Institution: The University of Manchester

Unit of Assessment: UoA 11 Computer Science and Informatics

a. Context

Computer Science at Manchester has a strong history and culture of impact; early Manchester computers were commercialised by Ferranti, virtual memory is an integral feature of the most widely shipped operating systems, and during the REF period software building on Manchester research shipped with Microsoft Windows and on over 14 million Apple computers.

Non-academic user groups for the unit's research include organisations for which computer science is central to their mission, and organisations that apply computing in different domains. Examples of impacts within computer science include the use by Apple of dynamic binary translation to support their transition to Intel processors, and the development of World Wide Web Consortium (W3C) standards that underpin the semantic web. Examples of impacts in applications include text-mining services in Elsevier's SciVerse, the creation of the Semantic Biochemical Journal, and the use of computer vision and knowledge representation techniques in medicine. Every command on the recently-launched Lunar Atmosphere and Dust Environment Explorer spacecraft has been verified by TraceContract, a system developed at NASA's Jet Propulsion Labs at Caltech in collaboration with Manchester researchers.

The principal types of impact in terms of the definitions in the Main Panel B criteria are:

- *Economic impacts*, for example through spin-out companies that directly market the research (e.g., see Transitive, KSS Fuel, KSS Retail in Case Studies), or licensing of technologies to organisations that enable the development of new or enhanced products or services (e.g., The Pixel Farm (see Case Study), Biochemical Journal, Elsevier).
- *Health impacts*: through the use of techniques that support analysis of medical images, e.g. for clinical workflows, image biomarkers and orthopaedics (see Case Study), and through the application of knowledge management techniques in clinical systems by Siemens.

These impacts are drawn from across the unit; the 5 impact case studies emerged from 5 different research groups, and impacts from every research group are described in this document.

b. Approach to impact

The commitment of the unit to establishing and maintaining relationships and activities that increase impact is reflected in the structures for fostering collaborations and knowledge transfer. Throughout the REF period, the unit has had significant academic roles for an External Affairs Director, a Public Engagement Coordinator, and a Continuing Professional Development Coordinator, supported by an External Affairs Office that, amongst other things, coordinates outward-facing events, runs an Industry Club, and created our LinkedIn alumni group which connects us to over 900 members in a wide range of organisations around the world.

Interactions and Impacts. A wide range of mechanisms are used to foster impact; our objective is to ensure we cover the full spectrum, from reaching out to the public, through establishing and maintaining meaningful relationships, to direct participation of commercial organisations in research collaborations that in turn feed through to wider application of research results. The following list outlines the range of impact related activities in the unit.

- *Public Engagement.* To ensure that the unit contributes to the perception and health of the discipline, we participate in a wide range of public engagement and education activities informed by our research. Founded by graphics researchers from the unit in 2008, the annual UK Schools Animation Competition, which has had sponsorship from Google, EA Games and NESTA, in 2013 attracted 1,120 entries from 154 schools. Pi-Face, which allows the Raspberry Pi to control and manipulate the real world, was developed in our Advanced Processor Technology group, who have also been taking the Raspberry Pi into schools through STEMNET, with about 25 students currently qualified as STEMNET Ambassadors. To shape future computing education, Furber Chaired the Royal Society Advisory Group on Computing in Schools, and the unit plays a substantial role in the Computing at Schools (CAS) movement (e.g., we host the CAS regional hub, and launched the regional Apps for Good initiative with over 100 teachers). Research work into Phantom Limb pain was showcased in the Pain Less exhibition at the Wellcome Antenna gallery in the National Science Museum (summer 2012). In addition, the unit: participated in a graphene exhibit at the Royal Society Summer Science

Exhibition that attracted 14,000 visitors; contributed to Revolution Manchester, the newest gallery at the Museum of Science and Industry in Manchester; and provided the Science Communicator in Residence at the Manchester Science Festival.

