Institution: Imperial College London
Unit of Assessment: 11 Computer Science and Informatics
a. Context

Research in the Department of Computing at Imperial not only covers the breadth of the core discipline, but also reaches out through interdisciplinary collaborations to tackle the College's strategic priorities for impact and value nationally and globally. Our research profile reflects our belief that computer science can and should play a major part in advancing the field, in securing the economic health of the UK, in tackling key global issues and in contributing to improvements in the quality of life. The sectors on which we exert impact include:

- **Industry:** Our relationships are with companies in Information Technology, Manufacturing, Defence, Energy, Life Science, Healthcare, Finance and Security. We engage with them through collaboration (e.g. joint research centres with Intel, NEC and Syngenta), development of start-up companies (e.g. IXICO and Maxeler) and patenting and licensing. Between 2008 and 2013 we have engaged in research collaborations with more than 50 companies in the UK and overseas. Substantial indirect impact arises from PhD students and researchers who take up employment in industry as a result of their expertise from research in the Department.
- **Public Health:** Our research on new technologies for diagnosis and intervention has been adopted by clinicians and has led to improvements in patient care in hospitals in the UK and overseas. Our research has been used in large-scale clinical trials within the NHS (see IXICO case study). Since 2008, our research has led to the formation or development of six health-related start-up companies – Cardiovascular Imaging Solutions (CVIS), EquinoxPharma, InforSense, IXICO, Sensixa and Smart Surgical Appliances.
- **Public Policy, Engagement and Outreach:** The Department is actively engaged with the UK government and internationally in order to inform and shape public policy, in particular in the areas of Defence and Security (see **section b.4.ii** for details). Our research is actively disseminated through public lectures, exhibitions, media and outreach (see section **b.4.iii** and **b.4.iv** for more details).

b. Approach to impact

The Department has made maximising the impact of its research on industrial, government, the health sector and the wider community a key priority. This is in accordance with Imperial's publicly stated mission: "*To develop our range of academic activities to meet the changing needs of society, industry and healthcare*". To fulfil this mission, the Department employs a wide range of mechanisms to support the dissemination and transfer of knowledge and technology:

1. Stimulating Intellectual property generation and commercialisation

The creation of intellectual property and the commercial exploitation of research are integral to our activities to maximize impact and are facilitated and supported via the following mechanisms:

i) Startup Companies and Intellectual Property generation: The Department actively encourages staff to exploit their inventions. Imperial College has a pipeline agreement with ***Imperial Innovations***, a specialist university spin-out company listed with a market cap of £300M in June 2013. Imperial Innovations provides staff and students with advice and support on intellectual property generation, protection, technology transfer, company incubation and investment. An **Innovation Fellow** (*Knottenbelt*) acts as liaison, giving advice and proactively identifying promising work. Since 2008 staff from the Department of Computing have registered over 66 invention disclosures, filed 24 patents, established 5 license agreements and founded/developed eight startup companies: CVIS, EquinoxPharma, InforSense (merged with IDBS), IXICO, Maxeler, Monoidics (recently acquired by Facebook), Sensixa and Smart Surgical Appliances. The Department is also a prime contributor to ICStartup.com, which facilitates the creation of student and staff ventures using Imperial's existing entrepreneurial network and Digital Accelerator Programme.

ii) Staff Encouragement and Reward: Our academic staff are encouraged to spend 20% of their time on outreach/impact related activities. Such activities are considered alongside research and teaching contributions in annual appraisals and cases for promotion. Impact is also a key component of our mentoring scheme for PhD students, post-docs and junior academic staff.

2. Engagement and collaboration with Industry

i) Corporate Partnerships Programme (http://tinyurl.com/ctmwv7y) is designed to promote the relationships with companies interested in sharing our expertise in cutting edge computing research. The programme has more than 30 companies as members including ARM, BAE, Barclays, Facebook, Google, IBM, Intel, Ocado and Microsoft.

ii) Industrial Liaison Board (http://tinyurl.com/l57tf5m), established in 2008, identifies and tackles shared strategic issues through open dialogue with Imperial's industrial client base. Board members are from Amadeus, ARM, Betfair, Deutsche Bank, DSTL, Formicary, Google, HP, IBM, Imperial Innovations, Mind Candy, Morgan Stanley, Ocado, Orange and the Chartered Institute for IT (BCS). The board advises the Department on the industrial relevance and suitability of its teaching and research strategies. Furthermore, it helps to identify opportunities for commercialisation of research and to explore other ways in which the Department can foster a higher level of industry involvement in its education and research programmes.

iii) Industrial Collaboration: Most of our research includes collaborations with industry, e.g. through partnership in EPSRC & EU projects, RAE/Industry funded fellowships, and direct industrial funding. We give three examples. *Calcagno's* bug checking software was used by the startup Monoidics (*Calcagno* is a founder) with customers such as Airbus. Monoidics' success is evidenced by the recent acquisition by Facebook (http://tinyurl.com/pj5aj7j) of their assets. *Yoshida's* session type research has been used to specify and verify business and financial protocols for web services, governance for workflows and business activity monitoring via JBoss and Cognizant. The formalization of JavaScript by *Maffeis* resulted in the discovery of numerous security vulnerabilities in major web applications, from companies such as Facebook and Yahoo.

