Impact template (REF3a)

Institution: University of Bristol
Unit of Assessment: 11-Computer Science and Informatics

a. Context

The key strength of Computer Science at the University of Bristol is the wide diversity of research fields and methodologies it embraces, each of which lends itself to achieving impact, in a variety of different ways. We engage with a wide range of partner industries (from finance to micro-electronics to media), each demanding different approaches for enabling impact. Almost all research conducted within the UoA is either associated with external industrial collaborators, or influenced and informed by them, with a view to delivering impact. All Research Groups have an extensive portfolio of industrial projects and partners who they engage with regularly and who monitor their work closely.

In some fields, greater impact is achieved via patenting, in others via standardization or direct technology transfer to users, and others still via providing consultancy and advice, or by interaction with advisory bodies, and (in selected cases) through the formation of spin-out companies. Our strategy is, therefore, adaptable and dynamic; responding to different opportunities and possibilities appropriately. During the REF period one can see different impacts, some direct (as in spin-out activity) and some more subtle and long term (as in work on applications of Computer Science to foundational questions in biology and medicine).

The UoA reorganised its research activities after RAE2008 to provide a smaller number of more focused Research Groups; motivations for this included the wish to increase the ability for Groups to improve the follow through on their research activities, to share best practice, and so to increase the overall impact of their work. Subsequently, each Group is referred to by the following shorthand BIG (Bristol Interaction and Graphics), CG (Cryptography Group), ISL (Intelligent Systems Laboratory), MG (Microelectronics Group) and VIL (Visual Information Laboratory).

b. Approach to impact

The UoA has the benefit of a number of staff who have considerable industrial experience (i.e.> two years), prior to joining the UoA, including **Achim**, **Bull**, **Calway**, **Coyle**, **Cliff**, **May**, **McIntosh-Smith**, **Mirmehdi**, **Preist**, **Smart**, **Tryfonas**, who together bring over 100 years of industrial experience between them to the UoA's activities. **Bull**, **Cliff**, **Gregory**, **Martin**, **May**, **Pradhan**, **Smart** have also, between them, 75 years of experience for serving on boards of directors of companies. These staff bring their contacts, relationships and expertise to bear on all work in the UoA which is particularly relevant for issues related to enhancing impact.

The various types of impact the UoA achieves are now outlined. Deliberate focus is placed on specific examples which are not represented by the impact case studies, so as to highlight the wide ranging influence of impact.

General Industrial Links: Computer Science's research is augmented by various industrial links ranging from joint appointments and visiting fellowships, to direct sponsorship of students, to joint research projects and participation in collaborative networks. For example, **Martin** holds an 80% appointment with BT. Conversely, IBM's Rodric Yates and BT's Ben Azvine hold Visiting Fellowships which are partly spent at ISL, whilst Microsoft's K. O'Hara holds a Visiting Professorship with the BIG Group.

At the Group level, research collaborations with the following companies (amongst many others) have been active over the REF period, resulting in joint work, funding, or technology transfer:

– BIG: Autodesk, Microsoft, Nvidia, Smart, and Texas Instruments;
– CG: Barclays Bank, Cryptomathic, Cybernetica, EMVCo, Galois Inc, Google, Hewlett-Packard, IBM, Infineon, Mastercard, Microsoft, Orange, Partisia, Silicon Basis, and Trend Micro;
– ISL: BT, General Dynamics, GCHQ, Google, Nokia, Scottish & Southern Energy, and Western Power Distribution;
– MG: AMD, Apple, ARM, Broadcom, Cadence, ESA, IBM, Infineon, Intel, Imagination Technologies, Mentor Graphics, Nvidia, Samsung, STMicroelectronics, Xilinx, and XMOS and

– VIL: Aardman Animation, Arkive, Arri, Backflip, BAe Systems, BBC R&D, DSTL, ITV, Jaguar LandRover, ProVision Communications, QinetiQ, RFEL, Samsung, and Toshiba.

