Institution: University of York
Unit of Assessment: 11: Computer Science and Informatics
a. Overview

Our Unit of Assessment comprises staff from the Department of Computer Science at York (hereafter referred to as CS). One joint appointment (Franks) is returned under UoA 5, Biological Sciences. The Department has 9 research groups that provide a balance of ***software and systems engineering*** research and ***fundamental computer science and technologies*** research. The groups, together with major research foci, are indicated below.

Software and Systems Engineering Research Groups
Advanced Computer Architectures (**ACA**: neural architectures, prognostics and diagnostics, grid computing)
Enterprise Systems (**ES**, est. 2009: model driven engineering, model transformation, stochastic modelling of systems, software testing)
High Integrity Systems Engineering (**HISE**: safety engineering and formal methods)
Human Computer Interaction (**HCI**: games immersion, web accessibility, digital cultural heritage)
Programming Languages and Systems (**PLASMA**: functional and graph programming, formalisation of security properties, models of distributed computing)
Real-time Systems (**RTS**: timing and scheduling analysis, systems-on-chip, mixed-criticality systems, real-time programming languages)
Fundamental Computer Science and Technologies Research Groups
Artificial Intelligence (**AI**: search-based decision support, constraint solving, machine learning, natural language processing, hyperheuristics, economic models of gaming)
Computer Vision and Pattern Recognition (**CVPR**: principles of pattern recognition, robust and effective machine vision algorithms)
Non-Standard Computation (**NSC**: fundamentals and applications of nature-inspired computation, quantum information processing, complexity, simulation of complex systems)

All groups have a research group leader responsible for the ethos and ambition within their group. CS research is overseen by the Departmental Research Committee (DRC), chaired by the Deputy Head of Department (Research). The DRC meets every three months and has ECR and Research Associate (RA) representatives.

Eight CS academic staff are also members of the York Centre for Complex Systems Analysis (YCCSA). YCCSA's goal is to foster inter-disciplinary research and its members are drawn from the Departments of Biology, Chemistry, Computer Science, Electronics, English, Environment, History of Art, Management, Mathematics and Physics. CS is the largest contributor to YCCSA.

b. Research Strategy

Position with respect to RAE2008. As set out in RAE2008 documentation, our Department's 2010 move to the new Heslington East Campus was integral to our plans. Most CS staff and students are housed in the £14m Computer Science Building. The adjacent Ron Cooke Hub (RCH) is a £20m University-wide investment to co-locate researchers from YCCSA, our Enterprise Systems group, high-tech start-up companies, and CS's Continuing Professional Development (CPD) activities. We grew to 46 staff (target was 48). Below we show how we continued to progress our six strategic objectives and give evidence of continued vitality and sustainability.

1) ***To support the continued success of established research groups***. We built specialist labs for the HCI, RTS, CVPR and NSC groups. Five groups welcomed additional staff and the achievements of staff in the three further groups were recognized via promotion. RAE2008 groups were awarded 21 full best paper prizes in venues of international standing and ACA, led by Austin, was awarded THES Engineering Research Team of the Year 2011.

2) ***To nurture emerging research activity by forming new groups.*** The Enterprise Systems Group was established to develop HISE's Model Driven Engineering research (led by Paige). It has 4.2 FTE academics, has produced 100+ papers since Jan 2008, and its *Epsilon* tool suite attracts 9000+ downloads a year. Its two ECRs have 1800+ and 500+ Google Scholar citations respectively (360+ and 110+ in Scopus). The group graduated 7 PhDs in the REF period, and currently has 13 PhD and 7 Engineering Doctorate students. It also generated £1.46m in research income.

3) *To enable blue-sky research that is original and rigorous*. We recruit, support and reward staff who engage in such work (e.g. Pirandola, promoted to Reader three years after appointment to Lecturer). It is also celebrated in our annual best paper awards. The giving of postgraduate research methods modules at York, presenting of empirical methods tutorials at international venues (e.g. SBST 2012), and Cairn's co-editing of *Research Methods for Human Computer Interaction* (2008) further illustrate our commitment to methodological rigour.

4) *To enable international collaboration.* We supported this by Royal Academy of Engineering (RAEng) and Royal Society distinguished visitor scheme sponsorships (to host John Knight and Marie-Claude Gaudel), funding staff study leaves, hosting conferences (e.g. ETAPS 2009 with c. 500 attendees) and 30 international visitors, and seeking increased participation in EU projects. (We have 16 active or awarded EU projects at 31/7/13 – the REF financial cut-off date - with York CS budgets of over £6m.) About 1/3 of our REF outputs have international co-authors.

