Institution: Heriot-Watt University

Unit of Assessment: Computer Science

a. Context

Main non-academic beneficiaries: Our main research directions aim at transforming (i) the speed and usability of high-performance computing (HPC); (ii) software verification for large-scale and safety-critical applications; (iii) the quality and potential for multimodal human/computer, and human/robot interaction; (iv) fundamental techniques for optimisation, data analytics, pervasive computing and autonomous robotics. Our potential user pool therefore covers all users of HPC and safety-critical software, and all who interact with computer devices, with foci in mobility, dialogue, collaboration, multimodal interaction, education, creativity, and problem-solving. Below we list, by research area, examples of our user-groups. In each case, we have engaged with the listed group during 2008-13, either in the context immediate impact, or towards facilitating future impact.

Intelligent systems: current and recent research users: Industry users of optimisation and data analysis, including, AWE, BAE Systems, BP, Motorola, Renishaw, Sumerian Europe Ltd. SMEs that serve the energy sector (Epistemy Ltd, Hydrafact Ltd, Intelligent Sensing Anywhere P.V., Lux Assure Ltd). Energy-conscious householders & facilities managers - approx. 150 houses and other buildings in Italy, Portugal and Scotland are engaged in projects where we are developing predictive energy management software. Telecomms and mobility software houses (re our pervasive and ubiquitous computing research), including IBM Research Labs (Israel), Intel Labs (Ireland),NEC Europe, Portugal Telecom Inovação, Telecom Italia. Providers of industrial software and business-process management software (also re our pervasive & ubiquitous computing research), including SETCCE (Slovenia), Trialog (France). Many Industry Research Labs depend on our 'JournalToCs' current awareness service, a product of information filtering and metadata research by the Inst. for Computer Based Learning (ICBL), an impact-focussed HWCS unit. 24 licensees (total £62k) include: the V Sarabhai Space Centre (India), CDM Smith Inc. (USA), Novo Nordisk AS (Denmark), Freemantle Hospital (Australia), United Nations FAO (Italy). The free service has over 10,000 users, and 40 bodies use the API, incl. Atira (Denmark) in the 'PURE' Research Information System. Publishers**:** Associated with JournalTOCS, ICBL recommendations for RSS feed metadata have been adopted by 100s of publishers (for approx 12,000 journals).

Interaction: current and recent research users: Internet service providers and similar: (re our dialogue systems research) FVA New Media Design (Italy), iSOCO (Spain), Liquid Media (Sweden), Nuance Inc. (US), France Telecom/Orange LabsYahoo Iberia (Spain). Hospitals and medical services providers: (associated with dialogue systems applied in healthcare, and with interaction design for ICT in hospitals) Edinburgh Sick Kids Hospital, OBS Medical. Schools**:** around 2,600 school pupils in Scotland so far have used our educational interaction research, schools in Scotland, Portugal, and Sweden are evaluating our interactive robot tutors work, and 42 autistic pupils in the UK have engaged with our multimodal interaction research. Users with large-scale media/text processing needs (re Texture Lab image/text browsing work): IKEA Comms (our impact is manifest in the content of ~2 billion IKEA catalogues to date), Rolls-Royce, Skanska plc.

Rigorous systems: current and recent research users: Users/suppliers of safety-critical systems: (re our AI/verification research) BAE Systems, Praxis High Integrity Systems. Users of HPC/ embedded systems & assoc. software suppliers: (re our parallel/multi-core research) Absint (Germany), Andor Technology, Codeplay, EDF Energy (France), Ericsson, Erlang Solutions, Maple Inc., Maxelier Systems, Thales Optronics, Xilinx Ireland. All schoolchildren in Scotland learning computing, from 2014, Scottish examinations will use our 'Haggis' pseudocode (see part (b)).

Main Types of Impact: Our research primarily leads to **economic** impact, via (i) helping industry improve processes and products; (ii) providing methods that software houses and consultancies exploit, growing their businesses as well as knock-on impact for clients; (iii) engaging in digital economy initiatives that improve speed and quality of product design, and/or lead to new market opportunities. Our second main impact is **societal**, with foci on education (interactive systems that enhance learning and education) and vulnerable groups (for example, autistic children and children who have suffered bullying). We are also growing **environmental** impact via research in energy management, marine conservation, and as a side effect of other energy-related research. Finally, **health** impact is expected in the short and medium terms from current projects (including fitness-oriented gaming, interactive systems for treating depression, and robot-assisted stroke rehabilitation), and in the longer term via our collaborations with the MRC Human Genetics Unit.

b. Approach to impact

Overall approach: Our approach is characterised by agility, engagement, and interdisciplinary interaction. That is, we (i) adopt an increasing variety of approaches; (ii) exploit and create new opportunities to engage with users and beneficiaries; (iii) recognise that impact in several of our research streams can be accelerated by collaborating with academics closely linked to our impact areas. In 2008-13 we have exploited mechanisms and opportunities provided by HWU, SICSA, Scottish Enterprise, RCUK, the TSB, and others, as well as creating our own mechanisms to support this, regularly capitalising on funded research involving industry/societal organisations.

