ICT International Review Framework

University of Edinburgh

Introduction

Information and Communication Technologies (ICT) does not define a research community. ICT is not, therefore a single community (in Edinburgh and elsewhere) – rather it is a collection of communities that in some cases overlap and are interdependent and in others are disparate and disjoint. ICT, by its nature, depends on a wide range of research – from the basic science of computation and communication, through its physical layers in silicon, neurones and beyond, to its applications across a wide range of disciplines and domains. This is reflected at the University of Edinburgh by a wide variety of research across this spectrum. This programme supports a research portfolio, (currently over £30m funded from EPSRC ICT programme), predominantly in the Schools of Informatics, of Engineering, and of Physics within the College of Science and Engineering, but also in the Schools of Arts, Culture and Environment, and of Philosophy, Psychology and Language within the College of Humanities and Social Science. The research ranges from theory to application, from devices to systems, from silicon to wetware, and from technological to social concerns.

The School of Informatics defines itself in terms of the foundations and applications of a new science of information, *Informatics*, which underpins ICT. The School has a mission comparable to that of other sciences supported by EPSRC.

- To increase the understanding and exploitation of the fundamental properties of systems that store process and communicate information through leading edge research and innovation.
- To enhance the excellence of the research base by supporting a high quality portfolio of research and postgraduate training.
- To support a pool of talented researchers at all stages of their careers.
- To enhance the performance of other disciplines and user communities through the provision of knowledge and trained personnel.

The School has a broad portfolio of research and training in the areas of: Foundations of Computer Science; Computing Systems Architectures; Adaptive and Neural Computation; Intelligent Systems and their Applications; Communicating and Collaborative Systems; Perception Action and Behaviour.

The Electronics and Communications (EC) Programme at Edinburgh supports a broad and deep portfolio of research and training in digital signal processing and its application to communications, radar, audio and medical systems, in integrated circuit design, system-on-chip design and neural computation, in future systems and services for automated telephone, advanced Internet communication, at the interface between signal processing and usability engineering and in computation and communication in micro-electro mechanical systems (MEMS).

The objectives of the EC programme are to increase the understanding of the algorithms, computational paradigms, technologies and design disciplines that underpin future innovations and products, through the support of leading edge research. The programme aims to extend the excellence of the research base by supporting and developing a high quality portfolio of research and postgraduate training and by supporting a pool of world-class researchers at all career stages. It also aims to support, to enhance and extend research in many other disciplines and user communities through the provision of many levels of collaboration – from support in developing technologies, through the invention of novel approaches to existing and new problems in computation, communication to the generation of new hardware and software products.

The Edinburgh Parallel Computing Centre (EPCC) provides a bridge to the world of advanced computing for industry, commerce and research. Founded in 1990, it is a leading European centre of expertise in advanced research, technology transfer and the provision of supercomputer services to Universities.

The e-Science Institute provides programmes of visitors and meetings to stimulate research in e-Science and hosts the office of the UK e-Science Envoy. The National e-Science Centre coordinates and supports the UK e-Science programme, projects to develop e-Science and leadership in data access and integration systems as part of OMII-UK.

1. To what extent is the ICT community addressing key technological/societal challenges and engaging in new research opportunities

1.1. What are the key challenges and research directions in ICT research?

The key challenges are

- scale – the continuing effects of Moore's Law
- social embedding – ubiquitous, global computation; security and trust.
- embodiment – the changing physical realisation of computation and communication
- innovation – application domains (e.g. the interface between silicon technology/processing and life sciences) that look beyond industrial horizons and make good use of academic skills and motivations.
- interfaces – distributed sensing and action
- autonomy – cross-layer configuration and optimisation of decentralised systems

1.2. Does the EPSRC ICT programme reflect accurately the breadth of activity of the ICT research Community?

As indicated above, ICT does not correspond to one natural community, rather it contains several communities, and intersects with many more. Individuals often belong to more than one research community. Some communities, particularly those that straddle disciplines and include a strong element of interdisciplinarity, cannot, by definition be well-represented by single EPSRC structures. Nonetheless, a wide range of important work is funded by the EPSRC ICT programme, largely as a result of the flexibility and creativity of Programme Managers and the inventiveness and perseverance of academics. EPSRC should consider how to support the emergence of new disciplines, such as Informatics.

