International Review of Mathematical Sciences 2010: Form for the Submission of Evidence

Please complete and return this form to MathematicsIntReview@epsrc.ac.uk by **30 September 2010.**

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The purpose of this review is to benchmark UK research activity in mathematical sciences against the rest of the world, and it will be used to help inform future strategy and funding policy. It is *not* a review of individual institutions or researchers. Please therefore ensure that your comments address and illuminate for the panel the UK-level issues flagged in the attached evidence framework (see **Annex A**).

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Statement of interest (please indicate your reasons for making this submission - 200 words max.):

The UK Computing Research Committee is an expert panel of the British Computer Society, the Institution of Engineering and Technology, and the Council of Professors and Heads of Computing. Its members are leading computing researchers from UK academia and industry. We are responding because of the vital contribution that a strong dynamic research community in mathematics makes to the strength of UK computing research. The 2008 RAE found UK computing healthy and growing, more rigorous, more interdisciplinary, more experimental and more user-oriented than ever. One fifth of all publications were world leading, with nearly two thirds rated as internationally excellent. Computer science has strong interdisciplinary links with mathematics, biology, medicine, and the creative sector: for example, applying programming languages to cell biology, using sophisticated mathematical techniques to model networks, and building computers that mimic the brain. The 2008 RAE confirmed the broad impact of UK computing research on industry, through major IT led businesses, such as ARM; collaborations with multi-national companies, for example Microsoft and HP's UK research labs; and successful spin-outs.

A. What is the standing on a global scale of the UK Mathematical Sciences research community both in terms of research quality and the profile of researchers?

The UK's standing in research quality and profile of researchers is outstanding in many areas of mathematics of relevance to computer science. The UK computing community welcomes the increasing interest of leading mathematicians in problems inspired by computing, and is excited by the opportunities this offers for advances. Dynamical systems, topology, number theory, stochastic processes, statistics, and operations research all provide current examples, and Bayesian statistics, logic, and combinatorics, in particular, are areas that have been transformed over the past few decades by their importance to computing challenges, with UK scientists in academia and industry taking the lead. While it is not the purpose of this paper to delineate the boundary between mathematics, and other sciences such as computing, physics and biology, it is clear that to see the whole spectrum of mathematical activity in the UK, one needs to look beyond mathematics departments.

Some examples give a flavour of the breadth and richness of engagement:
- Bayesian statistics are becoming increasingly widely used in data mining, natural language understanding, image analysis and risk assessment, with strong groups at Edinburgh, Oxford, UCL, and Cambridge, and broad industry take up
- algorithms and discrete mathematics at Cambridge, Warwick, Oxford, Leeds, Durham and Queen Mary, in particular the award of the to Mark Jerrum of Queen Mary (with Sinclair of Berkeley and Vigoda of Georgia Tech) of the AMS Fulkerson Prize in 2006
- stochastic modelling of programs and processes at Oxford, Edinburgh and Glasgow, with a paper on biological applications of these techniques by Kwiatkowska (Oxford) and others receiving the Top Cited Article award in the journal Theoretical Computer Science for the period 2005-2010.
- web science at Southampton, Oxford, Cambridge, Edinburgh and IBM: Ian Horrocks (Manchester now Oxford) devised a logical technique for reasoning about web pages now widely used as an international standard
- mathematics of networks and complex systems at Warwick, Cambridge and Imperial: Cambridge statisticians and computer scientists are at the forefront of international activity and standards for measuring internet performance
- information security, both specialised cryptography and broader systems and approaches at Cambridge, Belfast, Bristol, Imperial, Royal Holloway and UCL, with strong interaction through government, industry and GCHQ's Heilbronn Institute
- logical foundations of programming at Oxford, Edinburgh, Cambridge, Imperial, Queen Mary and Microsoft Research: Sir Tony Hoare and the late Robin Milner both held Turing Awards, the computing "Nobel Prize". Abramsky (Oxford), Burstall (Edinburgh) and Plotkin (Edinburgh), have all recently been awarded major international retrospective prizes, and O'Hearn and Cook received widespread recognition for practical new techniques for proving programs terminate
- work in quantum information science at Imperial, Oxford and Bristol, drawing together computing, mathematics, physics and electronic engineering

