Institution: Keele University

Unit of Assessment: B11 Computer Science and Informatics

a. Overview

Research at Keele is managed and supported primarily through multidisciplinary Research Institutes (RIs), which provide excellent administrative support, identify funding opportunities, provide assistance with grant applications, help to increase impact and encourage multidisciplinary research. In addition to providing wide-ranging practical support, the RI structure also allows the University to focus its resources on specific areas of strength. Computer Science at Keele is an integrated dynamic research cluster within the **Environment, Physical Sciences and Applied Mathematics (EPSAM)** Research Institute, but it also interacts closely with the RI for **Science and Technology in Medicine (ISTM)**. Further infrastructure is provided through the University's Research and Enterprise Services which gives assistance and advice on, for example, funding opportunities, including dedicated posts to support European funding applications and engagement with industry, contracts, IP and technology transfer, governance and enterprise.

As well as supporting research within its constituent disciplines, EPSAM and ISTM actively promote interdisciplinary and multidisciplinary research. This has been particularly valuable to Computing research, supporting successful collaborations with researchers in Neuroscience, Mathematics, Chemistry, Forensic Science, Physics, Biology, Psychology and Medicine. EPSAM provides funding to the Computing Research Cluster to support a range of activities including travel and conference attendance, a seminar programme and pump-priming for specific research activities, including support for studentships through the institutional Acorn scheme. The processes for recruiting, monitoring and more generally supporting research students and their supervisors are also managed through EPSAM.

The Computing Research Cluster has two research groups:
Software Engineering: (Kitchenham, Brereton, Linkman) – the Group's research focuses on empirical software engineering, with substantial external funding and a strong international profile for research relating to evidence-based software engineering.
Computational Intelligence and Cognitive Science: (Channon, Day, Lam, Collins) – the Group's research focuses on simulating and applying biologically inspired and conventional machine learning models of intelligent systems, in order to widen our understanding of their fundamental properties and, through our interdisciplinary collaborations with staff in EPSAM, ISTM, other UK and international universities, and industry, to extend their range of applications.

b. Research strategy

In Computer Science, our research strategy is to focus on two main areas of research: **Software Engineering (SE)** and **Computational Intelligence and Cognitive Science (CICS)**. We aim to maintain our position as one of the leading centres in the world in the areas of systematic review research in software engineering and in evidence-based software engineering. We aim to establish ourselves as a hub of research excellence in applied computational intelligence with many multidisciplinary collaborations, in particular in the area of biomedical research linking to Keele's internationally-leading research in biomedical sciences and bioengineering in ISTM, which has been facilitated through a £335,000 EPSRC 'Bridging the Gaps' project. The University has shown a strong strategic commitment to Computer Science research, investing significantly in two new senior appointments aligned to the CICS group and to software engineering, and in new equipment and research infrastructure through strategic deployment of HEFCE Research Capital and institutional funding. Peter Andras (currently Reader at Newcastle University) has recently been appointed to a newly created Chair in Computer Science, and is taking up the post in mid 2014, and will provide leadership of the CICS group. A senior appointment in software engineering is currently being advertised with a start date of early 2014.

Kitchenham, Brereton and Linkman's research has been primarily in the area of **empirical**

software engineering with a strong focus on **evidence-based SE (EBSE)**. EBSE research has built on the foundational paper presented by Kitchenham at the 26th International Conference on SE (ICSE) in 2004 (348 citations, Google Scholar, 08/2013). In the previous assessment period we addressed the viability of transferring evidence-based practices to SE (EPSRC-funded project, 2005-2006, rated 'outstanding') and were subsequently awarded further EPSRC funding (Evidence-based Practices Informing Computing, 2007-2009) and EU funding (Evidence-based risk management in global software development, 2011-2013) to investigate methodological aspects of the systematic review process in SE (a key element of EBSE). Since 2007, the research has led to over 40 high-impact publications in leading journals and conferences (for example, IEEE Trans. on SE, Empirical SE, J. of Information and Software Technology, J. of Systems and Software, ICSE) and has transformed the ways in which the SE community makes use of empirically-based evidence. As well as the ICSE (2004) paper, Brereton *et al.* (doi:10.1016/j.jss.2006.07.009) has been highly cited (296 citations, Google Scholar, 08/2013) and is one of the three most downloaded articles in the J. of Systems and Software (08/2013). The Keele technical reports that provide guidelines for conducting systematic reviews (SRs) have also been very widely cited (1370 citations across the two technical reports, 08/2013). The impact of this work has been substantial, with the SE research community publishing over 200 SRs, most of which have followed the recommendations encapsulated in our guidelines.

