Institution: Middlesex University

Unit of Assessment: 11 - Computer Science and Informatics

a. Overview

This submission comprises 56 staff (53.1 FTE) - 12 Professors, 8 Readers and 36 lecturers, of whom 12 are early career researchers, with just 4 of these having a reduced number of papers. The submission has been structured around three groups: algorithms and software engineering (27), networks and distributed systems (14) and interaction design (15). These groups reflect intellectual clustering of our work based upon methodology and underlying bodies of knowledge but do not reflect formal internal structures. They also represent three areas of activity that have been developing over several years as a result of deliberate plans and are hence fundamental to our strategy as discussed below. The period since RAE 2008 (when 22.3 FTE staff were submitted) has been one of continuous growth and development, including the cultivation of strong leadership, with increased income and considerable investment by the institution leading to an environment capable of sustaining further rapid development in the years to come.

Algorithms and Software Engineering

This area is primarily concerned with formal modes of analysis, ranging from fundamentals such as logic and graph theory through to model-based systems. It includes some activity that is concerned with meta-analysis such as applying theorem proving to security cases or verification through model-checking, hence our rationale for including 'software engineering' in the description. We have also included here work which focuses on the interaction between algorithms and architecture, such as cellular automata, neural computation and quantum systems. The mathematical nature of this work, and our rationale for prioritising this area, is discussed more fully in our strategy section. There is a medical focus to some of this work, reflecting the development of algorithms for medical imaging using electrical impedance tomography, ultrasound and similar technologies. This work is carried out jointly with colleagues in biomedical science who have been submitted to REF unit 3, and we allude to this in places below where joint infrastructure forms part of our environment.

Interaction Design

This area centres on the work of the internationally recognised Interaction Design Centre, created 20 years ago by Harold Thimbleby and Ann Blandford (both of whom are still visiting Professors here). It has evolved considerably in that time, and now includes work in areas such as the visualisation and manipulation of complex data, rehabilitation robotics, brain computer interaction and the legal and ethical aspects of technology use. Staff in this area also have responsibility for leading the UK Visual Analytics Consortium, a group comprising Middlesex, Imperial, UCL, Oxford and Bangor Universities, funded by the US and UK governments for coordinating transatlantic work on visual analytics.

Networks and Distributed Systems.

This area focuses on the technical and theoretical aspects of distributed systems and supporting network technologies. A particular emphasis is on wireless technologies, including areas such as cellular handover algorithms, and emergent properties and trade-offs including energy consumption, performance and adaptive mechanisms to support applications such as gaming and media streaming. Mathematical modelling, including Markov techniques, and simulation are used extensively. Examples of problem domains being explored include sensor network coverage, security and authentication systems, energy efficiency and system security.

b. Research strategy

The research strategy for this unit is firmly embedded in the University strategy for the development of STEM activities across the institution, which we outline here so that issues such as sustainability and investment can be appreciated within this context.

In 2008 the University took the strategic decision to focus on the development of STEM subjects in both teaching and research, re-opening some areas (including engineering and mathematics) that were closed during the difficult recruitment period of the 1990s. This task was given to the Dean of

Computing, Professor Martin Loomes. It was very apparent that developing research in areas such as engineering and mathematics *ab initio* was highly unlikely to succeed. A strategy was proposed, and accepted by the institution, that computer science, already showing strong growth and potential in research, should be used as a vehicle for development, with priority being given to those areas that could subsequently be extended to underpin future developments in mathematics and engineering. This resulted in a major programme of investment in computer science research (staffing, infrastructure and facilities), and a significant re-focusing of activities to de-emphasise areas such as software project management and information systems, whilst strengthening formal, theoretical aspects of computer science and computer systems engineering.

To ensure synergies between research strengths and teaching provision, several major curriculum changes were made. These include a radical new theoretically-based computer science degree, and BEng/MEng programmes in areas such as computer systems engineering, embedded systems and robotics. New mathematics degrees are being launched in 2014. This alignment is crucial to ensure that research and teaching form an integrated unit capable of sustaining a large and growing research base, with associated laboratories and facilities.

