Environment template (REF5)

Institution: University College London

Unit of Assessment: 11

a. Overview

We present evidence to support the following primary claims about our research environment, which mark it out as being among the best in the world:

Excellent new staff: We have recruited 33 internationally leading scholars, 20 of whom are Early Career Researchers (ECRs), expanding the UoA from the previous RAE by 61%.

Retention of excellent staff: During the entire REF period only 5 staff (less than 6%) have left the Department of Computer Science (CS) for reasons other than retirement. Staff choose to stay.

Strong central support: We have made optimal use of strong support from UCL and the Faculty of Engineering in which we reside to manage expansion and development.

Strategic vision: We have a strategic vision of our distinct role in the development of the international research agenda in experimental computer science that informs all our activities.

Outstanding Infrastructure: We have a first rate organisational and physical infrastructure enabling us to attract substantial funding and high levels of engagement from all sectors of academia, business, finance, industry, government and the general public.

Comprehensive staff support: We have an excellent staff support and development culture and processes that impact our researchers at all stages from pre-PhD to emeritus professor.

Wide engagement: Our research is informed and developed by rich interactions with industrial sectors, policy makers, government, schools and the general public.

a1 UCL: UCL is a wonderful environment in which to do research. It is entrepreneurial, open, collegial and ideally placed intellectually and geographically. In CS, we have exploited the potential of this outstanding environment to significantly grow the size and quality of our research. Our CS research takes place in a UCL environment surrounded by other world-leading scholars in science, engineering, humanities and the arts. Our location in the heart of London gives us access to many other world-leading academic and non-academic institutions and activities. This benefits all departments at UCL, but is particularly important for CS, since our field is one that draws on and contributes to a wide range of other disciplines and fields of human endeavour.

a2 Structure: Our research is organised into 11 groups and 8 centres. Research **groups** focus on a specific sub-discipline within CS, while **centres** are intellectually cross-cutting, inter-disciplinary homes for co-ordinated programmes of research involving staff in the CS department and other departments or institutions. Groups provide the focus needed for coherent intellectual investigation of a sub-discipline, while centres ensure that groups remain outwardly active, responding to opportunities for applications and cross-pollination of ideas. Centres act as bridges, forming the connections to other sub-disciplines that make Computer Science such an exciting, rewarding and vibrant field of intellectual endeavour. Each group and centre has a leader who is internationally eminent and who evolves strategy, coordinates recruitment and manages members.

a3 Our 11 groups: Bioinformatics; Financial Computing & Analytics; Human Centred Systems; Information Security; Intelligent Systems; Media Futures; Programming Principles, Logic & Verification; Software Systems Engineering; Systems & Networks; Virtual Environments & Graphics; Vision & Imaging Science. These groups collectively cover a broad range of activities and sub-disciplines within CS, allowing us to form partnership and activity across the CS spectrum.

a4 Our 8 centres: Bloomsbury Centre for Bioinformatics, Centre for Computational Statistics & Machine Learning (CSML), Centre for Digital Humanities (CDH), Centre for Health Informatics & Multiprofessional Education (CHIME), Centre for Inverse Problems (CIP), Centre for Medical Image Computing (CMIC), Centre for Research on Evolution Search and Testing (CREST) and UCL Interaction Centre (UCLIC).

a5 Our research users: UCL's CS research users are varied, as with any strong comprehensive

world-leading computing activity. They include academia, business, commerce and industrial sectors, government, regulators, healthcare and the service and entertainment sectors (see our submission under REF3). Some centres are co-located to ensure maximum synergy, while others are distributed across a number of departments or link with other institutions.

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b. Research Strategy

b1 Leadership by scholars for scholars: It is UCL's policy that all its leaders, from Provost to heads of research groups and centres, are scholars first and managers second. This has a profound effect on the way in which UCL conducts itself. For UCL CS the effect has been particularly strong: both the current and the former deans of engineering and the current head of department are world-renowned computer scientists. Decisions are based on the intellectual case and never in the interests of managerial expediency. This affects all our activities. For example, recruitment and promotions are based on scientific and engineering merit, and support is given to initiatives that are intellectually exciting, innovative and imaginative, not necessarily those that will accrue the highest immediate financial reward. In this section we outline our strategic plans and the evidence of their success in fostering a vibrant research environment.

b2 Experimentation grounded in theory: Our research is underpinned by a symbiotic relationship between theory, experimentation and empiricism. We develop theory that generates hypotheses that can be verified or refuted experimentally. Our experimentation helps to formulate and refine theory, thereby creating a virtuous circle between theory and practice. Our shared experimental orientation emphasises measurement, methodological rigour and ultimately reproducibility. Not only does this bind together our research but it determines our strategy, guides our recruitment policy, directs our investment and underpins our research education. We have established CS as a world-leading centre for research in experimental computer science.

b3 Broad coverage of CS: Our distinctive intellectual position as a focus for experimentation grounded in theory requires wide coverage of the CS intellectual landscape. This ensures that we draw on appropriate theory (derived from multiple sub-fields). It allows our experimentation to be conducted in real world settings. We maximise the development of links between our CS research and the many other leading centres of research activity within UCL and internationally. Our size allows us to achieve our strategy of sustained coverage across a wide spectrum of CS activity.

b4 Strategic plans (2006-2016): Our strategic plans are developed and refined with awareness of and respect for the RAE/REF cycle, but are not dominated by it. Plans described in our RAE2008 submission have all been implemented. For example, we planned the development of quantum computation and big data research linking bioinformatics and CSML, and appointments in networks, ubiquitous computing and graphics; all have been achieved. The most recent strategic plan for development of CS research was approved in 2011 and covers the period from 2011 to 2016; this has shaped a period of significant growth. UCL has strongly supported these strategies with funding for both staff and facilities. In the 2008 RAE we reported the construction of a purpose-built home for CS on the Bloomsbury campus (a £26m investment). The expansion of CS means that we have now outgrown this facility. UCL has already drawn up plans, to be implemented by 2016, that will provide new premises for the enlarged CS.