During the assessment period, many SRs and mapping studies have been performed in order to evaluate procedures for conducting SRs and mapping studies, address methodological research questions relevant to researchers and practitioners, and to aggregate evidence about SE techniques and tools. SRs have been published on topics such as the Technology Acceptance Model (Brereton output 2), software metrics research (Kitchenham output 4), Global Software Development, the UML and the teaching of programming. Methodological studies have addressed such topics as search strategies, completeness, reliability and repeatability (Kitchenham output 3, Linkman output 1). A number of 'tertiary studies' that identify and analyse trends in published SRs, as well as extracting 'evidence-informed' guidelines for the teaching of software engineering, have also been undertaken (Linkman outputs 3 and 4, Brereton output 4). The first tertiary study, published in 2009, is in the top three most cited and most downloaded articles in the Journal of Information and Software Technology (08/2013).

Our recent study to aggregate evidence about methodological aspects of SRs in SE identified 68 papers reporting 63 unique studies published between 2005 and mid-2012, suggesting that the approach has had a substantial impact on empirical SE research (Kitchenham output 1). A major outcome of this study is a set of recommendations for updating the SR guidelines. The updated guidelines form part of a book on EBSE, currently in preparation, to be published by Chapman and Hall. It is anticipated that this will become the 'standard manual' for EBSE internationally. The location, aggregation and interpretation of evidence has fundamental importance for SE research in general and for the linking of this research to industrial practice and to effective societal and economic impact. Keele computer scientists have the highest profile in SE systematic review research in the UK and are one of the leading groups worldwide for EBSE research.

Within the **CICS Group**, Channon and Day use computational models and simulation to address fundamental issues surrounding evolution, machine intelligence, robotics and the emergence of complexity, as well as helping to solve real-world problems. Lam and Collins' research is directed towards automated object recognition, focussing particularly on medical applications, working directly with biomedical science and bioengineering colleagues in ISTM, and on analytical techniques (including machine learning) to enable classification and visualisation of large datasets. This research has high impact across a range of industrial and medical applications and forms the basis of the two Impact Case Studies.

Our EPSRC-funded research into evolutionary dynamics has led to the discovery that, as population size falls, the 'critical mutation rate' above which fitter alleles are lost transitions unexpectedly from near-constant (the previous assumption in evolutionary biology) to drop exponentially for small populations, leaving them spiralling toward extinction (Channon output 1). Current research is focusing on the implications this new understanding has for species under

threat of extinction, and its potential to aid population management and prevent extinctions. With regard to the evolution of neurally controlled agents, we have identified a significant weakness in the standard approaches taken in neuroevolutionary bio-inspired robotics, and we presented a solution that dramatically improves the quality of incremental evolutionary search for complex behaviours (Channon output 2). EPSRC funded work on the evolution of DNA sequences to bind to transcription factors and other proteins has led to a new understanding of optimal mutation rate control (in theory and simulation: Channon output 3). Following this, the project team has been awarded a BBSRC grant to advance knowledge of how bacteria evolve antibiotic resistance, with a view to helping to develop ways of preventing the spread of antibiotic resistant 'superbugs'. The CICS Group also undertakes research into the evolution of social learning, with two significant successes: we have presented the first example of a behaviour inaccessible to incremental genetic evolution alone being evolved through the addition of cultural transmission (doi:10/m7k); and we have provided the first definitive answer to the previously open question of whether or not the "variability selection hypothesis" is sufficient to explain the adoption of social learning in increasingly variable environments (Channon output 4).