1.3. Is the research community structured to deliver solutions to current and emerging challenges?

We have a long-standing and vital track record of technology and algorithm development leading to industrial application. Edinburgh has strength in depth across much of the ICT spectrum. This work clearly includes single-discipline "intra-disciplinary" research in electronics, communication, computation, cognition, etc. and inter-disciplinary study including researchers from, for example, Physics, Psychology, Biology, Medicine, Linguistics, Sociology and Music. As a result, research stretches from immediately "useful" application-driven work to the development of techniques and technologies that do not, as yet, have an immediate or obvious application. The current EPSRC policy values industrial collaboration and support, while encouraging "adventure" in research. This is both a challenge to academics and a highly laudable focus for the academic community, whose expertise and abilities should not be directed towards either direct competition with industry or in the form of a simple service to industry as a source of cheap research. Academic researchers should both solve difficult existing industrial problems and place on the shelves solutions to the problems that industry has neither addressed nor even envisaged. The local ICT community is structured to address both of these needs, and to enable multidisciplinary responses to new challenges.

It is worth commenting, however, that the removal of key industrial research labs from the UK has resulted in outsourcing of research grants to Universities by industry. The problem in undertaking such work is timescales are often extremely short. As a result, in some areas, we have seen an overall reduction in our ability to indulge in long term research as we attempt to satisfy a clear national need.

1.4. Are there significant research pioneers and challenges to nucleate significant effort?

There is a wide range of challenges across areas supported by ICT which will have significant societal and economic impact. This is easily demonstrated by the sheer scale of international efforts in this area by industry, government and academe. These rapidly evolving and important technologies will continue to generate new research challenges.

The UK has its fair share of research pioneers in the area. Locally, we have pioneers in, for example, communications, radar and audio systems (Mulgrew), Signal Processing (Grant), Mobile *ad hoc* Networks (McLaughlin), spiking computation on silicon (Murray), evolvable and reconfigurable SoC hardware (Arslan) and integrated vision sensing and processing (Denyer, Renshaw), foundations (Plotkin, Bradfield, Stirling, Simpson, Longley), vision (Fisher), modelling (Hillston, Gilmore), reasoning (Bundy, Sannella), databases (Buneman, Fan, Libkin), linguistics (Steedman) dialog (Moore), planning (Tate), neuroinformatics (Willshaw), machine learning (Bishop, Williams), robotics (Vijayakumar, Webb), compilation (O'Boyle), low-power architecture (Topham). Clearly many major UK pioneers in related areas also work within the EPSRC ICT community – Edinburgh does not enjoy a monopoly.

1.5. Is the current research portfolio robust and responsive enough to deal with any major perturbations?

A robust research portfolio must have a spectrum of work from foundational work to innovative market related development. Furthermore, it must have a track record of moving fundamental work steadily towards applications. There are many examples of this in Edinburgh. Such a balanced portfolio allows a response to any major changes, alongside an immediate and demonstrable impact on current industrial products. It is, however, clear and necessary that different projects and initiatives target different shades of this spectrum. Currently, EPSRC encourages and funds adventurous research. This must be maintained for our long term research health. Over-focused calls based on what are considered fashionable areas will, in the long term, weaken our underlying research strengths. A robust portfolio must also have breadth as well as depth - emerging problems may require integration of results and methodologies from other areas/disciplines The key is flexibility and in particular the ability to respond rapidly, but in a principled manner, to is what is required. It is essential that PMs and APMs be in a position to put in place funding in new areas rapidly when necessary. It is not clear that funding mechanisms always foster and support this flexibility.

2. To what extent is the ICT research base contributing to other disciplines and multidisciplinary research?

Electronics, and informatics (communication, cognition and computation), now permeate all disciplines, including the humanities and social sciences as well as the sciences. Novel computation, communication and hardware make it possible to address new forms of research question, through modelling and simulation, data collection and analysis, and visualisation, and can lead to both novel theoretical methods and new products. Moreover, understanding computation provides new ways of understanding the world – an intellectual revolution. Computational thinking – **understanding systems in terms of the ways they store, process and communicate information** now pervades theories in all disciplines, and computational modelling allows us to explore the emergent behaviour of complex systems.

The ICT community in Edinburgh, in both Informatics and Electronics/Communications encourages, facilitates and has a strong track record of interdisciplinary engagement, and is realising this intention via strong links across all Colleges with the University and more widely both within the UK and internationally, linking to both academic and industrial research bases elsewhere.