5) *To enable research across disciplines*. Provision of dedicated space in the RCH for YCCSA facilitated the interactions of over 70 academics, RAs and research students (RSs). We appointed quantum information processing specialist Pirandola (2010), animal society computational modelling specialist Franks (2011), and metaheuristics, games and gaming specialist Cowling (2012, to a chair). Each secured an RCUK grant starting in 2013 or 2014, Pirandola has given 14 invited talks, and Franks has a recent paper in *Science* (*DOI: 10.1126/science.1224198).*

6) *To enable initiatives leading to industrial applications.* We were partners with major industrial and governmental stakeholders, e.g. in the Software and Systems Engineering Institute and International Technology Alliance, which provided c. £3.6m research funding. The 36 RSs in our Engineering Doctoral Training Centre in Large Scale Complex IT Systems (2009-current) are industrially co-supervised, with impactful research an expectation of the programme.

Vision and Strategic Themes for 2014-19. We will continue to combine fundamental and applied research, seeking to lead our academic discipline and realise impact outside it. We will support our groups to remain leaders of their specialist areas. We will harness the abilities of all groups to remain one of the most impactful UK CS departments. We will increase collaboration within CS, across disciplines, and across institutions to engage with important research challenges. Three **Primary Themes** (PT1-PT3) will provide strategic research foci within the Department (and beyond) and we aim to create world-leading research and impact contributions in them:

- **PT1**. **Advanced Architectures and their Applications**. This includes not only multicore, concurrent, and distributed embedded systems (the EPSRC's *MACDES*) but also systems-of-systems, mixed-criticality systems, and specialist hardware research.
- **PT2**. **Games and Gaming**. This encompasses both "fun" and "serious" games, e.g. where games are harnessed to provide insight into social, political, and economic phenomena.
- **PT3. Inter-disciplinary Research**. Concentrating on the challenges arising from topics such as protein folding, harnessing physics and chemistry for computation, pedigree construction, network modelling, and discipline-specific data analyses.

PT1 is a contemporary focus for our well established software and systems engineering groups. PT2 is a new focus drawing on HCI and RTS for immersion and real-time aspects, fundamental technologies groups (principally AI), and expertise of our neighbouring Department of Film, Theatre and TV (whose recent appointments include two with very strong CS backgrounds). PT3 continues our (particularly NSC's) goal to contribute to fundamental complex systems science and to have an impact on big problems facing the sciences and society. Each theme has a critical mass of contributing CS researchers with diverse perspectives who can generate research agendas with the intellectual excitement to inspire staff, students, and sponsors. We have always sought to blend academic research excellence with impact: the Primary Themes will enable us to continue to do so.

Vitality and sustainability. MACDES and systems-of-systems will remain major challenges facing software and systems engineering, with the former being an explicit EPSRC ICT priority. Mixed-criticality systems present major challenges (as referenced in the EU FP7-ICT workshop report *Mixed Criticality Systems*, Feb. 2012.), which our strengths enable us to address. Funding for new PT1-focussed projects *starting 2013* was over £1.2m (e.g. Burns' EPSRC EP/K011626/1 and Soares-Indrusiak's EU PROXIMA). The 2012 Chancellor's statement identified UK games as a crucial creative industry. Global revenues are predicted to be $82bn by 2017 (Creative Industries Knowledge Transfer Network European Games Workshop Report, 20th March 2013). PT2 embodies our intention to engage in world-class research with application to an exceptionally vibrant sector. Cowling's successful leadership of the 2013 £1.16m EPSRC NEMOG games

proposal (EP/K039857/1, with CASS and Durham Business Schools and York's Department of Management) and of the Intelligent Games & Games Intelligence (IGGI) EPSRC Doctoral Training Centre proposal (with Essex and Goldsmiths) boosts our PT2 ambitions. These projects exemplify our plans to collaborate. PT3 aligns with UK and EU funders' clear indication (reflected in RCUK and emerging Horizon 20-20 themes) that inter-disciplinary collaborations will be needed to address major problems. Stepney's 2013 EU EvoEvo grant (York CS budget £539k) will continue international complex systems collaboration. All research groups can contribute to one or more of the Primary Themes, which reflect our strategic foci. We will continue to improve our development of staff, students, facilities and general environment, impact, national and international collaborations, and contributions to the discipline to remain a centre of CS research excellence.

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c. People, including:
I.   Staffing strategy and staff development

Our strategy has anticipated the retirement of senior researchers in the next 10 years. We sought to appoint and promote in support of RAE2008 Strategic Objectives and current Primary Themes. We also sought to actively develop leadership in current staff and recruit excellent junior staff and develop them to become independent, internationally influential researchers.

Appointments. *To Lecturer*: Alexander (systems-of-systems); Dodds (formal models of languages); Pirandola (quantum information); Franks (animal society modelling); Kolovos and Rose (model driven engineering); Power (human computer interaction); and Soares-Indrusiak (low power, systems-on-chip). Poulding was appointed as Lecturer, left, and re-joined as an RA. *To Senior lecturer*: Calinescu (stochastic modelling of critical systems); Chivers (security); and Oriol (software testing). *To chair:* Cowling (metaheuristics, games and gaming).