In addition, **Cliff** has served as Director of the UK's LSCITS Initiative from 2005, and in the period since 2007, he has been involved in interactions with a number of major companies and public-sector organizations. These include BAE Systems, the Bank of England, BT, Hewlett-Packard, IBM, the NHS Information Center, Rolls Royce, and Thales; as well as the UK government's Home Office and Office for Science.

Impact Via Advisory Bodies: The UoA aims to achieve impact by working closely with external advisory bodies including governmental, funding agencies, and other third parties. **Cliff** regularly works for the UK Government, including the Foresight unit in the Office of Science and the Department of Children Schools and Families. **May** sits on the board of numerous digital economy initiatives and advises the Royal Society on related activities. Both **Smart** and **Tryfonas** are members of the academic liaison panel of the Information Assurance Advisory Council (IAAC). **McIntosh-Smith** is the only computer scientist in the project working group leading EPSRC's £43M next-generation high performance computing procurement, Archer; he also sits on the TSB's Software Engineering Working Group, and is an invited Member of the Numerical Algorithms Group Ltd's council of academic advisors. **Eder** sits on the TSB's Energy Efficient Computing steering group and **Bull** is advising TSB on its future imaging strategies.

Standardization: Crucial input continues to be provided that assists authors of industrial standards. Exemplars are provided by the IEEE 1363.3 standard on Pairing Based cryptography (see **REF3b: CRYPTO**). The influential Algorithm and Key Size Recommendations document produced by the ECRYPT Network of Excellence has been edited by **Smart** from 2008-2012. The follow up document, also edited by **Smart**, is funded by the European Network and Information Security Agency (ENISA). This document series feeds into a number of company's cryptographic decision processes, and is referenced by a number of EU directives and member state definitional standards.

The VIL has contributed to standards on HDR extensions, with the BBC, to the next video coding standard (H.265-HEVC) (**Bull** and **Agrafiotis**). **McIntosh-Smith** is a member of Khronos and is helping design the OpenCL 2.0 parallel programming model with many-core processors, as well as one of the first members of the new Heterogeneous Systems Architecture (HSA) Foundation.

Technology Transfer: Through their strong links with UK MoD and DSTL (via the DIF-DTC and UDRCs), **Calway** and **Mayol-Cuevas** have delivered significant impact in sensor processing (SLAM licences to Thales, Intelligent Micro-Air Vehicles), with DSTL and Blue Bear, and fusion (exploited by RFEL in 2012), and with Samsung Korea for their flagship humanoid robot project; further SLAM exploitation is described in [**REF3b: SLAM**]. In addition **Achim** and **Bull** have delivered an optimised image and video enhancement toolbox to General Dynamics and **Agrafiotis** and **Bull** have delivered optimised air-ground video link solutions to MBDA.

Patenting: Patenting is performed only in situations where a clear commercial case exists; or where the work is conducted with organisations for which patenting is the business norm. Despite this limitation, patent licenses have been granted to ProVision Communications for a number of technologies [see **REF3b: Provision**]. In addition, US Application 12732006 has been licensed to SQR Systems Limited (a start-up company by a PhD graduate from VIL), and **Martin's** work with BT has led to three granted patents and four under review within the 2008-13 period.

Spin-Outs: Three established academic-led spin-outs (Identum, ProVision and XMOS) are described in detail in REF3b. A recent spin-out is Dyadic Security. Other spin-outs from Computer Science have resulted from (undergraduate and postgraduate) student led research and include: Overlay Media (bought by InMobi), SnapFashion, and SQR systems. Former student and CEO of SnapFashion (Jenny Griffiths) was recently nominated for Computer Weekly's "Most Influential Woman in IT" award for 2013. These spin-outs are aided by ongoing involvement in the SET-Squared partnership; which provides advice and incubator space for new technology start-ups.

