEEVS on e-voting, work that also builds on that of other members of the group on practical cryptography [Gross:1-4]. Another major strength is in developing human factors and usable security: for example, systematic approaches to designing and evaluating CAPTCHA security were developed and applied [Yan:1-4], and we investigated human bias in decision making [van Moorsel:1]. A noteworthy research strand developed in identity and access management [Gross:2], especially through involvement in the User Managed Access standard [van Moorsel:2].

Goals. We treat security as a holistic challenge, taking into account human factors, economic incentives and generic dependable and scalable system requirements. For example, through Hao's ERC grant, we will develop next-generation e-voting technologies that are secure, dependable, usable and suitable for large-scale elections [Hao]. We will pursue multiple routes to establishing the security of business and societal infrastructure, including compositional analysis of security protocols and identity management systems, and analysis of system topology to judge security properties in clouds. The development of usable security mechanisms will continue to be a core part of our research [Yan]. We will drive the establishment of a science of cyber security, building on our participation in the GCHQ/EPSRC-funded Research Institute in the Science of Cyber Security [van Moorsel, Gross]. In particular, we aim to develop and evaluate rigorous decision-making methods for information security that account for human factors and business incentives [van Moorsel].

Human-Computer Interaction and Ubiquitous Computing

Achievements. We have pursued theory, methods and technologies for experience-centred approaches to human-computer interaction and context-aware interaction. The volume and quality

of internationally leading research in these areas is evidenced by the 29 papers and notes (including eight best paper and honourable mention awards) at ACM CHI'12/13 (nearly double that of any other university outside the USA). Research in theory and methods for human-centred design has led to new understandings of experiential qualities of user experience of technology such as spirituality [Wright:1], beauty [Wright:2], materiality [Kirk:1] and the engagement of users through empathic process [Wright:4]. These theoretical and empirical inquiries have been operationalised in design methods for hard-to-engage user groups, e.g. victims of domestic violence [Wright:3], stroke survivors [Balaam:1], and people with dementia [Olivier:2]. Research in interaction techniques and technologies has resulted in enhanced real-world ('in the wild') understandings and design guidelines for situated interaction technologies such as digital tabletops [Kirk:1, Balaam:1] as well as award-winning and patented technologies for wearable, mobile and tabletop interfaces [Kirk:1, Olivier:3-4] and context-aware interaction [Olivier:1, Ploetz:1-2].

Goals. We will continue to develop theoretical and practical understandings of experience-centred approaches to design and evaluation of digital technologies [Wright, Kirk, Balaam]. We plan to develop theory, methods and technologies for emerging participatory technologies and processes of civic engagement in education, public health and social care, and local democracy [Olivier, Wright, Balaam, Kirk] much aided by the award of a CDT in Digital Civics. We will further develop approaches in machine learning for activity recognition and apply these to problems of behaviour imaging, both for context-aware computing and digitally enabled healthcare interventions [Ploetz]. We will leverage our expertise in activity recognition to continue research into enhanced interaction techniques and technologies for natural and situated interaction [Olivier, Ploetz].

Distributed Systems

Achievements. We made significant advances in techniques that can deliver performance and quality of service levels needed for large-scale practical applications. Results have been embodied in open-source systems, used worldwide by academia (OGSA-DQP [Watson:3]) and industry (e-Science Central, used by Unilever), and standards development (PROV [Missier:1], used by Oracle). Recognition can be seen in the award of the SiDE Digital Economy Hub, which builds on the group's advances in design and application of adaptive distributed systems in grid and cloud computing to address societal challenges. Advances have been made in representing and enforcing the terms and conditions of resource usage [Shrivastava:2-3], policies for hosting Grid-based applications to provide high service quality and efficient resource management [Mitrani:3] (BT applied for a patent for the approach), and in replication techniques for cloud systems and mobile ad-hoc networks [Ezhilchelvan:1-4].

