Institution: University of Leeds

Unit of Assessment: 11 Computer Science and Informatics

a. Context

For more than 55 years, the School has excelled at translating world class research (3.05 GPA in RAE2008) into substantial impact. Across the UoA (organised into five research themes), we generate impact in the form of algorithms, software and online resources through dissemination, outreach, licensing and spinouts. Each theme benefits a wide range of users:

- **AC (Algorithms & Complexity):** Delivering impact in the transportation sector (see Impact CS, ICS) and now reaching out into data centre management (the latter in collaboration with **DSS**).
- **AI (Artificial Intelligence):** Making diverse multi-sector impact across advanced manufacturing, retail management (see ICS), utility services, security and education.
- **BMH (Applied Computing in Biology, Medicine & Health):** Bringing revolutionary approaches to pathology, radiotherapy & neurology, and novel solutions for patient scheduling and medical data system management, with clinicians and partners in the NHS.
- **CSE (Computational Science & Engineering):** Providing solutions to computationally demanding problems in industry (consumer products, automotive and manufacturing, see ICS), with further direct contributions to the software industry and open source community.
- **DSS (Distributed Systems & Services):** Delivering impact to major providers and users of grid and cloud systems and services, as well as to aerospace and automotive engineering.

b. Approach to impact:

Our world-leading expertise, acute awareness of end-user needs and successful track record in industrial partnerships have placed us in an excellent position to solve complex problems in high-value areas with international impact. We use extensive structures at the School, Faculty and University levels to support: **1)** the identification of partners, end-users and ongoing partnerships; **2)** innovation-driven research; **3)** proof-of-concept and commercialisation activities; **4)** outreach.

1) Partnership with end users: Our success builds both on long standing relationships and on identifying and developing new relationships with industry and with academia (see also REF5). E.g. in CSE, our >20year partnership with **NAG** – the world's largest commercial provider of numerical algorithms and services (with heavy uptake in engineering and finance) – exemplifies our approach which is founded on (i) delivering impact: a significant number of Leeds-authored routines in the NAG library; (ii) two-way training: Two PDRAs have worked directly with our NAG partners since 2008; three NAG staff did PhDs with us; and (iii) a two-way knowledge exchange: In this period, Brodlie (emeritus) was NAG's Chairman of the Board; Jimack is non-Exec member of the Board. Our >30 year collaboration with **Shell** demonstrates our ability to combine our research with delivery of highly specialised solutions: e.g., Shell's Lubricants division uses our new solvers to simulate high pressure engines. Recent support includes direct industrial funding, partnership in a Marie-Curie Knowledge Transfer project and a CASE Studentship. Also in CSE, Duke has developer access to **Kitware**'s widely used Visualization Toolkit, and has contributed visualization components. Kitware are among 5 international partners on our subsequent multifield topology project [Duke1] (EP/J013072/1, £920k). [Duke1] spurred a relationship with **Microsoft Research** (and a Microsoft-funded PhD) that rapidly led to major innovation [Duke4]; this should revolutionise Haskell software profiling and deliver indirect impact across domains.

Our >10 year partnerships, e.g. with **Rolls Royce**, **BT**, **BAE** systems, **NHS** (£3.5m since 2008) drive research and innovation in DSS: we delivered a cloud brokerage system [Djemame4] to **BT**, a Grid Applications Performance Prediction Tool, and dependable high-performance Cloud architectures to **Rolls Royce** and **Cybula** and more (see BMH below). In new partnerships, we built performance evaluation tools for cloud services [Djemame1], now exploited by the UK's no.1 cloud provider, **Flexiant** and we are creating further data management systems in partnership with Jaguar Land Rover.

In AI, our >10year partnership with the **Ordnance Survey** (**OS**) on ontology research (6 joint publications; ~£200k funding since 2008) led to the Leeds-developed open source software [Dimitrova2] for knowledge capture used by industry partners on three EU projects, and a new KTP project with **Blueclaw** [Dimitrova4]. The Mapping the Underworld (MTU) and subsequent VISTA projects, undertaken in collaboration with >20 industrial partners, led to VAULT, **the first worldwide system to deliver real time integrated utility data to industrial users** across the sector, now live in Scotland (implementation in England is projected); it won the Built Environment

