Institution: Birmingham City University

Unit of Assessment: Computer Science & Informatics (UOA 11)

a. Overview

Research in this UOA is organised into three disciplinary groups: Software Engineering (SE), Digital Media Technology (DMT) and, a newly formed, Cyber Security (CS), all undertaking fundamental and applied research in a collaborative environment. SE comprises **Chapman**, **Liu,** and **Bowen**; DMT comprises **Athwal**, and **Köküer**; and the CS comprises **Abdallah**, **Bowen**, **Palomar**, **Chehab** and **Haidar**. Two externally facing centres, namely the Knowledge Based Engineering Laboratory (KBE Lab) and the Centre for Low Carbon Research (CLCR), draw on these specialisms for multidisciplinary external engagement and for knowledge exchange which is essential for ensuring downstream impact.

Research from this UOA was returned to General Engineering in RAE 1996 and 2001, reflecting the focus on application of computing techniques to automotive and manufacturing engineering and supply chains logistics. Subsequent research has focused increasingly on the digital and computing domains through the application of methods such as modelling, signal processing, artificial intelligence and visualisation to engineering-related applications.

During 2001–07 the Faculty became the academic component of a subsidiary of the University, with strategic targets to support and revitalise the regional economy through applied research, technology transfer, knowledge exchange and consultancy. The increased focus on technology transfer resulted in this UOA not being returned to RAE 2008. In 2009, significant restructuring of the University resulted in the Faculty being re-integrated into Birmingham City University. Since then, the Faculty has received significant and sustained investment to establish new research centres and revitalise research.

b. Strategy

Research in this UoA focuses on advancing the realisation of digital information systems to facilitate solving “real-world” problems. Our research investigates aspects across the whole lifecycle from knowledge capture, through software development, to exploitation in domain-specific applications. Research encompasses: 1) innovative knowledge-based applications, 2) development of supporting tools, 3) improvements to software construction methodologies and, 4) contributions to underpinning theoretical frameworks for assuring desired qualities such as correctness, security and resilience. The first aspect is exemplified by the work **Athwal** on the interaction between actors and virtual objects in live TV. The second is illustrated by the work of **Chehab** on designing an innovative decision support tool, based on self-organizing neural network, to improve accuracy of network intrusion detection. Software development methodologies are typically exemplified by the work of **Abdallah** and **Haidar** on using generic protective wrappers to architect and implement secure web services. Lastly, **Liu**’s work on the formal model-driven method (rCOS) and its modelling tool exemplifies our theoretical work.

Our approach relies on collaborative working with regional, national and international partners, focusing research increasingly on significant known and emergent global challenges. This UOA has had considerable success in bidding for commercial contracts and technology transfer activities and this has been repositioned in this REF period to support research funding applications. Increased recognition of research reputation coupled with an excellent delivery track-record has resulted in this UOA securing significant research income over the REF assessment period from a variety of regional, national, and EU sources. This level of research income has enabled significant improvements in research capacity and infrastructure, leading to enhanced outcomes in our core research groups: Software Engineering, Cyber Security and Digital Media Technology. Engagement with research partners has increased significantly through the outward-facing KBE Lab and CLCR, which are highly effective in creating and sustaining partnerships with industry and collaborations with EU stakeholders. There has been substantial investment from the University and the Faculty in research laboratories, in funded PhD studentships and in support mechanisms for developing research bids and managing research projects. The research capacity of the wider academic staff has been grown through mentoring, Individual Performance Review,

formal allocation of research time and investment in funding of staff PhD study.

