Institution: University of Exeter

Unit of Assessment: 11 Computer Science and Informatics

a. Context

Research by the Computer Science group at Exeter is focused on aspects of artificial intelligence, particularly machine learning, optimisation and knowledge representation. We find our main impacts through interaction with industry, public bodies and the media. As part of a wider College of Engineering, Mathematics and Physical Sciences, we achieve additional impact chiefly through interdisciplinary collaboration with colleagues in the College and throughout the University. We strongly participate in University strategies related to interdisciplinary research, such as the EPSRC Exeter Science Exchange initiative and the University Systems Biology science strategy theme. We are supported by College and University research and knowledge transfer resources.

b. Approach to impact

Research collaborations

In a collaboration involving Engineering, the University of Exeter Business School, Brunel University, Cadbury and Delcam, Everson has been engaged on an EPSRC Research in the Wild project on the co-creation of physical products. This focuses on the technological and social mechanisms of involving consumers in the design and creation of individual products for themselves, the consumer. The prototypical products are chocolates, made by additive layer manufacture – 3D chocolate printing. Although the project is at an early stage, it already has wide reach, being reported widely in national and international news (e.g., www.bbc.co.uk/news/technology-14030720) and an associated video has been viewed more than 540,000 times (www.youtube.com/watch?v=BIFi8but3Vw). A spin-out company (www.chocedge.com) has been launched and Thorntons, a major UK chocolate producer, has now adopted this technology and is offering services to customers using ChocEdge machines.

We are active on the boundary between computer science and water distribution systems engineering. Work is focused around using computational tools to model water and hydrological systems to improve both drinking and bathing water quality, in addition to the prediction and mitigation of flooding in the UK. All such activity has industry or government body involvement. A CASE studentship with water consultants, Mouchel, and their clients, a large UK water company, is investigating the development of hyperheuristics and multi-objective optimization in combination with new discolouration risk modeling to deliver optimized flushing scheduling and prediction of discolouration events. Keedwell is a co-investigator in an EPSRC-funded consortium of 14 industrial partners, including Yorkshire Water, Thames Water and United Utilities (see gow.epsrc.ac.uk/ViewGrant.aspx?GrantRef=EP/H015736/1 for others), which is investigating the use of cellular automata and high performance computing to enable rapid simulations of sewer and above-ground flooding. The involvement of a wide range of industrial partners has been designed to ensure clear pathways to impact.

We have a fruitful and enduring collaboration with Motorola. Everson's work on Bayesian change-detection was declared a trade secret, so it is difficult to quantify its impact other than its value as intellectual property to Motorola. The trade-secret status prevented publication. Since the initial contracted research, an industrial CASE award with Motorola on multi-objective optimisation of mobile networks and another on visualisation and understanding of many-objective sets have been completed.

We have identified bioinformatics, systems biology and healthcare technologies as areas in which we have potential to make impact and we are strategically developing research collaborations with a view to short and long term impact in these areas. We recognise the impact that next generation healthcare technologies will have on the health and financial wellbeing of the UK and international populations, and consider that our research can be instrumental in realising those benefits. Yang collaborates on cancer informatics with AstraZenica on a project which aims to identify the relationship between cancerous genes and suppressors. Further aspects of this work are explored in conjunction with DSTL. The appointment of Ying in the REF period has strengthened the group in this area and he is funded by the Royal Devon & Exeter Hospital on machine learning for radiation therapy targeting. Keedwell has an active EPSRC-funded collaboration with the University of Exeter Medical School using ant colony optimisation for genome-wide association discovery for diabetes. Keedwell, in collaboration with Bioscientists and clinicians at the Royal Devon & Exeter Hospital, has also developed a new model for predicting *C. difficile* infection severity for patients on admission. This research, which has attracted recent national media coverage, has been identified as having potential high impact and Keedwell is exploring with the NHS routes to ensure its clinical impact.

The significance of smart-phone and tablet technologies for delivering healthcare has been recognised by us as an area of high impact. NHS funding to deploy tablet-based checklists for care on psychiatric wards, developed by Fieldsend, is being sought by the local NHS Trust. Everson is working with colleagues in the Medical School and the College of Life and Environmental Sciences to develop phone apps to monitor and promote physical activity in the general population.

Knowledge Transfer Partnerships
Everson and Fieldsend have been involved in a number of collaborations with NATS, including a KTP on optimising short term conflict alert systems, which is described in a Case Study. In addition to the technical and safety benefits to NATS, the project is delivering highly-skilled people to industry – the KTP associate completed a PhD in Exeter and now works for GCHQ. A further KTP with AI Corporation used novel multi-objective optimisation methods for maximising credit card fraud detection rates, while minimising the false detections.

We recognise KTPs as an important and fruitful way of ensuring impact, and we are in frequent contact, through the Director of Research and other routes, with the Research and Knowledge Transfer office of the University, seeking to engage in new KTPs. This has resulted in a KTP between IMC Corporation, Everson and Fieldsend to develop self-optimising very low-powered battery mesh radio networks for which a patent is being sought, and two new KTPs with Welsh Water involving Keedwell and the Centre for Water Systems. These KTPs, like those with NATS and the AI Corporation, draw on optimisation expertise in the group and we have sought to build strength in this area with recent appointments (Moraglio and Ying).

Open Innovation Platform
Exeter's strategic use of HEIF funding established a series of interventions to boost innovation and external partnerships. Among these, an Open Innovation Platform grant to Everson, matched by contributions from eCow, a firm manufacturing products for monitoring dairy cattle, has led to a novel and reliable method of accurately tracking cows in the farmyard from video streams. Additional funding is being sought to build on this for detecting lameness and monitoring livestock welfare.