2.1. Have multidisciplinary research and approaches become embedded within the community?

We believe that they have and we are confident that a survey of the current EPSRC portfolio will show that a large percentage of projects are at least multi-disciplinary and in many cases inter-disciplinary. This question is, however, predicated on the assumption that inter- or multi-disciplinarily is necessarily a "good thing". Our extensive experience of multi-disciplinary projects indicates that this is not 100% true. When cross-disciplinarily work is appropriate, it is capable of generating some of the most exciting research, the best science and the most innovative products imaginable. However – enforced inter-disciplinarily is an undesirable distortion of the field. There is much to be done in (for example) straightforward design research for System-on-Chip, looking beyond industrial horizons, without involving biologists, chemists, or even, in a multi- rather than inter-disciplinary mode, computer scientists.

Locally, fruitful, long-term and funded collaborations exist with colleagues within this University and elsewhere in, for example, Physics, Psychology, Linguistics, Chemistry, Biological Sciences, Astronomy, Medicine, Neuroscience, Music and Geology. These are now well-established and act as a catalyst to new projects spanning these disciplines.

2.2. Is there appropriate dialogue between the ICT community and other disciplines and are there any barriers to an effective communication flow?

Yes, there are both dialogues and barriers. For interdisciplinary activity to work, both sides need to see the value of the interaction … marriages of convenience are generally unhappy and end in divorce. Some of the underlying problems in interdisciplinary work are well known to us and are intrinsic to interdisciplinarity (finding a common language, form of research agenda, disciplinary culture). Some are structural (despite best efforts, interdisciplinary projects are problematic to review and assess). We know that EPSRC makes strenuous efforts at PM/APM level to ensure that referees and panels with the right mindset are chosen, but the path to funding is still fraught. As an example – a recent large-grant proposal involving 5 Universities was stopped at the earliest stage by reviews from thoroughbred neurobiologists who clearly did not value, or perhaps even understand, the ICT interest and the computer science research agenda upon which it was based. It will be resubmitted, but at a cost of manpower, loss of time and, possibly, opportunity.

2.3. Are the developments to date sustainable in the future?

As things stand, yes. There is, however, a real and ominous danger in sight. EPSRC policy seems poised to change, in response to political rhetoric, to return to the 1980s policy that, by funding and other means, encouraged ever more applied work.[1] The Electronics and Communications ICT community in Edinburgh is extremely is well-placed to respond to such a

[1] It is ironic that this 1980s/early 90s policy led, after some funding of dreary, incremental research, to the encouragement towards "adventure" in proposals that we currently applaud and follow.

change of emphasis and direction if it has a mind so to do. However, the unavoidable implication will be that star researchers will move to other pastures, and the capacity for innovative work at the core of our research areas will be lost. In effect, existing solutions will simply be taken off the research shelves to satisfy the needs of short-term applications. Eventually, the shelves will be empty – or even worse, laden with solutions that are the IP of researchers outside the UK. This is fatal to the sustainability of a true ICT research community, as opposed to simply an ICT development community, in the UK.

2.4. What evidence does EPSRC have to demonstrate the impact it has had in this area? Is there multidisciplinarity within ICT?

Locally, EPSRC funding has supported inter- and multi-disciplinarity in, for example, on-chip neural computation, its relationship to eScience and, more recently, is receiving proposals in silicon imaging in bio-fluorescence and diagnostics. However, major interdisciplinary structures such as the Centre for Communication Interface Research, the Human Communication Research Centre, the Institute for System-Level Integration and the Scottish Microelectronics Centre owe relatively little to EPSRC – at least in terms of their inception and initial funding. The impact of these initiatives in terms of new software and hardware products, trained personnel and new technologies is substantial and growing. It has proved difficult to involve EPSRC in initiatives that gain funding from multiple sources.