Promotions. Davis (real-time systems) was promoted to our most senior RA grade (Researcher Grade 8). *To Senior Lecturer*: Bate (embedded systems); Jacob (formal modelling); Kazakov (artificial intelligence); Pears (vision processing); and Soares-Indrusiak (as above). *To Reader*: Cairns (immersion) and Pirandola (as above). *To Chair*: Audsley (embedded systems); Cavalcanti (formal methods); Kelly (safety); Paige (model driven engineering); and Wilson (computer vision).

Alexander, Audsley, Bate, Cavalcanti, Davis, Dodds, Kelly and Soares-Indrusiak will all contribute to PT1 and the appointments of Cowling, Pirandola and Franks support PT2 and PT3. Our appointment and promotion strategy is yielding success: for example, Davis and first-time lecturers were co-authors of 6 Best Papers, and in Jan-Jul 2013 submitted and were awarded EU projects with York CS budgets of £1.6m+ (PROXIMA, DREAMCLOUD, and MONDO). Cowling's contributions were indicated above. Appointed or promoted staff are PIs for 10 EU projects.

International staffing. We aim to attract outstanding researchers from across the world and in RAE2008 our academics originated in the UK, North America, South America, Europe, Asia and Australia. We sustained our international profile in the REF period by appointing 4 European (non-UK), 1 Brazilian and 1 Canadian citizen to full academic positions, as well as 7 UK citizens. We encourage such staff to develop their home and international networks and support staff to take up international opportunities: Petrie was the Lund University Lise Meitner Chair for 9 months in 2012 and Bate took up a 50% Visiting Chair (2011-) in Mallarden (Sweden), with one of the world's largest real-time systems groups (with on-going co-supervision of researchers). Senior Lecturer Luettgen left to take up a chair in Germany.

Fellowships. Recognising that fellowships are a critical part of staff development for exceptional researchers, we have encouraged and supported fellowship applications and related nominations/proposals across all career stages. Three senior staff (Hancock, Cavalcanti and Clark) gained 5-year Royal Society Wolfson Research Merit Awards, recognising scientific achievement and vision, but also providing access to Royal Society networks and support. The research fellowships (starting 2013) of Pirandola (Leverhulme, 21-months) and Pears (Royal Academy of Engineering, 1-year) allow pursuit of personal visions, freed from non-research commitments. Exceptional RAs are encouraged to apply for awards**:** Ge obtained an RAEng International Exchange Award to pursue a research collaboration in China in 2012 and Royal Society applications from RAs are under review.

Leadership development. The University's THES award-winning *Leadership in Action* programme allowed 5 senior staff to explore aspects of motivation, holding sensitive conversations, communications, and staff development. Two staff attended York's *Research Leaders* programme, running for the first time in 2013 and designed to prepare staff for being an effective PI. We aim for

all new academic staff to follow this programme in the future. New lecturers follow York's two-year development programme: the York Certificate of Academic Practice. They are mentored by group leaders and colleagues and (in research matters) by the Deputy Head (Research). Particular support for proposal writing has helped five first-time lecturers become PIs. Co-option onto projects with senior PIs (formally or informally) also develops project experience.

Performance Review and Promotion. Annual personal development reviews appraise all research activity, allowing research staff to explore recent achievements and plan for the coming year and beyond. Appraisal for professorial staff is conducted by the Head of Department, with all other staff appraised by their research group leader or supervisor. Informal advice and mentoring is provided within groups on an on-going basis. Our staff are encouraged to develop their engagement with the research community (e.g. by editorial and conference roles) and identify training needs. Since 2011, the Deputy Heads (Teaching and Research) have given early stage support to help staff construct their promotion applications. In the second year (2012) of this more intensive approach, all 7 candidates who applied were promoted.

Concordat. In 2010, we benchmarked ourselves against the *Concordat to Support the Career Development of Researchers* leading to the development of a formal RA training programme, guided by the Concordat and discussion with RAs (led by Alexander, an ECR and former RA Representative). The training programme includes a 6-session grant proposal writing module with over 20 takers over the two years it has run (enabling RAs to assist with grant proposals and create four fellowship applications in 2013), sessions on promotion, career planning, running conferences, and writing and reviewing papers. Further training needs are discussed in performance reviews and the University runs a wide-ranging series of skills and development modules. The University achieved the European Commission 'HR Excellence in Research' Badge with its Concordat action plan (2010-12) and renewal followed in 2012 when a new action plan and report were submitted detailing progress, achievements, actions, and KPIs for 2012-14.

Providing Staff with Resources for Research. The Departmental Research Committee annually solicits proposals for study leaves. Normally four staff take sabbaticals in any academic year. Staff can negotiate teaching buyouts and leave for setting up spin-outs etc. ECRs have reduced non-research duties (for 3 years) to assist development as independent researchers. New staff are given £6K-£8K start-up funds, with further access to group funds. By collegial agreement group budgets are based partly on their staffing and research student profile and partly research funds generation, providing appropriate incentives yet supporting fundamental research. Groups spent £1.129m in devolved funds over the REF period. Research students are allocated individual travel budgets by the Department to ensure quality of research experience.