Day's EPSRC-funded research includes the use of neural networks for the automated element-specific detection of sensitive substances illuminated by the latest X-ray scanning equipment (Day output 1). This work is highly collaborative with EPSAM colleagues in Chemical Sciences (Haycock, Austin) and Criminology (Kearon) and is the first to show that self-organising neural networks can effectively be used to make chemical-element determinations based on a target's transmitted X-ray signature. This has applications in domains as diverse as airport security scanning, provenance of ancient artefacts, and tracing illegally modified firearms – a socially important application that led to the UK Forensic Science Service supporting this work. A separate international collaboration, partially funded by SciSite Ltd. (now Scicorr Ltd.), has resulted in the development of a new reservoir computing neural network (Day output 2) that is better able to diagnose the structural integrity of reinforced concrete structures based on non-invasive electromagnetic survey data (Day output 4). Work is continuing to develop this very promising strand of research, potentially extending the work to employ multi-sensor data fusion techniques to supplement the analysis of electromagnetic-survey data. Other collaborative research with colleagues in Analytical Chemistry and Forensic Science (Drijfhout, Adam) is developing neural network tools and techniques to assist law enforcement and forensic investigators in their attempts to determine more accurately and more readily the post-mortem interval in homicide cases using forensic entomology data. The team has demonstrated for the first time that a self-organising map can be systematically and accurately used to automate the clustering and classification of the profiles of insect larvae varying in age from one to nine days old, without the need for subjective expert interpretation of the data (Day output 3).

Medical applications of Lam's BBSRC-funded work on automated object recognition benefit greatly from productive collaborations with biomedical scientists and bioengineers in ISTM (Richardson, Yang, Sulé-Suso), and include the identification of tissue boundaries in computer tomographic (CT) scans, new fractal algorithms to characterise the quality of transplanted cell growth from post-operative biopsies, and algorithms to improve not just the tracking of cells but also the auto-focus method used in high throughput phase contrast microscopy. One project (Lam and Collins) developed new (multi-scale) fractal algorithms to model and characterise the quality of transplanted cell growth from post-operative biopsies (Lam output 1, Impact Case Study 1) in order to facilitate a high quality medical capability for large-scale, in-vitro patient-specific generation of cartilage growth for the treatment of arthritis. This work has attracted the interest of oncologists and has led to a joint publication in Laboratory Investigation (Nature Publishing Group) with colleagues in ISTM. Research on the classification and visualisation of 'big data' has led to the development of the first practical exploratory framework that unified Independent Component Analysis and Projection Pursuit (Lam outputs 1 and 4). Research funded by the company Forensic Pathways on source camera identification in digital image forensics has led to the development of a benchmarking signal/component separation procedure based on the eigen-analysis approach to non-parametric spectral decomposition, which was shown to better characterise and classify sensor pattern noise in low SNR conditions typical of most mobile/phone devices (Lam output 3, Impact Case Study 2).

At Keele, the importance of research-led and research-informed teaching is also recognised. Computational Intelligence is a strong thread within our undergraduate programmes, with a specialist dual honours programme on Smart Systems. Also, EBSE research (and especially the use of the SR methodology in SE) contributes strongly to both undergraduate and postgraduate programmes as well as, more generally, to SE curricula development (Brereton output 4).

c. People, including:

i. Staffing strategy and staff development

Keele aims to provide a research environment that is attractive to new researchers, and which supports and nurtures researchers at all stages of their careers. All new appointments must demonstrate excellence in their research outputs and potential, consolidating and complementing existing research strengths. New early-career staff are allocated additional research time and reduced teaching and administrative duties during their first three years of appointment, and are mentored by senior staff and attend a structured staff development programme, including mandatory training for supervising research students.

Research excellence is a key criterion in all promotions procedures, such as that of Channon to Senior Lecturer. Dedicated research time, based on research performance, is allocated within an overall workload allocation model and reviewed annually. Annual research planning and performance review monitoring progress against research targets (publications, grant applications, PGR supervision, conference presentations) forms part of the annual appraisal process.

The University has shown a strong strategic commitment to and investment in Computer Science research, investing in two new senior appointments, one aligned to the CICS group and the other in software engineering, and in new equipment through strategic deployment of HEFCE Research Capital and institutional funding. Peter Andras (currently Reader at Newcastle University) has recently been appointed to a Chair in Computer Science, and is taking up the post in mid 2014. Andras has a strong, international research profile and funding track record in Complex Systems and Computational Intelligence which will fit very well with the expertise in the CICS Group, and will provide important research leadership of the group. A senior appointment in software engineering is currently being advertised with a start date of early 2014.