b5 Mechanisms for strategic planning.

b5.1 Institutional-level support and strategy: UCL has provided extensive support for our research with central officers to manage calls for ERC, CDT/DTC and Programme grants. Programme grants are also supplemented with studentships, typically, 1 fully funded four year studentship per annum from central funds. UCL is also funding a Business Development Manager for the department's programme grants to help grow links between programme grants and industry. There is a central UCL research strategy with overarching Grand Challenges, backed by institutional funding and cross-faculty activities. Many of our staff have benefitted directly from pump priming support from central funds. For example, Ingemar Cox receive £30k for a project to support work on using social media to detect disease outbreaks, while Tim Weyrich received a £26k Capital Equipment Grant, for a Multi-Modal Document Imaging Suite and £13k for cross-disciplinary development within UCL to supplement his EPSRC "Bridging The Gaps Grant". Danny Alexander received central funds to support three PhD studentships addressing UCL's grand

challenges. UCL also provides funding to support research and business start ups, from which we have benefited. For example, UCL supports approximately 120 UCL-wide "impact" studentships, providing 50% funding for PhD studentships matched by industry or other non-RCUK funding. UCL Advances maintains a comprehensive set of connections with small and medium sized companies, complementing CS's own contacts and facilitating matched funding.

b5.2 External Advisory Board: Our External Advisory Board (EAB) provides advice on all aspects of our operations, particularly concerning research structures and strategic areas of growth. It advises on the value of our courses and research supervision for UK industry and on our outreach and entrepreneurial initiatives. EAB members include high-level policy makers in the software sector: for example, Prof Sir John O'Reilly, currently UK Government Director General of Knowledge and Innovation, Andrew Herbert OBE, former Head of Microsoft Research for Europe, Middle East and Africa, and Ben Laurie, founder of Apache Software Foundation (now at Google).

b5.3 Strategic research fund: This £70K yearly fund was established by the department for small proof of concept projects. It has pump-primed initiatives that were too premature for external investment. For example, Kyle Jamieson's ArrayTrack, described in REF3, was initially funded through this scheme and subsequently attracted €150K from an ERC Proof of Concept fund.

b5.4 Strategic Planning Retreat: The department's academic staff attend a two day planning retreat once every two years. These help to ensure that all staff contribute to and support strategic plans for our research. The retreats also enhance collaboration between our groups and centres and have helped to inspire synergetic projects that define CS grand challenges.

b6 Achievements and strategic development and expansion of groups and centres

b6.1 Bioinformatics: The Bioinformatics group is internationally recognised for its work in applying machine-learning algorithms to problems in biology, and for the Web tools that it makes available to the community (used 500-600 times daily). Research highlights include applications of large-scale machine learning systems to predict the function of genes (ranked 1st out of 54 in the recent Critical Assessment of Function Annotation challenge), novel applications of graphical machine learning techniques to predict protein structure and transforming the way that computational approaches for inferring evolutionary relationships are benchmarked. Jointly with the Department of Genetics, Evolution & Environment, we have recently appointed Christophe Dessimoz, who received the SIB Young Bioinformatician of the Year Award in 2012.

b6.2 New Financial Computing & Analytics (FCA) group. Our newly founded FCA group includes three existing faculty and two world-leading recruits (Tomaso Aste and Guido Germano). Members of FCA are acknowledged worldwide for their research on the effects of IT on financial markets. Studies span algorithmic trading to risk management, and have been deployed across the financial sector. For example, our fraud detection techniques are used by the London Stock Exchange; our findings on high frequency dynamics are integrated into the algorithmic trading systems of banks including Credit Suisse, Morgan Stanley, and Nomura; and our risk analysis studies are used by the Bank of England. The group supports the DTC in Financial Computing.

b6.3 Human Centred Systems group and UCLIC: UCLIC is internationally leading in HCI theory and user-centred design methods. They have advanced conceptual frameworks based on experimental and in the wild studies on behavioural change, cognitive modelling, collaborative learning, information interaction and digital healthcare. We have significantly expanded UCLIC by recruiting Professor Yvonne Rogers, recently elected to the CHI Academy; Paul Marshall (embodied interaction); and Nicolai Marquardt (physical computing). We have recently launched a significant (£2.1m) joint research institute, funded by and in collaboration with Intel Corp., on sustainable cities and have become involved in the BBC/UCL User Experience Network.

b6.4 Information Security group: The Information Security group has become a leader in Cyber Security Research, nationally (selected as an Academic Centre of Excellence in Cyber Security Research by EPSRC and GCHQ) and internationally (publications in top conferences, keynotes, funding). The group's research has both widened the perspective of security research to include human aspects, and shifted the emphasis from theoretical to real-world performance of security mechanisms. We have expanded the impact of our capability in applied cryptography (e.g., ERC award recipient Jens Groth developed the first non-interactive zero-knowledge proofs efficient

enough to be used in practice) by appointing two highly regarded researchers (George Danezis and Emiliano De Cristofaro) who are developing real-world solutions for Critical National Infrastructures and Healthcare, respectively.

b6.5 Intelligent Systems group and CSML: The Intelligent Systems group is an internationally leading research group with many substantial theoretical and applied contributions in machine learning, computational statistics, computational models of argument, and quantum information. For example, we have highly cited contributions on kernel methods, support vector machines, and multitask learning; we have won competitions at leading conferences for our statistical natural language processing methods; our PRoNTo machine learning software for neuroimaging has been downloaded by 122 labs in 34 countries since being released in 2012; and we are the scientific coordinator of PASCAL2. We have strengthened the machine learning activities in the Intelligent Systems Group with three excellent new staff: Sebastian Riedel (funded by a Marie Curie Career Integration Grant); David Silver (currently on a Royal Society Fellowship); and Thore Graepel (a joint appointment with Microsoft Research Cambridge). We have also founded a quantum information activity with two exceptional appointments, Simone Severini and Fernando Brandao, both of whom have fellowships, Simone from the Royal Society and Fernando from EPSRC.