Support for equality and diversity. In 2011, we became one of only three CS Departments among 90+ Athena Swan Award holders, recognizing our determination to address gender equality issues. We monitor committee memberships, UG/PG recruitment, and representativeness in promotional literature, encourage participation in local and national efforts (one female student won Hopper Colloquium 2012 and Yorkshire Business Event 2012 prizes), and host high profile women speakers (e.g. Sue Black). Senior women have taken prominent research roles: Stepney is Director of YCCSA, Petrie was Physical Science Ethics Chair, and Cavalcanti is Chair of the Research Studies Committee. The Ron Cooke Hub maintains a prayer room. In addition, digital inclusivity is a major research theme within the Department and we are regularly assisted by the communities we serve, e.g. in our empirical work on web access by visually impaired people.

c. II.Research students

Research students are the largest component of our community and produce some outstanding research. Our students should: be able to independently carry out original and rigorous research; be able to communicate their results effectively; have contributed to and feel part of the academic community; and possess the skills, self-reliance and confidence to progress in whatever they do next. We strive to attract high quality students, monitor progression effectively, and provide diverse skills and other training. Commitment by supervisors to nurture students is crucial.

Recruitment. The Research Studies Committee allocates studentships (including EPSRC and Departmental awards) on merit, but interests of early career staff are taken into account. We usually offer 5 EPSRC scholarships per year (with a few partial fees waivers). 33 EPSRC LSCITS Engineering Doctorate studentships have also been awarded, with external sponsor 'top-up' contributions. Specific recruitment mechanisms include paid summer internships to inspire gifted students, e.g. in 2010 and 2011 we funded 3 top MEng students, resulting in two international

conference (full) best paper prizes and a GPU acceleration competition win. (2 are now RSs.) From Oct. 2013 three MSc programmes will adopt a 10-credit IEEE conference paper supplement to the 90-credit research project, encouraging early engagement in research practices: a small fraction of top students progressing to a PhD will have considerable research benefit. We offer a PhD scholarship for the student showing the best MSc performance. Perhaps the strongest indication of quality of intake is that 30 of our 100.5 REF period graduates have secured lectureships or higher (7 UK, 8 EU, 15 overseas). We now aim to increase the number of doctoral degrees awarded per research active academic from 2.89 to 3.5. Future provision of conference scholarships for the best published MSc project papers should attract research-minded students.

Development. Students undergo an induction week on arrival, with training modules throughout the first year (e.g. how to do a literature survey and how to give a presentation). We run open modules on a variety of topics, e.g. how to write an academic paper, how to review an academic paper, career planning, and how to run a conference. After training, RSs may act as class demonstrators. At their forum meetings, our RSs present work, discuss issues, and organise academic and social events. The RS Training Officer organises training (largely delivered by senior staff). Students are guided by their supervisors to produce high quality publishable papers: the 100.5 RSs graduated during the REF period have published on average 3.55 conference papers and 0.75 journal papers with their supervisors (including papers post PhD completion). The *York Doctoral Symposium*, a real but friendly RS-organised conference with UK and international submissions, provides transferrable skills development opportunities. It is underwritten by the Department but our RSs invariably find sponsorship from big players such as Microsoft, IBM, and Credit Suisse. Our RSs make an exceptional contribution to our environment; their initiative, enthusiasm, achievements and collegiality are greatly valued.

Progress monitoring. PhD progression procedures and guidance are detailed in our Research Student Handbook. A supervisor provides general guidance with an "assessor" giving formal assessment and advice roughly every six months. These points allow progress and written, oral and presentational skills to be assessed and developed. Our Research Student Committee meets every three months to consider progress and (with the RS representative) general RS welfare.

d. Income, infrastructure and facilities

Income. Total research income of £17.19m was reported at RAE2008. Our total income reported in REF4a is £19m. HESA benchmarking data available for 2009/10, 2010/11 and 2011/12 place us 8th in the Russell Group for income per academic. Income from UK industry, commerce and public corporations was high in 2008/2009 and 2009/2010 reflecting major projects coming on-stream, with corresponding decline when they ended. We have anticipated retirement of senior staff in the next REF period and have recruited significantly at junior levels. 8 full-time staff, including 5 ECRs, took up their first academic posts. In Jan-Jul 2013 Davis and first-time lecturers submitted and were awarded EU projects with York CS budgets of £1.6m+: PROXIMA, DREAMCLOUD, and MONDO. (Also, two EPSRC First Grants were submitted before 31/7/2013 but awarded after that date.) Realising that our traditional industrial and governmental funding would come under increased pressure due to the recession we determined to increase our EU income. RAE2008 reported £1.487m of EU project funding whilst REF4b reports £3.924m. As of 31/7/2013, we have 16 live or awarded EU projects with York CS budgets of £6m+. These provide links to leading EU academics and industry and will lead to further collaborations.