We operate within the framework of a number of university policies that, for example, implement the Concordat to Support Career Development of Researchers, and ensure Equality and Diversity is always respected. The latter is overseen institutionally by the Equality and Diversity Committee, with the University Research Committee and Postgraduate Research Committee having this within their remit for research and PGR students. The University has recently achieved the HR Excellence in Research award status.

The University has been a Member of the Athena SWAN Charter since 2005, and received the Bronze Swan Award in 2006 in light of its commitment to assisting the recruitment and retention of women in Science, Engineering and Technology, which has since been renewed. Amongst Computer Science staff, women are strongly represented. A third of the submitted staff are women and the two professorial posts are held by women. We have also benefited from the two-year appointment of Prof. June Verner, University of New South Wales to an EU Marie Curie Fellowship (2011-2013).

ii. Research students

Postgraduate students are recruited nationally and internationally, and are funded through a range of mechanisms. Although the number of PGR students graduating in Computer Science during the census period is small, our strategy has been one of successful growth, with the number of registered PGR students increasing considerably during the REF period, and there are currently 17 PGR students within Computer Science, who benefit from the RI structure and the excellent training and support they provide for PGR students – there are currently 120 PGR students in EPSAM. There is strong institutional support to help achieve the strategic aim of PGR growth

through an institutional matched funding scheme called 'Acorn' (£450,000 per annum), and other initiatives such as part-time Teaching Fellows, fees waivers, and the Keele International Student Scholarships (KISS) for international PGRs. Computer Science has particularly benefited from these initiatives – for example, in addition to numerous Acorn funded students and international PGRs benefitting from KISS, currently three Teaching Fellows are studying for a PhD.

In keeping with Research Council and University expectations, a first class supervisory and training environment is provided. During the census period, a new Learning and Professional Development Centre was established in 2011, providing both enhanced generic research training for PGR students and staff development courses for academic and research staff. Research training is extensively discussed and monitored at the institutional level by the University Postgraduate Research Committee. Supervisors are formally approved by the University's Research Degrees Committee, with mandatory staff development courses and joint supervision for first-time supervisors. All PGR students have a lead and second supervisor. Students enjoy excellent facilities, including individual networked PCs, access to the CUDA many-core (GPGPU) computer cluster, and access to appropriate licensed software and digital libraries. Students' progress and welfare are monitored within clear University guidelines, overseen by a Postgraduate Tutor, and regular formal reviews are conducted by researchers other than the supervisor. Attendance at the regular research seminars is expected, and all students participate in a generic training programme, addressing the Research Councils' agendas for key and transferable skills. In addition to giving internal presentations, students are encouraged (and are funded) to make regular conference presentations and attend advanced courses, both in the UK and overseas. The progress of all students is reviewed twice a year, and there is a rigorous, formal written and oral doctoral progression process after ten to twelve months. Completion within four years is expected.

Two PhD students with lead supervisors within the Computing Research Cluster have graduated during the assessment period. Another, whose PhD had a substantial computing element, was co-supervised by a member of the Computing Research Cluster. Of these three, two are in academic positions with UK universities and one is working in industry. Two PhD students have recently completed minor corrections, one has just submitted (11/2013) and taken up a post at Cambridge University and a further four are expected to complete in 2014.

d. Income, infrastructure and facilities

The Keele research community has grown significantly over the census period, evidenced by a 70% growth in its research income per staff FTE and a more than 50% increase in PGR numbers across the institution in the last three years. The RI structure considerably enhances the research environment for smaller research clusters like Computing.