category of the IET Innovation Awards 2012 (also "Highly Commended" in the IT category) and joint-first in the 2012 NJUG Awards ("Avoiding Damage"). Our follow up projects (EP/F06585X/1, EP/K021699/1 £988k, 2009-17, >40 industrial partners) will substantially extend the power of the system, incorporating dynamic sensor data [Cohn2]. Our relationship with **IDS** in MTU led to Technologies for Tunnelling and Underground Works (NMP2-LA-2012-280712: €861k, 2012-17, with **21 partners** across Europe, over half being industrial). Cognitive Vision projects with industrial collaborators (EU ~€2M) have involved software house **AKKA**, **Toulouse Airport**, **Trivisio** , **Technology-Initiative SmartFactoryKL**, **G4S**, and an Austrian care home, supported by DARPA, EPSRC & KT partnerships, e.g. with **Rinicom** on monitoring and security challenges.

2) Innovation driven research: We support staff in developing applied and translational research through funding of professional activities, strategic appointments, e.g. Head, and sabbaticals, e.g. supporting Hubbard's transition to translational cancer research; Magee to pursue R&D of his 3D histopathology algorithms; Xu to pursue new directions into energy efficiency of Cloud operations. We support an agile approach to opportunities by actively seeking new partnerships and new application domains. E.g., we approached **Procter & Gamble** (**PG**) following their successful partnership with others in Leeds, offering our expertise in numerical algorithms. This rapidly led to PG's direct investment in a new Simulation Centre (£238k, joint to SoC and Process Engineering) establishing Leeds as PG's key academic partner (for numerical simulation) in Europe. PG regularly provide mini-projects to our PGRs and recently co-funded a CASE Studentship, giving PGRs industrial experience and creating links for SoC academics with PG's R&D staff. Our support also triggered Cohn to attend EPSRC's 1st ever Sandpit, leading to MTU, and Hubbard to attend the EPSRC Maths-for-Medicine Sandpit, leading to MEDIC, a £1.2m 5-site cancer therapy grant.

3) Spin-outs, licensing and other commercialisation: Our track record in developing successful applications, from concept to product, builds strongly on SoC's history of practical applications, underpinned by cross-disciplinary collaborations and end-user input and evaluation (see also REF5). Two successful spin-outs are described in our Impact Case Studies (ICS): **Icona Solutions** (virtual environments for concurrent engineering), & **Tracsis** (scheduling solutions for transport), an EPSRC Growth Story. The 3rd case study arose from commercialisation of our AI research (**Irisys**, computer vision for people tracking), as did our latest spin-out: with the support and assistance of University's Graduate Entrepreneurship Project, SoC PhD, Olga Kubassova, span out her PhD work on MRI analysis for tumour detection, founding Image Analysis and launching its Dynamika software (used in clinical research and random clinical trials). The spin-out, winner of the Yorkshire Post Excellence in Business (University Spinout of the Year 2009) & Cisco's Everywoman in Technology ('Entrepreneur of the Year' 2012), employs 25 staff, generating a £1M turnover (2012).

Further impact from BMH also involved close collaboration with the **Leeds Teaching Hospitals NHS Trust** and the School of Medicine. The **Leeds Virtual Microscope** [Ruddle3-4], installed in St. James' Hospital, is used by clinicians for specialist training, and by UK/Ireland leading clinicians to inform new guidelines for bowel cancer screening; third party licensing is underway. Our quality assurance software for the latest generation of CT scanners [Magee1] was twice independently commercialised by **Modus** and **Aquilab** with SoC assistance. Other medical imaging software for pathologists [Magee2] was incorporated in **Aperio** software (guided by Magee as a consultant). In DSS, Quality of Service system for remote health monitoring delivered to **Rolls-Royce** [Djemame1] demonstrates ever-growing applications to engineering domains. With industrial partners, work is underway to validate the tool's readiness for further exploitation from banking to social services.

We support knowledge transfer through memberships in advisory boards and other bodies. E.g. **Kwan** was the Tracsis Director of the Board (2007-13). **Hogg** is Director of Medilink (2012-) & of the Leeds Innovation Centre (2011-); Member of the Leeds City Sustainable Economy & Culture panel and the Leeds City Region (LEP) Business, Innovation & Growth panel. See **Brodlie** and **Jimack**, above. We provide excellent training for a career in industry: 3 **NAG**, 1 **Irisys** and 1 **Icona** staff (see ICSs) did PhDs with us. ~25% of our PhD graduates since 2008 are in R&D (see REF5).

