Institution: Bangor University

Unit of Assessment: Panel B, UoA 11, Computer Science and Informatics

a. Overview

The School of Computer Science was established as a research-led, standalone discipline at Bangor in 2001 and is presently part of the College of Physical and Applied Sciences. Research is focussed on three themes, which can often overlap to maximise synergies and resources: Visualization and Medical Graphics; Knowledge Discovery; and Complex System Modelling. Many of our staff collaborate with researchers in other units, including Medical Sciences, Psychology and Electronic Engineering. One academic from the School (Hope) has been on secondment as the Executive Director of Innovation Research for the whole of Bangor University throughout the REF period.

b. Research strategy

Our consistent objective has been to enhance computing research within strategically targeted groups to support the economic, social and cultural well-being of Wales and the wider community it serves. The research ethos of the School encourages staff:

- to seek originality and depth in research;
- to work on problems with industrial impact and economic benefit;
- to enjoy a stimulating research culture, with an international perspective.

The Director of Research (John) coordinates research planning and monitoring of activities, and reports to the College Research Committee.

The School's three main research themes (detailed below) direct the expertise of our staff towards areas that have excellent opportunities for funding and high quality publications. We are addressing research problems within highlighted priority areas from the EPSRC such as Data to Knowledge and Digital Healthcare, and the Welsh Governments' priority economic sectors such as the Digital Economy. We are also positioning research activities to also take advantage of Horizon 2020 opportunities.

Visualization and Medical Graphics (John, Lim, Mantiuk, Roberts, Vidal, ap Cenydd)

This is the largest research theme within the School with six academics and five PDRAs. We are a founding member of the **Research Institute of Visual Computing (RIVIC)**, a collaborative amalgamation of visual computing research programmes between the computer science departments in Aberystwyth, Bangor, Cardiff and Swansea Universities. It was established in 2009 with a grant of £5M from the Welsh Government's Reconfiguration and Collaboration Fund. The grant proposal was coordinated by Bangor University and we administer the grant on behalf of the partner institutes, and also run the central administration for the institute. The strategic goal of RIVIC is to make Wales an internationally leading country in research related to visual computing. It has brought a significant investment in personnel across Wales, including funding for two academic staff and four PDRAs within the Visualization and Medical Graphics group at Bangor. RIVIC has enabled three visual computing themes to be developed at Bangor to international status:

1. Medical Graphics. The Bangor team are at the forefront of research developments in the use of virtual environments for medical procedures training and skills acquisition. Through collaborations with colleagues at Imperial College and, Manchester, Liverpool and Leeds Universities, we have delivered innovative software combining real time computer graphics, haptics and physiological modelling into clinical areas spanning interventional radiology,

radiotherapy treatment planning and neurosurgery. A successful pan-Wales proposal in 2011 established an Advanced Medical Imaging and Visualization Research Unit funded by a £1.2M grant from the Wales National Institute of Social Care and Health Research (NISCHR). The Unit is coordinated at Bangor and employs two PDRAs at each of Aberystwyth, Bangor, Cardiff and Swansea Universities to work directly with NHS hospitals and deliver visual computing solutions to enhance clinical practice.

2. Visual Analytics is analytical reasoning facilitated by interactive visual interfaces. This subgroup focuses on the investigation of analytic methods and the development of visual analysis tools that display and interact with large datasets. Building on a strong foundation of research into multiple and multiform views, we are developing a lead in this area. For instance, Bangor was a founding member of the UK Visual Analytics Consortium (UKVAC), which partners academics from Middlesex University (lead), Bangor, Imperial, Oxford and University College London. The UKVAC is working with the support of the US Department of Homeland Security via the US National Visualization and Analytics Center at Pacific Northwest National Laboratory, Washington State, and in close collaboration with the UK Home Office.
3. Visual Perception. We have established research into applied visual perception, especially in the context of new display technologies and high dynamic range (HDR) imaging. The sub-group investigates how the knowledge of the human visual system and perception can be incorporated within computer graphics and imaging algorithms. This includes designing and optimization of imaging algorithms that adapt to human visual performance and viewing conditions to deliver the best images given limited resources, such as computation time or display contrast. In 2012, Mantiuk was awarded an EPSRC First Grant to quantify image quality in computer graphics (EP/I006575/1). The grant led to the development of a new comprehensive image quality metric for high dynamic range scenes (HDR-VDP-2, source code released on Open Source basis), and the creation of a quality database for computer graphics artefacts (collaboration with the Max-Planck-Institute for Computer Science, Saarbruecken, Germany). The research outcomes include several high impact publications, including two ACM SIGGRAPH (ACM Transactions on Graphics) and two Eurographics (Computer Graphics Forum) papers, as well as several conference papers.