Engagement with knowledge exchange schemes 2008-13 has resulted in: a TSB project with BP, £693k to HWU, £300k to HWCS), four KTP awards (£409k with three SMEs), two EPSRC Industrial CASE studentships (BAE Systems and Motorola), an EngD studentship with Rolls Royce, two TSB feasibility studies (£75k (£30k to HWCS) with Lux Assure Ltd and £15k for HWCS spinout Totally Textures Ltd), two iCASE awards (Motorola and BAE Systems), and a joint EngD award with Rolls-Royce, a prestigious Royal Society of Edinburgh (RSE) Enterprise Fellowship (£50k), one award (£25k) from ITI Scotland, a technology transfer institute funded by Scottish Enterprise, one award (£100k) from EPSRC's Public Engagement scheme, one award from EPSRC's follow-on fund (£27k) and three from HWU's EPSRC Impact Acceleration Account (IAA) (£130k, plus £30k matching cash from Skanska plc and $30k in-kind from Berkeley's International Computer Science Institute (ICSI)). Agile engagement has supported all of these; e.g. the TSB award arose from exploratory internal meetings, then one KTP (Epistemy Ltd) built on their involvement with that project, and a further KTP followed a summer student project with them; the Lux feasibility study followed a £4k consultancy, and ICSI's engagement with an IAA followed Rieser's seminar at Berkeley during her research visit to Nuance Inc. (see below).

More examples of our approach: (i) Vargas engaged with another HWU School's alliance with Renishaw plc in 2011, leading to a £30k feasibility project; (ii) HWCS academics have given 1 talk and 2 posters at HWU's annual 'Industry Day' (numbers limited by annual themes); (iii) 3 HWCS entries so far to HWU's annual 'Converge Challenge' competition for business ideas (Wright-Hastie won the 'pitch' competition in 2011); (iv) around 15 stands/posters from HWCS at the annual SICSA 'DemoFest' events; (v) engagement with Knowledge Transfer Networks (KTNs) includes, for example 'Scalable Applications and Services – A new Dawn?' (2011), a KTN event where 3 HWCS academics presented to an industry audience (vi) Capitalising on EPSRC grant 'AI4FM' (2009-12), Ireland/Grov established a workshop series aimed at creating impact from our AI in Formal Methods research – Grov continues to organise these.

Further examples emphasising follow-through: SICSA's 'DEMOfest' is aimed at users: Loidl's exhibit 2012 concerned new data-parallel programming techniques; this led to interaction with Codeplay Ltd, who produce compilers for Sony Playstation; Loidl's PhD student subsequently took an internship (09/2012-03/2013) to explore aspects of his/Loidl's research in Codeplay's operations. Meanwhile, Robertson organised 'Look to the Future' – a conference for Scottish Computing Educators, which was partly supported with a $10k award from Google aimed at societal impact from her EPSRC PPE grant. Google's support helped bring invited speakers from MIT Media Lab, UCLA and CMU. This event catalysed significant developments on the Scottish computing education scene (see case study) and led to further ideas underpinning an IAA award which will engage pupils in a new concept in fitness-oriented smart-phone gaming with clear potential for health impacts. Robertson is now working with Ozakinci (health psychology, St Andrew's) and bidding to significantly expand this work towards nationwide trials in 2014. Also in education, Michaelson is the Royal Society of Edinburgh (RSE) nominee on the qualifications development team for the Scottish Qualifications Agency (sqa.org.uk) and advises a BCS/RSE project, developing material for the Computing curriculum. In these engagements, he (as language design expert), with Cutts (Glasgow, CS pedagogist), realised a new approach to psuedocode in teaching was needed. They subsequently developed the 'Haggis' language, optimised for learning programming and emphasising computational thinking. The first CPD courses for teachers were run in 2013, and Haggis will be used in all Scottish Computing exams from 2014 onwards.