The emergence of the EPSRC's five strategic ICT themes has increased our confidence that our Primary Themes are sustainable research foci. Their *MACDES* priority directly supports our PT1; their *Working Together* priority largely encapsulates the raison d'être of YCCSA and our PT3, and their *New and Emerging Areas in ICT* theme highlights quantum information processing (QIP) as an exemplar. The work of two staff is highly influential in QIP: Braunstein's work has been cited over 8000 times and Pirandola's over 600 times (Scopus). Many other research interests fall readily under the *Towards an Intelligent Information Infrastructure* theme. Finally, impact has been important to our Department since its inception and the recent emergence of impact as a priority of funding councils suits our traditional strengths. Our (successful) strategic decision to emphasise EU proposals has likely led to a low level of RCUK funding. Our funding priority for the next REF period is to increase RCUK sponsorship.

Professional Services and Other Income. Continuing Professional Development (CPD) forms by far the greatest component of our professional services (generating c. £1.9m in the REF period). Since 2008 CPD staff have delivered more than 1500 student weeks of modules at client sites (or

nearby conference facilities). We have secured training contracts extending over the next five years (estimated value over £1.5m). The modules are a vehicle for reciprocal knowledge exchange, disseminating our dependability research and providing continual contact with practising engineers.

We also maintain significant professional software and systems development expertise within the department: our ACA group successfully obtained £1.232m (non-research income, University Modernisation Fund) from HEFCE to develop YouShare, a cloud-based platform that allows users to securely make their research outputs usable to others on a cloud based system.

Infrastructure and Facilities Context. The new Heslington East Campus is the biggest infrastructural investment in the University's 50-year history. We created an Associate Head of Department role to represent CS interests to the University and the architects during the planning phase. We took this opportunity to create research spaces and facilities that work for us, improving our ability to engage in leading-edge research, providing a stimulating environment for CS staff and students, facilitating our ability to contribute to the discipline and achieve impact, and allowing researchers aiming to work across disciplines to be co-located with like-minded colleagues from other Departments. We moved into our new accommodation in Oct-Nov 2010 and below we outline specific aspects of our new infrastructure and facilities and indicate the benefits that they bring us.

Buildings, Offices and Labs. 33 CS academic staff are now housed in the Computer Science Building (a £14m investment) with 12 further academic staff housed in the Ron Cooke Hub alongside biologists, chemists, management and law specialists, mathematicians and environmentalists. Within the CS Building, each group's academics, RAs and RSs are co-located in modern office space, with breakout spaces to facilitate easy discussion. The CS Building also hosts group laboratories as outlined below. These underpin a great deal of empirical research and allow RAs and RSs to gain practical laboratory experience that is essential to carry out internationally leading research in some topics. The **HCI Interaction Labs** comprise two usability laboratories, three domestic environment labs (a kitchen, living room and dining room), and a control room with specialist equipment for usability research, games research and research with disabled and older people. Equipment includes a range of input devices, screen-readers, screen magnification programs, discreet webcams and screen capture software to monitor activities. The labs have greatly facilitated empirical work, e.g. they provided the controlled facilities for rigorous assessment of the effectiveness of the Web Accessibility Guidelines (see Power, REF2 Output 1), and 14 other research papers since Oct. 2012. Issues such as health and aging are priorities for EPSRC and EU Horizon 20-20. The **Real Time Systems Lab** supports real-time hardware analysis and sensor networking research, with the group's Virtual Lab servers allowing remote experimentation with lab development boards. It also contains a 'flex picker' used as a vehicle for real-time control research. The separate Crossrail Lab provides facilities for student teaching and individual projects in embedded and real-time systems. RTS is adopting an increasingly embedded systems focus, reflecting the research interests of its younger staff. Use of the facilities has been a critical element of the research reported in over 25 papers (including all REF Outputs for Audsley). The **Computer Vision Lab** suite has dedicated dark room and natural light laboratories. Equipment includes a laser range scanner (Cyberware 3030PS) for acquisition of calibrated shape, texture and reflectance data, and optical bench and light stage facilities for polarisation imaging, spectro-radiometery and photometric surface analysis. These were used for experimental evaluation and data collection for work leading to 50+ papers since Jan 2008. The light stage was a £15k investment in 2009 to support Smith (then ECR). The **NSC Robotics Laboratory** (opened 2012, shared with the Department of Electronics) is a £250K standalone building, located in close proximity to the CS building. It provides safe, constrained space for empirical testing of theories in robotic and autonomous system behaviours, e.g. swarms of airborne systems and underwater systems, and has already facilitated 7 research papers.

