Environment template (REF5)

Institution: Liverpool John Moores University

Unit of assessment: 11 - Computer Science and Informatics

a. Overview

Research in the School of Computing and Mathematical Sciences specialises in several areas such as networking, security and non-linear modelling for data analysis. To effectively conduct the research, the staff are organised and managed through two centres and two groups. One of the centres, PROTECT, is supported by four research laboratories. Each of these centres, groups and laboratories has a leader responsible for setting out a research agenda and managing its delivery. A number of measures such as regular research meetings and seminars are in place to promote collaborations among them for concerted efforts to target complex research challenges.

This submission to UOA 11 includes 9.7 FTE Category A staff. These are members of the following university research centre and research group:

- PROTECT - Centre for Critical Infrastructure Computer Technology & Protection: Carrying out research in trustworthy computer technology for the functional enrichment and security protection of critical infrastructure systems, with 6 staff included in the submission.
- Neural Computing Research Group (NCRG): Focusing on novel methodologies for computational data analysis with flexible non-linear models applied to real-world problems, with 4 staff submitted.

Among 10 academic staff returned in this UOA, there are 2 professors and 1 reader promoted since 2008 and 2 new lecturers.

b. Research strategy

The main research aim for this assessment period stated in our RAE 2008 submission was to consolidate and advance our research base. To fulfil the aim, a research plan was set out in the submission for two themes: networked appliances and neural computing. For example, a research centre for networked appliances was planned, and the development of advanced neural computing models was proposed.

However, since then, the rapid development of computing technologies has been posing serious security concerns and challenges to critical infrastructure system protection. Such protection is emerging as a strategically important research area and attracting much attention and investment from both government and industry. Since many technical issues of networked appliances are also key concerns for critical infrastructure systems, it is a natural extension of our research to address this new, emerging and critical challenge faced by such systems. This led to the creation of the PROTECT Research Centre, formally approved by the University in 2011.

Hence, the achievement of our research aim will be presented below in terms of the PROTECT Centre and NCRG group, although some work was done before the Centre's establishment.

The main research progress made during this assessment period is highlighted below in comparison with the same UOA's performance in RAE 2008:

- Increased staff submission: 10 academic staff are returned in this UOA, more than twice the number for RAE 2008.
- Increased research outputs: the annual average number of ISI listed outputs per person for this assessment period is over 1.6 times higher than that for RAE 2008.
- Increased quality journal outputs for the UOA: the proportion of the UOA's submission that comprises peer-reviewed journal articles has gone up to 97% from 88% for RAE 2008, indicating improved output quality.
- Increased research income apart from UK research council grants: the annual average of such income has risen by 35% compared with RAE 2008.
- Increased PhD awards for the UOA: the annual average of PhD completions for the UOA during the REF 2014 period is 40% higher than that for RAE 2008.
- Established technical leadership in large collaborative projects: this includes leading the most technically challenging work package (dynamic service composition) of a large EU project (2010-2014), ANIKETOS, involving 17 partners in 10 countries, with €741k awarded to LJMU.

- Founding of PROTECT: with an internal investment of over £200k in staff and facilities.
- Continued investment in research facilities: the annual average investment related to the research for this UOA has risen by 15% compared to RAE 2008.

The above evidence points to a continuing growth of the School's research activity and quality since RAE 2008. More specifically, the key research conducted, major achievements made and future research strategy for each of PROTECT and NCRG are summarised below. The summary uses [Surname i] to refer to the ith output of Surname for a named person in REF2.

1. PROTECT

The Centre's key aim is to research underlying theories, methods and mechanisms for developing practical solutions and tools to facilitate the configuration and interoperation of critical infrastructure systems in an adaptive, autonomous, secure and visual manner. The research requires cross-subject collaboration involving areas of security to safeguard systems against cyber attacks, networking to support the systems' distributed operations, game techniques to advance their user interaction and visualisation, and software engineering to build autonomic capability into the systems for intelligent operations. These areas are supported by four research laboratories with over £1m external funding for the assessment period. The main research activities and achievements are listed below, followed by the Centre's future research strategy.