Supporting Impact-oriented activity: HWU's 'Converge Challenge' award (EU 2010-13) boosted industry engagement throughout HWU by providing Business Development Executives (BDEs) and marketing staff. We have engaged fully with this, with similar support from SICSA, and added our own initiatives, including empowering staff with the necessary time and costs to (i) attend events and prepare demos and posters; (ii) prepare knowledge-exchange oriented bids; (iii) make visits

(or invite visitors) to foster impact oriented collaborations. One example is Rieser's internship at Nuance Inc (CA, USA, world-leading in speech recognition and conversational interfaces), April-July 2013. HWCS gave Rieser time for this research visit, where she consulted on the state-of-the-art in Natural Language Generation (NLG) and Dialogue Management, with focus on recent statistical/ machine learning approaches and scalability to market, and is at the forefront in setting Nuance's research agenda for NLG over the next 3 years. Other examples include: (i) funding a three-day visit by Corne to BP Sunbury in May 2013 to follow up future funding possibilities around outcomes of the TSB project, and a June 2013 trip to Denmark by ICBL staff, to visit users and licensees of JournalTOCS to inform its future development; (ii) providing office space and facilities to two startups: HWU IPE Spinout Epistemy (3 staff, 2010-13), and HWCS spinout Totally Textures (2008-13, 1.5 staff), with value c. £30k; (iii) recognising impact-oriented achievements elements equally with research achievements, via School announcement and recognition in our 'Professional Development & Review' process. Another way impact is incentivized is by using potential impact as a criterion in studentship competitions. For example, Scholz's 2013-16 studentship will work with Intel to explore their experimental SCC architecture towards next-generation systems on chip, and Vargas' 2013-16 DTA will work with health scientists on robot-assisted stroke rehabilitation.

c. Strategy and plans

Building on plans to escalate engagement with our environment's impact-oriented mechanisms, HWCS has a **Director of Enterprise, Impact and Innovation** (DEI^2) who works with research staff and students, providing support at all stages of the research/impact cycle. Support includes training and public/industry engagement, elaborating longer term implications of blue-sky work, establishing engagement with users to maximise potential for 'impact-ready' research, and everything in between. The DEI^2 works closely with our BDEs to open and maintain channels with bodies such as ScotlandIS (the body for Scotland's ICT industry), and to develop new alliances with user organisations centred around our research. The DEI^2 also works closely with HWCS staff to refine strategy/goals around impact. Developing strategy is currently oriented around four enablers: (i) learning from exemplars**:** material is distributed to staff and presented at HWCS meetings, to maximise awareness of opportunities, and to continue to spark enterprising activity; (ii) user talks: regular speakers from industry, government, society; (iii) HWCS talks: regular engagement with potential users by our staff; (iv) bespoke mechanisms: we will augment HWU, SICSA and other support by establishing budgets for impact-oriented travel, demo and showcase events. Our overall goals are to ensure every researcher is aware of the potential users of their research, encouraged to engage therewith appropriately, and has the resources to realise those engagements. Future plans for late 2013 and beyond are to capitalise on significant new aspects of our environment, including (i) the "Data Lab", a £10m SICSA-led Scottish Innovation Centre (SIC); (ii) the £10m HWU-led Oil and Gas IC; (iii) the £7.2m (HWU and Edinburgh) 'Robotarium' partnership, with 30 industry collaborators; (iv) the CDT-RAS Centre for Doctoral Training (see REF5 part (d)), with 32 industry collaborators (~£37m including in-kind and HWU commitments) (v) relocation to HWU's new 'Sir Charles Lyell Centre' (£17m) of ~220 scientists from the British Geological Survey (BGS) in 2015. The SICs, CDT-RAS, and the Robotarium partnership, each awarded late 2013, incorporate multiple ways to facilitate delivery of impact from our research. The Data Lab SIC and Robotarium (with three HWCS co-investigators) will boost engagement with users around each of our research areas, while the Oil and Gas SIC will help us escalate engagement beyond the impacts we have already achieved in that sector (see 'oil' impact case study). Meanwhile, the DEI^2 is leading discussions between BGS staff and HWCS researchers on, for example, collaboration to help businesses exploit environmental data, and on potential new services based on accelerated modelling of geo-processes. Finally, our newest recruits consolidate our potential impact profile and add many new elements, including: economic impacts around business process workflow, societal impacts in disaster response management, and environmental and health impacts from streaming and linked-data research.

d. Relationship to case studies

Three of our Impact Case Studies (ICS) exemplify 'capitalising on funded research involving industry/societal organisations' (part (b)). The 'education ICS follows EPSRC funding to translate research into societal benefit. The 'health information' ICS follows an EU project that worked directly with health information providers, and the 'oil' ICS results from exploitation pathways in TSB and KTP projects. Finally, the 'IKEA' ICS builds on unique capability fitting an industry need; IKEA Comms AB discovered our capability via web search, and we followed through.