b6.6 New Media Futures group: The Media Futures Group is internationally known for frameworks for information retrieval and efficient methods for evaluating IR systems. Methods from the group have been adopted by the National Institute of Standards and Technology (NIST), USA, and have become standard approaches for efficient evaluation by the information retrieval community. This group was founded with three existing members of staff and a new recruit Emine Yilmaz. Emine joined us from Microsoft Research, bringing both strong academic and theoretical knowledge and deep commercial experience of search engine technology.

b6.7 New Programming Principles, Logic & Verification group: As part of our strategic plan we have acquired a new group in Programming Principles, Logic And Verification with five academic staff and a further recruit, Tom Dillig. This is a strategic move into verification, an area of increasing importance to industry. Peter O'Hearn is well known as the founder of separation logic; he is seconded to Facebook until 2015, where he is overseeing the deployment of advanced program analysis techniques. Byron Cook is a joint appointment with Microsoft Research; his work on termination has had a profound impact. We are further extending this group by recruiting David Pym, who will be joining us after the REF period and so is not formally returned.

b6.8 Software Systems Engineering group and CREST: The Software and Systems Engineering group has led the widespread uptake of search-based optimisation within the international SE community, and has played a major role in extending engineers' ability to automate software testing. The group has undergone significant expansion with the recruitment of CREST comprising four academics. Mark Harman is the founder of Search Based Software Engineering and also internationally leading in Software Testing. Two new academic staff have been appointed as part of the strategic plan (Earl Barr and Shin Yoo, both ECRs with outstanding track records in software testing, as evidenced by three best paper awards in the past four years).

b6.9 Systems and Networks group: The Systems and Networks Research Group is renowned internationally for its contributions to the design of algorithms, protocols, and systems that underpin Internet; to wireless networks; to large-scale distributed systems; and to network and computer systems security. The Systems and Networks Group has pioneered the design of practical multi-path transport and congestion control for the Internet and data centres, culminating in Multipath TCP being standardized and subsequently deployed by Apple as part of iOS7. The group has made fundamental advances in wireless systems: improving capacity by exploiting physical-layer information in bit-rate adaptation, and producing dramatic accuracy improvements in indoor wireless localisation. The group has also made significant practical advances in achieving strong confidentiality for users' sensitive data. In 2012, Mark Handley received the IEEE Internet Award for career-long high-impact achievements in the areas of Internet multicast, telephony, congestion control, and the shaping of open Internet standards and open-source systems in all these areas. Peter Kirstein, emeritus professor, leads the Silk project, which extended the Internet to parts of the Caucasus and Central Asia that were hitherto unconnected.

b6.10 Virtual Environments & Graphics group and the Centre for Digital Humanities (CDH):

VECG is known for demonstrating the impact of fundamental computer graphics and real-time systems research through user experiment and deployment of novel systems. The impact of our work is broad, with algorithms being used in major software packages (e.g. Adobe Lightroom, MeshLab and DirectX) and work on the borders of neuroscience showing the impact of body image in spatial user interfaces. The group has expanded with three excellent new appointments, Niloy Mitra, Mandayam (Srini) Srinivasan and Tim Weyrich. Niloy received the 2013 ACM SIGGRAPH Significant New Researcher Award for his contributions to geometric analysis of shapes, 3D modelling and computational design tools; he received an ERC Starting Grant for this work. Srini was hired from MIT and has been awarded an ERC advanced grant.

b6.11 Vision and Imaging Science, CMIC and CIP: The VIS group has high visibility in all of the top tier international conferences in Computer Vision (CVPR,ICCV,ECCV), graphics (SIGGRAPH), imaging science (SIAM) and medical imaging (MICCAI), with major impact in video tracking, non-rigid shape reconstruction, and face/object recognition, for example achieving the top score in the Labelled Faces in the Wild (LFW) face recognition challenge, together with extensive and widely used public domain software packages in medical image modelling, inverse problems, and registration. CMIC is a hub, bridging between systems developers and clinical practitioners, with industrial contracts alone worth over £5m, and a reputation for ground breaking developments such as the development of MRI as a reliable biomarker for degenerative neurological diseases, the first clinically viable microstructure imaging technique (NODDI) and a new method to match diagnostic MR images to ultrasound images of the prostate, "Smart Target", that is poised to change national guidelines on prostate cancer detection and treatment. The group has significantly expanded with five new appointments (Dean Barratt, Gary Zhang, Ivana Drobnjak, Danail Stoyanov, and Lourdes Agapito). Dean Barratt, the lead of "Smart Target", was previously a RAE/EPSRC Fellow. Gary Zhang pioneered the development of NODDI. Ivana Drobnjak leads research on optimising generalised pulse sequences for MRI. Dan Stoyanov (robot vision) holds a RAE Fellowship. Lourdes Agapito holds an ERC Starting Grant for Human Motion Analysis from Image Sequences. We have founded a Centre for Inverse Problems (CIP), jointly with Mathematics and Statistics. "Inverse Problems" is concerned with the mathematical, statistical, and computational aspects of determining a postulated model from observed data. We have made two appointments in this important emerging area: Marta Betcke has been awarded an EPSRC Early Career Fellowship to develop Compressed Sensing methods in imaging, and Bangti Jin is a prolific applied mathematician bridging between Machine Learning and Inverse Problems.

b6.12 Centre for Health Informatics & Multiprofessional Education (CHIME): CHIME is internationally recognised for health informatics research linking information, quality and governance for health across clinical care settings, including the requirements, interoperability standards and semantics of Electronic Health Records (EHRs), information security and the trustworthy re-use of EHRs for research. CHIME has a history of leadership of EU, MRC and EPSRC research programmes, cumulatively worth over £55 million, in EHRs, decision support, telehealth, patient centred care and health information security. It is a global pioneer of electronic health record interoperability, having co-founded the openEHR Foundation and having led the development of the ISO EN 13606 EHR Communications standard. CHIME is a WHO Collaborating Centre for the Community Control of Hereditary Disorders.