Keele has made strong strategic use of HEFCE Capital Funding to support areas of research excellence through improvements to the research environment and infrastructure, and through substantial improvement to the library and ICT facilities. Since 2009, over £220,000 of HEFCE Capital Funding has been invested in Computer Science research, including over £80,000 on a high-performance (General-Purpose Computing on Graphics Processing Units) computing cluster, over £90,000 on a VICON Motion Tracker system, and over £40,000 on research laboratory infrastructure. The cluster, which is shared with other EPSAM researchers, has particularly benefitted CICS research by enabling computationally intensive research work to deliver substantive results at a rate that would otherwise be impractical (e.g. some of the results reported in Channon output 2). In one recent advance, Channon used Nvidia's CUDA many-core (GPGPU) technology to speed up computational experiments from 1.4 years (maximum, per run) to 3 days, enabling a step change in the rate at which the research could be advanced. Of particular value to the SE researchers, who undertake SRs as part of their research on EBSE, has been the improved access to on-line journals and indexing services.

Over the assessment period, Brereton and Kitchenham have received funding from the EPSRC (EP/E049184/1, £358k, with £180k to Keele, 10/2007-12/2009) with collaborators at Durham, and from the EU (PIIF-GA- 2009-253754, £190k, 06/2011-05/2013) for systematic review and EBSE

research. Plans are to continue research in this area, focusing on the transfer of knowledge from SRs to SE practice, and on mechanisms for improving the quality of primary empirical studies. Further applications for funding include one proposal awaiting a decision from The Leverhulme Trust and two EPSRC proposals currently in preparation.

Research income for CICS research has included an EPSRC grant (EP/H031936/1, £426k, with £110k to Keele, 01/2010-06/2013) for interdisciplinary evolutionary systems basic research (Channon outputs 1 and 3) with collaborators at Manchester, Middlesex and Warwick. This has led to a follow-on BBSRC grant recently being awarded (BB/L009579/1, £450k, with £100k to Keele, 01/2014-12/2016). An EU Horizon 2020 application is planned to follow on from the results reported in Day's outputs 1, 2 and 4.

Lam and Collins' research (Lam outputs 1 and 3, Impact Case Studies 1 and 2) is funded by Chipman Technologies (£85k equipment and technical support) and the BBSRC (BB/J012998/1, £92k, 01/2013-01/2017). The BBSRC project team has recently been awarded additional funding (circa £600k over 5 years) from the Medical Research Council (start date in early 2014). Plans include a KTP proposal with a new industrial partner on cloud security/privacy (in preparation and following on from Lam output 2), as well as targeted EU Horizon 2020 applications.

e. Collaboration and contribution to the discipline or research base

Members of the SE Group have a long-standing research collaboration with Prof. David Budgen at Durham University across a range of SE topics. This group (with Budgen) forms the organising and steering committee of the annual International Conference on Evaluation and Assessment in SE (EASE). EASE was founded in 1997, and the proceedings are ranked 'A' by ERA; the conference has been hosted several times by Keele University, but has also been located in Durham, Spain, Italy and Brazil.

Kitchenham and Brereton have collaborated with many European expert empirical SE researchers, including Dag Sjøberg (Oslo University), Tore Dybå (SINTEF, Norway), Dietmar Pfahl, Martin Höst and Per Runeson (Lund University), David Budgen (Durham) on work relating to the assessment of the quality of SE papers and on analysing trends in the quality of human-centric experiments in SE (3 publications, Brereton outputs 1 and 3). Also, an EU Marie Curie Fellowship has supported a successful collaboration with Prof. June Verner, University of New South Wales (2 publications). Kitchenham and Brereton have recently undertaken a distributed quasi-experiment to assess the clarity and completeness of structured abstracts, through collaboration with Budgen (Durham), Amnart Pohthong (Prince of Songkla University, Thailand), Stuart Charters and Shirley Gibbs (Lincoln University, NZ) and Jacky Keung (Hong Kong City University) (1 published and 1 submitted paper). This work provides valuable input to an EPSRC proposal that is in preparation.

Brereton and Kitchenham were joint organisers with Budgen (Durham) and Prof. Shari Lawrence Pfleeger (Dartmouth College, USA) of a workshop for representatives from industry on evidence-informed software development, specifically on translating the outcomes of systematic reviews in software engineering to practitioners. The workshop, together with a recent conference paper, provides the foundations for a Leverhulme Trust application for funding (submitted 09/2013).

In addition to their substantial work on SRs and EBSE, Kitchenham and Brereton have contributed to the discipline in a number of ways. They have both been members of the EPSRC Computer Science Peer Review Panel throughout the assessment period, and their studies of the value of using structured abstracts for reporting primary studies resulted in the Journal of Information and Software Technology adopting this form for all published papers, with a number of other SE outlets encouraging its use.