Providing Consultancy and Advice: Since the last RAE, within the CG, **Smart** has provided

consultancy to a number of companies (for example EMVCo and Visa). **Tryfonas** has acted as expert witness, in court, for a variety of organisations including Cardiff Trading Standards, and has provided expert advice to the Metropolitan Police as external consultant. **Warinschi** acts as one of a handful of University Liaison Advisors to the Trusted Computing Group, and **Tryfonas** and **Smart** have been appointed to the list of experts for ENISA for the next three years. In ISL, **Cliff** has worked with various financial institutions in the City of London and since Jan 2012 has served as an expert witness in a long-running (and on-going) IP dispute conducted in the Chancery Division of the London High Court. In the MG, **McIntosh-Smith** has provided consultancy on emerging many-core computer architectures and their potential for impacting high performance computing to a wide range of companies, including ARM, GCHQ, NAG, AWE, Cresset BioMolecular Discovery, Red Oak Consulting, and ESROE. **May** has provided consultancy for Hewlett-Packard, Picochip, Atlas Venture, Amadeus Capital Partners, TTP Ventures, Cazenove Private Equity and Quester. He also sits on the board of 3C Research, a Bristol innovation commercialization vehicle. In the VIL, **Bull** has provided consultancy services to ProVision (see **REF3b: Provision**). **Mayol-Cuevas** has acted as a Senior Advisor to TrakMark, **Mirmehdi** was a Technical Advisor to Reckitt Benkiser Plc and Backflip Ltd, **Subramanian** is an advisor to Rubin Anders Scientific, and **Mayol-Cuevas** and **Calway** have provided consultancy on SLAM to ASL (see **REF3b: SLAM** and [**Mayol-Cuevas-2**] for more detail).

End User Engagement: A key method of grounding research to obtain impact is by executing one's research with end users; this is typified by the work of the BIG group. The Group's research is performed either directly in deployment settings or with 'gatekeeper' organisations that provide access to the opportunities of real settings. For example, research undertaken in UK and Indian classrooms to understand the educational and cultural challenges posed by new forms of multi-touch surfaces, or by collaboration with clinical psychologists to develop intervention strategies that fully integrate computer games [**Coyle 1-2**]. Work that has had direct impact on society includes that done with the Guardian News and Media Sustainability Team [**Preist-1**]. Another example is **Fraser** and **Cater**'s work on the "University of Local Knowledge" project with Knowle West Media Centre (Bristol), the BBC, and the Arnolfini Gallery (Bristol).

Public Engagement: A key method of achieving impact, for the UoA, is via public engagement, as a means of showcasing research to a wider audience. All areas of the UoA have a strong track record in public engagement through television, radio, lectures and displays. Of particular note is the animal biometrics work [**Burghardt-1,3**] [see **REF3b: VAB**]. Other media highlights have included coverage of **De Bie**'s work on predicting the hit potential of pop songs (covered in national and international press, radio and TV). Also included, is work [**Cristianini-2**] on event detection in Twitter feeds (covered on BBC TV and Radio, as well as national press and other outlets). **Cliff** regularly gives lectures as part of "GCSE Science Live" to up to 2000 year 10-12 students at a time.

Support of Staff To Achieve Impact: This UoA has appointed an academic School Impact Director, who works with all staff to explore partnership and funding opportunities. Individual Research Group meetings focus on pull-through of research outputs into development of successful impacts and opportunities. Some Groups are also supported by a specific set of Industrial Advisory Boards (IABs). The CG has created a dedicated IAB consisting of distinguished security professionals representing companies such as Detica, Hewlett-Packard, Intel, Microsoft, Trend Micro, as well as two security consultants and a representative of GCHQ. The GCHQ representative acts as an academic liaison advisor to the University as part of its Academic Centre of Excellence in Cyber Security Research (ACE-CSR) status. A similar IAB is in the process of being set up for the ISL. The VIL regularly receives advice and guidance from the IABs of the Electronic and Electrical Engineering Department and the Centre for Doctoral Training in Communications. The Faculty of Engineering also has an Industrial Liaison Office to help facilitate new and emerging industrial relationships.