1.1. Research Activities and Major Achievements Since 01/01/2008

Network and Information Security: This includes finding theoretically sound and practically effective techniques and building the associated tools to tackle security challenges in applications such as critical infrastructure services, e-commerce and cloud-based systems. The key research topics include (1) system-of-systems security, (2) security protocols, and (3) forensic analysis, which are important for the long-term development of our layered security framework for preventing, detecting and investigating cyber attacks.

The achievements of the above research include over 70 refereed publications (e.g. [Shi 1-4, Llewellyn-Jones 1-3]). The work on topic (1) has resulted in our key role in a large EU FP7 project ANIKETOS for secure and trustworthy composite services with a total grant of €9.6m, a security tool and a patent. The research on topic (2) has pioneered autonomous fair exchange in ubiquitous networks, and generated a novel efficient key management scheme exploited for secure satellite communications by SELEX ES Ltd. The work on topic (3) has generated a patent, leading to the creation of efficient software tools with their trials conducted by Merseyside Police.

Networked Appliances: This covers general internetworking research with a specific focus on building systems and frameworks for networked appliance solutions and services. Our key research topics include home networking and entertainment, sensor networks and applications, distributed and embedded systems, and network management.

One of our main achievements in this area is the publication of over 50 refereed articles. Our work on networked appliances has led to the development of novel approaches and tools for auto-configuration of networked appliances in smart home environments, involving international collaborations with Panasonic Technologies Laboratory and Monmouth University in the USA (e.g. [Merabti 1]). The research in sensor networks has produced effective monitoring and controlling schemes and middleware for network management, supported partly by an EPSRC research grant with reference number EP/D000092/1 for 2006 - 2008. Our interdisciplinary effort on exploring networking techniques for healthcare has generated innovative methods and prototypes such as a consultation system for Merseyside Speech and Language Therapy Unit.

Computer Games Technology: A central theme of our research in this area is the provision of methods and tools that allow different techniques to be developed, integrated, evaluated and used effectively for a range of game applications. It targets (1) games middleware and tool development, (2) multiplayer online games, (3) game AI and (4) character animation.

The above research has led to over 60 refereed publications. It is associated with projects supported by BBC R&D in the last 5 years. This includes the achievements of Homura, a novel 3D game engine (topic (1)); NetHomura, a novel networked game middleware (topic (2)); and Charisma, a novel 3D character animation framework (topic (4)). Our effort in topic (3) has produced several frameworks for designing digital interactive storytelling systems, and resulted in the development of novel algorithms with Onteca Ltd for procedural content generation. Several

projects on AI and character animation have been subject to collaboration and publication with researchers from Chinese universities (e.g. [El Rhalibi 1 & 3]).

Autonomic Software Engineering: Our work in this area is on improving the software engineering process and constructs essential for providing autonomous, safe, reliable and predictable software systems. In particular, novel applications of mathematical formalism and modelling to emerging technologies such as critical infrastructure systems, cloud computing and the Internet of services/things are analysed, developed and implemented.

The achievements of this research include over 50 refereed journal and conference publications (e.g. [Randles 1-4]) resulting from the above work. In addition, software has been developed and deployed based on our developed principles of self-organisation to aid the East Lancashire NHS Dental service. An international research group for degeneracy and selection has been founded online based on our research and initiative. In cooperation with partners from Hamburg University, mutual validation of the complementary techniques devised by each side has taken place.

Critical Infrastructure Protection: This research promotes cross-subject collaborations among the four laboratories to advance and integrate their research for fulfilling the Centre's primary aim of developing trustworthy computer technology for the protection of critical infrastructure systems. This is a recently expanded subject to our existing research. While our achievements in the area need more time to emerge fully, we have already had some successes, e.g. in the development of a modelling tool for critical infrastructure and research publications (e.g. [Merabti 3]).

