Institution: Royal Holloway, University of London

Unit of Assessment: 11 Computer Science and Informatics

a. Context

At Royal Holloway, research in Computer Science, Information Security and Mathematics has been restructured during the REF period. This resulted in the Information Security Group (ISG), which was submitted with Mathematics in 2008, being designated a separate department and its staff being submitted in either UoA 10 (1 member) or 11 (6 members) according to the nature of their research. This restructuring was carried out in response to a new institutional strategy that includes foregrounding the work of ISG and responding to the shifts in the needs of research users and funders, which encourage all research units to develop a spectrum of activities that allows end-user benefits to be quantified by economic, policy, health and; society, culture and creativity impacts.

The joint submission of Computer Science (CS) and a significant proportion of ISG reflects the increased collaboration between the two departments, which has resulted in joint grant income and outputs, as well the coordination of research and third-stream activities in general.

One important vehicle for these developments is a new overarching theme of *Big Data*, which pools together our long-standing strengths in information security, machine learning, and algorithm design and analysis which are covered by the research groups Information Security Group (ISG); the Computer Learning Research Centre (CLRC); the Centre for Algorithms and Applications (CAA) and the Centre for Software Language Engineering (CSLE). The creation in 2012 of the Distributed and Global Computing (DGC) group completed the spectrum – from cloud middleware through service-oriented computing to data analytics and security. Royal Holloway thereby positioned itself as a privileged research partner for the many companies and organisations that are considering restructuring their business and decision-making processes based on data analytics as well as moving to cloud infrastructures.

b. Approach to impact

During the current REF period we have begun formulating our impact strategy and achieved:

1) Direct economic impact in the form of improvements to the performance of existing businesses and, especially in the information security area, the mitigation of potential future losses by both improved risk assessment and the design of security protocols.
2) Policy impact in the form of changes to regulations or guidelines informed by research evidence as well as engagement in policy debate and development of international standards.
3) Impacts on society, culture and creativity through (a) the enhancement of engineering-related school education *via* conventional outreach as well as the provision of Computing Diploma advanced classes developed and hosted within the unit, and (b) applications to aspects of the creative arts such as the use of textual signatures to 'blend' collaborative-written novels.
4) Health impacts from work in the elucidation of human gene maps and protein complexes.

Each established research group has achieved impact in one or more of these categories. Our fifth group, DGC, comprises staff recruited in the last 18 months; impacts arising from these appointments will be reported in the next exercise.

Our groups' intellectual property often takes the form of new algorithms or new tools that are widely taken up by industrial research labs and users, as well as by other researchers, such as (i) the developments of the Support Vector Machine theory and Kernel methods along with gene identification and protein complex elucidation techniques and tooling within the CLRC, and (ii) the Generalised LL and other generalised parsing algorithms with their associated tools, as well as agent systems, constraint solvers, and graph algorithms within the CAA, CSLE and DGC.

Not all of these impacts lend themselves to presentation as an individual case study; for instance, our parsing algorithms are embedded into tooling developed by Eindhoven University and CWI Amsterdam; these in turn are used for industrial research applications, yet it is difficult to trace explicit connections between our algorithms and business process improvements that are implemented in commercial-in-confidence domain-specific languages using our technology.

Clear impact stories however do exist, especially in the information security and machine learning

areas. CLSC produced one of the first (if not the first) open-source implementations of Support Vector Machines (SVMs). Reliable algorithms (such as SVMs) and availability of open-source software have been key enablers to the explosion of analytics and big data. The books produced at Royal Holloway on these technologies are still the reference material for the many courses that universities worldwide have mounted on Machine Learning during the REF period, including those provided on-line through, for example, Coursera.

The ISG focus has always been both pragmatic and theoretical, and this powerful symbiosis has produced clear impact. The recent recognition of ISG as an Academic Centre of Excellence in Cyber Security Research by the RCUK Global Uncertainties Programme and GCHQ, and the award of one of two national Doctoral Training Centres in Cyber Security, testify to the tangible value of its research. ISG has become a source of trusted and expert advice and has created major impact benefitting users ranging from individual companies (SMEs and global) to governments. A high-profile example was the security counter-expertise and migration-planning reviews for the Dutch government on smart transport-ticketing technology migration in Amsterdam, Rotterdam and nationally. The group's expertise also makes a significant contribution to a range of international standards such as ECRYPT cryptographic algorithm and key-length recommendations, GSM/3G Mobile Security standards and ISO/IEC standardisation.

Impact beyond academia is driven by dissemination and collaboration, which is achieved through industrial and organisational representation on the management committees of our research groups and through networking and consultation meetings including: (a) the twice-yearly ISG programme of networking dinners; (b) the ISG UK and international alumni groups that include thousands of influential information security professionals; and (c) the CS Industrial Advisory Board, which includes representatives from a broad spectrum of businesses including Microsoft, Oracle, Kalido, Investec Asset Management and Blackrock.