b7 Strategic aims and goals: We have identified three strategic themes that link the research groups and centres in the UoA: Networked Systems, Intelligent Systems and Interactive Systems. During the next REF period we will develop these themes, from which we will launch CS grand challenges for strategic support. We will grow **Digital Healthcare** and **Health Informatics,** bringing together Computer Science, Medical Physics and the Department of Primary Care and Population Health. This will build on and complement the recently established hub of the national UK health informatics research institute, the MRC Farr Institute, exploiting our research activity in HCI, software engineering, bioinformatics, intelligent systems and networks applied to healthcare. This will leverage CS investment in our secure data centre. We have established research in robotics for healthcare. These strands will be brought together, establishing a centre with new research activity in real-time automation and robotics. We will further develop the **Life Sciences Interface**, through the work of CMIC. We will create a new Institute of Image Directed Healthcare with Surgery, Radiology and Obstetrics. CMIC has had major input into The Wolfson Experimental Neurology Centre and received significant awards from the NIHR Biomedical Research Centres at

UCLH, Great Ormond Street Hospital and Moorfields Eye Hospital to facilitate clinical translation of our imaging technologies. We will grow our capacity in **Quantum information**, launching a new research group and centre while also strengthening links with the London Centre for Nanotechnology. We will develop a **new centre in computational design**, linking recent activities in automatic and semi-automatic design, drawing in users across UCL including Bartlett School of Architecture and Mechanical Engineering, targeting advanced manufacturing. We will also continue to develop the **big data infrastructure**, expanding on leadership provided by the Media Futures, Financial Computing and Analytics, and Intelligent Systems groups, developing strategic partnerships with Security and Crime Science, MRC initiatives, financial institutions and retail collaborators. We plan to develop the **EIT ICT Labs**, a large EU-funded consortium that will translate research into products and services. We will increase the number and size of our strategic industrial partnerships, building on the success of our BBC, Intel and Cisco initiatives.

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

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cI.1 Excellent recruitment and retention: Building on the plans outlined in the last RAE submission, a further review of our strategic direction was taken in 2010 culminating in the 2011-2016 strategic plan. This plan identified 10 new positions to build strength in existing and new research directions, to be recruited over the period 2011-2016. The plan has informed the main thrust of our expansion but has been adapted in response to emerging opportunities and specific approaches that the department has received. On two occasions we have been approached by internationally leading research groups (CREST and PPLV) from other universities that wanted to move to UCL. As evidence of our ability to recruit internationally we note that of the 33 new recruits listed in this REF return, 25 are non-UK citizens. *Only seven staff left* (two of whom retired). This exceptionally low turnover provides concrete evidence that we have excellent mechanisms to reward and retain excellent staff.

cI.2 Industrial secondments and collaborations: We support staff interchanges with industry in both directions, ensuring our research is informed by real world problems and is used in industrial applications. Wolfgang Emmerich moved 80% FTE to take up the position of CEO and Chairman of Zuhlke Engineering Ltd., a 600-strong software and systems engineering company whose UK office is around the corner from UCL; Peter O'Hearn is seconded until 2015 to Facebook, where he will be deploying program analysis and verification techniques; Angela Sasse served as Visiting Professor at the Defence Academy at Shrivenham and chair of the Human Vulnerabilites SIG of the Cybersecurity KTN; Dipak Kalra on a 3-month sabbatical with Roche; Christopher Clack was founder and a director of the Financial Services KTN from 2009-2010; Anthony Steed is founder and CTO of ASIO Ltd; Andrew Bud, Chair of the EAB, is also Director of The Media Institute, a joint UCL/industrial research centre serving the UK creative sector; Hugh Varilly has joined UCL CS from IBM as RAEng visiting fellow; Byron Cook and Thore Graepel are both joint appointments with Microsoft Research Cambridge; and David Silver is working with Causata and DeepMind. Our DTCs also offer extensive opportunities for industrial collaboration. For example, the Virtual Environments, Imaging and Visualisation (VEIV) Engineering Doctorate has worked with over 50 sponsoring companies including established large companies such as BBC, Microsoft, Disney, Arup and Electronic Arts (EA), and innovative companies such as Passion Pictures (a double Oscar-winning London-based production house) and The Foundry (an award winning graphics tools company). The DTC in Financial Computing has support from 24 companies including RBS, Barclays, Deutsche Bank, CitiGroup, UBS, Credit Suisse, and BNP Paribas. We also receive many other studentships from companies. For example, Microsoft Research has committed to share funding of a further four studentships per year, while others, including SAP, BBC, Elekta, Philips, Siemens, VisionRT, PeerIndex and Imagination Technologies, have all sponsored students. UCL offers 50% support for impact studentships (with 50% matching funding from industry). UCL CS has started 9 such impact studentships in the past three years.

cI.3 Promoting and supporting women in CS research: The Department earned an Athena SWAN Bronze Award in 2012. The submission described a number of Departmental initiatives to recruit, retain and promote women, and to encourage female participation and retention in Computer Science. We have appointed an Athena SWAN Champion who is responsible for

monitoring these initiatives. UCL policy is that academic staff returning from maternity or carer leave are entitled to a one term sabbatical to re-establish research; the department supplements this with a £10,000 Post-Break award to help academic staff get back up to speed with their research after experiencing a long break. We make full use of support offered by funders to support our female researchers; for example, we have used support from the Daphne Jackson Trust which provides additional support in the form of flexible part-time, paid fellowships to ease the return to work after a career break. Our DTC students represent the next generation of CS researchers and here we have been particularly successful in attracting and supporting excellent female scholars. For example, in 2011 the DTC in Financial Computing funded more female than male PhD positions. We aim to ensure equality of opportunity in recruitment and promotion procedures; for example, all appointment panels involve both women and men, and senior promotions panels consider all eligible staff systematically to ensure that no-one is overlooked. Recognising that the underrepresentation of women in computer science extends back into interest in computing in schools, we have implemented a programme of engagement with girls' schools promoting STEM subjects and computer science in particular. Two groups from such schools have visited the department this year and we have given presentations at two other schools. We have also taken over the organisation of the London Hopper Colloquium and Karen Spärck-Jones Lecture; this is coordinated by Caroline Wardle, now appointed as a visiting Professor. These events are important in giving a specific venue for female graduate students to meet and present their work (London Hopper) and showcasing the work of successful women in computer science research (Karen Spärck-Jones).