<u>Knowledge Discovery</u> (Kuncheva, Teahan)

The knowledge discovery area is comprised of two academics, each leading one of the two subthemes:

1. Pattern Recognition and Machine Learning (Kuncheva). The aim of this research theme is to develop internationally leading research on classifier ensembles and their applications, through individual research (a second edition of a monograph is being prepared) and domestic and international collaborations. Encouraged by the results from a recent collaboration with a medical team from Swansea, we seek to expand the applied research of the (virtual) group into other health domains such as ageing, obesity and mental health.
2. Artificial Intelligence and Intelligent Agents, AI:IA (Teahan). This research theme addresses theoretical and applied research into artificial intelligence (AI) and intelligent autonomous agent systems, with specific focus on evolutionary algorithms, natural language processing and information retrieval. Four PhD and 1 MPhil student completed in the REF period and currently there are 6 PhD students with projects in: Chinese and Arabic Natural Language Processing; information retrieval for peer to peer networks and motion capture data; agent-based modelling for Malaria; and conversational agents for e-learning. We were the first to develop a framework (jGE) for using Grammatical Evolution (GE) to evolve Java programs (this was prior to GEVA being produced by the Dublin GE research group). jGE has been downloaded by researchers from the USA, UK, Netherlands, Poland, Brazil and Colombia. A paper published at IJCAI'11 describes a modification to GE that significantly outperforms other GE and Genetic Programming implementations on standard benchmarking tests.

Complex system modelling (Mansoor, Weng)

The goal of this research theme is to use mathematical modelling techniques to enhance multi-disciplinary research into real-time system modelling and security. There are three broad research sub-themes carried out:

1. Complex real-time systems simulation research with practical application at Europe's largest pump storage facility. Understanding of the complex nature of the plant's dynamics can be gained by hardware-in-the-loop real-time simulations, leading to insights that enhance the plant's performance.
2. Optical Communications Networks research involves using extensive numerical simulations to explore the transmission performance and other characteristics of optical networks. These models have been used to rigorously verify experimental results carried out by the Optical Electronic research group in the School of Electronic Engineering at Bangor University. Models have also been developed to investigate schemes for adaptive dynamic bandwidth allocation in optical orthogonal frequency division multiple access and passive optical networks.
3. Security and Water-Marking research is concerned with both theoretical and practical aspects of digital watermarking. Mathematical modelling is used for watermark encryption and video hashing. Several new algorithms have been developed to improve security issues in multimedia processing and analysis.

During the next 3 years the School intends to leverage on the existing expertise in system modelling and visual analytics to develop new research activities in Computer Network Security. We see considerable interest in this domain from industrial partners in the Local Police Authority, EADS, Taiko Electronics and others. We are planning to draw on the European Social Fund to provide "Big Data" visualization services to local businesses. This activity will be able to utilise the HPC Wales supercomputer facilities, enabling businesses to better understand their data and gain a commercial/organisational advantage.

