Institution: University of Oxford

Unit of Assessment: 11 (Computer Science and Informatics)

(a) Context

Over the past decade, the Department of Computer Science at the University of Oxford has been transformed from one whose focus was primarily theoretical to one whose research profile runs the gamut from pure theory to deployed applications. Most research in the department and in the Oxford e-Research Centre (OeRC, which forms a small part of our submission under UoA11) has either already demonstrated significant impact or now has the clear potential for significant impact. The department has delivered **economic impact** (e.g., spin-out companies); **impact on practitioners and professional services** (e.g., development of international standards); and **health impact** (e.g., work with the US Food and Drug Administration on computational models of new drugs and treatment regimes). The department seeks direct impact in all of the following application-oriented research areas: Automated Verification, Computational Biology, Information Systems (Databases, Knowledge Representation and AI), Programming Languages, and Security. The bulk of the research in the department is focussed around these themes, as described in REF5. In addition, the Algorithms theme and the Foundations, Logic, and Structures theme provide rigorous theoretical underpinnings for the above problem-oriented research themes, and offer longer-term impact opportunities of their own (e.g., in finance, economics, and quantum technologies). The OeRC is focussed on developing the use of computing technology across a wide range of application areas including energy, digital curation, and radio-astronomy.

(b) Approach to impact

Our approach to impact is based around the following key principles:

- *Embedding the impact agenda into our staffing strategy.*
- *Embedding impact into the development of our research themes.*
- *Developing impact through direct collaborations with users.*
- *Embedding the impact agenda into our research environment.*
- *Public engagement and awareness of impact.*

Embedding the impact agenda into our staffing strategy. As described in REF5, the highly decentralised nature of Oxford's resourcing model, coupled with the fact that the department is substantially in surplus, enables us to hire staff in areas that address the immediate needs of industry, commerce, and government; it also allows us to invest strategically in areas that have longer-term impact potential. We give academics specific credit in calculating their loads (teaching, examining, and administration) for impact-related activities, and we have recently given both sabbatical leave and extended special leave to academics developing spin-outs (e.g., Professors Oege de Moor and Stephen Pulman). The need to carry out research with impact is embedded within our recruitment and promotion processes: candidates for academic positions at all levels are evaluated on their previous and planned impact, and impact is explicitly a criterion when evaluating academic promotion cases. We appoint Visiting Professors from industry to help keep our teaching and research relevant; we currently have Stefan Murer of UBS and Stephen Emmott of Microsoft. In addition, Luca Cardelli has taken up a joint Microsoft-Oxford Royal Society Research Professorship in the department. Finally, Oxford University's Mathematical, Physical, and Life Sciences (MPLS) Division – of which Computer Science is a part – has initiated a range of schemes under which awards are made to individuals who have contributed particularly to the impact agenda. In this UoA, Professor Tom Melham was the recipient of such an award in 2013.

Embedding impact into the development of our research themes. As described in our REF5, research themes within the department are continually renewed and refreshed. This has enabled us to develop research themes that directly engage with the impact agenda. The most important single example of this aspect of our impact approach has been the establishment of the *Oxford*

Cyber Security Centre, a major new initiative that was created as a direct response to the pressing needs of industry, government, and society to address the enormous and rapidly growing problems associated with cyber security that have become so apparent in the age of the internet. The Computer Science Department has performed research in security for many years (notably the work of Professors Gavin Lowe and Bill Roscoe and their group on cryptographic protocols and their verification). However, by 2010/11 it had become clear that a co-ordinated approach to security research and its impact was required, and so the department created a new research theme in this area (led by Bill Roscoe). Professor Sadie Creese was appointed to this theme in 2011, and four subsequent academic appointments have been made to reinforce the theme. Although it is led from Computer Science, cyber security demands much wider expertise, and so the Cyber Security Centre was established (with Creese as Director). This highly interdisciplinary initiative involves the Department of Computer Science, the Oxford Internet Institute, OeRC, Oxford's Saïd Business School, the Blavatnik School of Government, and the Oxford Martin School. The Centre's mission is to become a "one stop shop" for all aspects of security, from the highly technical and mathematical through to security management and practice. Industry and government experts were involved in planning the centre, and an advisory panel was established, chaired by Baroness Pauline Neville-Jones. After the Cyber Security Centre was established, Oxford was recognised as a Centre of Excellence in Cyber Security by GCHQ, and was later awarded both seed funding by the FCO to establish a "Capacity Building" centre for the government, and an EPSRC-funded CDT for Cyber Security, admitting its first intake in 2013.