cl.4 Appraisal, recognition and promotion: As noted above, all staff are automatically considered for promotion each year. This ensures that valuable yearly feedback is routinely given to *all* staff. In addition to feedback from the promotion round, all staff are appraised at least every two years. The appraisal is an opportunity to review all aspects of their work and careers and to identify specific stretching objectives to focus their work for the next period. This is also the forum within which research quality and integrity is considered. The role and value of appraisals was the focus of a session at the departmental retreat in March 2013.

cl.5 Nurturing early career researchers and new starters: New academic recruits are assured that the development of their research careers is a top priority. This is made manifest in a number of ways: allocating start-up funds that can pay for any equipment that they require and support their participation in conferences, workshops and other research meetings (this is budgeted at £20k per person but may be considerably higher, based on need); allocating each new recruit an academic mentor to advise on matters that affect their work, from understanding local procedures to taking a strategic view of their research goals; supporting the funding of two PhD studentships within their first three years; and limiting their teaching to the equivalent of one module (half unit) in their first year so that they can retain research momentum. This is extended to two years if they are awarded an EPSRC first grant. We also augment first grants with departmental funding to extend RA hires by a further 6 months: EPSRC support is now capped at a level that only supports an RA for 12 months, which we view as inadequate for initiating a significant CS project. We recognise the often precarious and vulnerable position of post docs on short term contracts. UCL is signed up to the *Concordat to Support the Career Development of Researchers*. We provide training and career development programmes for our RAs. We use the flexible funding from longer, larger grants to help to retain RAs through the exigencies of specific funding mechanisms.

cl.6 Sabbatical support on merit not merely accumulated service: Sabbaticals are used to achieve specific goals as outlined in a proposal submitted by the academic concerned, possibly prompted by the outcome of an appraisal. Sabbaticals are allocated on merit to support research. An applicant need not wait for some arbitrary period (e.g. seven terms, semesters or years) to be awarded a sabbatical. Examples are to achieve a specific research goal such as linking into a new area or application domain (Robin Hirsch linking logic research with verification), refocusing research after an intensive administration role (Ann Blandford after stepping down as Director of UCLIC), developing links with industrial partners (Jan Kautz unpaid sabbatical with NVIDIA Research, Danny Alexander three month unpaid sabbatical with Microsoft Research Cambridge), as well as particular personal situations that have taken their toll on available time for research. In 2011, Anthony Steed had leave from teaching to work on Chirp, now distributed through ASIO, a spinout from the Department.

cI.7 Extensive fellowship successes: The staff submitted have been exceptionally successful in gaining awards of highly competitive fellowships, underscoring the leading nature of our research. There are a large number of staff who were on fellowships for part of the assessment period. They include: Lourdes Agapito, Jens Groth, Kyle Jamieson, Niloy Mitra, Srini Srinivasan (all ERC); Danny Alexander, Marta Betcke, Fernando Brandao, James Brotherston, Massimiliano Pontil, Yvonne Rogers (all EPSRC); Danail Stoyanov, Shi Zhou (both RAEng); David Silver, Simone Severini (both Royal Society); Janaina Mourao-Miranda (Wellcome); and Ivana Drobnjak (Leverhulme). For those fellows who are not permanent staff there is a procedure for considering whether their appointments should be made proleptic. For permanent staff there is the possibility for additional teaching to be undertaken during the fellowship in exchange for a correspondingly reduced load once it has expired.

cI.8 Visiting scholars: The department hosts between 50 and 100 research visits per year. Among our academic visitors since 1st Jan 2008 are 5 Turing award winners (Vint Cerf, Bob Kahn, Barbara Liskov, Adi Shamir, Les Valiant FRS) and many other leading scholars such as Jim Duncan (Yale), Geoff Hinton FRS, Frans Kaashoek (MIT), David Mazieres (Stanford), Michael Mitzenmacher (Harvard), Barbara Ryder (Virgnia Tech), Peter Shor (MIT), Mike Terry (Waterloo), Marcel Van Herk (Netherlands Cancer Institute), Martin Wainwright (UCB) and Pamela Zave (AT&T). We have also hosted high profile visits from industry leaders such as VPs for research at Microsoft and Yahoo (Jeannette Wing and Ricardo Baeza-Yates) and Radia Perlman, network and security head for Intel, Jessica James, head of FX QSG Research at Commerzbank as well as visits from policy makers such as Shari Lawrence Pfleeger, Research Director of the US Institute of Information Infrastructure Protection.

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c. II.   Research students

cII.1 Extensive funding underpinning: We aim to ensure that any exceptional applicant to UCL CS will secure funding. We define exceptional as having top grades from a leading institution and/or prior publication in a first tier venue. An increasing number of our successful applicants have both, including many graduates from our own bachelors and masters programmes. In addition to the Doctoral Training Centres (DTCs) funded by the EPSRC there are a number of funding routes available to applicants. As noted above, some are funded completely or partially by industry. We have an internal departmental fund of three fully funded (Overseas or EU) studentships available each year. We also offer partial funding for students who for whatever reason are unable to fund the full costs of their study. For each of the past two years, a research student in the department has been awarded a Google Fellowship that pays fees and stipend for the remainder of their studies, and also gives them an internship at Google Labs, and this year one of our students was awarded an Intel studentship paying fees and stipend for the remainder of their studies.