CS research has been at the forefront of advancing information security by linking emerging experimental and theoretical methodologies across disciplines (cryptography, mathematics, network communications, artificial intelligence, ICT and economic and social dilemmas). The group has an extensive knowledge base and a long experience of public-private cooperation. Our contributions include building abstract high-level frameworks for capturing, evaluating and comparing identity management architectures [**Abdallah** 3], cyber threat models that form the basis for digital security assurance, testing and compliance [**Abdallah** 1], authentication and access control in fully decentralized networks [**Palomar** 3], and assurance and dependability. Novel techniques for designing modular security architectures have been developed for a variety of security controls such as authentication, anonymous authorization, auditing, firewall and intrusion detection. Some of these controls have been implemented as reusable components denoting security wrappers which can be readily integrated within other systems [**Abdallah** 2, **Haidar** 1, **Palomar** 1,2]. With EPSRC funding, our research [**Abdallah** 1, **Haidar** 1] has contributed to building the security layer for the Application Hosting Environment. This tool is used for securing information sharing on the grid and has been used to support hundreds of e-science users worldwide. The CS's strategic plan brings into focus emerging challenges such as security and privacy in smart cities, vehicular *ad hoc* networks and healthcare technologies. Building security in by design and through the application of design principles is another focus for our research. Other themes includes development of data mining algorithms and evolutionary neural networks for the detecting patterns of abnormal security behaviour as well as the security issues in Big Data and cloud computation.

Research in SE covers both empirical software engineering and formal software engineering methods. Its thematic areas include theories, techniques, tools and experiments of software modelling, design, and verification and validation. The formal model-driven development method (rCOS) [**Liu** 1,2,4] and the work in [**Bowen** 1–4] are on unifying semantic theory software systems, including distributed component systems, object systems and service-based systems [**Liu** 3]. These support integration of techniques and tools [**Liu** 1–3] for development lifecycles of software applications. Empirical software engineering research is led by **Chapman**, with a focus on developing knowledge-based engineering as an innovative method for design automation and for virtual product development. He leads the development of models for capturing and representing domain-based knowledge [**Chapman** 1] to be integrated into the computational models of automated tools through service-oriented architecture [**Chapman** 2-4]. This work is reflected in the accompanying impact case study. In addition, empirical research on decision support tools and visualization tools is being conducted in collaboration with the CLCR. The models and techniques developed in the formal theories effectively support the empirical software engineering principle of separation of concerns to improve their practical applicability [**Liu** 1–4]. **Bowen** has worked on a project with Praxis High Integrity Systems (now Altran) to apply the Z notation to the specification and testing of air-traffic control software. Since 2010 **Liu** has led the development of initiatives to apply rCOS to Electronic Health Record architecture for safe and secure healthcare applications.

SE plans to consolidate, grow, and collaborate with other groups and centres. The research will continue its theme of theories, techniques, tools and experiments in software modelling, analysis, design, verification and validation aimed at solving real world problems in trustworthy computing systems, including embedded systems, web-based systems, cyber-physical systems and smart cities. Thus, SE group is able to provide sound support to the abstraction, architecture, and development techniques underpinning ambitious applications in KBE Lab (cyber-physical components) and CLCR (enterprise modelling) as well as other interdisciplinary projects such as smart cities and assisted living.

Research in DMT is led by **Athwal**, and includes **Kökü**er, three early-career researchers and a dozen PhD students. **Athwal**'s work covers digital music and sound processing, image and video processing [**Athwal** 1] and mixed reality [**Athwal** 2]. **Kökü**er focuses on analysis of audio, speech, music and biomedical signals using pattern recognition and machine learning algorithms. **Athwal** has developed computer-based methods for introducing more expressiveness into music by

investigating harmonic excitation effects that can be used to give users intuitive control over the perceptual features of audio signals, and by probabilistic methods for introducing human-like variability into synthesised sounds. The research on bird recognition [**Kóküer** 2] is multidisciplinary work which introduces a new approach to automatic analysis of bird vocalisations. This can be extended to environmental assessment and bioacoustics research and has led to collaboration with Ohio State University and the University of Birmingham.