- operations research at Lancaster, Nottingham, Cardiff and Southampton , stimulated by a recent major EPSRC Science and Innovation award: the group's OR based software is about to be rolled out for runway scheduling at Heathrow.
- recent winners of the BCS Roger Needham Award, the UK's flagship award for computer science research conducted within ten years of a PhD, have included a number of international researchers, with a strong mathematical trend in nearly all recent awards: Joël Ouaknine (control theory), Byron Cook (logic), Wenfei Fan (logic and databases), Mark Handley (network modelling), Andrew Fitzgibbon (computer vision), Ian Horrocks (logic and the web) and Jane Hillston (stochastic processes)
- it has been exciting to see the UK leading in the use of new computing technologies in mathematics – for example Gonthier (Microsoft Research Cambridge) made the first machine checked proof of the four colour theorem, Gowers (Cambridge) has helped initiate PolyMath, a new web-based approach to collaborative problem solving, and Linton (St Andrews) leads the international GAP consortium for algebra software

B. What evidence is there to indicate the existence of creativity and adventure in UK Mathematical Sciences research?

The examples we have listed in Section A provide evidence of community actively engaging in new research opportunities to address key technological/societal challenges in relation to computer science, in collaboration with scientists in academia and industry. Mathematicians have tackled new problems, in new ways, with new collaborators, and have not been afraid to move into new areas, many of which did not even exist twenty years ago.

We would be cautious about suggesting mechanistic interventions intended to "increase the volume of high-risk, high impact research", as we believe that for the highest standards to be maintained, research priorities should be decided by scientists on scientific merit, and academic institutions should facilitate as positive and supportive a culture as possible, even when times are hard, while taking care not to introduce unnecessary barriers.

See also our response to section H.

C. To what extent are the best UK-based researchers in the Mathematical Sciences engaged in collaborations with world-leading researchers based in other countries?

In the fields of relevance to computing there is a high degree of international collaboration of the highest quality, as evidenced by joint papers, UK leadership of international collaborative research endeavours, major projects funded through the EU and other sources, and partnerships at departmental and individual level. As an example, Gottlob (mathematics of the internet) and Kwiatowska (stochastic modelling of software), both at Oxford, hold ERC senior fellowships including substantial international collaboration. Many individuals and departments have strong links with the countries *mentioned, often facilitated by national schemes, for example the China Scholarships Council for collaborative PhD training.*

The Newton Institute and the ICMS are a valuable resource for enabling international collaboration, and a number of recent programmes have emphasised the deep connections between mathematics and computer science, bringing together top flight academics from both fields: for example at the Newton Institute Logic and Algorithms (2006), Analysis on graphs (2007), Combinatorics and Statistical Mechanics (2008) Statistics for Complex Data (2008) Stochastic processes in communication science (2010), Discrete analysis (2011) and Syntax and semantics (2012).

The UK's involvement in projects run by the Royal Society, IMU and other bodies to support mathematics in the developing world has been noteworthy.

D. Is the UK Mathematical Sciences community actively engaging in new research opportunities to address key technological/societal challenges?

See answer to Sections A, E and F.

E. Is the Mathematical Sciences research base interacting with other disciplines and participating in multidisciplinary research?

The examples we have listed in Section A provide evidence of a community actively engaging in new research opportunities to address key technological/societal challenges in relation to computer science, in collaboration with scientists in academia and industry. Mathematicians have tackled new problems, in new ways, with new collaborators, and have not been afraid to move into new areas, many of which did not even exist twenty years ago.

Opportunities such as joint seminars, study groups, shared PhD training, interdisciplinary workshops or joint coffee rooms provide opportunities for increasing interaction and understanding. It is the nature of mathematics that, while the outcomes of such interaction may be concrete and "reportable", like a joint paper or a new theorem, they may, equally valuably, be a shared insight, a pointer to other relevant work, a key counter-example or clarification as to why an approach is doomed to fail.

Mathematicians are becoming increasingly involved as part of the team in major interdisciplinary EPSRC projects – for example all three digital economy hubs involve mathematicians and statisticians – and likewise it is routine for large mathematics initiatives to involve computer scientists, for example EPSRCs mathematical doctoral training centres all involve aspects of computer science, and the computer science community welcomes the opportunities these provide for broadening the education of computing PhD students.