In 2012, Kitchenham presented the keynote at the EAST conference, and a presentation at the IT University Copenhagen. She has been Associate Editor for Information and Software Technology, with responsibility for a section on systematic reviews, and from 2006-2008 was a member of the Simula Research Laboratory Scientific Advisory Panel overseeing the Software Engineering

Group. In February 2012, Kitchenham was invited to spend a month visiting the Computer Science department at Hong Kong Polytechnic University where she gave two seminars to the CS department (one on systematic reviews and the other on structured abstracts) and one presentation on systematic reviews to the Hong Kong Chapter of the IEEE. She also visited Beijing and gave a presentation on systematic reviews to both the Computer Department of Peking University and the Software group of the Chinese Academy of Science. In 2008, Brereton peer reviewed research at BESQ Research Centre (Sweden). BESQ (Blekinge Engineering Software Qualities) was sponsored by the Knowledge Foundation (KK-Stiftelsen) with matching funds from industry, with funding in excess of €8.5M over six years. Also in 2008, Brereton was an international member of a panel for the JACQUARD Software Engineering Programme funded by the Netherlands Organisation for Scientific Research (Physical Sciences).

The CICS Group has developed productive collaborations with colleagues in Analytical Chemistry, Forensic Science, Physics and Applied Geophysics in EPSAM, with colleagues in biomedical sciences, bioengineering, neuroscience and physiotherapy in ISTM, and with Kearon in Criminology. Day continues to collaborate with colleagues from Psychology, Neuroscience and Physiotherapy to explore how robotics can be used to assist subjects with locomotive impairments (e.g. following a stroke) or neurodegenerative disorders such as Parkinson's Disease. Day's productive collaborations with Haycock and Austin (Chemical Sciences) and Kearon (Criminology) and Drijfhout and Adam (Analytical Chemistry and Forensic Science) have been described above.

Day and Butcher (Life Sciences) have established a productive collaboration (two journal papers, 2012 and 2013) with colleagues from the University of Ghent in Belgium. The Ghent group are one of the internationally pre-eminent groups in the development and application of reservoir-computing neural-network techniques in engineering and robotics. This collaboration is expected to continue as the work of a new doctoral student gets underway. The UK National Physical Laboratory, following a presentation of how effectively our techniques can be applied to real world structures, has also expressed interest in working with Day and Butcher to develop this work further. Following a very well received presentation at the 2013 meeting of the European Association of Forensic Entomologists in Portugal, our recently published work on the automated neural network analysis of forensic entomology data will be the basis for an application for EU funding in 2014.

Through an EPSRC-funded project, Channon works with partners Drs Chris Knight, Rok Krasovec, Roman Belavkin and John Aston, from the Universities of Manchester, Middlesex and Warwick, to advance understanding of (amongst other things) the evolution of DNA sequences and their bindings to transcription factors and other proteins. This ongoing collaborative project involved both the evolution of wetware (biological) DNA and the much faster evolution of sequences in computer experiments using tables of DNA-to-protein binding affinities (Channon output 3). The team will begin a follow-on BBSRC-funded project on mutation rate plasticity in January 2014.

Lam and Collins have strong research collaborations with medical researchers and practitioners, and with forensic scientists both at Keele and in industry. Active collaborators in ISTM include Prof. James Richardson and his research team at the Robert Jones and Agnes Hunt Orthopaedic Hospital in Oswestry, with whom research is focused on automated object recognition (Impact Case Study 1, Lam output 1), and Drs Ying Yang and Josep Sulé-Suso focusing on non-destructive analysis of cells. Application-driven research in the forensic science domain has been in collaboration with Criminal Records Direct Ltd. (formerly Assuramed Ltd.) and with Forensic Pathways Ltd., as well as with forensic science researchers at Keele University (Impact Case Study 2, Lam output 3). Recent work on the security and privacy concerns raised by the increasing adoption of cloud computing has led to Lam's appointment as Editor-in-Chief of the new open-access Journal of Cloud Computing, the inaugural issue of which is published in November 2013.