4) Impact through outreach and dissemination: We disseminate tools and research capabilities to the public, potential end-users, industry and UK government organisations, through publications, open source software and licensing. The Quranic Arabic Corpus [Atwell3] is widely-used (~1M visits) by Arabic/Quranic scholars and the general public; software for ontology creation [Dimitrova2] (developed with the OS, >1000 sourceforge downloads) is used to develop a Decision Support System for **SNCF** (see REF5). Extensive outreach activity ranges from training for using facilities (e.g. White Rose & regional N8 grids, the Leeds Powerwalls) to youth education (e.g. the

Leeds Headstart summer school builds on our unique strengths and Engineering ethos to promote Computing, its applications and its interfaces to engineering).

- **Institutional facilities, expertise and resources** support our impact strategy at every stage of the above pipeline. The University's Research and Innovation Service provides a route for staff to undertake specific consultancy projects, with a share of the income made available to staff for funding personal development. The University invested heavily in the Leeds Innovation Centre, supporting licensing [Magee3], spin-outs (Tracsis) and their continued partnership. A Faculty wide Innovation Hub serves as the point of contact for industry (offering business support, liaison services, knowledge transfer facilitation), and provides internal enterprise and organisational support for staff to apply their research and collaborate with industry. The School has a lead role in the Faculty's HEIF5 funded Digital Technologies Innovation Hub, providing a central point of contact for research software, contract research and industrial secondment. A Faculty team and School representative manage the translation of research outputs into practical resources.
- **We reward staff for their achievements:** Through promotion for innovation & impact (Ruddle, Dimitrova + see REF5), allocated workload (e.g. Cohn), sabbaticals (above) and salary increments.

c. Further Strategy and plans

Developing our strategy for impact: A culture in which staff view outreach, translation and knowledge transfer as integral to research informs the strategic activities described above, our research and our training of future researchers. Support for the translation of our research through licensing and commercialisation activities involves a range of mechanisms and processes, from preliminary proof-of-concept funds, to advanced seed-corn funds, specialist input, business advice and more. A coordinated strategy supports staff along every step of the impact-generation pipeline:

- **Promoting a culture of innovation and collaboration:** We encourage SoC staff and PGRs to take an active part in activities/networks that focus efforts around real world problems and grand challenges (from the Yorkshire Centre for Health Informatics, to revolutionising the carbon footprint of the digital economy). To grow the already substantial body of user-driven research, we run networking activities, including joint workshops with academics and users and mentoring, e.g. through alumni such as Dr Dan Crow (ex Apple, Google and CTO Songkick and Index Ventures). Further partners are identified through our staff's professional activities, networking, Sandpit & EU meetings. The UoL designated Business Development Managers (one per priority area) supports this strategy too. E.g., further to the more mature examples in part b, cutting edge NLP research [Markert1] is now leading to medical diagnostic methods in neurology [Markert2] [text removed for publication].
- **Focussed investment:** As part of the organisation of our research into themes, we identified strategic priority areas – aligned with national and international challenges, and with EPSRC priorities – in which we have invested (via sabbaticals, appointments, large equipment, see REF5c,d). These helped inform the UoL priority areas for innovation (Stratified Medicine, Medical Technologies, Digital Technologies) that are earmarked for strategic investment.
- **Other Plans:** We shall continue to support a pipeline of impact generation outlined above including guidance and mentorship from our research leaders and expert research offices, and seedcorn funding (for travel/research/development). Identified priority areas (see above and REF5) will guide us in building new partnerships and identifying new opportunities. We will run Impact Away-Days, strengthen partnership with our alumni in leading positions and continue to take leading roles in University, national and international networks. We are also enhancing our Industrial Advisory Board (IAB) with a view to deepening awareness and two-way contributions. We will continue to incentivise impact generation (e.g. through reduced workload-allocation).

d. Relationship to case studies:

Our three ICSs exemplify our approach: drawn from AI (computer vision), CSE (visualization) and AC (scheduling), these advanced cases inform our strategy and approach to numerous other projects (above and REF5). ***User-driven research*:** All ICSs exemplify this. **Tracsis** research built on a long term partnership with the transport sector; **Icona** & **Irisys** research was seeded by industrial contacts. ***Spin-out support*:** Tracsis is a prime example of UoL support through the IP Group, and Icona through industry and White Rose funding. ***Continuing links***: **Irisys** sit on IAB; Kwan was CTO and DOB at **Tracsis** (2007-2013); Tracsis co-funded 2 Dorothy Hodgkin PGRs+4 student placements. **Southern Railway** & **ScotRail** continue to provide advice & real-life data sets.