cII.2 Taught research foundations: There are specialist MSc and/or MRes courses offered in all but one of the research groups' areas. These programmes deliver a research basis for graduates who go into industry and for PhD candidates. Guest speakers contribute to modules that highlight industry applications; these are open to PhD students and help to place their research topics in an industrial context. In their later years, PhD students co-supervise MSc projects. Each research student is in a research group that provides the appropriate research environment for his/her topic, including seminar series, reading groups, meetings with academic and industrial visitors, and attendance at workshops and visits to other universities or companies linked with that group. Throughout the PhD programme, we run bespoke CS training that supplements more generic research training courses offered by UCL. Courses include 'how to do research in computer science', 'how to write a literature survey in computer science', and 'how to write a computer science thesis'. UCL has an extensive range of courses that are open to PhD students. A system of 'Roberts points' is managed through the UCL Online Research Log to ensure that students engage with a substantive programme of training as well as logging their progress. This includes self-assessment tools to help students choose courses that will be useful for their research studies and their future career. Students are encouraged to get involved in business courses, workshops, and entrepreneurship training run by UCL Advances and other organisations.

cII.3 Supervision support: Each student has a principal and co-supervisor. Supervisory meetings are held on a regular basis, normally at least fortnightly. There are annual vivas that include an

assessor external to the supervisory team; our administration team is proactive in ensuring that these take place within the agreed timeframes. Joint primary and secondary supervision of students with other departments brings together distributed research groups and further cements collaborations between CS and other groups across Engineering, and other faculties.

cII.4 Nurturing research student engagement: All students are expected to submit papers to international conferences. There is a departmental budget to ensure that students can attend conferences and other relevant events if there is no specific travel funding allocated to their studentship. We encourage students to attend conferences at which they are not speakers to nurture their wider involvement in their technical and scientific communities. We also encourage research visits, secondments, and engagement with professional bodies and research users.

cII.5 Placements and secondments: We actively encourage and support students to undertake internships with companies. We have a well-established programme for arranging placements. Examples in the last year have been visits to Microsoft Research, IBM Research, Intel, Google, Siemens, Philips, Elekta, Cisco, and financial services institutions. Participation in internships reflects our overall shift in emphasis that is producing more enterprising, practical, innovative and articulate students.

cII.6 Public engagement: Peter Bentley and Sue Black spearhead UCL CS public engagement activities. Both are well-known and widely recognised for this work. Sue won the PepsiCo Women's Inspiration Award (WIN) award in 2011 and was instrumental in securing significant funding for and public engagement with Bletchley Park. In 2013 she was listed in the Guardian's "Ten women in tech you need to meet". Peter is well known for his popular science books, each of which has sales in the tens of thousands (one of which, Digitized, was sponsored by the department to showcase global CS research to a wide audience). Peter is also widely known for his stethoscope iPhone app; this has been downloaded over 3 million times and was, for a while, the world's best-selling iPhone app (out of all 250,000), demonstrating the potential to quickly generate unprecedented levels of public interest. They are, of course, both also outstanding researchers: between them they have given 14 keynotes and have 6 best paper awards. Peter and Sue provide specific, topic-tailored advice, training and planning to help all CS staff maximize their engagement with the general public. Our mission is not merely to promote awareness, but *understanding*. We are open and responsive to the media, understanding their needs while ensuring our messages remain accurate and undistorted in order to maximise exposure of our research staff and our outputs such as apps, books, and other literature.

cII.7 Developing leadership and research organisation skills and experience: We encourage students to become involved in organising events. For example, in 2011 our students organised a one-day student conference in the department with all the talks and posters presented by their peers. In 2012, our students organized a larger conference for UK PhD students in which they managed all aspects including admissions, reviewing, scheduling and execution. Larissa Romualdo Suzuki, a PhD student at UCL, has helped Caroline Wardle organise the London Hopper in 2012 and 2013, including managing the poster competition and acting as official photographer. There were about 60 attendees each year, primarily PhD students and postdoctoral researchers. While a PhD student in CS, Yue Jia was programme chair for the 5th IEEE Mutation Workshop in Montreal.

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d. Income, infrastructure and facilities

d1 Technical infrastructure: We have a dedicated 3 petabytes of online storage for big data processing (50% of UCL's entire online storage), with access speed of 40GB/s, some of the fastest available. We also established a £1m secure data centre, the first in a UK University, which will be used to store UK Government IL3 classified data. Our Heterogeneous Experimental Network (HEN), the second of its kind in the world, was updated and allows experimentation with topographies of 100s of cores, and a dedicated configurable departmental cluster of 3000 cores is available for high performance research needs. This is continually upgraded, with an average core life of 18 months. Our Virtual Reality lab was upgraded to High Definition and we support the public facing server cluster running the Bioinformatics group's suite of over 20 protein structure analysis methods, which have attracted between 500 and 600 uses per day throughout the REF period. Central support for technical infrastructure is complemented by a dedicated team of 10.7FTE

research technicians for CS with an average of 10 years technical experience. They provide tailored research support, building enhancements for Arduinos and Raspberry Pi, projection systems, lenticular screens, super dark rooms for reflection experiments and a Hadoop cluster, and manufacturing bespoke prototypes such as wearable computing and HCI test systems. Our technical support team is closely involved with central UCL planning for future upgrade of stores, clusters and access speeds. We also have world-class clinical facilities, including 4 3T MRI scanners, the UK's first PET/MRI facilities and a comprehensive range of preclinical imaging systems, including unique experimental facilities in confocal micrendoscopy and photoacoustics.

d2 Consultancy: As explained in REF3, since 2008 UCL CS has delivered 35 significant consultancy projects worth over £800,000. UCL CS staff have founded many companies, including ASIO Ltd., FS-Net, Helicon Health, Res Novae, Monoidics (recently sold to Facebook), Sageta and Satalia (NPComplete Ltd). Our staff are on the executive and/or scientific boards of many other companies, including Dexela, Facebook, Green Sunbird, IProov, IXICO, Meganexus, Message Automation, Replicus Software Corp, SonaCare Medical LLC, Synthace, VisionRT, Yooshr Ltd. and Zuhlke Engineering Ltd. We have also provided consultancy to policy makers and governmental bodies, such as the British Standard Institute (BSI), Cabinet Office (many programmes), European Institute for Health Records (EuroRec), Foreign and Commonwealth Office, Home Office, International Standards Organisation (ISO), NHS National Knowledge Service, the IHU in Strasbourg, NIST (USA; various programmes), Ministry of Health (Singapore), Office of the Ontario Privacy Commissioner, Ofgem and the World Health Organisation (WHO).