In addition, many collaborations begin with a direct approach from potential industrial partners who have located our work through the Web or other media. For example, Rohde & Schwarz followed up online material on the CSLE's reverse compilation tools and embarked on a project to extend the tools for use in migrating their software to new architectures. More recently, publicity for our Big Data initiative generated unsolicited approaches from organisations as diverse as British Gas, IBM, the Bill & Melinda Gates Foundation, the England and Wales Cricket Board and HCL Axon (a major SAP consultancy specialising in Customer Relationship Management). Many ISG projects have been suggested by industry or government and, given the security sensitivity of the research, there is a great deal of private communications and advice beyond published research results. Industry trends have triggered ISG developments such as the Smart Card Centre in 2002 (which has over 25 industry supporters), the diversification into security of human interfaces and social factors, as well as major thrusts into digital forensics and critical infrastructure.

Special events are organised throughout the year, which include the annual Hewlett Packard Colloquium on Information Security (now in its 24th year), the annual Smart Card Centre Open Day (now in its 7th year), industry-sponsored technology clubs (on topics such as authentication, cybersecurity, and PKI), the twice-yearly Industrial Advisory Board meetings, and the Cyber Security Centre of Excellence workshops and open-days. Members of the ISG were also instrumental in the formation of the IISP – the UK professional body for Information Security Professionals.

A variety of institutional-level services and funds support the development of impact. The Research and Enterprise Office provides legal and financial advice to departments during the drawing up of agreements and partnerships with external agencies, commercialisation, setting up of spin-out companies, patents, licenses and intellectual property rights, as well as administering the Research Strategy Fund which provides seed funding to develop research proposals for external funding bodies. It also provides support for the preparation of large multi-partner grant applications and research networking events for early career staff. Royal Holloway has two further seed funds that support commercialisation projects: the Gateway Fund supports the exploration of new ideas that have the potential to meet a social or market need; the Park Fund enables the identification of routes to market from intellectual property derived from recent research.

c. Strategy and plans

CS and ISG will continue their support for developing impact by expanding on current activities including, in addition to peer review of research proposals and funding bids, making impact a stand-

ing agenda item for departmental meetings and reviews as well as an integral component of staff appraisals.

As part of its successful bid for RCUK/GCHQ academic centre of excellence status, ISG committed to one extra engagement event each year alternating between the ISG ACE-CSR open day and the ACE-CSR workshop. The former will showcase current work of ISG to industry/government, whereas the latter will promote knowledge sharing and research collaboration between the ACEs.

A clear lesson from the ISG experience has been the importance of maintaining good alumni relations in applied disciplines, and the immense value of advanced teaching programmes that create a pipeline for future industry interaction. The general techniques of machine learning pioneered in the CLRC have well-known applications in finance and bioinformatics; more recently, machine learning has come to prominence in web-based marketing and data analysis. We are now building on our reputation for core theoretical results in machine learning and the newly acquired expertise in cloud architectures by offering new masters programmes in Data Science and Analytics, Computational Finance and Machine Learning, which naturally complement the existing well-known programme in Information Security. The existence of these programmes acts as a feeder channel for new research students and projects and because all programmes are offered with an optional year in industry, there will be an opportunity to engage with the companies and organisations where students are placed and identify where our research can have an impact on their activities.

Royal Holloway has revised its policy on consultancy to enhance opportunities for impact; the Department has appointed an Impact Officer with a remit to promote the impact culture, liaising with individual members of staff as appropriate to advise on maximising the impact of their own research and liaising with colleagues in other departments. The Departmental Impact Officer is a member of the Departmental Research Committee and a cross-faculty training workshop focused on impact is made available as part of the broader 'On Track' programme of staff researcher training.

Visibility of our intellectual property is enhanced through faculty-specific communications officers who support public engagement activities including public lectures, extensive schools contact and a week-long Science Festival of events culminating in an Open Day on a Saturday when families are invited on to campus for hands-on activities, demos, talks and live experiments in all the science departments. A Research Information System (PURE) maintains a complete publication record for each academic along with CV's, project listings and connections to blogs and other pages.

At professorial level, promotion is through a banding scheme with four elements: research; teaching; external engagement and impact; and leadership and enhancement. External engagement means contributions to the wider society, the economy or other areas of public practice. These criteria, suitably moderated are also applied at lecturer, senior lecturer and readership level. By rewarding wider engagement, we seek to ensure that the institution achieves significant impact.

d. Relationship to case studies

The work on SSL/TLS (Secure Socket Layer/Transport Layer Security) by Prof Paterson and his team was based on an international and ubiquitous standard that is relied upon by most of our industry and government partners. The analysis required knowledge of several information security disciplines: cryptography, protocol design, attack strategies and application design. The weaknesses we discovered were briefed to our partners and action was taken both in standardisation groups and through the delivery of best-practice advice to rectify the problem.

The award winning work of Prof. Mitchell shows that the ISG standards contribution is a sustained and valued research commitment over the long term, which is extremely important in information security as changes to algorithms and techniques may take many years before they are in widespread use. The specific standards are used by and relied upon by virtual all organisations that provide information security protection.

The foundational and applications work by the CLRC has had a deep influence on the teaching and application of machine learning, with applications in data analytics, biology, medicine, fault prediction and fraud detection. Data analytics in particular is a burgeoning field with significant economic impacts in retail, business-to-business and financial transactions.