Goals. We will continue to identify scalability patterns that map efficiently to clouds, including patterns inspired by functional programming, irregular workflows, and those for event data [Watson]. We will develop our work on dynamic methods to partition distributed applications over federated clouds so as to meet security, availability, performance and price requirements [Gross, Watson]. We will increase our collaboration with statisticians on data models and management, and extracting knowledge from data [Missier]. We will continue to address scalability in distributed algorithms and concurrency, for example by trading certainty for high probability in correct event ordering [Ezhilchelvan]. Leveraging our expertise in quantitative methods, we will conduct research in predictive modelling for socio-technical systems, taking into account human factors, energy use and economic incentives [Thomas, Mitrani, van Moorsel].

c. People, including:

i. Staffing strategy and staff development

Staffing strategy

Our staffing strategy aims to create critical mass in research groups while giving individuals freedom to pursue new opportunities. This was exemplified by strategic appointments in the two newly established groups. To support growth of BNC, we recruited Krasnogor as Professor, Zuliani as Lecturer, and a Senior Lecturer (to join in January 2014); together with new research staff, this creates one of the largest computational synthetic biology groups in the UK. In DI, Wright joined as Professor, Kirk as Senior Lecturer, and Balaam and Ploetz as Lecturers, establishing one of the largest world-class groups in HCI and ubiquitous computing. To maintain (e.g. in anticipation of retirement) and strengthen (e.g. following major funding awards) established areas, we recruited four Lecturers (Freitas, Gross, Hao and Missier) in applied formal methods, cyber security, and

information management.

In order to bring fresh ideas and approaches to the unit, we have sought to recruit from as wide a field as possible. All academics appointed in the review period have a PhD from outside Newcastle, over 50% of academic staff are now international and, during the review period, approximately 70% of academic appointments and 60% of full-time research appointments fell into this category. The international standing of our staff resulted in three overseas Professorial appointments: Peter Ryan (U Luxembourg), Katinka Wolter (FU Berlin) and Christian Kray (U Münster). The international dimension of our approach to staffing is further reflected through the range of visiting scholars, e.g. Gabriel Ciobanu (Romanian Academy), Ian Hayes (U Queensland), Jetty Kleijn (Leiden U), John McCarthy (UC Cork) and Avelino Zorzo (PUCRS Porto Alegre).

Our goal of industry relevance is enhanced by a programme of Visiting Professors and Fellows, e.g. Steve Hodges (Microsoft Research, Cambridge), Mark Little (Red Hat), Tom McCutcheon (DSTL), Simon Shiu (HP), and Stuart Wheater (Arjuna). Recognition of their beneficial influence led to the University establishing a "Visiting Professors of Practice" scheme, with Simon Mercer (Microsoft Research) and Andreas Roth (SAP) the first appointed in the unit to advise on strategic industry challenges that will help focus our research.

Future staffing will be consistent with the strategy described above, and will make the most of the opportunities for collaboration and growth afforded by our new facilities in Science Central. Already-approved hiring will strengthen the cloud and big data area with a further chair and lectureship. We will leverage investment from other units to create critical mass for multi-disciplinary research: two lectureships in the newly awarded CDT in Digital Civics will further strengthen DI-related research (complemented by four lectureships outside the unit, in medical and social sciences); we will complete the Faculty strategic hiring in computational synthetic biology with a lectureship, matched by one in the Faculty of Medical Sciences.

Staff development

We attach equal importance to developing academic and research staff. We use similar mechanisms for both groups, but tailor support to the individual's career stage. Probation is followed by bi-annual Performance Development Reviews (PDRs). We use training provided through the University's Staff Development Unit, from short initial "getting those grants" courses for PDRAs and academics, which are tailored to Computer Science, through the 8-month PI Development Programme, to leadership programmes for senior staff.

Academic staff development: We have introduced measures to help new academics form their research strategy and working practices. We provide all new academics with resources of time (additional research allocation in the workload model), funding (personal allocation for initiatives, travel and equipment), mentoring, and a first research studentship. When applying for grants, academics at all career stages are supported by designated experienced colleagues who advise on proposals and help preparation for interviews, e.g., by running mock panels. This supplements the University's own reviewing process for larger proposals and all fellowship applications.

Research staff development: We work with the University's HR team to ensure compatibility of policies and practices to the Concordat (for championing it, the University received an HR Excellence in Research Award in 2010). With the University, we have introduced a Career Pathways Framework that assists research staff in planning development via independent appraisal, mentoring and career advice. Faculty Research Fellowships offer support in developing careers of outstanding research staff (e.g. Mokhov from the unit won a fellowship and progressed to a Lectureship in the School of Electrical and Electronic Engineering). The success of our approach is evidenced by the range of recent academic destinations of RAs, including: Leong (Senior Lecturer, Sydney U of Tech), Lindsay (Lecturer, Swansea U), McGough (Lecturer, Durham U), Phithakkitnukoon (Lecturer, Open U), Taylor (Lecturer, Dundee U), Obrist (Lecturer, U of Sussex), Roggen (Reader, U of Sussex), and Wallace (Reader, Dundee U).