3. Knowledge/Technology Transfer

A strategic part of our impact and outreach focuses on the transfer of research outcomes to stakeholders in industry and governments, and on the shaping of future leaders in the area of IT innovation and research.

i) Joint Research Centres: A particularly successful strategy for knowledge transfer into industry is the creation of joint research centres. The centres enable long-term, sustainable relationships with industry. One such example is the ***Syngenta Innovation Centre*** (*Muggleton, PI*), which aims to address biological research challenges of the main business sectors at Syngenta (seeds and crop protection) by applying predictive models developed in the Department to Syngenta's empirical data. Other examples are the ***Intel Collaborative Research Institute*** for Sustainable Connected Cities (*McCann, PI*) which aims to address the social, economic, and environmental challenges of city life with computing technology and the ***NEC Smart Water Lab*** (joint with Civil Engineering), which develops technologies to improve ageing water supply infrastructures to make these more efficient, robust and sustainable.

ii) PhD Students: During the REF period 156 PhD students have graduated from the Department. Almost half went on to work for industry (in addition to the 40% of our more than 200 post-docs who left). This is a potent mechanism for the transfer of our research, especially into the UK industrial base. Over 30 studentships are funded by industry and have technology transfer as part of their remit. These include CASE awards with major UK companies including ARM, Arup, BAE Systems, BAE Systems Detica, Codeplay, GSK, IBM and The Foundry and directly funded by partners including AMD, Dyson, Google, Intel, Microsoft, SAP and VMWare.

iii) Consultancy: Staff are encouraged to capitalise on their specialised knowledge and expertise by undertaking external consultancy work through ***Imperial Consultants***. Since 2008, ICON has brokered 23 consulting projects for the Department with 17 external clients including private individuals, high-tech startups, and large multinationals such as Microsoft, SAP, Sony, GSK, BAE, Dyson, Renault and Wien Energie. We have signed a MoU to set up a major new research centre with Dyson as a result of Davison's consultancy with them – see **section b**.

iv) Open source software: Our research produces software used in industry. The policy language Ponder2, (Dulay, *Lupu, Sloman*) is used by more than ten companies; the protocol language JBoss-Scribble (*Yoshida*) is used and developed by RedHat and the machine learning language Progol (*Muggleton*) is used by Syngenta, Astellas Corporation (Japan), Future Route and Equinox Pharma. We also contribute to large open source projects, such as the bug finder KLEE (*Cadar* is the chief maintainer), which has thousands of downloads and over 250 subscribers to the mailing list; and the Clang compiler's OpenCL support (*Collingbourne*, a student of *Kelly*), which is extensively used by ARM, AMD, and Fujitsu; and the performance modelling tools PIPE2 (*Knottenbelt*) and JMT (*Casale*), co-authored with institutions overseas, that have a cumulative download count of 80,000+ in the REF period.

v) Secondments: Staff are encouraged to use EPSRC impact schemes: This led to three Knowledge Transfer Secondments (KTS) grants to support secondment of staff into organisations, three PhD Plus awards to allow finishing PhD students to develop impact from thesis work, four Pathways to Impact awards and one Bridging the Gaps award.

4. Creating direct and indirect benefits to society

i) Improving public health and quality of life. Over the last decade the Department's work on health-related research has impacted healthcare and improvements to the quality of life. Six out of the eight startup companies in the Department concentrate on this area. Research funding for impact-related activities include an EPSRC Pathways to Impact award demonstrating end-to-end security of NHS patient data (*Pietzuch*) and EU eTRIKS knowledge management platform being developed for the pharmaceutical industry (*Guo*). The Department has established very close links with the Imperial College Academic Health Sciences Centre, which provides a unique route for fast translation of research into healthcare (*Guo, Knottenbelt, Pietzuch, Rueckert, Toni, Yang*).

ii) Influencing Public Policy. The Department actively engages with the UK government to shape public policy. Examples include Chair of the Lead Expert Group for the GO Science Foresight report on Future Identities (*Hankin*) and provision of advice and presentations to government departments, such as the Government Data Service (Cabinet Office) and HMRC. We have MoD funded projects that influence security policy via collaboration with CESG and DSTL (*Gardner, Lupu, Russo Sloman, Wolf,*). In June 2013 we hosted an R&D Innovations in Cybersecurity workshop (http://tinyurl.com/ongy4qq) to inform research strategy (*Huth*). Our staff (*Hankin, Sloman*) are active Executive Committee members of the UKCRC, which provides computing community responses to Government consultations. The Department is also actively engaged overseas, such as through IST Advisory Group (*Hankin*) of the European Commission DG Information Society and Media and its successor, the newly created CONNECT Advisory Forum (*Hankin*). Our advice on Smart Cities has been sought by the Greater London Authority (*McCann*).

