

Institution: The University of Nottingham

Unit of Assessment: Computer Science and Informatics (11)

a. Context

Computing at Nottingham focuses on engaging world-leading research with real-world problems. During this REF period, research in the School has produced demonstrable impact in the areas of Economy (six spin-out companies, improved systems, reduced costs), Society, Culture and Creativity (new artistic performances, extensive public engagement), Health (new diagnostic and imaging techniques), Public Policy and Services (advising government agencies), and Environment (reduced emissions). In partnership with our collaborators we have worked to ensure that our impact is experienced locally, nationally and internationally. Our five research groups target particular user communities in order to maximise their impact:

- *Automated Scheduling, Optimisation and Planning* (ASAP) – has delivered scheduling innovation to international airports (improved take-off time prediction), the manufacturing sector (material cutting), transport companies (delivery scheduling), service industries (employee rostering), and HE institutions (timetabling and resource planning).
- *Computer Vision Laboratory* (CVL) – has provided innovative computer vision and image processing techniques to a range of interdisciplinary and industrial users including plant and crop scientists (improved growing techniques), healthcare professionals (medical image analysis), and SMEs (Everimaging Ltd – image manipulation).
- *Foundations of Programming* (FOP) – has provided advanced language technologies to a range industry users including Microsoft and Standard Chartered Bank (professional training), and users of high-assurance statistical models (improved modelling languages).
- *Intelligent Modelling and Analysis* (IMA) – has transferred techniques and tools for sophisticated data modelling and analysis to industrial and governmental users including the National Health Service (diagnostics for different forms of cancer), GCHQ (data analysis in the security services), and the UK Border Agency (cargo screening).
- *Mixed Reality Laboratory* (MRL) – has developed novel interactive technologies in partnership with the creative industries (performances, new interfaces for entertainment, collaboration with artists), museums (e.g. Tate, Science Museum, Acropolis Museum), media companies (e.g. BBC, Merlin Entertainments), and worked closely with companies focusing of user interaction (e.g. Microsoft, Yahoo, Google, Sony, Google).

This work is further complemented by the *Horizon Digital Economy Research Institute*, which provides a hub for a diverse range of research users, managed as a network of over 300 members. These include industrial and governmental users of novel digital technologies, including SMEs and multinationals (technologies and strategy), government agencies (policies and standards), local councils (collaborative services), and close links with the Connected Digital Economy Catapult through a shared appointment of the Chief Innovation Officer.

b. Approach to impact

Nottingham adopts a shared ethos of “computing in the world”, in which fundamental advances in Computer Science are connected to knowledge and methods from other disciplines so as to enable deep collaborations with research users in diverse sectors. Our research is therefore strongly user-focused, interdisciplinary and impactful, and we exploit a range of different mechanisms to realise our vision of user-inspired research.

The School **engages with industry** through a variety of mechanisms including Knowledge Transfer Partnerships (KTPs), EPSRC funding for Pathways to Impact (PTI) projects, CASE awards, project partnership, directly funded research projects, and collaborative research through

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PhD projects within the Horizon Centre for Doctoral Training.

ASAP has worked with KLM on crew scheduling, 3T Logistics on transport planning operations for manufacturing and distribution companies, Microlise on telematics-based prognostics and maintenance management systems, Midland HR on workforce scheduling, and Webroster on workforce management. A PTI project between ASAP and the Numerical Algorithms Group (NAG) focused on the portfolio selection problem. An initial CASE project with National Air Traffic Services NATS led to a new take-off time prediction system that has been running live at Heathrow Airport since 2012, resulting in reduced airline fuel costs and environment impact.

Novel methods for displaying high dynamic range images developed and patented by the CVL group (US patent 7639893) are used by Everimaging Ltd in products with more than 10M customers. Work on facial expression recognition conducted in collaboration with users in the entertainment industry has been deployed on Alton Tower's new ride, The Smiler.

The School's industrial collaborations resulted in joint studentships with GE Aviation, Google, BAE, Experian, BT, Microsoft, Nokia, XRCE, Areva T&D (France), and Ordnance Survey. Our recently funded CDT will provide an additional 30 industrially sponsored studentships.

Through Horizon the School has a *collaborative partnership network of over 300 research users*, including SMEs, multinational companies, charities and local councils. A dedicated transformation manager works with this network and builds links between users and researchers via a portfolio of integrated workshops and joint events. Horizon is an active member of the local NottTuesday business-networking endeavour to further engage with local industry.