Evidence of the success of these measures is provided by the *research fellowships* recently awarded to staff in open competitions: Durrant (Leverhulme; 11% acceptance rate), Hao (ERC; one of seven in CS in UK), Comber (Marie Curie; 18% acceptance rate), and Ploetz (DFG). In 2010, Khomenko completed an RAEng/EPSRC Fellowship (one of 11 awarded) which led to further EPSRC funding (VERDAD) and in 2011 Hallinan completed an RCUK Academic Fellowship, gaining a full lectureship after the award.

Equality and diversity: Our policies on equality and diversity are consistent with the University's *Single Equality Scheme* and are monitored by the Head of the School of Computing Science. Equality impact assessments are applied on staff promotions and REF submissions, and key staff have received relevant training. In 2009, the University was granted an institutional Athena Swan Bronze award, and aims to achieve Silver by 2015; the unit is seeking Bronze in 2014. The Equal Opportunities agenda is complemented by the Dignity at Work and Study Code of Practice which promotes a working environment in which harassment and bullying are unacceptable.

ii. Research students

Research students (RSs) are essential to our lively and successful research environment. Our strategy has been to grow the PhD cohort sustainably. Distinctively, we fully integrate RSs into the life of the unit, treating them as far as possible as full members of research groups while they receive a balanced training and supervision programme.

Recruitment

We have been proactive in growing our RS cohort while maintaining quality, in spite of changes to funding regimes: in the review period, we recruited 117 RSs (almost four per academic staff member), with EU and non-EU in almost equal proportions (RS income in the review period exceeded £1.5M from EU and £1.2M from non-EU students). To help recruit the best students, we provide a £1.2K annual top-up to all PhD scholarships funded in accordance with HEFCE guidelines, and matching funds for partial scholarships (four students in the last 2 years). Responding to changes in RCUK funding, we directly funded 20 full studentships in the review period. We increasingly seek CASE awards (five during REF period), and industry scholarships (incl. BAE, GCHQ, Microscoft (three), Redhat (three), and Siemens). We were awarded funding for nine RSs as part of the AHRC Creative Exchange Knowledge Exchange hub in digital public space. We also run specialist MSc courses closely associated with our research groups, to form a solid base for RS recruitment. To further improve access, we recently introduced a four-year Integrated PhD programme (offering specialist MSc-level training and research preparation before commencing the PhD). Our new CDT in Digital Civics will proactively seek and value the participation of disabled students.

Integration with the UoA's research

In order to ensure that RSs play a full part in our research community, we have created work spaces close to and mixed with the staff members of their research groups. For example, the Culture Lab – home to the Digital Interaction group – is a flexible open plan environment with workshops that are ideal for design-led and practice-based research. This intimate connection between RSs and the research culture encourages students to excel: 20% of our submitted outputs are co-authored with PhD students. Examples of RS success are: Maciej Machulak (PhD submitted 2013), vice-chair of User Managed Access standardisation proposal founding Director of CloudIdentity Ltd; Tom Bartindale (PhD 2013), previously sub-editor of ACM CrossRoads; Ahmed Kharrufa (PhD 2010) who founded a start-up related to his award-winning research (best paper award DIS 2012, top 1% of 440 submissions); other awards for RS work include Kantara Initiative Identity Deployment of the Year 2011 (IDDY) Award (Maciej Machulak), Innovative Service Delivery at Bright Ideas in Health 2013 (Dan Nesbitt, MPhil 2013), EuroITV 2013 (David Green, current student) and a team of RSs from the BNC group qualified for the world finals of iGem 2013, a competition in engineering genetics with 200 participating institutions.

Training

RSs take part in the University's Research Student Development Programme in which students broaden skills by taking 120 credits of relevant taught modules run by the University and credit-bearing activities specific to Computer Science, including advanced courses for RSs, e.g. in design of CS experiments delivered by Roy Maxion (CMU) in 2009, and theory of reaction systems by Grzegorz Rozenberg (U Leiden) in 2011, seminars, writing skills training, conference and summer school participation, and workshop organisation as appropriate. Conference, workshop and summer school attendance is strongly encouraged and is funded by an annual allocation per student. Participation in prime international meetings hosted by the unit is always fully funded over and above the standard support, e.g. recently Petri Nets 2011 (seven students) and CONCUR 2012 (15 students). The AHRC Knowledge Exchange provides a unique training programme tailored to research and design methods for digital interaction.