Developing impact through direct collaborations with users. Over 60 distinct companies have funded or collaborated in our research projects since 2008, providing over £3M of direct funding and a substantial amount in indirect contributions. These include computer industry giants (such as Google, Microsoft, and Yahoo), SMEs (such as Verum and Lixto), defence companies (such as BAE, QinetiQ, and Northrop), and well-known companies in other domains (such as BP, AstraZeneca, GlaxoSmithKline, EDF, and the Ordnance Survey).

Oxford University has a well-established infrastructure for supporting the exploitation of University IP and the establishment of spin-out companies. In particular, Isis Innovation Ltd was founded in 1988 as a wholly-owned subsidiary of the university with the specific aim of supporting academics in developing the impact of their research. As of 31 July 2013, Isis had 29 active "projects" (managing particular pieces of IP) for Computer Science and OeRC. The following spin-outs involving staff submitted in UoA11 arose over the REF2014 period: Colwiz (web based support for research), TheySay (sentiment analysis), and Semmle (program analysis), with several more under development. Five further Isis spin-outs led by other UoA11 staff and students were launched in the REF2014 period; two more are under development.

A related route to impact through interacting with users is via Open Source. A large number of pieces of software developed at Oxford have been released under Open Source, including PRISM and CBMC (verification), Chaste (biological modelling), MayBMS (probabilistic database management), and HermiT and ELK (OWL reasoners). We also contribute to other open source developments such as BOINC (see case study [5]) and Debian.

Standardisation initiatives involving research provide another natural route to impact. Examples of our involvement in standardisation efforts throughout the REF2014 period includes work on the CellML standard for the definition of models in the biology domain (http://www.cellml.org/); the work of OeRC on supporting the Oxford Text Archive and British National Corpus (http://www.natcorp.ox.ac.uk/); and work with the W3C Consortium on the OWL 2 Ontology Language (http://www.w3.org/TR/owl2-overview/).

We constantly seek to nurture new industrial partnerships, and to this end we hold annual "Industry Days", which showcase departmental research to potential industrial users. These days are typically attended by 80-100 industrial participants and highlight 25-30 items of research. These are supplemented by our industry newsletter *Inspired Research*, which we have published since 2010 (see http://www.cs.ox.ac.uk/industry/public/newsletter.jsp). Oxford encourages academics to undertake consultancy work based on their research, both by a provision that automatically allows them to do 30 days per annum without reduction in salary, and by helping them find and organise

this work through Oxford University Consulting, part of Isis Innovation Ltd. Academics in this UoA have reported over 750 days' consultancy in the period since 2008, for organisations such as EDF, BAE, Intel, the NHS, Verum and TATA.

Embedding the impact agenda into our research environment. Our aim is to foster an environment in which world-leading research flourishes all the way from inception to end use, and where the pursuit of impact is an integral part of academic life. The key mechanisms we use in the department to create such an environment are described below.

First, the department has long had an External Advisory Board consisting mainly of industry experts, which advises the Department on strategic directions to keep our research and teaching relevant to the needs of industry, commerce, government, and society. Individual members of the panel also provide valuable links for us. Initially chaired by Martyn Thomas CBE FREng (founder of Praxis), it is presently chaired by Graham Spittle CBE (IBM).

Second, an important source of impact arising from our research environment is through our Software Engineering Programme (SEP), which offers part-time MSc programmes in Software Engineering and Security to software engineers working in the most demanding industrial contexts (see case study [1] for a concrete example of how our interaction with SEP users delivered impact). SEP initially emerged from a programme of training developed by the Department for IBM. SEP contributes to our impact environment in two ways. On the one hand, it gives a direct route for feeding our research results into industry: about half of the modules are based wholly or in significant part on UoA research done since 1992, and this material is delivered to professionals in a position to directly deploy these results in state of the art software engineering environments. On the other hand, SEP provides a route through which our researchers can engage with software engineers in cutting edge domains, prompting new research questions and directions. Since its launch, SEP has grown steadily, to the point where there are now over 300 students enrolled. Since its foundation the programme has had over 1,000 registered students, from hundreds of organisations.