The School works in **partnership with government organizations** including DSTL, Cabinet Office, GCHQ, and EPSRC. For example, we provided the technologies to support creativity greenhouse virtual sandpits for EPSRC, while GCHQ directly fund work on modelling expert variation and on intrusion detection systems.

The School provides a **broad range of industrial training**. This includes the delivery of Open Data Master Classes in numerous cities throughout the UK to promote the use of open datasets and tools. Hutton published a best-selling Haskell book that incorporates material and examples from five of his published research papers. Microsoft converted this into a 13-part video lecture series for professional programmers in 2009, which to date has been followed by 60,000 users and received 1 million lecture downloads. The book is also a key component of in-house Haskell training at Standard Chartered Bank in London and Singapore.

Research in the School has led to the **formation of 6 spin-out companies**. Aptia Solutions Ltd was formed to commercialise ASAP research into maximising the use of high-value manufacturing materials. The company released its first products in 2008, and now has over 7000 customers in 40+ countries, including major names in aerospace and formula one racing. Two former members of the research group are full-time employees. EventMAP was formed to commercialise collaborative research between ASAP and Queen's University Belfast in timetabling and resource planning for HE institutions. Since 2008, turnover has doubled each year, and the company now employs 8 full-time and 5-part time staff, with clients including leading institutions in the UK, France, Finland, UAE, USA and Australia. Staff Roster Solutions was formed in 2010 to license and support software for employee scheduling developed within the ASAP group, and has already achieved sales in excess of £330K to customers in the healthcare (nurse rostering), aviation (crew scheduling) and retail sectors. Nottingham Prognostics Ltd was formed to develop a clinical test for breast cancer typing resulting from collaboration between IMA and the Breast Cancer Pathology Research Group that identified previously unrecognised sub-classes of breast cancer. Pro-Creative Diagnostics Ltd was formed in 2012 to exploit multi-target tracking algorithms developed by the CVL group that reduce the time taken to perform a World Health Organisation standard sperm assessment by a factor of 6, with a 55% saving in costs and improved reliability. The resulting system has replaced manual fertility analysis at Queens Medical Centre in Nottingham, and sales have been made to eight other NHS fertility clinics, with a number of additional sales in progress. OpenBrain was formed in 2012 to provide a next-generation computing platform for scientific and business analytics based on a new programming language for

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statistical computing developed in collaboration with neuroscientists in Leicester.

Public engagements activities reflect the School's user-centred research, which focuses on collaborative development of new applications, interactions, devices and technologies that engender new experiences "in the wild". This research has involved staging a series of high profile public events since 2008 that have directly engaged *over 200,000 participants in 18 countries*, while indirectly reaching millions more through associated national and international media coverage. The MRL has expanded its highly successful engagement with artists, performers, and cultural institutions via collaborations with the artist group Blast Theory on FlyPad, Ulrike and Eamon Compliant, Riders Have Spoken, and I'd Hide You, and with artist collective Active Ingredient on Exploding Places, The Dark Forest, A Conversation Between Trees, and Timestreams. In collaboration with Horizon, the group has also worked in partnership with B3 Media on Talentlab and hosting artists in residence, with Slingshot on the ORCHID project, and Urban Angel on The Malthusian Paradox. Further examples of public engagement include the Broncomatic ride at EPSRC Pioneers, The Experiment Live performance at the Mayhem Horror Film Festival, and the continued tour of the Rider Spoke game over several international cities and festivals between 2008 and 2011. Our bespoke public engagement videos, published on our Computerphile YouTube channel, received more than 1 million downloads during 2013.

Shaping strategies and policy. Members of the School have used their research expertise to shape and influence government policy and industrial strategy. Much of Horizon's work has implications for policy and standards, and members of Horizon have been active in advising policy makers including the Cabinet Office, the Department for Business Innovation and Skills (BIS), and the Technology Strategy Board (TSB). McAuley was appointed as Chief Innovation Officer of the Connected Digital Economy Catapult, set up by TSB to help UK businesses to innovate in the digital world. Aickelin advised GCHQ on selection of security experts and the UK Border Agency on cargo screening. Rodden provides strategic advice to Microsoft Research and DSTL, and was co-author of the Microsoft supported HCI 2020 'Being Human' report articulating a future vision of interaction, which was distributed to over 15,000 in industry and research.