Supervision and progress monitoring

Each RS has a main supervisor with whom they meet frequently, and two co-supervisors, with whom they meet formally at least thrice-yearly. Early-career academics initially co-supervise with more experienced colleagues. Following the University's Code of Practice for Research Degree Programmes, supervisory teams formally monitor RS progress through annual reports. An independent Progress Panel assesses the student's papers, oral and poster presentations to determine whether progress is satisfactory; recommendations are assessed externally by the Dean of Postgraduate Studies.

d. Income, infrastructure and facilities

The richness and sustainability of our project portfolio derives from a strategic decision to seek funding that fits – both in size and type of support – the specific nature of our research goals.

Our research in Systems and Human Computer Interaction was supported by the flagship Digital Economy Research Hub SiDE (EPSRC, £12.1M incl. £6.8M for UoA as leader, 2009-14) which advances areas where digital technologies can deliver social benefits (e.g. accessibility, transport, connected homes and creative industries). Related awards include: MyPLACE (EPSRC, £1.3M incl. £1M for UoA, 2013-16) investigating digital tools enabling people to engage with organisations dealing with urban environments; SALT (TSB, £1.4M incl. £0.5M for UoA, 2011-14) analysing the use of assistive technologies and developing related experience centred design methods; TRUMP (EPSRC, £1.6M incl. £0.3M for UoA, 2011-14) exploring mobile technologies supporting chronic disease management; and The Creative Exchange hub (AHRC, £4M incl. £0.8 for UoA) concerned with the meaning and value of digital public space for the creative and cultural sector.

We pursued foundational CS research in response to the direct needs of industry through: DEPLOY (EU FP7, £8.9M incl. £1.5M for UoA as leader, 2008-2012) advancing formal engineering methods for dependable systems, with partners including Bosch, SAP and Siemens; COMPASS (EU FP7, £5.4M incl. £1.1M for UoA as leader, 2011-2014) developing model-based techniques for systems of systems, with partners including Bang & Olufsen and Insiel; DESTECS (EU FP7, £2.4M incl. £0.3M for UoA, 2010-2012) advancing collaborative modelling and co-simulation in embedded system design, with partners including Chess ES and Verhaert; and PRiME (EPSRC, £5.6M incl. £0.2M for UoA, 2013-2018) investigating uncontrolled energy consumption and unreliability in many-core systems, with partners including ARM Ltd and Altera Europe.

The long-term sustainability of our research was recognised by support from three EPSRC Platform Grants: Networked Computing in Inter-Organisation Settings (£0.4M, 2005-10) investigating trust, security and fault tolerance in middleware; TrAmS (£0.8M, 2007-11) investigating formal methods for fault-tolerant ambient systems; and TrAmS-2 (£1M, 2012-16) on the management of dependability in the resource-limited ambient environment.

In the area of foundations of computing science, AI4FM (EPSRC, £0.5M, 2010-14) investigates the use of AI ideas to support theorem provers, and Taming Concurrency (EPSRC, £0.6M, 2013-17) defines new ways of reasoning about concurrency in software. Concurrency research was further supported by VERDAD (EPSRC, £0.4M, 2009-12) which incorporated verification into the design of asynchronous circuits; and is currently supported by UNCOVER (EPSRC, £0.6M, 2013-16) aiming at theories and tools for complex evolving systems.

We secured EPSRC funding to develop computational and laboratory resources for synthetic biology EP/J02175X/1, £5M incl. £0.8M for UoA, 2012-17), together with an Innovation and Knowledge Centre SynbiCITE (£6.2M, 2013-18), ROADBLOCK (£0.7M, 2012-15) integrating algorithms and tools for synthetic biology with wet lab techniques, and (P/K039083/1, £5.5M, 2013-18) aiming, in particular, at computational models of synthetic ecosystems. Moreover, Krasnogor has secured a prestigious EPSRC Leadership Fellowship AUdACiOuS (£1M, 2013-15) aiming to make E. coli bacteria easy to program. This is one of only two such awards in synthetic biology.