Novel interdisciplinary applications drawn from computing are also playing a role in *motivating and refreshing the undergraduate mathematics curriculum, and a glance at the web pages of leading mathematics departments shows, for example, modules on network modeling, social networks, or data mining. Such applications also provide lively examples for outreach activities such as the EPSRC funded MathsBuskers or cs4fn – "facebook friends" trumping the Bridges of Konisberg.*

F. What is the level of interaction between the research base and industry?

The examples we have listed in Section A provide evidence of a community actively engaging in new research opportunities to address key technological/societal challenges in relation to computer science, working alongside researchers in industry and government laboratories. International industry research labs based in the UK, such as HP, Microsoft, IBM and Qinetiq, and government research facilities such as the Met Office, DSTL and GCHQ, all collaborate actively with academia and add to the richness of the UK research base.

Mathematical techniques related to computing are key to many sectors of the economy, such as finance, defence, energy and software, and the demand for mathematics graduates remains high. Autonomy, founded in 1996, and utilizing mathematics, statistics and computing research from Cambridge to enable companies to extract meaning from data, is a striking example of the successful exploitation of mathematical IP, with a current market cap of $7 billion, making it the second largest pure software company in Europe. There are many other more recent examples.

The main route of transfer of mathematical knowledge and skills to industry is the production of highly trained graduates, and the value to an organization of people with undergraduate or postgraduate degrees is likely to be skills in problem solving, and familiarity with a wide technical area, rather than any explicit IP they bring.

Much interaction of mathematicians with industry does not follow the models of technology transfer familiar to HEI knowledge transfer professionals, and is not readily captured by the standard metrics used in the national HEIF/HEBCIS survey, or mechanistic approaches to "impact". Interaction with industry, government or the NHS through student and staff exchange, seminars, study groups and the like, allows new ideas to be discussed and assessed, but the outcome might be a joint paper, a new approach to a problem, or a change in policy or processes. For example, computer scientists with expertise in risk assessment are working with medics on new techniques for "triage" in trauma care, and the recently funded Nottingham Digital Economy hub includes significant statistical work on preference and advertising.

The Industrial Mathematics KTN, managed by the Smith Institute on behalf of the Technology Strategy Board, has been particularly helpful in areas related to computing, pioneering new models of interaction, including "technology translators", and other funding streams such as EPSRC's knowledge transfer accounts have allowed universities to experiment with more flexible models, for example allowing staff to spend time working with industry researchers.

G. How is the UK Mathematical Sciences research activity benefitting the UK economy and global competitiveness?

The contributions of UK mathematics to societal challenges, industry problems, and the production of highly trained graduates all actively benefit the UK economy and global competitiveness, as discussed in other sections.

H. How successful is the UK in attracting and developing talented Mathematical Sciences researchers? How well are they nurtured and supported at each stage of their career?

Talented mathematical sciences researchers are in demand around the world. The strong scientific reputation of the UK in mathematical areas allied to computer science means it is still regarded as an attractive destination for academics, and a number of excellent international appointments at all levels have been made in recent years. However it is inevitable that the present downturn will have an effect. UK HEIs have rarely been able to afford start-up packages of the kind on offer in other countries, and in recent years not just the US, but European and Asian countries too, have grown in attraction as places to work. UK teaching loads, approaches to teaching, and the importance placed on instruments such as the National Student Survey, are sometimes found onerous by recruits from countries with different traditions.

PhD students are a vital resource for research in mathematical areas allied to computer science, often providing the "glue" that brings disparate research teams together, and we would be concerned at any cuts in the number of studentships available, or over centralisation of resources into a small number of doctoral training centres. While the UK's reputation still makes it a popular destination for talented international PhD students, it is becoming increasingly hard for UK universities to match the generous funding, free from fees, often available for PhD students in the US and Europe.

We are particularly concerned at the effect of increasing managerialism on UK mathematics. We believe that research merit in areas of mathematics related to computing should be assessed on the strength of the research produced, and this approach was taken by the Computing subpanel in the 2008 RAE, which was pleased to receive a wide variety of mathematically based work. We are concerned to hear of HEIs using overly formulaic approaches to assess individuals, based on indicators such as numbers of publications, citation counts, journal impact factors, lists of supposed "top journals", or grants earned, none of which is appropriate to mathematical areas allied to computer science.

Such approaches discourage more radical or interdisciplinary work, as individuals fear risking promotion prospects, institutional selection for the REF, or being viewed by their peers as not doing "proper" mathematics. This can be particularly unsettling and demoralising for early career staff. In addition working with other disciplines requires engaging with different publication cultures – in the case of computing, publication in highly selective peer-reviewed conference proceedings, or contributions to software – and it is important that national and institutional processes recognise this.