2.5. Is the transition from main-stream areas to multidisciplinary areas as expected?

A strategy that views multi- and inter-disciplinary work as simply an alternative to “mainstream” work is fundamentally flawed. The core disciplines of computation, electronics, informatics and communication will be required for the foreseeable future, both to extend and to expand work in these fields, for application within those fields, and to support work in application domains and across disciplines. Locally, we have seen and have encouraged a growth in multi-disciplinary and inter-disciplinary work. Areas such as computational linguistics, systems biology, and social informatics rest on foundational research in informatics. Much of the mainstream development in technology is being undertaken and funded by industry – we can simply buy the results and it is foolish to compete. As an example, silicon foundry production is not an area of active research in Edinburgh. On the other hand, novel design on silicon and post-processing of silicon are research strengths that we have fostered that are arguably **intra**-disciplinary. Our interdisciplinary work in medical electronics, medical signal processing and computation in nano-scale silicon, builds directly upon both this mainstream research and our links with other disciplines. We believe that this holistic approach – fostering the best in “mainstream” research while facilitating and encouraging appropriate interdisciplinarity, is the vital and difficult balance that must be struck.

3. What is the level of knowledge exchange between the research base and industry that is of benefit to both sides?

There is substantial local interaction between academe and industry. This exchange is recognised by Scottish Enterprise support, and comes in many forms ranging from involvement of companies and organisations such as Motorola, ST Microelectronics, LG and JLP(USA) in projects to spinout companies, from the long-established Wolfson Microelectronics, through Vision Group and Indigovision, to our most recent spin-outs, Microemissive Displays, Spiral Gateway and Ice Robotics. Many of these companies can trace their roots directly back to EPSRC mechanisms. Given this healthy relationship it is unhelpful to *require* formal industrial involvement in a certain percentage of projects. This places differential strain on the discipline as some areas are more appropriate for industrial involvement than are others.

3.1. What is the flow of trained people between the industry and the research base and vice versa?

In addition to our spin-out companies, we provide skilled research manpower for many of the UK's most innovative companies. This is academically satisfying, as it takes our knowledge into industry, is practically useful, as there are too few academic posts to support all of trained output and beneficial, as it seeds new collaborations within the employing companies. The flow is largely from academe to industry - the flow of industrial staff into academe is modest. This University stimulates these through the successful EPIS programme, supported by Scottish Enterprise. Permanent moves from industry to academe are rarely financially attractive. Nevertheless, we have recently recruited as members of academic staff several leading researchers from industry and from industrial research laboratories – these include, Robert Henderson, one of ST microelectronics' finest analogue VLSI designers, Nigel Topham, in low-power embedded processor design, Philip Wadler, in Programming Language Design, and Kousha Etessami from Bell Labs .

3.2. What is the relationship between UK academe and industry both nationally and internationally?

We find it easy to work with industry where mutually agreeable timescales, research aims and possible funding mechanisms exist and impossible when they do not. There is a significant amount of industrial interaction via EC projects.

Industrial projects are generally not a major part of our EPSRC portfolio. Rather they are funded by industry, on industrial timescales and at industrial levels. We "use" EPSRC as a route to baseline funding of fundamental work, to allow us to place new research results and theories on the shelves.

For example, while Spiral Gateway and Microemissive Displays owe their inception to EPSRC-funded work, the grants in question did not involve major industrial collaboration. Indeed, major industrial collaboration would have resulted in a less flexible IP arrangement and would almost certainly have prevented the spin-outs from happening.

So, currently, we seldom need to call on EPSRC to support our interactions with industry.

However, this position may deteriorate as the effects of FEC sink in. Multinationals have made it clear that it is cheaper to contract research elsewhere in Europe, US and the world than in UK. We will need to find mechanisms to ameliorate this.

3.3. Does EPSRC enable this knowledge exchange through its different schemes?

Broadly, yes, although this has, historically, been a pendulum that has swung from "industry must be involved" (late 1980s) to "research must be adventurous" (early 2000s). It would be helpful to have EPSRC recognise the high latency (5-30 years) of the pipeline leading from foundational research to application, and to develop and maintain a balanced portfolio of both industrially-focussed, relatively incremental research and longer-term, more speculative research, with appropriate criteria for application and ultimate assessment of success.

3.4. What is the scale of industrial R&D in ICT and what is the trend?

As noted above, the removal of key industrial research labs from the UK has resulted in outsourcing of research grants to Universities by industry. It also reduces industry's capacity for long term research in the UK, which has many implications for the ICT community. There are exceptions. Microsoft Research Cambridge, HP Research Bristol, Intel research Cambridge, XDC Edinburgh. Fewer opportunities, however, now exist, for example, for PhD students who wish to undertake innovative research in large laboratories, outside academe. Small, more agile companies, including our own spin-outs, offer better opportunities.