Current Position compared with RAE2008

In RAE 2008, the research plan for the School was based upon the continued development and expansion of the Visualization and Modelling, and the Knowledge Discovery research themes, a particular goal being to establish an internationally leading reputation in these areas. The Visualization research team has grown in size since 2008 as a result of significant investment, and the work being carried out in Medical Graphics, Visual Perception, and Visual Analytics themes is of international significance. The Visual Analytics research also supports the Complex Systems Modelling area, which has been established during this period with the recruitment of a new lecturer. This modelling research has subsequently focussed on multidisciplinary applications. The Knowledge Discovery theme has continued within two distinct streams. The Pattern Recognition and Machine Learning stream set off to explore the application potential of state-of-the-art methodologies such as classifier ensembles to neurocomputing. Since 2008, advances were also made in the baseline research, contributing tools and new methodological knowledge to the area. The Artificial Intelligence and Intelligent Agents theme has also grown since 2008. We have developed state-of-the-art software for evolutionary algorithms (Grammatical Evolution) and are developing novel compression-based character-based language models for natural language processing applications and machine translation for Chinese and Arabic.

c. People, including:

i. Staffing strategy and staff development

As a relatively small School, our strategy for expanding our research base has been to target early career researchers within one of our research specialities. Mantiuk, Vidal, ap Cenydd and Weng have all joined the School as new lecturers during the REF period, and have been supported and mentored by senior staff. This strategy has resulted in early successful grant awards. For example,

Vidal was awarded an EU Marie Curie Actions Career Integration Grant of €100K in 2012. The members of the School are truly international, originally from Bulgaria, China, France, Iraq, New Zealand, Poland, South Korea, as well as England and Wales! No academic staff left the School during the REF period. Three out of the twelve academic staff are female (25%). The University has an active Athena SWAN Group that is developing interventions to better support women working in the sciences in the University, and achieved a University Bronze Award in 2011.
An annual performance review is held for all staff (including PDRAs) with strategic objectives and targets being set. Promotions are awarded on merit, with research excellence being a major criterion. Kuncheva was appointed to a Personal Chair in 2010 in recognition of her research achievements. New appointees are given minimal teaching and administrative duties during their first year of appointment.

Research assistants within the School are supported in their career development and given the opportunity to be involved in the development of grant proposals. All of our PDRAs in this period have gone on to find research posts at Bangor or other Universities at the end of their contracts, and in two cases to industry, one at BBC Research and Development. Vidal, who was a PDRA in the School during RAE2008 went on to posts in France and the USA, and has now returned to the School as a lecturer. ap Cenydd had been a PDRA at Bangor for four years, before being appointed to a lectureship in the School in 2013.

The University achieved the HR Research Excellence Award in 2012 which acknowledges our alignment with the principles of the Concordat. A Researcher Development Group and the University's Research Strategy Group monitor improvements to support researchers and develop the University's Concordat Action Plan. The University's Academic Development Unit offers courses and support for both new and experienced staff. Activities focus on the specific needs of researchers and include workshops and seminars on topics such as writing papers and research bids, project management and setting career goals.

ii. Research students

The recruitment of three PGR students has been supported via the University's widely advertised "125 Scholarship" scheme (marking the 125th anniversary of the establishment of the institution), and some emphasis has been given to allocating these studentships to newly appointed staff members. Two PGRs have also been recruited via the 'Knowledge Economy Skills Scholarships' scheme. This is a major European Convergence programme led by Bangor University on behalf of the HE sector in Wales where students are required to conduct an internship of 8 weeks, and undertake an intensive skills enterprise programme leading to a Postgraduate Skills Development Award, which has been mapped to the European Credit Transfer Scheme. Many self-funded PGRs have also been recruited internationally. A scholarship has also been gained from Y Coleg Cymraeg Cenedlaethol, the pan-Wales Welsh-medium virtual HE institution funded by the Welsh Government. We also support part time PhD study, for example, we have one part time student who works at Glan Clwyd Hospital and has been funded with a grant from a local cancer charity to investigate the use of augmented reality in radiotherapy treatment planning.

Every postgraduate research student is assigned a research committee consisting of their supervisor and two other members of the academic staff. A formal meeting of the committee is held annually to assess the progress of the student. A summary report is agreed and signed off by the student. Informal meetings can also be held with committee members at any time. In addition, the University runs an Early Researcher Development Programme, which emphasises the importance of developing personal and professional transferable skills alongside the research skills and techniques necessary for postgraduate study and research. The development of journal-paper writing skills is emphasised and all students submitting their PhDs are expected to have published at least one journal paper. The efficacy of these procedures is evidenced by the high success rate of PGRs. PhD student registrations over the REF period are: 2008/9 – 5; 2009/10 – 12; 2010/11 – 13; 2011/12 – 15.5; 2012/13 -13.