Broadening the user base. The School continues to grow its research user base through a range of strategic initiatives. The University established the *Advanced Data Analysis Centre* to build upon data analysis methods and techniques developed within the School. The centre engages with other disciplines and external industry users by providing state-of-the-art data analysis consultancy services such as statistical analysis, clustering, classification and data mining.

The Horizon Digital Economy Institute conducts user-led research in collaboration with its network of hundreds of partners. Researchers in Horizon have benefited from the involvement of partner organisations in agenda-setting "theme days" to inform the initial design of projects, with partners acting as advisors throughout each project. A total of 9 theme days have been held, with 112 partner organisations attending these events. Additional agenda-setting engagement from partners has been achieved through more than 50 targeted project meetings and workshops.

Horizon CDT students are making social and economic impact by engaging with partners through internships (100+ so far), practice-led projects, or their core PhD research. Horizon is also shaping academic capacity and innovation internationally, through establishing a new International Doctoral Innovation Centre in China to train a further 50 international students.

Using institutional facilities. Each of the above routes to impact has been and continues to be supported by University of Nottingham central facilities. Examples include institutional support provided through Business Engagement and Innovation Services (BEIS) for contract negotiation, IP protection and consultancy advice, and support through the Technology Transfer Office (TTO) for spin-out formation, legal advice and access to seed funding from the University, angel investors and venture capitalists. BEIS also facilitates KTP and CASE awards.

c. Strategy and plans

The School strategy for achieving impact is to build upon the success of targeted engagement with a broad range of research users in order to solve real-world problems and drive fundamental new

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advances. The School plans for impact and knowledge exchange are aligned with the University Plan, and the School will make full use of the support provided by BEIS and TTO for increasing the impact of its research. Specific School plans to support and encourage impact through knowledge exchange and public engagement activities involve:

- A new research facilitator post to assist staff in securing funding for impact activities;
- Acknowledging and rewarding these activities as part of the performance review process;
- Prioritising PhD funding for projects with matched funding from external organisations;
- Continuing to encourage applications for CASE awards;
- Greater emphasis on industrial relevance of research in academic appointments;
- Helping staff learn how to maximise impact activities through the School's grant academy;
- Giving staff the opportunity (by making adjustments to workload) for commercialisation of their research, including the formation of spin-out companies.

With the University support, the School will:

- Encourage the use of the EPSRC Impact Acceleration Account funding by providing matched funding and support for writing applications;
- Reward research groups involved in setting up spin-out companies by giving them back the value released by the University shares in the company;
- Hold workshops where potential industry users can hear staff research presentations;
- Use contacts with industrial users to inform the direction of research and teaching;
- Encourage PhD students to attend courses on turning ideas into industrially relevant projects.

The School plans to expand the range of users and the breadth of its impact by leveraging the University support provided by BEIS and TTO, and by working with staff at our two international campuses in China and Malaysia to extend our reach into new global markets. The University Plan sets in place extra support for impact and knowledge transfer activities, in addition to existing activities such as KTPs, including expansion of the Corporate Partnerships Programme. The School is already benefitting from the Corporate Partnership with Unilever set up by the University, in the form of two new research projects with the Horizon and MRL groups.

The School will build on Horizon's extensive range of contacts and expertise in establishing more ambitious collaborations and interactions with industry, government organisations and the public. The School is already benefitting from advice and assistance from Horizon's Knowledge Transformation Manager in establishing new contacts with research users.

d. Relationship to case studies

The *Heathrow*, *Aptia* and *Logistics* case studies are representative both of ASAP core research on scheduling and optimisation problems, and of their approach to impact. The underlying research was carried out in response to real-life problems and in close collaboration with the users. The Heathrow case study started with a CASE award and was developed in conjunction with NATS at Heathrow. EPSRC Pathways to Impact institutional funding was used to develop optimisation methods for other international airports. The formation of the spin-out company Aptia Solutions Ltd built upon a CASE award and Teaching Company Scheme, and the Logistics case study grew from an initial KTP project with 3T Logistics Ltd. The *Thrill* and *Theatre* case studies represent core MRL research activities on innovative approaches to human-computer interaction. The research was developed in collaboration with artists, and later involved close engagement with industry leaders such as the BBC and Merlin Entertainments Group.