4. To what extent is the UK ICT research activity focussed to benefit the UK economy and global competitiveness?

The ICT community at Edinburgh has a distinguished record of transfer via commercial contracts with a wide range of companies of different sizes, spin-out/start-up companies and applied research with industrial partners and other user groups. It sees a demand for collaborations and joint work from UK, Europe, US and the Far East. NeSC, for example, has had over £3 million of projects in collaboration with industry and now leads the technical programme of the DTI's Knowledge Transfer Network "Grid Computing Now!".

4.1. What are the major innovations in the ICT area?

This question suggests implicitly that innovations will have been seen to benefit the economy and global competitiveness within the timescale of a review period. This view towards assessing innovation is almost certain to fail to provide an encouraging result, as the industrial innovations from the ICT community in academe are likely to be based upon work within the community from some years past. Likewise, major innovations now in academic research are likely to impact 5-20 years, or more, from now. For example – our work on systems that use 100nm transistors cannot have an impact until 100nm transistors are in production … some 5 years from now at the earliest. The recent introduction of generic types in Java can be traced to UK research innovations dating to the 1970s. Work on process algebras from the 1980s is now bearing fruit in applications to systems biology. Today, we are, effectively, preparing the science for the technology of the future. While we believe this to be a key part of what academics should be doing, it will not score well in terms of industrial impact over the likely period under review.

4.2. How successful has the UK ICT community been at innovation?

This is an extremely open question – how to measure success? Clearly, the sheer number of spinout companies from this University (in both Informatics and Electronics/Communications) suggests that local innovation, some of it sponsored and facilitated by EPSRC, is healthy. Furthermore, much of this innovation comes directly from our section of “the ICT community”. Immediately-exploitable work in Electronics and Informatics has formed spin-out and start-up companies. However, much of our more blue-sky work cannot possibly reach applications, and thus be used as a measure of innovation, for some years. The response to the question must therefore be that, where measurement is possible of local success, it is excellent.

5. To what extent is the UK able to attract young scientists and engineers into research, nurture and support them at every stage of their career to benefit the UK?

We recruit and compete internationally for PhD students, Research Fellows and new academics. Most of our recent appointees to lecturing positions are from overseas and the most difficult category for “recruitment” is that of UK-based PhD students (who are fundable from EPSRC DTA funding!). It is interesting to note that EngD programmes (e.g. that at ISLI) appear to have more success in attracting UK nationals than do PhD programmes. Although EngD's are designed for company-based project work we have used them (with the company's and student's agreement) for PhD-style research.

All academic and research staff are mentored and appraised regularly as part of our University-wide appraisal and mentoring schemes. The teaching workload for new staff during their first year the above loads is minimised. Academic staff receive significant support in both their teaching and administrative duties; any job not requiring academic expertise or authority is undertaken by the appropriate member of administrative, computing or technical staff.

More widely, it is impossible to generalise. Anecdotally, colleagues in comparable institutions enjoy the same successes and bemoan the same problems in recruitment as are described above. It is our guess that the underlying problem is that electronics, communications and informatics/computer science are, in this country, seen by many as difficult disciplines leading to uncertain job prospects and unstable employment. Clearly this situation does not apply in much of continental Europe and beyond and it is frustrating to receive high-quality applications from excellent researchers whom we cannot fund. If we cannot turn the tide of opinion of UK students and school students, it would at least be helpful to have more flexible funding mechanisms for those who are keen to join our research programmes.

5.1. Are there areas of weakness - is the UK producing a steady-stream of researchers in the required areas and/or are there areas that should be declining to reflect changes in research climate?

The UK has relatively little world-class research in algorithms, complexity, and systems. There has been a decline in mainstream hardware design research as that becomes progressively automated and industrialised (although there will always be a need for developers of the automation who understand design). In the design area, we should be aiming to produce researchers with broad minds – who are not simply interested in, for example, squeezing the last mW of power out of a standard microprocessor architecture. This is where engagement in multidisciplinary projects can open minds and where multidisciplinarity is, of itself, valuable. DTCs represent an excellent mechanism for delivery of interdisciplinarity at this stage and age and we hope to propose a new DTC in maths, computer science and electronics for signal processing and communications.