Funding for our recently prioritised area of computer security includes: SEEVS (EU ERC Starting Grant, £1.1M, 2013-18) developing next-generation e-voting technologies for large-scale elections; FutureID (EU FP7, £13.2M incl. £0.2M for UoA, 2012-15) developing privacy-aware and usable identity management infrastructure; Cybercrime Network (EPSRC, £0.1M, 2012-15) facilitating interaction in the area of cybercrime; Academic Centre of Excellence in Cyber Security Research (GCHQ, £40K, 2013-17); Research Institute in Science of Cyber Security (GCHQ/ EPSRC, £3.5M incl. £0.4M for UoA, 2013-16); and Trust Economics II (DTI/HP, £0.3M, 2008-11) investigating

methods and techniques for trade-off decisions between security and productivity.

We have pursued investment in specialist infrastructure that closely follows our research strategy. The key facilities that have been grown significantly since 2008 include:

- Culture Lab: a purpose-built design facility for practice-based research in digital media, human-computer interaction and ubiquitous computing. We built on previous investment with £325K in core funded PDRAs, and £120K on equipment. The facility includes office space, workshops (with 3D printing, laser cutting and pick-and-place electronics fabrication), media production facilities and a performance research space. It accommodates the Digital Interaction group (its 60 members and RSs constitute 80% of the building's permanent residents).
- Synthetic Biology Lab (£0.8M) which allows computational designs to be implemented in bacterial systems. It uses shared facilities in the Centre for Bacterial and Cell Biology such as: world leading microscopic facilities, state of the art laboratories, proteomics facilities, high-throughput DNA sequencing equipment, robotics and microfluidics. It also provides a unique environment for interacting with a range of leading bacteriology laboratories.

The unit's physical environment has benefited in the past three years from a further £100K investment in the general accommodation for all staff and research students.

The University and City have recognised the wider significance and growth in the unit's research by investing in Science Central (£50M from the University on a site jointly developed with the City of Newcastle). This will house the entire unit (research, teaching, staff, and students), including new laboratories designed to promote the collaborative and relevant research that has always been part of our vision. We will be joined there by new laboratories from other units keen to collaborate on digital aspects of sustainability, transport, energy and devices and drives. Prior to the move, the Cloud Innovation Centre (£2M) will start up in 2014, using the research base on cloud and big data to help address real commercial needs through co-location and collaboration with industry. Facilities will include private cloud infrastructure, public cloud access, decision theatre and learning lab infrastructure.

e. Collaboration and contribution to the discipline or research base

Our vision of computing science research that is relevant to industrial and societal need requires that we support collaboration across disciplines and with external stakeholders. We have a long history of industry collaboration and of working with cognate disciplines such as electronic engineering and, as indicated in Sections (b) and (c), since 2008 we have pioneered collaborative work with health and social science (inspiring work in the DI and Systems groups), and biology and neuroscience (leading to advances in the BNC group). We support appropriate collaborations by: giving researchers individual funds that they may freely deploy to initiate collaborations through visits or exploratory studies; establishing distinctive research centres to act as contact points for reaching potential collaborators; and using multi-partner projects for national and international collaboration. Evidence of the success of our approach is found in the current project portfolio: among currently active projects, 73% involve substantive collaboration with external researchers, businesses, or government. The strength of industry collaboration has been recognised by Red Hat decision to locate one of its research centres on campus.

Local collaborations

At the University level, we have established several robust long-term interdisciplinary collaborations. Some 21 projects in the unit's current portfolio involve collaboration with other units. As an exemplar, our work with the School of Electrical and Electronic Engineering involving asynchronous circuits, sensor technology and resource-aware computing has been sustained by (in the review period) over 60 seminars, is key to five currently running projects, has produced over 11 journal/conference papers, incl. [Khomenko:4, Pietkiewicz-Koutny:2, Romanovsky:4], and has had industry impact in automating construction of asynchronous circuits and improvements in business process analysis [ICS4]. A further major exemplar has been investment in the DI group's engagement with other disciplines through Culture Lab: 17 current DI projects involve collaboration with researchers in medical sciences, sociology, education, transport, business, design and arts, and now the Digital Civics CDT will provide a step change for this work under a unified theme.