d3 Grant proposal development support: Support for the intellectual construction of the proposal is provided at four distinct levels: generic, mechanism-specific, subject-specific and proposal-specific. We provide: workshops aimed at generic training in CS grant writing, largely aimed at ECRs and those joining us from non-UK HEIs; regular tutorials and Q/A sessions on specific mechanisms for funding (e.g. ERC, first grant, platform, programme grants etc.); subject-specific mentoring and review through the research groups; and regular proposal-specific reviews for each proposal itself through our internal grant review process. This internal review process simulates the real review process, with mock refereeing and interviews. A dedicated member of the professional services team, Olivier Delacroix, provides high-level support for financial planning and detailed administrative aspects of proposal writing. He helps post-award management, freeing staff to focus on the intellectual agenda. We have a dedicated departmental finance team, headed by Dawn Bailey to help staff to manage the finances of awarded grants and a dedicated departmental HR manager, Lynette Hothi, who oversees the process of recruiting research staff. This infrastructural support has been very successful as evidenced by our funding success over the REF period.

d3.1 Four DTCs: UCL CS has a leading role in four of the sixty EPSRC DTCs in the UK. They are in Financial Computing (FC), Virtual Environments, Imaging and Visualisation (VEIV) (EngD), Mathematics and Physics in the Life Sciences and Experimental Biology (CoMPLEX) and Security Science (SECReT). FC and VEIV are led by Computer Science, while one of the two programme directors for CoMPLEX is a member of CS and a number of students are supervised or co-supervised from Computer Science. SECReT is coordinated by the Department of Security and Crime Science with significant input in both lecturing and supervision from CS. In November 2013, the EPSRC awarded funding for 7 new UCL CDTs (with 2 others pending a decision). Of these, 3 will be led by UCL CS, while another 3 heavily involve UCL CS as a key partner.

d3.2 The Doctoral Training Programme (DTP): CMIC is one of the founders of the UCL Doctoral Training Programme (DTP) in Medical and Biomedical Imaging. This programme, with strong support from industry and healthcare providers, is now accepting its 5th intake, has a faculty pool of 40 supervisors for methodological research and a similar number of clinical supervisors. We receive 250 applicants per year for 12 places.

d3.3 Longer larger grants: We have secured and lead four programme grants: DAASE (PI Mark Harman, £6.8m; £2.5m for UCL), Intelligent Imaging (PI David Hawkes, £6m; 2.7m for UCL), CHI+MED (PI Ann Blandford, £5.8m; £2.8m for UCL), and Resource Reasoning (PI Peter O'Hearn, £2.2m; £1m for UCL). We also won a leadership fellowship for Danny Alexander (£1.6m) and platform grants for CREST (PI Mark Harman, £900k) and UCLIC (PI Ann Blandford, £400k). Christopher Clack secured £2m funding from the TSB, ESRC and NERC to create and run the Financial Services KTN. We often secure large standard grants for example, Productive Security

(PI Angela Sasse, £1.2m), Robotic Teleoperation for Multiple Scales (PI Srini Srinivasan, £2.4m) and Pain Rehabilitation (PI Nadia Berthouze, £1.2m). From the ERC we have also secured an advanced grant (Srini Srinivasan, £2.5m), and four starting grants for Lourdes Agapito (£230k to UCL), Jens Groth (£1.1m) , Kyle Jamieson (£1.1m), and Niloy Mitra (£1.1m). We also won other EU grants for which UCL draws significant support. For example, PASCAL 2 (PI John Shawe-Taylor, £1.8m for UCL), BEAMING (PI Anthony Steed, £1m for UCL) and CompLACS (PI John Shawe-Taylor, £900k for UCL). We also secured £1.1m for the CRUK and EPSRC Comprehensive Cancer Imaging Centre, just renewed with a further £2m (PI David Hawkes in both cases). CMIC also won three Wellcome/EPSRC grants for £1.7m, £1.8m and £2.1m. We have also just been informed that we won the Wellcome EPSRC Innovative Engineering in Healthcare Foetal Surgery worth £11m (PI: Sebastien Ourselin) and participate in the EPSRC IRC "Early-Warning Sensing Systems for Infectious Diseases" awarded £11.1m (of which £734k specifically for UCL CS).

d3.4 Improving grant success rate: Our success rates for funding have improved steadily over the period, partly through our support mechanisms and partly because we have hired world-leading researchers with each and every appointment. For EPSRC, which has relatively reliable review processes, our success rate has risen from 38% to 56% (by number of grants) and from 31% to 61% (by value of funding). This boosts our research base and frees more staff time for the research work itself, because staff are not continually chasing grant applications.

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e. Collaboration and contribution to the discipline or research base

We have extensive on-going collaborations too numerous to detail here. We focus on some of the more significant collaborations.

e1 Significant industrial partnerships: Our Intel sustainable and connected cities institute has already received £1,009,717 cash support from Intel, supplemented by £108,694 from UCL's Vice Provost for Research and £201,975 from the Vice Provost for Enterprise, drawing on UCL's Knowledge Transfer and Impact Acceleration Accounts from EPSRC. A further $500k will come from Intel in years 4 and 5 of the institute. A similar Cisco institute has just started with £340k cash; we expect it to grow. Thomson Reuters have provided hardware, software and streaming financial data for the Financial Computing Laboratory worth £300k. In partnership with the BBC we founded the **London Media Technology Campus,** a new, high-quality, research space for 80 researchers at One Euston Square near our main Bloomsbury site. Master Research Agreements have also been negotiated with Siemens, Philips and Elekta in medical imaging and image directed therapies. Successful scientific collaborations have been formed with a number of SMEs in the medical device and software areas, including VisionRT, Dexela, Biotronics3D, Sonicare, Mauna Kea Technologies, Viking3D and Supersonic Imagine. In 2010, with support from the TSB, we established **the Media Institute**, bringing together the best minds in digital media from academia and industry, with over 150 partners, accelerating and expanding innovation and media research.