In addition to the departmental seminar series, RIVIC runs an annual Graduate School where all postgraduate students from the RIVIC partners can present their work. Eminent researchers from

the visual computing field are invited as keynote speakers.

d. Income, infrastructure and facilities

Of the £5M grant awarded to RIVIC by the Welsh Government, £1,176,237 has been invested directly in the School to develop the research base and infrastructure at Bangor. An additional £800,952 is administered by Bangor to fund RIVIC-wide initiatives across Wales such as a visiting fellows programme, the graduate school, and knowledge exploitation activities brokering new projects with industry. Other research spend in this period amounts to £1,020,804, a per capita expenditure of over £100K for research active staff across the REF period (although it should be noted that this includes four members of staff who only joined the School in the latter half of this period).
Our hardware facilities within the School include a rear projected stereoscopic powerwall (2.8m by 1.8m screen), a wide range of haptics devices, various desktop stereo and head mounted displays, high resolution and high speed cameras, a 3D printer, magnetic and optical trackers, and an eye tracker. In addition, the Visual Perception laboratory is set up for conducting subjective experiments measuring performance of the visual system as well as quality evaluation of visual content. The laboratory provides high quality, colorimetrically calibrated displays and well controlled viewing conditions. A unique piece of equipment is a custom-built high dynamic range display, which produces images of extremely large contrast (up to 240,000:1) and brightness (up to 2,500 cd/m^2).

Bangor University has secured over £30m public funding towards a £46m Arts and Innovation Centre, Pontio, set to open in May 2014. As well as contributing to wider impact of the university, creating and sustaining over 100 new jobs and contributing an estimated £15m annually to the wider economy, the centre will offer a £9m innovation/engagement space where interdisciplinary research can be applied to strengthen the regional economy. A novel part of the innovation space that is being led by staff from the School of Computer Science will be an advanced 3D visualisation studio. Cross disciplinary projects are now being established within this facility with colleagues in sports science, music, archaeology, psychology and medicine.

e. Collaboration or contribution to the discipline or research base

<u>Fellowships and Awards</u>

- Hope was awarded the Order of the British Empire (OBE) in the Queen's birthday honours, 2012, for services to innovation and computing.
- Kuncheva is a Fellow of the International Association of Pattern Recognition.
- John is a Fellow of the Eurographics Association; and a Churchill Travelling Fellow.

<u>Academic Leadership</u>

- Roberts was co-chair of Eurographics 2011 (hosted by Bangor), and John was co-chair of Eurographics 2008 (Crete). Roberts was also the Chair of the Eurographics UK Chapter until 2012.
- John is a member of the annual Eurographics Best PhD Thesis Awards Committee.
- Roberts was chair of the Visual Analytics Science and Technology (IEEE VAST) conference 2011 and 2012 and subsequently has sat on the conference advisory board.
- John and Roberts are members of the EPSRC College.
- Roberts was an invitee to the Dagstuhl Seminar on "Information Visualization - Towards Multivariate Network Visualization", May 2013.
- Weng is a Visiting Scholar for research collaborations at Peking University and the Chinese Academy of Sciences.
- Mantiuk is a management committee member and work group leader for the COST Action IC1005: HDRi: The digital capture, storage, transmission and display of real-world lighting.

Research Collaborations are an important element of all our research themes. In addition to the collaborations already highlighted in the Research Strategy, computer scientists from France, Spain, Italy, Japan and South Korea have visited Bangor or have sent PhD students for periods from 1 to 6 months. Overseas visits are also a regular occurrence. Weng was awarded a Santander Mobility Scholarship in 2012; John was awarded a Churchill Travelling Fellowship in 2013 and travelled to Singapore and Australia to foster new research collaborations. One visitor to Bangor funded by the RIVIC Visiting Fellows programme was Hoshi from Nagoya Institute of Technology in Japan. We are exploring medical simulator applications for a novel non-contact Tactile display based on airborne ultrasound.