Interdisciplinary research investment. The top two floors of the Ron Cooke Hub were developed in consultation with their future residents to provide the ideal environment for collaborative and cross-disciplinary research, facilitating the interaction process of "coming together, thinking together, working together", through a focus on open, joint spaces and informality. It comprises traditional staff and student offices, a meeting room, hot-desk space for visitors, a common room, a seminar room, and a large informal open space (the "Island of Interaction"). The RCH houses YCCSA, space for CPD, start-up incubator space, Science City York (a University-City Council collaboration with 10 staff), and our Enterprise Systems Group.

Exploiting the space. Our new accommodation allows large-scale seminar attendance (120 in CS and 220 in the Hub). Our weekly in-term Departmental research seminar series provides both a social focus for the Department and an eclectic intellectual stimulus for staff and students alike. We hosted more than 120 speakers in the REF period, including UK Grand Challenge Speakers (A. Bangham, M. Sloman, A. Sloman, J. Taylor, N. Shadbolt, D. Duce), Distinguished Speakers (M. Nixon, I. Sommerville, and T. Maibaum) and International Distinguished Speakers (T. Henzinger, M. Beaudouin-Lafon, B. Meyer, J. Knight, M-C Gaudel, B. Wolff, J. Shaffer, M. Sebag, R. Sebastiani, and D. Floreano). We now host two public lectures in CS each year, alternating internal and external speakers (J. Clark, C. Bishop, J. Timmis, and S. Furber).

General. We have 4 dedicated CS Research Support Office staff, who assist with research grants before and after award. We have 15 Technical staff. 3 Experimental Officers support specialist hardware and software construction and general research infrastructure management. Further support is available from central IT services. Our library has extensive hard-copy journal collections and e-access agreements with leading publishers (e.g. ACM, IEEE, Springer).

Plans. We now seek to fully exploit our huge recent infrastructural investments, e.g. by increased community service (conference and workshop hosting), impact activities, exploiting specific facilities such as the Robotics Laboratory to attract research students (and also leasing such facilities on a commercial basis), and hosting a strategically constructed programme of visitors. We will budget for specialist equipment in our financial plans to allow sustained engagement with contemporary vital themes. We will also work with other Departments to fully exploit resources for common benefit. We plan, of course, to benefit from our envisaged 1/3 share of the IGGI CDT income (incl. a budgeted £6.7m from EPSRC across three participating sites).

e. Collaboration and contribution to the discipline or research base

Support for and Exemplars of Research Collaboration.

Networks. Networks play an on-going role in establishing sustained collaborations. York's participation in the 2012-2018 EPSRC DAASE Programme Grant (£6.83m, UCL, Birmingham, Stirling and York) is the most recent result of sustained collaboration that started with the EPSRC SEMINAL Network (1998-2001). Membership of the DesignArtist EU Network of Excellence has facilitated successful two EU real-time proposals (T-CREST and Juniper). We were/are also members of the EPSRC Systems-NET, Vision and Language, AI & Games Technologies, and Cryptoforma networks and the EU PASCAL2 (principled adaptive systems design), CyPhERS (cyber physical areal-time systems), TACLe (code level timing analysis), and eAccess+ (accessibility) Networks. York led the EPSRC Creative Speech Technology Network (2011-2013).

Discretionary funding is mostly devolved to the research groups who then provide the support needed to sustain successful relationships. Departmental and University funding is typically used to develop new collaborations or activity. For example, a UoY seedcorn grant enabled Davis to visit Cucu-Grosjean (INRIA, France), leading to the 2013 EU FP7 proposal PROXIMA (top ranked in its category, and Davis's first as PI). He was also sponsored to attend ECRTS 2010, where he founded the International Real-Time Scheduling Open Problems Seminar, an event expressly designed to foster collaboration. (It is now a regular ECRTS event.) 6 collaborative papers followed with Altmeyer (Amsterdam) and Maiza (INP Grenoble/Verimag) on integrating cache related pre-emption delays into schedulability and Rapita Systems Ltd. sponsored an EngD student.

Hancock organised a meeting on "Function Prediction in Complex Networks" at the Royal Society's Kavli Centre in May 2012. As a result, international collaborations were established via an EU Cost Network, an international Summer School at the University of Bologna's Bertinoro International Centre for Informatics, and a FAPESP grant from the Sao Paolo State (Brazil) to work on network evolution with the University of Sao Carlo.