- *Establishing and Maintaining Relationships.* Successful research translation often builds on existing relationships. To help establish such relationships, the unit regularly hosts large-scale open events such as the annual Turing Lecture, and during the REF period hosted the Turing Centenary Conference (which featured 9 Turing Award winners among its invited speakers). In addition, 13 commercial partners attended the launch event for the Doctoral Training Centre in Computer Science. To provide a more formal context for maintaining relationships, an Industry Club has been established that has over 50 members, including Barclays, IBM, Irisys, Meridian, BBC, Met Office, Microsoft, TalkTalk and RBS. To build on and strengthen such relationships, we have thriving visitor and sabbatical programmes, and during the REF period we hosted 8 extended visits from industry (including from IBM, NHS and Imagination Technologies) and 5 staff from the unit have spent sabbaticals outside academia (at Siemens, Wiley-Blackwell, Elsevier, Microsoft Research and IBM). Such mechanisms have enabled us to develop long-term strategic relationships, for example with AstraZeneca and Toyota in imaging, and with Siemens Healthcare on medical informatics (Siemens has supported around 35 person years of translational research in the unit in the REF period).
- *Industrial engagement in research education*. To ensure that our research students have direct experience of commercial research, all students in the Doctoral Training Centre (DTC) in Computer Science carry out impact studies into research that has (and has not) had significant uptake, participate in study groups that investigate industry-nominated projects, and have placement opportunities. Although the centre is only in its 2nd year, already 14 non-academic organisations have directly contributed to its activities, including IBM, BBC, Oracle, ARM, Fastbleep and Central Manchester and Manchester Children's Foundation Trust. Furthermore, there is direct industrial engagement with research student projects, for example we have had CASE awards with BioMed Central, Pfizer, BAE Systems, ARM and KSS Fuels.
- *Knowledge and technology transfer*. To help bridge the gap between basic research and commercial exploitation, we have been increasing our engagement in mechanisms that bring basic research into direct contact with commercial requirements and opportunities. The unit has participated in 14 Knowledge Transfer grants during the REF period, more than double the number of comparable projects during the previous RAE, in areas such as data deduplication (with Greater Manchester Police), science-as-a-service (with Eagle Genomics), and facial feature tracking (with BunnyFoot Ltd). We see participation in research projects with industrial partners as important for enabling technology transfer, and have increased our engagement in EU projects, with expenditure per annum increasing by 47% from 2008 to 2012. Industrial collaboration has also been supported by an Innovative Medicines Initiative grant (Open PHACTS, with 13 industrial partners) that integrates highly heterogeneous pharmacological data sources using semantic web techniques, and by TSB funding in Agricultural Sensing, Image Biomarkers, and Cloud Analytics for the Life Sciences. Direct industrial funding of research has increased by 45% from 2008 to 2013, with partners including Siemens, Microsoft, AstraZeneca, Pfizer, Google, Toyota and Xyratex. To support Continuing Professional Development (CPD) that builds on our research, our Advanced Professional Education unit has developed distance-learning programmes in Digital Biology, Multi-Core Computing and Software Engineering. Our CPD units have run with 98 participants during the REF period, and in addition, 32 senior NHS IT staff participated in the first run of our Informatics for Healthcare Systems CPD module, which in future will be taken by all new NHS Clinical Bioinformaticians.
- *Direct commercial exploitation of research*: Much of the economic impact of our research comes through spin-out companies or licensing. A total of 10 spin-out companies have been active during the REF period, in areas as diverse as binary translation (Transitive), intelligent pricing support systems (KSS Fuel, KSS Retail), e-assessment (Assessment21), conference management systems (CoolPress), document management (Lost Island Labs), and medical image analysis (Imorphics). In addition, licensing agreements and collaborations on knowledge exchange projects have enabled the application of Manchester research in areas such as image processing for cinema and games (The Pixel Farm), text mining services for large document archives (Elsevier) and scientific workflow platforms (Eagle Genomics).

- *Open Source Software and Standards*: we have made many high profile software systems publically available in ways that allow diverse organisations to apply or experiment with research from the group, and helped to found the Software Sustainability Institute. For example, influential software from Manchester includes: the Taverna e-Science workflow environment (61K downloads during REF), the OWL Application Programming Interface (51K downloads during REF), the VXL Computer Vision libraries (45K downloads during REF) and the Utopia information integration and visualisation platform (50K downloads during REF). In addition, the original version of the Narrator screen reader that ships with Windows operating systems was developed by accessibility researchers in the unit. We also contribute to standards; for example, key W3C standards on ontology and query languages (OWL 2, SKOS, SPARQL) and on provenance (PROV) have authors from the unit).

Agility. The approach adopted demonstrates agility in a number of respects: (i) by developing mechanisms that cover the wide spectrum of activities from public engagement to direct commercial exploitation, many different types of impact are fostered; (ii) by providing an annual budget of over £200k to research groups to support activities that include relationship-building and pump priming, groups can move rapidly to create or follow-up opportunities as they arise; (iii) by supporting an external affairs office with wide responsibilities and skills, we provide administrative support that can be deployed to make, for example, public-engagement activities manageable for academics; and (iv) by providing ongoing relationship management through the industry club, we always have access to a significant pool of commercial contacts from many relevant sectors. In addition, the unit has benefited from institutional EPSRC Knowledge Transfer (£8.3M) and Impact Acceleration (£3.2M) Accounts, which have enabled rapid exploration of opportunities for commercial application of research (14 awards in the REF period).