1.2. Future Research Strategy

The University's Research and Scholarship Strategy 2012-17 provides key criteria for us to pursue research excellence during the next assessment period. To achieve this, the PROTECT Centre will focus on the strategic goal of researching underlying scientific theories (e.g. composable security properties), methods and mechanisms to support the development of system-of-systems and techniques for their management. They will be equipped with game-featured user interactions to secure system configuration and interoperation in an adaptive, autonomous and user-friendly manner. These techniques will provide effective and visualised ways to tackle challenging problems with the operation and management of complex critical infrastructure system protection. The work will engage with potential users such as Thales (UK) Ltd National Security and Resilience Division to maximise its impact.

Our strategy for fulfilling the above goal includes two major phases. The first phase is to enhance and expand our research in the key areas presented earlier in a more collaborative manner for the development of essential methods and tools needed for the envisaged techniques. The second phase aims to harness the research work output from the first phase to produce these techniques. In other words, the plan is to build a rich research base in the first phase on which to construct the techniques in the second phase. It will also include attracting external funding from sources such as EU Horizon 2020 and EPSRC to expedite the development.

Recently the University launched a strategic investment programme for recruiting outstanding researchers to strengthen and expand existing research activities. This provided the Centre with 4 additional academic staff to boost its effort for the fulfilment of the above plan.

2. NCRG

The group has maintained and further developed its expertise in non-linear modelling for decision support for clinical medicine and computational marketing. This is evidenced by involvement in research grant funding since 2008 totalling in excess of £750k.

The impact of methodological research on computational marketing includes personalised recommender systems used routinely by www.LeShop.ch (2006-2009) and an innovative web portal nominated as a finalist in the Stockholm Challenge (iShakti, 2010). The research is also actively used by the Merseyside Fire and Rescue Service for risk stratification and by Salford Local Authority for commissioning public health interventions.

2.1. Research Activities and Major Achievements Since 01/01/2008

Research activities are focused on interpretable machine learning models. This area of research straddles rigorous statistical analysis and non-linear computational data analysis. Two specialist areas of focus are survival modelling with flexible semi-parametric models and source identification in brain tumour spectroscopy. The group was the first to introduce regularised neural

network time-to-event models with Automatic Relevance Determination and among the first to introduce Independent Components Analysis (ICA) for tumour grading with Magnetic Resonance Spectroscopy (MRS).

Since 2008 these two research avenues have been progressed further and two further directions opened – generic interpretable models based on information geometry and scalable structure finding algorithms suitable for large data sets.

Achievements in research are reflected by the grant income and publication output. These can be summarised as follows:

- Survival models were extended to competing risks, retaining Bayesian regularisation and direct modelling of the event rates (hazard) over time [Lisboa 1]. Previous regularised survival models were applied and shown to be robust in generalisation [Jarman 1].
- Convex Non-negative Matrix Factorisation (CNMF) was established to be more accurate and interpretable than ICA, demonstrated by detailed histological comparisons [Lisboa 3].
- The theme of interpretability was developed further by:
  - using kernel methods to extend an optimal linear visualisation method [Lisboa 2]
  - demonstrating the effectiveness of our Orthogonal Search Rule Extraction methodology for automatically deriving low-order Boolean rules from noisy data [Etchells 1]
  - introducing the first principled approach to retrieval-based classification, using Fisher Information to set the geometry of data space [Lisboa 4].

The achievements in originality and quality are reflected in sustained citation levels for papers with methodological development, application case-studies and review papers signposting important directions for the future. Two of the papers won awards for Most Cited Article 2006-2010 and Top 10 Most Cited Article during 2000-2010 from the journal Neural Networks.

2.2. Future Research Strategy

The main research focus on methodology remains flexible (non-linear) models that are interpretable by domain experts. Interpretation is at the heart of usability since it provides insights about the data and its relationship with the inferences made by the model, which significantly adds to the value of the inferences alone. This will retain two of the above directions still requiring further development: CNMF, with Marie Curie funding, and Fisher Information Networks.