International Visitors. Research groups host visitors as part of their modus operandi. We hosted 30 researchers over the REF period. Three examples follow. Kelly secured a Royal Academy of Engineering Distinguished Visiting Fellowship to enable Professor John Knight (Virginia Tech) to work on safety assurance at York in 2010, which led to Bate's study leave at Virginia Tech in 2011. Their work on Assured Argument Development was adopted by the US FDA as 'best practice' and strongly recommended to infusion pump manufacturers. The EPSRC SEBASE project funded Poulding (RA) to visit Helene Waeselynk (LAAS CNRS, Paris), resulting in a Best Paper prize at SBST 2011, with the EPSRC DAASE programme grant funding a visit by Waeselynk to York in July 2013 (a conference paper has been submitted). Shenping Xia was an academic visitor from the Chinese University of Defence Technology, sponsored by the China

Scholarships Programme. The collaboration (with Hancock) on hypergraph learning won Best Paper prize at ICIAP 2009 (from 168 submissions). Further work was funded by the Chinese National Science Foundation. Other visitors included: Nietlisbach (Zurich); Perez-Palacin (Saragossa); Nipkow (Munich); Kikuchi, (Fujitsu Research, Japan); Pölzlbauer (Graz); Guerra (Madrid); Rensink (Twente); Mullane (Limerick); Lee (Hong Kong); and Fields Medal winner S-T Yau (Harvard).

Study leaves. Study leaves are a significant investment in staff and research development: in any academic year 4 staff will usually take study leave, varying from a single term through to a full academic year (for staff exiting major administrative posts). Staff use them in different ways, e.g. to establish new personal research agendas, and to build new or develop existing collaborations. *Exemplars of successful study leaves*. Building on previous collaboration sponsored by the Royal Society, Cavalcanti's 2009 study leave at Paris-Sud with (Légion d'Honnaire) Marie-Claude Gaudel led to an extensive Acta Informatica publication on testing and refinement (Cavalcanti, Output 1). In 2013 Gaudel received an honorary doctorate from York recognising her sustained collaboration. A Royal Society award facilitates current collaboration. Frisch's 2009 study leave visiting Peter Stuckey (Melborne) led to a publication on the rigorous treatment of undefinedness (Frisch, Output 4). A subsequent (2011) study leave largely maintained relationships within the UK, particularly with St Andrews, who are collaborators on Frisch's other REF outputs.

Support for and Exemplars of Sustainable Interdisciplinary Research. YCCSA facilitates both organised and serendipitous interaction. Around 10 internships a year are used to forge relationships via co-supervision across Departments. Weekly seminars spark collaborative ideas. Exemplars of support for collaboration with specific Departments are given below. **Electronics**. A University sponsored CS/Electronics 'sandpit' event over 2 days led to two collaborative proposals being awarded £10k each to develop ideas over the summer of 2012. The work of one, on the use of pheromone signalling for load balancing, resulted in the Best Paper prize at NESEA 2012 and a subsequent journal paper in 2013 (Soares-Indrusiak, Output 4). Importantly, the sandpit has led to two on-going collaborations. **Biology**. An YCCSA presentation by Young (Biology) on bacterial genomes sparked a successful CS/Electronics/Biology Plazzmid proposal (EPSRC, 880K). The research on building and analysis of testable models of biological evolutionary processes and computational metaphors and algorithms based on them led to an invitation to join the successful EU EvoEvo project (York PI is Stepney, York CS budget £539k, starting 2014). **Chemistry**. Co-supervision by Sebald (Chemistry) and Stepney (CS, NSC) of a Nuclear Magnetic Resonance MSc student established a new research direction (Stepney, Output 2) and an on-going collaboration. This led to a successful Leverhulme feasibility award (formally in Computer Science, but employing senior researcher Bechmann from Chemistry) exploring liquid-state NMR implementations of Boolean gates and classical computing (Stepney, Output 4). A Royal Society sponsored residential event followed as a result of observations by a collaborator at Leeds. Clark (YCCSA and NSC group member, and Hub resident) subsequently employed Bechmann on a grant he held, producing a paper in a top NMR journal challenging extant theory of NMR spectroscopy (Clark, Output 4). The work won a bronze medal and $2000 at the Human Competitive Awards at GECCO 2013. A collaborative proposal with Chemistry and Electronics is now in preparation. Overall, YCCSA-CS staff have been co-authors of 10 REF-period full Best Paper prizes.

Research Users Influencing Activities. Our software and systems engineering research groups engage with and respond to the concerns of our end-users. We illustrate this with an established area (safety) and one of our most recent research foci (model driven engineering).

In 2006 York staff established a series of colloquia to inform research into Goal Structured Notation: the *GSN User Club*, now called the *Assurance Case Forum*. There have been 10 forum meetings since 2008, with attendees from 52 organisations. Presentations are mainly by GSN end-users. Their contributions, together with regular engagements with our safety research sponsors, have informed safety argumentation research over the REF period, with particular topics including: arguments for COTS software; argumentation patterns; modular argumentation; safety cases for Health IT; autonomous systems safety cases; and comparison of approaches to certification (McDermid, Output 4). This programme of work on argumentation (30+ papers) has been largely sponsored by end-users and inspired by interactions with them.

Our open source (Eclipse project) model transformation framework Epsilon is led by Kolovos (ECR) and has been trialled by at least five engineering organisations. Direct discussion with and assistance to these organisations, coupled with wider open source community engagement via the

project forum (4000+ posts) informs Epsilon development and other Model Driven Engineering research. Joint research using Epsilon with BAE Systems on problems of managing models with around 900K elements (*A Reflective Approach to Model-Driven Web Engineering*. Clowes et al. LNCS Vol.6138, 2010) established a need for research on scalability of model management, culminating in the MONDO EU project (starting Nov. 2013, Kolovos as PI) with industrial partners including Softeam and the Open Group, who will further inform our research.