Third, staff from this UoA are able to take advantage of the many opportunities provided by the large and rapidly growing research and innovation ecosystem both within the University of Oxford and also within the Oxford region. Three key examples are as follows:

- The *Oxford-Man Institute of Quantitative Finance* is an interdisciplinary centre founded in 2007, with funding currently committed to 2017, researching areas relevant to the finance industry. Cumulative funding for the Oxford-Man Institute to date exceeds £25M. Computer Science has been actively involved from its inception, for example by demonstrating to industry the potential of massive web data extraction for improving financial predictions.
- The *Bristol-Oxford Nuclear Centre* was launched in 2012 as an interdisciplinary and inter-university resource in nuclear technology, with Computer Science being involved through research on autonomous and safety-critical systems. Our involvement in this centre led, for example, to the development of collaborative links to Rolls-Royce Plc.
- Professor Jim Davies from this UoA is the Director of the *Oxford NIHR Biomedical Research Centre Informatics Programme*, leading the development of the data architecture for Genomics England Ltd, the Department of Health company responsible for the UK 100,000 genome project. His team is located on the medical campus, delivering new infrastructure for research relating to cancer, infectious diseases, and cognitive health, integrating data and providing services across Oxfordshire and the Thames Valley, and making use of semantic and model-driven technologies. This engagement between Computer Science and Medicine is key to the Big Data Institute at Oxford, part of the £90M Li Ka Shing Centre for Health Information and Discovery.

Public engagement and awareness of impact. As can be seen from the BOINC case study, we have played an important part in the movement to engage the public in science using their own computers and the internet. In addition, staff are encouraged to engage in awareness/engagement opportunities relating to impact, and to this end professional media training is made available to them. The Cyber Security Centre is frequently asked to comment in the media about the issues of

public interest that arise in that domain, and staff from this theme have given evidence at a number of select committee hearings in support of national policy making.

The Computer Science and OeRC websites are regularly updated with items highlighting the impact of our research. Stories are also placed with the media by a Publicity Officer, who also liaises with the University Press Office; in April and May 2013 alone we logged 40 items of media coverage of our research work.

(c) Strategy and Plans

Our strategy for impact is largely embodied in the key principles described in section (b). In addition, our post-REF2014 impact strategy will be informed by two overarching strategic goals:

- *Impact through interdisciplinarity*; and
- *Development of impactful research themes.*

With respect to interdisciplinarity, Oxford University's MPLS Division, of which we are a part, has developed a research strategy focussed on a set of interdisciplinary research themes, including many that are relevant to this UoA. Chief among these are autonomous systems, cyber security, big data, and machine learning. The impact agenda was one of the major drivers behind the development of these themes. Apart from the cyber security activities described above, we have established collaborations with other Oxford departments around these themes in the areas of autonomous systems, intelligent information systems, and synthetic biology. We are also forming an interdisciplinary centre in machine learning. To facilitate further impact opportunities, we are currently appointing a Senior Business Development Manager in ICT, with the specific remit of making links between University research and industrial needs.

With respect to the development of impactful research themes, we foresee major opportunities arising from the rapidly growing importance of cyber security, big data, and e-commerce, and the increasing adoption of verification and ontology technology by government and industry. It is certain that computing and IT will play an ever more important role in medicine and the study of biological systems, with medical applications playing a major part in our future impact. We plan to make further appointments to pursue this. Our Computational Biology theme has developing impact arising from its work in modelling organs (particularly the heart) and from tissue modelling (including cancer), including Chaste, a major Open Source software project in this area developed in collaboration with major pharmaceutical companies (including GlaxoSmithKline and AstraZeneca). The theme is also developing impact from its work on the in-silico screening of proposed drugs for potential cardiotoxic effects and is influencing policy at the US Food and Drugs Administration. Computer Science has a huge amount to offer to the design of IT systems used in healthcare, whether in security, creating novel applications, or handling clinical data in patient records or clinical trials. We anticipate major growth in the collaboration with Medicine led by Davies and detailed above, and, moving forward, an initiative that will transform the management of NHS data in Oxford and beyond.

(d) Relationship to case studies

In what follows, references such as "[1]" correspond to the numbers at the end of case study titles. Two case studies [3,4] came from the establishment of companies by members of the UoA developing their research. Four case studies [2,6,7,8] resulted from collaboration with large companies, and are examples of the close and sustained interaction with business that we foster and consider core to the discipline. Case study [1] arose because the founders of the company encountered Oxford research as SEP students, and developed a novel way of using it, evidencing the relevance and broad utility of our research. Case study [5] arose from collaboration between Computer Science, OeRC, and Physics, and is evidence of our public engagement and open-source work.