In collaboration with the University's Centre for Public Health and Research Institute for Sport and Exercise Science, two additional directions will be developed with external funding. One is Public Health Commissioning. The other is Sports Analytics, with funding from a leading Premier League Football Team (£117k), for injury modelling with comprehensive training and match data, and from Prozone (£146k from the company, TSB and ESRC) for match performance analysis and player valuation.

c. People, including:

i. Staffing strategy and staff development

The UOA's **staffing strategy** complies with the University's Research and Scholarship Strategy 2012-17 including measures for encouraging, supporting and rewarding staff for excellent research. Its implementation is evidenced at both University and School levels. Notably, the investment in the PROTECT Centre mentioned in Section b supports the delivery of the UOA's research strategy. A dedicated technician team is assigned the responsibility for the maintenance of research facilities within the School. Since 2008, over £1.4m has been spent on refurbishing and upgrading computing labs and offices to provide modern working environments for both staff and postgraduate researchers.

A range of **career development support mechanisms** is offered to staff. This includes induction and training programmes, run internally and by the University Research and Innovation Services, with focus on early career researchers. Various internal and external career development opportunities are also offered to staff at all levels, e.g. workshops on grant application and management. 7 researchers related to this UOA have benefited from these programmes.

Staff are given reward and promotion opportunities. Several funding schemes are available, e.g. early career fellowship fund and faculty research grants, to support researchers for excellent

research. All the lecturers appointed by the School since 2008 have benefitted from these grants. The annual professorship and readership conferments as well as professorial pay enhancement scheme offer promotion opportunities and reward good research performance. 2 professors (El Rhalibi and Shi) and 1 reader (Llewellyn-Jones) returned in this UOA have been promoted through these conferments since 2008.

At the School level, staff development is supported via a number of mechanisms such as the personal development and performance review (PDPR), contributions to the School's seminar programme including best practice seminars, funded participation at high quality conferences, research sabbaticals and research studentship awards. Research active staff are recognised by an average reduction of 28% in teaching and administrative workloads. Early career researchers also enjoy these lighter teaching and administrative duties, are each assigned a senior colleague as a mentor, and have opportunities for integration with well-established research teams and participation in research supervision and funding applications.

The University has a robust action plan delivered through the **Concordat** Task Group including members from the School, and overseen by the University's Research and Scholarship Committee. The Group has used the Careers in Research Online Survey (CROS) to identify areas for improvement and take necessary actions, e.g. addressing specific training needs. It supports researchers in attending skill development and networking events involving the UK Vitae North West Hub of which the University is an active member. The University was awarded the European Commission's HR Excellence in Research award in May 2012.

The School supports **international staff** appointments and visits. Its recent recruitments have included three international applicants as lecturers. Since 2008, the School has also appointed a visiting professor Prof. R. Yun from China, approved a sabbatical leave for a research visit to Australia, and hosted visiting scholars for their research sabbaticals from Algeria, Belgium, China, Columbia, France, Italy, Jordan, Spain and Thailand. For example, the School had international visitors: D. Bacciu, Pisa; J.D. Martín, Valencia; and V van Belle, KU Leuven. This includes the primary supervision of the thesis awarded the 2008 Caianello Young Investigator Award for the best PhD thesis on neural networks that year in Italy (D. Bacciu). These activities have helped to develop collaborative research with results such as [Lisboa 3 and Llewellyn-Jones 3].

The University organises regular training events on **equality and diversity**. All the senior staff of the School have undertaken the training. Academic appointments and promotions are routinely monitored and reported in terms of equality and diversity. The University holds a membership of the Athena SWAN Charter and is working towards the Athena SWAN Bronze award by 2014. Senior mentor roles were introduced by the University in 2012 to support female researchers.

ii. Research students

The School benefits from well-established international collaborations for **PGR student recruitment** to get well qualified students from the collaborators' countries such as Spain and Iraq, in addition to usual recruitment approaches such as Web-based publicity. For strategically important research areas, the School invests in PGR studentships totalling 23 since 2008, amounting to over £1m. These have led to an increase in student numbers and PhD completions.

A range of **training and support mechanisms** is available within the University via its Graduate School. The Head of School Research is a member of the University and Faculty research committees and in charge of the PGR students within the School, supported by one full-time administrator. A PGR student representative regularly attends School research committee meetings for student feedback. Also the Postgraduate Research Experience Survey is used to collect student views on the improvement of their training and support.