Moreover, DMT has used computational optimisation to realise real-time versions of sophisticated psychoacoustic models and is building on this work to explore the potential replacement of simplified models by a more accurate representation of human auditory processing in many real-time applications. These include loudness monitoring of environmental sounds, loudness metering in the broadcast industry, optimising hearing aids and automated mixing. With existing EPSRC seed money, DMT is developing musical semantics into a larger collaboration with QMUL and the Birmingham Conservatoire. **Kóküer** aims to apply novel techniques to the source separation of musical signals. Future work includes recognition of multiple bird species vocalising concurrently in a noisy environment. In the area of mixed reality, DMT has developed CGI techniques to compensate for human inaccuracies when attempting convincing interaction in live broadcast, and seek to extend these methods to sophisticated interactions including grasping manipulations and interaction with reactive virtual creatures. DMT has also contributed its expertise to interdisciplinary projects through EU-funded projects such as EPIC (European Platform for Intelligent Cities), Climate KIC-Transitions and Creative Digital Health Solutions.

The UOA has established a thriving and vibrant research environment which will be further consolidated. Towards 2020, our strategy for shaping our future research aims at (1) continuing strong partnerships with research users, (2) maintaining excellence in core disciplinary subjects; (3) harmonising theory and practice more effectively; (4) increasing collaboration within EU projects; (5) achieving stronger impact (6) building flexibility to quickly respond to changing external priorities (7) crossing boundaries with multi-disciplinary projects, (8) greater use of EU funding for EU priority themes including the Ageing Society, ICT, Future of the Internet, Internet of Things, Smarter Cities.

c. People:

***Staffing strategy*:** This UOA aims at providing a clear, transparent and fair research culture in which new and existing staff are empowered to maximize their potential and advance their careers to achieve their aspirations. In line with the previously described strategy, there have been a number of recent appointments in Computer Science and Software Engineering. These have been strategically made to grow research excellence capabilities and to enhance the broader research culture. To this regard, **Abdallah** was appointed in 2012 as Professor of Information Security in order to establish research excellence in cyber security, a new area of growing importance to many BCU inter-disciplinary research groups as well as to our external research partners. With substantial University financial support, a focussed cyber security research group was established in 2013. **Bowen**, an international authority on dependable systems, was appointed as Professor of Computer Science to lead research in innovative methods for system dependability and security assurance and to link interdisciplinary research across the Faculty. **Haidar** and **Chehab** were appointed as part-time Senior Research Fellows to lead research themes in security architectures and identity management respectively. Having been an Assistant Professor in the IT Security Research Group at Carlos III University of Madrid, Spain for 8 years, **Palomar** was recruited at Reader level to provide research expertise in designing cryptographic algorithmic solutions to secure multidisciplinary applications in emerging areas ranging from Internet of Things, smart city, assisted living, and smart transportation. While she was at the IT Security group, **Palomar** and other members of the group cooperated with **Abdallah** on reasoning about privacy protocols. This resulted in two joint publications. The group has built on the expertise of organically developing researchers such as Austin, Bhogal, Kay and Clark in network security, databases, application security, and forensics.

SE builds on the growing expertise of another set of organically developing researchers (Maitland, Evans, Cox, Lancaster, While) in requirement engineering, web services, and data retrieval

Chapman, promoted to Professor in 2011, has an excellent track record in building sophisticated knowledge-based tools to support design innovation, development, and manufacturing of technologically advanced products. SE's research capabilities have been strengthened with the appointment of **Liu** as Professor of Software Engineering in 2013. **Liu** has a well-established international reputation in the theoretical underpinning of frameworks and methodologies for engineering, integration, and reasoning about software components and systems.

During this REF period, **Athwal** was promoted to Professor for his research leadership in digital media technologies. His research focuses on image, sound, and video processing and their applications in music, TV and film, and multimedia systems such as biometrics and vehicle crash test analysis, as described in one impact case study. The group includes **Kökü**er**,** a Senior Research Fellow (recently submitted a Readership promotion application), specialising in sound recognition and speech processing as well as other staff (Foss, Stables, Wang and Williams) whose research capabilities will be further developed within the next REF period. One of **Athwal**'s research students, Stables, was awarded his PhD in 2013 and has recently secured a lectureship in the DMT group.