5.2. Is the demand from undergraduates to become engaged in research as expected?

We see strong demand for PhD places from European and overseas undergraduates but the UK demand is weaker than it was 5 years ago. We see significant demand from undergraduates for entry to our Neuroinformatics programme and in the area of Systems Biology. There is strong demand for places in emerging interdisciplinary areas. The ablest graduates from our bachelor's programme routinely express interest in our Masters and PhD programmes. However, given the state of undergraduate funding, it is unsurprising that large numbers of qualified students with large debts choose to earn the substantial salaries they can command rather than continue with postgraduate study. It is extremely difficult to attract good postgraduates from the UK. We have buoyant applications from well-qualified overseas graduates.

5.3. How does the career structure for researchers in the UK compare internationally?

Overall the career structure is poor. There is no clear, reliable and well defined path from PhD to a permanent academic position. Postdoctoral researchers often survive on short term contracts and although this University has powerful processes whereby PIs and Heads of Institutes assist in the career development of RAs, the career path for a researcher who is either unsuited to lecturing or does not wish to lecture is very poor.

In Edinburgh we do support our long-term researchers by offering open-ended contracts and provide advice and support in the planning of a research career. Many of our PDRAs go on to have successful academic careers in institutions all over the world.

6. To what extent is the UK able to attract and retain overseas scientists and engineers to the UK?

Edinburgh has been very successful in attracting overseas scientists. For example, over one third of AT staff in Informatics come from outwith the UK, and two thirds of these from outside Europe. As stated above, we have, in the past year, recruited several new professors, readers and lecturers, most of whom have come from overseas. In certain areas the salary difference between the UK and the USA is a real problem. In the middle and upper salary scales, there is a large divergence with UK industry.

6.1. How is the engagement between the UK and Europe?

We have productive relationships with leading centres in Europe. Edinburgh is heavily engaged in the European Framework Programmes. All the Schools have significant European engagements. In Physics EPCC is heavily involved in Egee and a range of supporting Grid-related projects. Informatics has engagements in a wide range of fundamental and applied projects including the Open Knowledge Initiative and the Adaptive Multimedia Initiative. EU funding is a significant magnet and the ability to nominate EU partners (without direct resourcing) in EPSRC projects is useful.

6.2. How is the engagement between the UK and the rest of the world?

We have excellent relationships with selected, leading international groups in most areas, particularly with the USA. One obvious example of this is the Edinburgh-Stanford link. However, the engagement goes far beyond this. As many of our researchers are internationally leading, we correspondingly interact at an international level. For example, in the area of e-Science we are fully engaged with the Global Grid Forum and in the direction of international Grid developments. There is, however, a definite problem with respect to funding as the radius of collaboration widens – and this was raised at the recent Platform Grantholders event. There is almost no serious joined-up thinking between funding agencies such as EPSRC, SFC and Scottish Enterprise. As the horizons widen, this simply gets worse and it is almost impossible to find single-source public-purse funding for internationally collaborative research.

6.3. Are there particular issues for the ICT programme area?

We do not believe that ICT is in any way unique in this respect, except that attractive, lucrative and stable opportunities for individuals with the skill set that is acquired in the Edinburgh ICT community are wide. We compete on a global scale in research quality, and therefore also in recruitment and retention. As a result, we suspect that ICT has a larger recruitment and retention problem than do most other disciplines within Science and Engineering. There is also competition with research Labs such as Google and Microsoft. The decreasing supply of PhD graduates is a major concern.

There are issues around the coherence and quality of the overall community in the UK. Outside of Theoretical Computer Science it has been difficult to achieve consensus on the quality of particular proposals and the overall direction of research. Recognizing excellence and driving EPSRC programmes from that perspective could achieve a marked improvement in the coherence and quality of reviewing. The feeling in Edinburgh is that proposal reviewers are often not particularly well chosen and excessive weight can be given to poor reviews from reviewers who are reviewing outside their area of main competence. This could be resolved by ensuring the overall management of the programme engages effectively with the body of excellent researchers we have in the UK.

7. What is the impact on a global scale of the UK ICT research community both in terms of research quality and the profile of researchers?

7.1. Is the UK internationally leading in ICT?

The UK is leading in some areas of ICT but not all. Given the size of the country, this is not surprising. However, as expertise changes over time, it does not make sense to focus efforts in certain areas to the complete exclusion of others as this goes against the need to develop a robust and reactive research base.