Contract Research and Consultancy
Galton has enjoyed a good relation with Ordnance Survey over a number of years. In 2005 he prepared a report for OS on *Vagueness and Uncertainty in Geospatial Data.* Dr Glen Hart, a Research Manager at OS, commented that "The report provided the foundation for research that emerged as our Vernacular Geography research programme" (Private communication, 2010). This joint venture continues, with interactions in both research and teaching planned.

Min's work on All-IP networks is funded by the Huawei Technologies European Research Centre in Germany and will have impact on industrial standards relevant to network fault localisation.

In addition to a long-standing research collaboration with NATS, Everson, in conjunction with Professor Bailey (Statistics), has consulted for NATS on the treatment and analysis of flight track data. Everson and Fieldsend are funded by the Met Office to model and optimise the Met Office's tape mass storage system, which handles petabytes of data. Everson's work has also had direct impact through contract research on image processing for novel strain gauges (www.moiretelltales.com) and through time-series modelling of buildings' energy use with C3 Resources.

Outreach
The group's research expertise has been brought to bear in a series of workshops for secondary school pupils. Over the past four years, workshops have been delivered by staff and postgraduate students to over 400 pupils aged 12 to 18 in schools across the Southwest with the goal of introducing children to the applications and excitement of computer science and encouraging them to consider computer science as a school and career choice. Particular workshop subjects directly resulting from our research include machine intelligence, optimisation, and knowledge representation. We also hosted the "Computing at Schools" conference in 2011. In conjunction with the Smallpeice Trust, we have established an annual four-day residential course for year 9 students to explore computer science and artificial intelligence. The theme of these workshops is "Can a machine act intelligently?" and draws directly on research conducted by us.

The Loebner Prize, an international contest and concrete realisation of the Turing test, was hosted by us in October 2011. The event, which aims to find the most human-like chatbot, attracted television, newspaper and internet media coverage. We also instigated a Junior Loebner Prize for schools, to

engage pupils in the applications of AI research. Keedwell has developed software to enable realtime webcasting of the 2012 and 2013 Loebner Prize contests, which were then viewed live from around the world. An exhibit, which allowed visitors to chat to the 2011 winning chatbot, was by created by Keedwell and shown at the Heinz-Nixdorf museum in Paderborn throughout the Turing Centenary.

c. Strategy and plans

The main research strengths of the group lie in machine learning, optimisation, knowledge representation and pattern recognition. Regular research meetings have recognised that the principal routes to impact for these research strengths lie in the application of the research to other areas of science and technology. Strategies for developing paths to impact are therefore concentrating on forming collaborations with researchers in other disciplines and industry as described above. We have also participated in the Exeter Science Exchange, an EPSRC-funded programme to inspire collaborations between disciplines. Among others, these include: work with psychologists on piloting a computer game for mental health, which is aimed at widening the impact of behavioural therapies by making them more accessible; work on attentional inertia with psychologists and Flybe, aimed at improving aviation safety; and on the application of additive layer manufacturing to the reconstruction and modelling of a Victorian computing device, which is aimed at public engagement with science.

Prof. Min, a recent appointment, has strong links with high impact through EU FP7 programmes and other industrial collaborations in the area of high performance computing and next-generation-internet. Our strategy to strengthen this group and its impact is backed by two lectureships to be appointed over the next two years.

With the aim of identifying and nurturing research with clear impact we actively seeks collaborations and CASE studentships, both through the University's Research and Knowledge Transfer office and though membership of industrial networks such as the TSB Knowledge Transfer Networks.

We are also involved in the strategic shaping direction of research, which has a direct effect on future impact. Galton has been instrumental in shaping the direction of UK and international research in ontology. He is a member of the first executive council of the International Association for Ontology and its Applications (IAOA) founded in 2009, which supports collaborations between research and industry. Until December 2012 he was co-chair of the Education Committee of the IAOA, and helped to organise a Summer School on Process Ontology in July 2011. He co-organised the first UK Ontology Workshop in 2010, which brought the research community together and identified areas of outreach to industry.

The value and importance of impact is recognised in Computer Science and the wider College. Impact activities form part of the annual PDR review system, including planning for the future and assessment of past impact-generating activities. Impact through outreach activities receives explicit loading in the College's workload model. Allocation of internal research funds is biased in favour of co-funding with industry, for instance via 50:50 funding of studentships, and we have been able to secure additional College funding for PhDs arising from KTPs. Support for staff, and especially newly appointed staff, on impact generation is provided via a mix of workshops and mentoring. The University holds an annual Impact Awards competition in part to highlight examples of impact. The College has a well-established Strategic Advisory Board, which meets bi-annually and whose members represent business and industrial stakeholders with interests across the College. Current members with particular relevance to Computer Science are Dave Andrews from IBM and Martin Keys from DSTL. The board provides a forum for industrial steering of College research, but also outreach and awareness-building of our research outcomes. Within Computer Science, regular research group meetings, together with impact monitoring through academic PDRs, led to our strategy of seeking wider collaborations by our staff and these remain the principal tool for shaping impact strategy.

d. Relationship to case studies

The case studies reflect our strategy of seeking interdisciplinary collaborations with industrial partners and with other disciplines, with the aim of applying our research expertise to applications in new areas. The case study on planning water distribution networks for the City of Ottawa arose through the collaboration of Keedwell with engineers in the University's Centre for Water Systems (CWS) and with a firm of water systems consultants. Likewise, work with NATS, described in another case study, exemplifies the application and development of expertise in the group across discipline boundaries to new areas, namely ensuring air traffic safety. This path to impact through consulting, contract research and publicly funded research is being pursued: the continuing research with the water system's consultants, KTPs and CWS will lead to extensive impact in the water systems industry and new research is tackling problems in new ventures with the Met Office and Huawei Technologies.