e2 Academic collaborations: For clarity we define a collaboration to be one that has led to a peer-reviewed co-authored paper and/or a funded research project in the REF period. According to this strict and measurable definition we have **352 collaborations**, including collaborations with **45 of the world top 50** according to the 2013 ShangHai JiaoTong ranking, ARWU and **49 of the world top 50** according to the 2013 Times Higher ranking (and **all of the top twenty** according to both rankings). UCL CS is also a major catalyst for research and entrepreneurship both within UCL, and with London's world-class companies and start-ups.

e3 Support for engagement with industry, users and policy makers: Our processes, policies and mechanisms for this engagement are primarily motivated by the need to inform research. Naturally, we also believe that our engagement leads to impact and adds value to the UK more generally. We have a dedicated industrial impact team of three, led by Jane Butler, who help to optimise interaction between our research base and its users. Jane Butler was a Technology Leader at Cisco and chaired the 6NET project which greatly widened internet access with IPv6. The impact team also curate impact information and link together colleagues, cutting across sub-disciplinary boundaries. REF3 contains evidence of the impact of these policies.

e4 Contribution to the discipline

e4.1 Funding committees: Naturally our staff have served on panels for all relevant UK funders, including EPSRC, ESRC, BBSRC, MRC. Anthony Finkelstein is a member of EPSRC Council and

Mark Harman served in the EPSRC SAT for ICT from 2009-2013. 30 of us (almost two thirds of all non-ECRs returned) are EPSRC college members. We have also served on EU funding committees for ERC (all levels) and for may other national funding councils including those for Australia, Austria, Canada, Chile, Czech Republic, Finland, France, Germany, Italy, Israel, Japan, Luxembourg, Mexico, Netherlands, Norway, Saudi Arabia, Sweden, Switzerland, Qatar and the USA.

e4.2 PhD examinations. We have examined 361 doctoral theses (141 overseas).

e4.3 Conference leadership: We have served on more than one thousand programme committees, including all the first tier conferences in each of the research groups' sub-areas of CS. Our staff have also provided **programme chairs** for many during the REF period, including BMVC, CAV, CoNLL, ECML, NIPS, IEEE VR (twice), IEEE ISMAR, Image Processing Conference, IPMI, ISSTA, MICCAI, Mathematical Methods in Biomedical Image Analysis (MMBIA), NordiCHI, Pacific Graphics, Privacy Enhancing Technologies (PETS), SPIE Medical Imaging and VSTTE.

e4.4 Keynotes: Our staff have given more than 70 plenary/keynotes at international academic conferences in the REF period, including keynotes at leading venues such as Byron Cook at Formal Methods in Computer-Aided Design (FMCAD 2008); Wolfgang Emmerich at the ACM International Symposium on Software Testing and Analysis (ISSTA 2013); Mark Harman at the IEEE/ACM International Conference on Automated Software Engineering (ASE 2012); Jens Groth at the Theory of Cryptography Conference (TCC 2012) and John Shawe-Taylor at the International Conference on Computational Linguistics (COLING 2008). Our staff also regularly give keynotes at other (not necessarily academic-only) technical conferences for opinion formers and policy makers: Sue Black at the United Nations Broadband Working Group conference 2013, Chris Clack at HIFREQ TRADE industry conference 2013 and Inside ETFs Europe conference 2012 (attended by 600 leading Financial Services executives), George Danezis at the NATO Partnership Symposium 2012 and Angela Sasse at the 2012 National Science Foundation's Secure and Trustworthy Cyberspace conference.

e4.5 Editorial boards: We have members serving on 67 different editorial boards in the REF period, including ACM Transactions on Computer-Human Interaction, ACM Transactions on Graphics, ACM Transactions on Programming Languages and Systems, ACM Transactions on Software Engineering and Methodology, Artificial Intelligence, Computer Graphics Forum, Evolutionary Computation, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Transactions on Medical Imaging, IEEE Transactions on Software Engineering, IEEE Transactions on Visualization and Computer Graphics, International Journal of Human Computer Studies, Journal of Machine Learning Research, Machine Learning and Physical Review E.

e4.6 Best paper awards include ACM Research Highlight for Siggraph (twice), ACM SIGCOMM Test of Time Award 2011, ACM Symposium on Usable Privacy and Security, BCS HCI, BMVC best industrial impact, CHI (twice), CHI Honorable Mention (six times), ECIR (twice), ECSQARU, Erbsmann Prize IPMI, FUSION, Human Factors Journal, Human-Centred Track of ACM Multimedia, ICML, Interactive Surfaces and Tabletop Conference, International Conference on Affective Computing and Intelligent Interaction, International Conference on Cognitive Modeling, ISSTA, MICCAI, NSDI, POPL most influential paper 2011, Requirements Engineering (RE), SPIE Medical Imaging, Ubicomp & WSDM.

e4.7 Other notable awards include ACM SIGGRAPH Significant Young Researcher Award, Best UK Vision Thesis, CNT Young Investigator Award, Digital Design of the Year Nomination, Hans Fischer Senior Fellowship, European Athletics Technology Innovation Award, IEEE Internet Award, Internet Society Internet Hall of Fame Pioneer, Media Young Researcher Award, Roger Needham prize, Oliver Lodge Medal, MICCAI Young Investigator Award, SIB Young Bioinformatician Award.

e4.8 Fellowships include RAE/EPSRC Research Fellowship, five ERC grants, EPSRC Dream Fellowship, EPSRC Postdoctoral Fellowship and Career Acceleration Fellowship, Royal Society Wolfson Research Merit Award, Fellowship Royal Academy of Engineering, Fellowship of the CHI academy, Fellowship of the Academy of Medical Sciences (FMedSci), Elected Member Academia Europaea. A complete list of our 17 competitively funded fellowships and their holders is given in Section cI.7, in which HEFCE also asks us to list competitive personal research fellowships.