Our staff recruitment processes place an emphasis on research. It is expected that new academic staff have both teaching and research expertise to advance this UOAs mission, and this is embedded in all staff contracts. **Abdallah**, **Bowen**, **Chehab**, **Haidar**, **Liu** and **Palomar** clearly reflect this expectation. At the same time, organically grown researchers are supported to advance their careers as exemplified by **Chapman** and **Athwal**. In addition, Raju (KBE Lab) and Melville (CLCR) were promoted to readerships in 2012.

Research performance is part of the annual staff IPR appraisal procedure and specific time is allocated within a well-developed and transparent Workload Allocation Model (WAM) for research, scholarship and development activities. The WAM is sufficiently flexible; periods of research leave for specific tasks can, and have been, supported (e.g., staff are encouraged to apply for sabbaticals) and WAM allocations for externally-funded research projects are put in place with other duties reallocated as appropriate.

Equality & Diversity: Research development is linked to the University's promotion system which incorporates research success targets as part of regular performance review. The inclusive approach outlined above has won the Faculty of Technology, Engineering, and Environment (TEE), within which this UOA resides, the Investor in People award in 2012.

Research students: There are currently 27 PhD students in the UOA's research groups, distributed as follows: 2 in CS, 13 in SE and 12 in DMT; it is anticipated that 7 will complete next year. The research students form an integral part of the research community, and the majority are accommodated in their discipline groups along with academic staff. There is a rigorous selection process, University-wide initial training programme (Postgraduate Certificate in Research Practice), 6-month review process, and preparation for viva and career development. This is overseen by a Faculty Director of Research Degrees. Supervisors are likewise managed and monitored, and there is University-wide training for supervisors and viva chairs. Research student processes are managed within the Faculty by a monthly Faculty Research Degrees Committee chaired by the Director of Research Degrees; its decisions are ratified for quality assurance purposes, and strategic policy made, by a University Research Degrees Committee chaired by a Pro Vice Chancellor.

Students are encouraged to contribute to teaching programmes (for which training is provided), to relevant externally-funded research projects, and to contribute to internal and external research conferences and publications. Additionally, students are encouraged to attend weekly research seminars and a weekly student-led event for sharing research best practices. Finally, the University has an ethics policy, and UOA staff contribute to an annual cross-university ethics conference. Moreover, all research projects, including research degrees, are reviewed by a Faculty Ethics Committee and this also forms part of University-level quality assurance procedures for external funding bids.

d. Income, infrastructure and facilities

The UOA has a healthy portfolio of research funding that allows continuing investment in infrastructure, studentships and facilities. We have obtained £3.5M of research income over the REF assessment period. UK funding sources include EPSRC, TSB, Birmingham City Council, NHS Trusts, large companies such as Rolls Royce and regional SMEs. A significant amount of UK government and industry funding has arisen from our portfolio of KTPs, and this has been supplemented by funding from the Strategic Investment in Low-carbon Engine Technology (SILOET) programme via Rolls-Royce. Smaller amounts of funds have been gained from the EPSRC such as the seed funding (£20K) to support the project "Large-Scale Capture of Producer-Defined Music Semantics" via the Semantic Media Network.

Wider partnerships outside the UK have ensured greater leverage of EU government funding for pan-European collaborative research and innovation projects for researchers in SE and DMT via the externally facing KBE Lab and Centre for Low Carbon Research:

- EU INTERREG IVB projects (2009-15) namely "Energetic Algae" (£900k for BCU) and "BioenNW" (£790k), where knowledge-based techniques are being applied to develop decision support systems. dates
- EU CIP project EPIC on "EU Platform for Intelligent Cities" (2011–13) has received a total €3.5M (€400K to BCU) to support research in the areas of data storage and visualisation for smart cities.
- EIT (European Institute of Innovation and Technology) KIC-Transitions project (2013-15) consortium is led by BCU and includes industry leaders IBM and ESRI, and ETH Zurich. Funded by EIT with a total €1.3M (€330K to BCU) this project is supporting research on visualisation of environmental factors on a city scale.
- European Regional Development Fund (ERDF) projects (2013-2015) "Creative Digital Health Solutions" total of £900K (£160K to BCU) involves digital media technology transfer to the NHS and SMEs in its supply chain and "Innovation Engine" total of £800K (£150K to BCU) to apply software solutions for innovations in healthcare and the environment in partnership with SMEs.

Newer members of the research groups have significant track record in attracting funding and managing successful research projects in their previous employment. For example Liu has obtained a total of US$1.2M grants since 2008 from Macau Science and Technology Development Fund to support five research projects in software engineering and applications, allowing him to sustain a strong research group including five postdoctoral research fellows, three PhD students and four internship fellows. He also participated in four research projects jointly with researchers in China supported by grants totalling £800K. Palomar has participated in five multidisciplinary research projects funded by the Spanish government including "SEGUR@: Security and Trust in the Information Society" (€31M for 2007–10) that involved a consortium of academic institutions and industry companies to develop a framework for security, privacy and trustworthiness in the information e-society, and "An Advanced Cyberdefence Simulator" (€10M for 2011–14), jointly with INDRA and the NICS Lab at the University of Malaga.

Going forward into the next REF period the UOA is confident that it can exceed the current funding success. We have a good set of projects that have only recently commenced. Many of our PhD projects started from 2009 onwards and are now producing results that will seed new large funding applications. Our new staff has excellent research and funding records, and in several cases their background in more theoretical or foundational aspects of computer science will complement the more applied expertise of many of the existing staff. The new staff also brings a host of international contacts and networks, that we expect to exploit by joining or building interdisciplinary teams to address societal challenges such as environmental concerns, health and wellbeing, and security and privacy.

The current high level of research income has and is being invested to strengthen the research infrastructure and supporting facilities. Six PhD studentships have been fully funded, whilst the large majority of the remainder benefit from bursaries giving full fee waivers. Students are accommodated in three separate suites of offices, two for SE and one for DMT, sharing these with

their supervisory staff. A further suite is planned for CS students. The EPIC project has allowed the establishment of a powerful server platform that hosts energy consumption and environmental data and this is being expanded via the KIC-Transitions project to include specialist analysis and control software from IBM. Research in DMT benefits from more than £2M of investment from the University in new state of the art TV, film and sound studios made in the last year.

The UOA provides consultancy and professional services via many technology transfer and industry support projects, examples of which are described in the impact statements.

e. Collaboration or contribution to the discipline or research base

Staff within this UOA has had extensive collaborations with other academics and industry, and the majority of these have been of an international nature. The funded projects described in the previous section are examples of computer scientists from our SE and DMT groups led by **Athwal** or **Chapman** collaborating in large interdisciplinary teams with mechanical engineers, musicians, biologists, city planners and healthcare professionals. Since 2006, **Bowen** has co-edited the EVA London Conference proceedings on Electronic Visualisation and the Arts, latterly in the BCS Electronic Workshops in Computing series. He has contributed a number of papers linking IT with for example museums and chemistry culminating in a co-edited book of selected papers in the Springer Series on Cultural Computing. Since 2010, **Liu** has developed research in the area of software engineering for healthcare, developed collaborations with hospitals and IT companies specialized in healthcare, and in 2011 founded the series of International Symposium on Foundations of Healthcare Information Engineering and Systems (FHIES) with proceedings published by Springer LNCS. Since 2012, **Palomar** has been conducting interdisciplinary research in collaboration with researchers at Simula Research Lab (Norway) and Deloitte Spain [Palomar 2]. Athwal has worked with the BCU Conservatoire to establish an interfaculty Music Technology Research group, resulting in joint publications, supervision, and projects.