Use is made of various funding sources to enhance impact; from Knowledge Transfer Partnerships, to EPSRC support, to MOD CDE calls, through to secondments (**Eder** and **Nuñez** were awarded Royal Academy of Engineering/Royal Society Industrial Secondments in the REF period). As can be seen from REF3b, use is also made of venture capital to support spin-outs.

Much impact, however, is done in an unfunded manner, or via standard research projects, by providing expert advice to Governments (e.g. in relation to financial markets [**Cliff-2**]), by providing deliverables which influence policy (e.g. the ECRYPT/ENISA document mentioned previously), or by collaboration with industry to develop products or create international standards (e.g. the work mentioned previously).

University Support to Achieve Impact: In addition to administering specific impact related projects and funding streams, the UoB's Research and Enterprise Development (RED) team provide support, and funds, for development of impact in a variety of ways. Interaction with RED is on an almost daily basis; in particular, exploiting their expertise in the preparation of proposals (especially pathways to impact plans), briefings by their research commercialization team, by support for patenting and licensing, and by engaging with their contracts teams in negotiating and finalising agreements. The UoA has a dedicated team of subject specialists within RED in all these fields, and staff regularly attend training sessions run by them. RED also hosts an Enterprise Education team which works to encourage, develop and embed the skills required for Enterprise and working with students and staff, both inside and outside of the curriculum, to support enterprise education. Impact is celebrated across the University by the Vice Chancellors Award for Impact.

c. Strategy and plans

The UoA aims to continue its broad spectrum approach to impact. Computer Science's strategy can be summarized under the following three subheadings.

Taking Advantage of Opportunities to Commercialise Research: Some examples of research in the pipeline which Computer Science expect to lead to significant industrial impact within five to ten years include haptic inputs/active tables (BIG), computing on encrypted data (CG), financial markets policy and big data (ISL).

The UoA will build upon its recognition by EPSRC and GCHQ as an Academic Centre of Excellence in Cyber Security Research. Computer Science has already used this new status to set up, with the help of BIS, GCHQ and Hewlett-Packard, a regional grouping of security companies with the aim of encouraging greater collaboration and information sharing across the sector in the west of the country. This initiative also feeds into plans to create a SME incubator unit in the area of CyberSecurity, based in Bristol, championed by RED and the CG.

Developing the External Awareness of the Research of the UoA: Computer Science will further raise awareness of University expertise and IP through influential positions, and increasing "brand" awareness of the UoA's activities at Bristol. For example, **Bull**'s Chairmanship of the BBC Anchor Innovation Group. Computer Science will place increased emphasis on showcasing its technology. As an example of our wider strategy is the new "Bristol Immersive Technology Laboratory", which will include a public showcase of emerging BBC and VIL technology that will inform both public and industry regarding future video acquisition, delivery and display formats.

A number of Groups are making use of social media technologies (Twitter, blogs, etc.) to increase awareness of their research outputs to a wider community; and this will be continued and extended. Computer Science's work on public engagement activities will also continue; with more emphasis being placed on media training for staff.

Staff Development: The School Impact Director will continue to work with Heads of Group, Head of School and other parties to foster a culture in which impact activities are firmly embedded in all staff activities; enabling staff to engage fully with the potential impact of their research throughout the lifetime of their projects and beyond. The key goal, looking forward, is to capitalize on extensive forms of industrial interaction; and turn them into even more cases of lasting impact.

d. Relationship to case studies

The five Case Studies chosen have been selected to highlight, in detail, Computer Science's diverse types of impact. In particular, spin-outs (Case Studies **ProVision**, **CRYPTO**, and **XMOS**), tech transfer (**SLAM**), public engagement (**VAB**), impact on industry wide standards (**CRYPTO**).