Supporting and Enabling Staff. In addition to the features highlighted under *Agility* above, which seek to remove barriers to impact, we see the following as important in supporting and enabling staff: (i) academic promotions include *Academic Enterprise and Knowledge Transfer* as one of the four main criteria; one member of staff in the unit has been promoted to Chair principally on this basis and two others have been promoted to Reader with a significant contribution from this criterion; (ii) flexible contracts have been used by staff working on impact activities, for example enabling them to retain part-time contracts at the university while devoting significant effort to spin-out organisations; and (iii) our duties allocation model provides credit for impact related activities, not only through school roles such as public engagement coordinator, but also by giving load credit for staff-led initiatives in areas such as standards. The university policy on percentage share of return on IP further incentivises staff by returning at least 85% of the first £1m to the originators of the IP. Research students own the IP they have created to encourage them to pursue its exploitation, and benefit from enterprise, impact and public engagement training, and industry-run study groups provide direct experience of commercially relevant problems.

Use of Institutional Facilities.

The university company UMI^3 provides expertise on intellectual property commercialisation and incubation to the unit's researchers, and manages the largest seed fund in Europe dedicated to one university, at £32m. UMI^3 has supported impacts mentioned in this section by advising on and investing in spin-out activities, including drafting and signing agreements and facilitating the transfer of IP. There are regular interactions between staff in the unit and UMI^3 in relation to commercialisation opportunities, and during the REF period there have been 50 invention disclosures from the unit, involving 29 people. For public engagement, the unit has ongoing interactions with the faculty media office, which has resulted in over 250 stories, in outlets including the UK national press, Radio 4 and 5, BBC TV, ITV News and the New York Times.

c. Strategy and plans

The research strategies of the university, faculties and schools are captured in annually updated documents with shared structures and themes. University strategies that emphasise impact within the research goal include *ensuring that translational research is given parity of esteem with basic research*, and within the social responsibility goal that we *advance public engagement with science and technology*. The university agenda sets the tone and provides a structural framework for more specific objectives and actions in faculty and school plans.

During the REF period, *the strategy of the unit has been to establish mechanisms that cover the*

full spectrum of activities of relevance to impact, from public engagement, through creation and management of relationships with commercial organisations, to commercial collaborations and exploitation of research results. To take these in turn

- In *public engagement*, we have roles within the school for a public engagement coordinator and a schools coordinator, who have been given the time and resources to establish and run high profile activities, such as our computer animation competition.
- In *relationship management*, our external affairs office has taken overall responsibility, for example by establishing an industry club as a context for strengthening industrial engagement in teaching and research.
- In *commercial collaboration and exploitation*, we have fostered the growth of research that is collaborative with industry through our research support manager and EU coordinator, with rapid growth in EU projects, technology transfer awards and industrial funding of research.

Having established broad based mechanisms that facilitate different types of impact, our strategy is increasingly *to ensure that opportunities for impact are systematically explored and followed through within research groups*. To bring this about, we have identified the benefits of a virtuous circle, whereby basic research is applied in challenging applications, which in turn identify open issues that inform additional basic research. Several examples of this virtuous circle have emerged organically, for example in medical imaging and e-Science, and we want to ensure that this model is nurtured where it exists and fostered more widely.

To do this, we plan to:

- document the key features of the virtuous circle at a unit level, to provide a model that is informed by examples of good practice, describes how the mechanisms described in Section b can be applied at different points, and makes barriers to success explicit;
- run unit conferences in which all research groups explore the extent to which their activities already benefit from the virtuous circle or could benefit from a more integrated relationship between core and applied research, and identify requirements that would help to develop the approach in different areas; and
- identify opportunities for improving the mechanisms that the unit has in place for the spectrum of impact activities from Section b, reflecting these and impact plans from research groups in future school plans.

We anticipate that the virtuous circle model will help to systematically identify places where there are opportunities for public engagement, commercial exploitation and new industrial collaborations. For example, at reviews of research groups we might: encourage the presentation of a poster or demonstration that would most effectively communicate the results of the group to a wider audience, and provide support from the external affairs office for refining outstanding examples; invite staff from the university commercialisation company UMI[3] to participate in a panel that reviews dragons-den style pitches on the most promising commercialisation ideas; and identify areas of research that align with the principal interests identified within the Industry Club, where there might be potential for new collaborations.

d. Relationship to case studies

This section briefly relates the case studies to the Approach to Impact material from Section b. (i) *Dynamic binary translation for virtualisation*: a spin-out company was created to commercialise the techniques developed, with the university exploitation company providing support, for example through funding and applications for patent protection. (ii) *Interactive Construction of 3D Models from Digital Images*: widespread interest in the technology was established through an open source release, subsequent to which the technology was licensed to a start-up with UMI[3] support. (iii) *Intelligent Pricing Decision Support Systems*: a spin-out company was created as the mechanism for refining the decision support technologies, which played a bridging role between users and university researchers. (iv) *OWL – an Ontology Language Standard with Sound Logical Underpinning*: open source software systems demonstrated research results in practice, which informed and validated *de jure* standards. (v) *Active Shape and Appearance Models*: spin-out companies were created either to commercialise specific techniques, or to support ongoing commercial engagement with the research activity, with support from UMI[3].