New student induction is compulsory. Each student is assigned at least two supervisors who must complete the University's supervisor training course. There are other training opportunities and online information for both students and supervisors. Each student is provided an office space, a high specification PC, research laboratories and access to the well-stocked University library.

Both the University and School offer conference travel grants to enable PGR students to attend conferences for the dissemination of their research findings. Normally, each student is funded to attend at least one international conference overseas.

Moreover, the School has hosted the Annual National Post Graduate Network Symposium

(PGNet) on the Convergence of Networking, Broadcasting and Telecommunications in Liverpool for the last 14 years, which was supported by EPSRC funding in its early years. The Symposium Steering Committee includes well-known professors and industrial experts in the subject field. On average, over 80 postgraduates from nearly 30 universities attended each symposium. All the students in the School are encouraged and funded to attend and present their work at PGNet.

In addition to the School's regular seminars and fortnightly research gatherings, an annual School PGR student conference also provides students with a formal venue for conference-like presentation and session chairing training, research idea exchange and progress reporting.

Student **progress monitoring** includes weekly meetings but also formal procedures in line with the University's Code of Good Practice, which are reported to the University Research Degrees Committee. This includes an annual progress report and an internal viva as part of upgrade from MPhil to PhD registration. These measures coupled with our success in student recruitment have helped to increase the annual average of PhD completions by 40% for the UOA since 2008.

d. Income, infrastructure and facilities

Specialist infrastructure and facilities underpin the UOA's research outlined in Section b. In particular, the PROTECT Centre provides state-of-the-art facilities for simulating and testing embedded control systems. The four laboratories supporting the Centre's research have their own rooms and specialist facilities. These include a small scale cloud infrastructure for experiments in cloud-based autonomous systems and security. A wide range of computing and networking facilities (e.g. NetFPGA OpenFlow and MICA2 sensor networks) is provided for simulating various networked appliances to support research in the area. Specialist game consoles, sensing devices and software tools are also available for prototyping and testing advanced game techniques. A technician team provides operational support and maintenance of the above facilities accessible by the School's staff and PGR students at any time during University opening hours or via the School's VPN. The NCRG has access to high-performance computers in the School and networked access to further computational resources at the University of Valencia.

The School makes regular **investments** in the research facilities to meet demands for advanced research and new technology deployment, normally comprising a comprehensive upgrade every five years. Since 2008, a total of £693k including RCIF/SRIF funding has been spent on the School's research infrastructure and facilities. Another £780k has been invested in refurbishing the School's offices and laboratories, and a further investment of £150k has been planned for the next two years to expand the range of research facilities, e.g. SCADA (Supervisory Control And Data Acquisition) devices, required by the Centre in line with its future research plan outlined in Section b. Also a further refurbishment of the School's remaining offices and laboratories (about 50%) is planned by the University for 2014 with an estimated cost of £400k.

The School actively encourages and supports **research funding** applications. Its main strategy is to focus research in evolving and emerging areas where our expertise can be applied, e.g. cyber security and critical infrastructure protection, which are more likely to attract investments from both government and industry. This targeted research is coupled with encouragement and support for wide external collaborations to increase opportunities for joint funding applications. The effectiveness of this strategy is evidenced from our success in funding applications.

For example, we identified secure systems composition as one of our key research areas, and invested in its research and external collaboration. This led to our participation as a key partner in the large on-going EU FP7 project ANIKETOS. Also, we took leadership of significant contracts from Unilever Discover for research in computational marketing, and secured a Marie Curie Intra-European Fellowship in 2013 for Bayesian analysis of Brain Tumours with MRS.

Since 2008, the School has obtained over £2m external research funding, including the grants of on-going and new projects, and the total income returned to this UOA is over £1m. Comparing with RAE 2008, the income from UK research councils is lower, but the annual average income from other funding sources has increased by 35%. Most of the grants obtained are from public sources including EPSRC and EU, and the rest from the private sector. For our future research income generation, we will evolve our current strategy with a focus on funding from public sources such as EU H2020, while exploring an expansion to other sectors for new funding opportunities.