7.2. In which areas, why?

In the design area, we believe that we are internationally leading in, for example, innovative (as opposed to mainstream) SoC design, in novel approaches to computation (building upon the strong machine intelligence community that built up in the 1980s) and in bringing design and technology (e.g. MEMS technology) together. Other areas of world-leading work at Edinburgh include in automated reasoning, currently being applied to issues of security engineering; neuroinformatics and computational neuroscience; speech and language technologies; databases and programming language design; planning, and its application to emergency response; mobile computing; high-performance computing; machine learning and its applications; computational systems biology; low-power systems design; bio-mimetic robotics, and speckled computing. Why? These are areas that require modest capital investment, lateral thinking and a lot of "cleverness".
They represent long-term programmes that have evolved from the research community in Edinburgh. We see this organic development of research strenght as an important aspect of the Edinburgh environment. This work has been supported by EPSRC, but predominantly through responsive mode support, together with some support from particular programmes. In the areas of speech and language technology, automated reasoning, programming languages, algorithms for communication and processing, for example, we compete with the best in the US. We should concentrate on developing such areas of research, while maintaining a more modest level of activity in areas where we are arguably in competition with industry.

7.3. Where are the highlights, why?

As above.

7.4. What are the trends, why?

Locally, the trend is towards inter-disciplinary research work – cognitive systems, computational biology, bio-engineering, bio-electronics and medical electronic, nanoelectronics and novel computation, supported by foundational work – for example on data, computation, communication, interaction and learning. This trend appears to be mirrored in collaborating and comparable institutes and institutions. Why? These are areas where exciting challenges exist, where academic "cleverness" has the potential to outstrip industrial muscle and where academics can learn from one another and from one another's disciplines.

7.5. What are the opportunities/threats in the future?

Opportunity – the UK has breadth and depth of expertise across a range of disciplines that will contribute to future ICT, and a track-record of fundamental research that has had long-term impact. At Edinburgh we have critical mass to rival competitors world-wide, coupled with a demonstrated ability to create effective multi-disciplinary teams working across institutional boundaries, and a track-record of innovation and technology transfer. We have the opportunity to respond to the challenges summarized in the first section of this response.
Threat – The biggest threat to this endeavour is short-termism, leading to incremental, safe research that fails to address the needs and demands of future technologies. We need continued

support for a balanced portfolio of research across the various dimensions mentioned in our first paragraph: from theory to practice, from devices to systems, from silicon to wetware, and from technological to social.

To give a concrete example – industry currently does not know how to do anything sensible with <100nm transistors, despite being able to make them. There is an embarrassing lack of new ideas as to what to do with ever-increasing complexity available in SoC systems. The opportunities in ITC are the will and the ability to tackle these threats now, before technology inflicts them upon us. This requires investment in research that industry will not, of itself, fund, whose results will not be "used" for some years.

8. What evidence is there to support the existence of a creative and adventurous research base and portfolio?

8.1. Comment on the balance of adventure and safety in the ICT research base portfolio.

This has been redressed in the past 5-10 years. The early 1990s saw much incremental and rather boring ICT research. The emphasis on "adventure" in proposals is to be applauded, although it should not become a necessary criterion (neither should industrial collaboration or multi-disciplinarily – we need a mixed economy). However, reviewers remain conservative and one cautious review can kill a proposal. Thus we see often see incremental work funded instead. A holistic approach to proposals should be matched by a similar approach to assessment and monitoring.

8.2. How do research groups foster adventurous ideas?

Internally, we do this by encouraging researchers to take time out from mainstream research to explore mad ideas and talk to researchers outside their own group. This is a double-edged sword, as such activity detracts from fulfilling the needs of research contracts. Platform Grant funding is helpful in this respect and for more long-term random research walks, the existence of funding for discipline-hopping (including DTCs) is to be applauded. This would be enhanced most by an extension of Portfolio Partnership funding that allows larger groupings to work for longer periods on more flexible research agenda. At present, the slightly curious criteria for Portfolio funding rule out many groups who would benefit and develop new areas of research. Clearly, the scheme should only be available to groups with a good research agenda and a good track record of delivering interesting research over a period of time. This is not measured particularly well by the current Partnership rules.