Research Users Informing Strategy. Users and collaborators strongly influenced our choice of Advanced Architectures and their Applications as a Primary Theme for 2014-2019. We have discussed aspects with: Dstl, who commissioned research in multicore critical application V&V; industrial partners concerned with systems on chip and multicore, e.g. BAE Systems and ETAS (who sponsor multicore work at York); and Rapita, a CS spinout engaged in relevant EU projects (who gave input to our work with Dstl). Significant recent engagement with the UK games industry (as part of two games proposals) has indicated that this vibrant sector can be an excellent collaborator and has informed our choice of Games and Gaming as a Primary Theme.

Personal Leadership and Recognition. The leadership and vision of York staff was widely recognised: McDermid was a member of the Defence Scientific Advisory Council (DSAC) and awarded OBE for services to the defence industry; Cavalcanti, Clark and Hancock gained 5-year Royal Society Wolfson Research Merit Awards; Braunstein was elected as Fellow of the American Association for the Advancement of Science and Fellow of the Optical Society of America; Burns and Woodcock were elected Fellows of the RAEng; Burns was also elected Fellow IEEE; and Petrie was recipient of the 2009 ACM SIGCHI Social Impact Award. In 2013, Pears gained a 1-year RAEng fellowship and Pirandola gained a 21-month Leverhulme fellowship. Pirandola was also a Marie Curie fellow (2008-2010). Franks held a 5-year RCUK fellowship until 2011.

Awards. The academic community has recognised our outstanding intellectual contributions to the discipline. This included two Most Influential Paper awards: the 2009 ACM International Conference on Functional Programming (ICFP) 10-year award (Runciman, PLASMA) and the (shared) 2013 IEEE Automated Software Engineering (ASE) 15-year (+1/-1) award (Clark, McDermid, NSC/HISE). All research groups received awards including 25 Best Papers. Examples: IEEE SoSE 2012 (Woodcock and Cavalcanti, HISE); Euromicro ECRTS 2011 and IEEE RTCSA 2013 (Davis, Burns, RTS); Peter Landin Prize at IFL Symposium 2008 (Runciman, PLASMA); HCI 2010 (Cairns, HCI); ICIAP 2009 (Hancock, CVPR); ACM MoDELS/UML 2010 (Kolovos, Paige, ESG); IJCNLP 2011 (Manandhar, AI); IEEE ICST 2008 (Oriol, ES). Austin's ACA group were awarded the *Times Higher Education Supplement* 2011 Research Team of the Year. Clark's CS-Chemistry collaboration gained $2000 and a bronze medal at GECCO 2013 Human Competitive Awards. Hancock (CVPR) was awarded a D.Sc. by Durham University. Rose and Kolovos (both ECRs in ES) won the 6th Tools Transformation Competition (at ICMT 2013). Poulding (now RA), Burles and Staunton (both PhD students) won the GECCO 2011 GPU acceleration competition. Powley (now RA) won the Toffoli Quad prize (2008) whilst an RS. Creuset (RS) won the 2010 SAIC Biometrics Award. Fan Zhang was a 2009 BCS Distinguished Dissertation Prize runner up.

Community Engagement and Leadership. CS staff gave 68 invited keynotes (11 by non-professorial staff). We fulfilled 58 Programme/General chairs/co-chairs roles (32 by non-professorial staff). Our staff were also active in editorial roles. Examples are: Editor-In-Chief of *Software Practice and Experience* (Wellings), *Journal of System Architectures* (Bate), *Formal Aspects of Computing* (Woodcock), *IET Computer Vision* (Hancock), *Leibniz Transactions on Embedded Systems* (Burns) and Managing Editor of Quantum Information and Computation (Braunstein). Other editorial roles by York staff include: associate/part editor (13) and editorial board member (18). Woodcock contributed to the Royal Academy of Engineering Awards Committee and Hancock to the Royal Society Newton International Fellowships Panel. We contributed to international standards including: Ada LRM 2012 (Burns); Real Time Java Specification (Wellings); OMG's Argumentation and Structured Assurance Case Metamodels (Kelly); and Interim Defence Standard 00-56 issue 5 (McDermid). York staff are also members of IFIP WG2.8-Functional Programming (Runciman), WG 1.9/2.15-Verified Software and WG 2.3-Software Methodology (Woodcock). York staff sat on 11 EPSRC funding panels and hosted ETAPS 2009 (c. 500 attendees) and the BCS Annual Conference 2012 (c. 200 attendees). Finally, reflecting our commitment to international collaboration and the importance of advancing the next generation of researchers we examined 47 overseas PhDs.