iii) Promoting Science through Public Engagement & Outreach. Our public engagement activities seek to inspire interest, debate and discussion about our work through lectures such as: Royal Society & Royal Society of Edinburgh Turing Event (*Pantic);* National Physical Laboratory, Royal Society & Royal Institute of Philosophy (*Shanahan*); through exhibitions such as: the Royal Society Summer Exhibition (*Yang*); Generation Next Festival, World Science Festival & Cheltenham Science Festival (*Shanahan*); Imperial Festival and Imperial Fringe (*Casale*, *Davison, Faisal, Muggleton, Pantic*). We publicise our work in the media such as: New Scientist, BBC Radio 4, The Guardian, The Times (*Cadar, Colton, Davison, Faisal, Ghosh, Pantic, Parpas, Shanahan*); and through the creative use of new and social media, such as: TeD talks and YouTube videos (*Donaldson, Davison, Faisal, Knottenbelt, Pantic, Shanahan*).

iv) Other outreach activities. The Department undertakes numerous outreach activities such as talks, workshops and interactive demonstrations with schools, local societies, teacher groups, and professional bodies such as the BCS, ACM, IEE and IEEE. The Ecobug smartphone app (http://tinyurl.com/msod6f4) was developed with secondary school students (*Knottenbelt, McCann*). The Department hosts two, annual one-day Taster Courses attended by 250-300 pupils that explain to prospective students how computing lies at the heart of many new developments in society. The Departmental Open Days showcase prize-winning projects to schools and industry (http://tinyurl.com/pjgf9s8). Since 2006 the Department has hosted an annual Game and Media event (http://tinyurl.com/bok524t) as a networking event for the computer games industry.

c. Strategy and plans

Strategy to maximise impact of research

Our strategy to maximize the impact of our research is to continue to develop long-term, strategic partnerships with companies that support a common research theme. As partnerships and research mature, a 'research-to-impact-to-research' cycle develops: research produces impact, leading to further research producing more impact etc. We will continue to work across a broad range of industrial sectors, as explained in **section b** and the span of our case studies discussed in **section d**. The core element in the Department's strategy to maximize the impact of its research is the proactive support of both staff and students in realizing impact and translating research by:

- Closer interaction and advice from our Industrial Liaison Board on strategies to encourage and foster a higher level of industry impact and involvement, including expanding our well-established *Applications of Computing in Industry* lecture series programme.
- Continued support for staff to apply for KTS awards, industrial fellowships, and sabbatical leave for impact-related activities. The Department will continue to encourage impact-related activities by recognising and rewarding those who engage in the activities described in **section b**.
- Conducting regular horizon scanning exercises to identify emerging opportunities for new partnerships with industry, including those that are likely to lead to impact.

Plans to develop impact emerging from current research

We have identified several research areas in which we have particular strength and which have the potential to produce significant impact. We intend to support these through various means:

- ***Establish new strategic partnerships with Industry***: The development of the College's new campus at Imperial West will lead to new opportunities for industrial collaboration. For example, MoUs have been signed for new joint research centres with Dyson in *Robot Vision* (*Davison*) and Huawei (*Guo*) in the area of *Big Data*. *Sensor technologies* for healthcare, smart cities and water monitoring should produce new impact through our existing NEC and Intel collaborations.
- ***Focus on core CS research that addresses industrial and societal priorities:*** For example, in the area of Security the Department will be hosting the EPSRC/GCHQ Cyber Research Institute on analysing software to reduce vulnerability to cyber threats (led by *Gardner*). We are planning to develop closer links to the Imperial College Academic Health Science Centre and its associated hospitals to increase and accelerate the impact of our research in the NHS.
- ***Involvement in Translational Research Projects:*** We will engage with government programmes designed to support translation such as the EU programmes of EIT ICT Labs and the TSB Catapult schemes to translate our cities research into industry. Imperial College is an associate member of EIT ICT Labs and the Intel Sustainable Connected Cities Institute (*McCann*) is situated to work with the Future Cities Catapult.

d. Relationship to case studies

The Department has submitted six case studies in distinct areas of research. They provide evidence of the success of the different approaches to impact described in **section b**. The first case study on **Machine Learning for Agrisciences** demonstrates how impact has been realized through an industrial collaboration with Syngenta as part of joint research centres (**b.3**) and collaboration with industry (**b.2**). The second case study on **Reconfigurable Computing** illustrates how our research has led to impact in several business areas via the formation of a start-up company Maxeler **(b.1**) as well as through close collaboration with industry (**b.2**) that led to changed business practices and improved business models. The third case study in **Computational Optimization** illustrates the impact of our research on the finance and energy industry through industrial collaboration (**b.2**). The **IXICO** and **InforSense** case studies demonstrate that the commercialization of intellectual property via startup companies (**b.1**) has generated significant impact in the healthcare area. This has also been supported through consultancy (**b.3**)**.** Finally, the sixth case study on **Body Sensor Networks (BSN)** demonstrates the impact on improving public health and quality of life through novel sensing devices and technologies that have had wide-ranging impact in sport, wellbeing and healthcare (**b.4**).