National and international collaborations

Our policy of giving staff individual research initiative funds has paid off in international

collaboration. As an exemplar, investment of individual funds by Koutny in bilateral visits with Leiden U (Jetty Kleijn and Grzegorz Rozenberg) sustained a collaboration that led to Koutny's Pascal Professorship at Leiden, and 18 journal papers and book chapters (incl. [Koutny:1-2, Pietkiewicz-Koutny:1,3]). We have invested in support posts targeted at securing and leading large EU projects; this helped us to lead international consortia receiving over £19M of EU funding in the review period, with 12 academic and 10 industrial partners. The extent of the international dimension of our research is exemplified by collaborations with researchers from, for example, Aabo Akademi, Aarhus U, AIST (Japan), Bonn U, Chinese U of Hong Kong, CMU, Concordia U, Evry U, Georgia Inst of Tech, U Illinois (U-C), Leiden U, Luxembourg U, McMaster U, MIT, U Queensland, Sao Paolo U, U Twente, UNC Torun, Wayne State U, and Xidian U. International industry partners include Bang & Olufsen, Bosch, Google, Hewlett Packard, Komatsu, Microsoft Research Redmond, SAP, Siemens, and over 20 other companies. An agreement with the National Institute of Informatics (Japan) in 2012 has so far led to four visits (two each way), including tutorials and workshops on dependable systems.

Collaborations with research users

Engagement with research users is important to ensuring the research relevance that guides our strategy. To help realise this, we have established several designated centres to provide points of access to our research, and to provide events and locations for external interaction. For example, the *Centre for Cybercrime and Computer Security* carries out research and education to make the Internet safer for families, businesses and organisations. It brings together police officers and research scientists to identify future modes of cybercrime and to design innovative, sustainable solutions. Complemented by EPSRC 'research in the wild' funds, the centre works with the Angelou Centre and other charities to develop secure methods for digital communication for women in disadvantaged groups. In another example, the *Centre for Software Reliability* maintains links with industry and government sectors which have a stake in the outcomes of dependability research. Since 2008, the centre has run 71 days of knowledge transfer events (avg. attendance 89) informing projects such as SafeCap (with Invensys Rail, now Siemens), DEPLOY (with Bosch, SAP and Siemens), and COMPASS (with Bang & Olufsen and Atego) that are related to verification and safety.

Exemplars of leadership of the UoA within the academic community

Selection panels, Fellowships and Visiting Professorships: ACM Turing Award Committee (Randell, 2005-9 member, 2008 chair – Senior Researcher during the review period); Fellow RAEng (Jones); Fellow ACM (Randell); U Minho Braga (Harrison); Seoul National U (Kaiser); 2011 Pascal Chair Leiden U (Koutny); Weizmann Inst of Sci (Krasnogor); NII Tokyo (Romanovsky); U of the Balearic Islands (Thomas); U of Sydney (Watson, Olivier)

International project selection panels: Italy (Fitzgerald); France, Germany, USA (Kaiser); Portugal, Romania (Koutny); Belgium, Israel (Krasnogor); Canada, USA (Romanovsky); Canada (Wipat)

Editorial boards of journals: J Appl Logic (Fitzgerald); IEEE Security & Privacy (Hao); Formal Aspects of Comp (Jones); ACM Comp Reviews (Kaiser); Int J Human Comp Studies (Kirk); *editor-in-chief* Trans Petri Nets and Concurrency (Koutny); Natural Comp (Krasnogor); *department editor* IEEE Security & Privacy (van Moorsel); Annals Hist Comp (Randell); J Syst Architecture (Romanovsky); BioIT (Wipat); IEEE Trans Inf Forensics and Security (Yan)

Hosting and organisation of international conferences and workshops: AdaEurope 2011, CONCUR 2012, DIS 2012, Petri Nets 2011, Pervasive 2012, SAFECOMP 2008

Steering committees: Board of FME (the FM conferences) *chair*, Theor Aspects of Comp (Fitzgerald); Eng Interactive Comp Syst *chair* (Harrison); Petri Nets *chair* (Koutny); Sci Board of ECLT *chair*, Nature Inspired Coop Strat for Optim (Krasnogor); DILS (Missier); Joint SC of ACM Pervasive and Ubiquitous Comp (Olivier); ERCIM SERENE (Romanovsky); UK e-Sci All Hands Foundation *chair* (Watson); ACM Designing Interactive Syst (Wright)

Program and General Chairs of international conferences: ACSD'10 (Khomenko); CONCUR'12 (Koutny); GECCO'10, ECSB I&II (Krasnogor); PERVASIVE'12 (Olivier); ACSD'13 (Pietkiewicz-Koutny); EPEW'08/11(Thomas); Cloud Eng'13 (Watson); DIS'12 (Wright)