The School actively supports **consultancy and other enterprise** activities as shown in REF3a/b.

e. Collaboration and contribution to the discipline or research base

As mentioned in Section d, the School encourages and supports **research collaborations** in the identified areas. Successful collaborations are valuable in terms of making more significant research findings and creating more opportunities for research funding through concerted effort, complementary expertise and established research networks. To achieve such collaborations, the School promotes the generation of quality papers on novel research findings via a long standing culture of wide internal research collaboration. The School also funds over 25 attendances of international conferences for paper publication per year. Moreover, the School provides financial and time support for its staff to maintain the memberships of over 20 professional bodies or working groups since 2008. These measures are intended to give the staff opportunities to network with people sharing similar research interests for external collaborations. Further support is also available via the University's early career fellowship fund to encourage research collaboration with some of the best academics at other institutions.

All the outputs listed in REF2 cover collaborative work with more than one author, and over 70% of them have at least one external author, including international authors in Europe, USA and China. All the income listed in REF4b involves internal collaboration, and over half of the income has external collaboration. A notable case of our collaborative projects is ANIKETOS mentioned earlier, with 7 academic and 10 industrial partners in 10 EU countries, including SAP - the world's largest business software company, to jointly address research issues such as system-of-systems security and trust in complex systems. Our involvement in this project followed on from our successful involvement in NESSI (Networked European Software and Services Initiative).

Furthermore, the NCRG coordinates long-standing collaborations with the University of Pisa on structure finding, KU Leuven on interpretable kernel models, Universität Autónoma de Barcelona on brain tumour spectroscopy, and National Cancer Institute in Milan on survival modelling.

The support measures stated above also apply to **interdisciplinary research**. In fact, some of the above collaborations, particularly by the NCRG, are for interdisciplinary research. Moreover, the University runs a series of Research Café events to share research expertise and encourage interdisciplinarity. For example, our work on Voice-over-IP consultations for the NHS Merseyside Speech and Language Therapy Unit requires joint research with staff in the Faculty of Education, Health and Community at the University, and our research in football performance analysis for Prozone Sports Ltd involves staff in the Research Institute for Sport and Exercise Science.

Our methodological research is driven by real-world applications. Collaborations with end users often help to better understand real world problems, which in turn **informs and adjusts our research activities**. This helps to bring our research closer to real problems so as to narrow gaps between theoretical research and practical applications. For instance, our collaboration with Thales Research and Technology (UK) Ltd raised a security cascading problem. This led to our re-adjusted research to tackle the problem. The work resulted in the generation of one patent from us and a number of invention disclosures by Thales.

During this assessment period, the staff returned in this UOA have also demonstrated their **leadership** in other academic activities. This is highlighted below with some examples:

- 28 advisory/standard body/council chairs and memberships, e.g. EPSRC Peer Review College Members (Merabti from 2000, Lisboa from 2010), IEEE Chair of COMSOC - Home Networking Committee 2010 – 2013 (Merabti), IEEE CCNC Steering Committee Member (Merabti from 2007 to 2013), Task Force Chair of the Data Mining TC of IEEE CIS (Lisboa from 2009), and EU H2020 Advisory Group Member (Lisboa from 2013).
- 30 conference/workshop chairs, e.g. Symposium Chair of IEEE ICC 2009 (Merabti), Workshop Chair of IEEE CCNC 2011 (Llewellyn-Jones), TPC Co-chair of ACM SIGGRAPH VRCAI 2012 (El Rhalibi), and Workshop Chair of IEEE WCCI 2012 (Lisboa).
- 27 invited keynotes/talks, e.g. at IEEE ICCT 2011 and IEEE Wireless Days 2012 (Merabti), IEEE SSCI 2013 (Lisboa), and ACM VRCAI 2012 (El Rhalibi).
- 20 journal editorships, e.g. Series Editor of IEEE Communications Magazine (Merabti from 2005), and Lead Editor of ACM Computers in Entertainment (El Rhalibi from 2010).
- 8 honours/awards, e.g. IEEE Communications Society Distinguished Lecturer 2011 – 2013 (Merabti), IEEE CS Certificate of Appreciation 2008 (El Rhalibi), and Most Cited Article 2006-2010 of the Neural Networks journal (Lisboa).