Interdisciplinary Research is also a major component of our research activities. The School is collaborating with researchers from many disciplines including Archaeologists ("Alternative Views on the lost heritage of Gwynedd" AH/K006401/1), Ocean Scientists (from Bangor University), and several companies including Conwy Valley Systems, GeoShow, Data Exchange (DSX), and EADS. Applications to psychology have been developed, including fMRI data analysis and affective computing, and eye-fixation based visual perception, through collaborations with colleagues from the School of Psychology in Bangor, and with researchers from Spain and Austria. The Advanced Medical Imaging and Visualization Unit have many collaborators in the NHS. We are also collaborating with the Schools of Sports Science and Psychology in developing virtual environments for training sports skills, as part of an international team including researchers from the Centre de Réalité Virtuelle de la Méditerranée in Marseilles, France.

Journal Editorships

- John is Associate Editor of Computer Graphics Forum.
- Roberts is Associate Editor of Information Visualization.
- Teahan is an Editorial Board Member of Computer Science & Systems Biology.
- Weng is an Editorial Board Member of Computational Science and Engineering.

IPC Memberships: Eurographics, IEEE VAST, Computer Graphics International, CyberWorlds, Applied Perception in Graphics and Visualization, Web3D, and Theory and Practice of Computer Graphics.

In addition our staff members regularly review papers for a long list of international journals, as well as refereeing grant applications to the Research Councils (UK and international) and charities.

PhD External Examinations for: Bournemouth, Eastern Finland, Imperial, Leeds, Limerick (Ireland), Manchester, NTU (Singapore), Oxford, Queensland (Australia), Surrey, Teesside, Warwick, UEA.

Invited Keynote Talks: The 23rd International Conference on Industrial, Engineering & Other Applications of Applied Intelligent Systems, Cordoba, Spain, 2010 (Kuncheva); Cardiovascular and Interventional Radiological Society of Europe Lisbon, Portugal, 2009 (John); International Conference on Pattern Recognition, Tampa Florida, 2008 (Kuncheva); Structural, Syntactic and Statistical Pattern Recognition, Florida 2008 (Kuncheva); Skövde Workshop on Information Fusion Topics, 2008 (Kuncheva); SUEMA symposium, 18th European Conference on Artificial Intelligence, Greece, 2008 (Kuncheva).

Invited lectures.
John: "Our wireless world: Celebrating the 100th Anniversary of the Nobel Prize to Marconi", organised by Italian Embassy in London, Institute of Physics, Italian Cultural Institute in London, Fondazione Guglielmo Marconi, The Royal Academy of Engineering, and The Marconi Society, 2009; CSIRO, Brisbane, Australia, 2013; BBC R&D, Mediacity, 2013; IET Wales North Prestige Lecture 2008 (*Roberts and John*);

Kuncheva: University of Salzburg, 2012; University of Navarra, Pamplona, Spain, 2011; The International Summer School on Pattern Recognition, Plymouth, UK, 2010 and 2011; Computer Vision Centre, Universidad Autonoma de Barcelona, 2011, 2013; University of Cagliari, Italy, 2009 (8 lectures); University of Waterloo, Canada, 2008.

Vidal: Workshop on Open Source Haptics & Applications, EuroHaptics 2008.

Prizes

The Visual Analytics team have been successful the IEEE VAST Challenge for three years running. The 2010 entry to this competition received an award for "Good analytic process and explanation"; the 2011 entry was awarded for "Outstanding Analysis Using Custom Tools"; and in 2012 an "Honorable Mention for Good Situational Awareness Snapshot". There have been four best paper prizes in this period (Theory and Practice of Computer Graphics conference 2009 and 2012, the Informa Healthcare 2010 prize, and the European Workshop on Evolutionary Computation in Image Analysis and Signal Processing 2010). Best poster prizes at the NextMed MMVR conference in California in 2011, 2012, and 2013. Second place in the Eurographics Medical Prize competition, 2009.