Staff have also collaborated with academic and industrial partners within their own and allied disciplines. Athwal works with staff from the Centre for Digital Music at Queen Mary University of London (QMUL) via shared PhD supervisions and collaborative projects facilitated by a visiting professor from that Centre. He also collaborates with the Symon Group at the University of Birmingham on the synchronisation of musical performance, and with the Norwegian University of Science and Technology (NTNU) on biometrics. **Köküer** collaborates with University of Birmingham, QMUL, Shandong University (China) and Royal London Hospital through joint publications, and shares research datasets with the Borror Lab of Bioacoustics in Ohio State University (USA). Chapman has undertaken extensive work on knowledge based engineering with Rolls Royce, as covered in one of the case studies. He has also collaborative links with Aker Solutions (Norway), Technosoft (USA), BAE Systems, Jaguar Land Rover, and Triumph. He organized the first ever Knowledge Based Engineering symposium in the UK, attracting significant interest from over 50 design and manufacturing companies. **Chapman** has collaborated with MIT, the NTNU, Harbin Engineering University (China), and TU Delft (Netherlands). While at MIT, he has co-authored two papers with researchers from MIT and Technion (Israel).

With respect to leadership in the academic community, in 2009 **Abdallah** was invited by the US director of cyber security education, along with several leading international authorities in cyber security, to survey the state of the art in information assurance and security education, with a view to highlighting good practice and identifying important gaps. An article, produced as a final report of this one-week meeting has since been used to influence policies on cyber security education in the US and EU. Bowen's participation in an EPSRC Network on formal methods and testing (FORTEST) resulted in a co-edited 2008 book of research papers in the Springer LNCS series (volume 4949) and a joint 2009 survey paper in the ACM Computing Surveys journal (with 168 citations on Google Scholar). He has also co-authored well-referenced articles in the Communications of the ACM (2008) and IEEE Computer (2009) on formal methods-related themes with authors from France, Germany, Ireland, and UK. In 2009, he co-edited the proceedings of the 1st ABZ International Conference on model-based formal methods (Springer LNCS 5238). As part of his activities as Chairman/Treasurer in the BCS-FACS Specialist Group on Formal Aspects of Computing Science, in 2010, he co-edited a book of research papers, published by Springer. In 2013, he co-edited a special issue of the Formal Aspects of Computing journal on selected papers

from the IEEE Software Engineering and Formal Methods conference. He has chaired several panels for the Academy of Finland to review Finnish research proposals. He is an associate editor of the Innovations in Systems and Software Engineering journal (Springer). Moreover, he is a Life Fellow of the British Computer Society and a Fellow of the Royal Society of Arts. **Liu** served on the Working Group on Software Intensive Systems and New Paradigms of Programming of Interlink (2007–10), a committee set up by the European Commission to decide on future areas for calls for EU-funded research projects (H2020) in ICT. He was invited by Chinese Natural Science Foundation to attend the meetings (2008–10) that defined the National Key Research Program on Trustworthy Computing, and the Forum of Experts in 2010 to define the national research agenda on Cyber-Physical Systems. Besides, he was also a co-convener of the EU-China Workshops in 2012 (in China, France, and UK) to define collaboration areas between EU and China. He current serves on the Scientific Steering Committee of the Health Architecture Lab in South Africa and is also member of steering committees of ICTAC (chair for 2004–12), FACS (chair for 2005–10), SEFM, and FHIES (chair). He gave keynotes at FSEN 2009, TTSS 2010&2013. He is Guest Editor of special issues of Formal aspects of Computing, Science of Computer Programming. Moreover, he is a Senior Member of the ACM. **Palomar** was awarded with the “Extraordinary Ph.D. Award” by the University Carlos III of Madrid in 2008 (top 5% of theses). Also, she is member of AENOR – Technical Committee of Normalization/AEN/CTN 197 “Expertise Services”/GT2, in charge of standardizing the auditory and expertise process, documentation and management in Europe.