Achieving this re-alignment in the period 2008-2013 has been exciting and led to many benefits, taking us well beyond the incremental development and consolidation envisaged in our 2008 RAE plans. It has been, however, a carefully managed process, with clear phasing to ensure that existing research-active staff were valued and developed, with new staff being introduced in ways that enabled them to contribute to developments without causing unintended deviation from the plan. We have deliberately avoided setting up formal groups, using the three strategic areas to conceptualise, prioritise and manage our research at high levels, whilst facilitating a wide variety of underpinning mechanisms for supporting and promoting activities. This has enabled us to encourage new informal groupings to emerge, reflecting the interests of staff without the need to disturb existing centres such as the Interaction Design Centre which has a long history. Groups are not resource centres in any sense, although all groups, including *ad hoc* formations that may only exist for a short period, have easy access to support for activities such as organising meetings, travel or equipping new facilities. Senior staff lead, rather than manage, such teams, and junior staff are not inhibited in any way from taking leading roles. This has proved an attractive feature for many of the new staff we have employed, who view Middlesex as a place where they can develop at a rapid pace not always possible in many traditional establishments with their more formal research structures. We have exploited this by recruiting several early career researchers who are ready to build upon periods of post-doctoral development at well-established centres of excellence and keen to develop their own research agendas.

A fundamental aspect of our strategy is to ensure that collaboration, both internal and external, is promoted, supported and valued. Competition is not used as a management tool in ways that compromise this goal. This is essential to meet our wider strategic objectives, where we want people and groups to be agile and cross boundaries, ultimately into new STEM areas, rather than being tightly focused and inward looking, whilst retaining technical depth to their work. This theme is developed in the final section (e) on collaboration.

A particularly successful aspect of our strategy has been our ability to recruit, develop and retain excellent staff at all levels, so that we have built critical mass within all three areas of research activity. During the period 2008 – 2013 we have lost only 5 staff who were research active from Computer Science, but have recruited 36. These new staff have typically been appointed from internationally strong departments, and have brought informal collaborative links with them. In all cases, we have encouraged this, and supported it financially where necessary. In the most recent recruitment round it was apparent that many successful applicants have been referred to us by collaborators and other recent recruits. Thus our strategic approach to collaboration is becoming self-sustaining, encouraging immediate collaboration and growth whilst avoiding the fragmentation and dilution of focus sometimes associated with major recruitment programmes.

During the initial phase of this strategy (2008-2011), great care was taken to manage the shift towards more theoretical and technical aspects of computer science to ensure that we did not

inadvertently create a portfolio which we could not support and sustain. The principal drivers were internal, with external factors informing, rather than leading, change. By early 2012 we had reached a size and maturity capable of supporting more diversity, and we have now started to align our portfolio more explicitly with national and international priorities.

Our aspirations for the theoretical areas of *algorithms and software engineering* are very ambitious. We have developed three key strands to our work during the period. First, we have established a significant kernel of foundational work in areas such as logic and complexity theory *[Bornat, Martin, Primiero, Chen, Gkorogiannis and Zhang]*. Second we have continued to develop a strong presence in the area of mathematical computation, with an emphasis on optimisation and learning systems applied to image analysis and neuro-computation *[Loomes, Huyck, Gao, Albrecht, Belavkin, Yang(X), Shi, Kotsia, Comley, Kim, Tizzard, Yang(Z), Karamanoglu and Cheng].* Finally we are applying formalisms within the software engineering process through approaches such as model-checking and formal verification *[Clark, Barn, Boender, Androutsopoulas, Kammueller, Raimondi and Nagarajan].* This strategy of developing foundations together with both tightly-focused external application areas and applications within the discipline has, we believe, allowed us to create a strong presence in this area capable of delivering world-class research, access multiple funding-streams and offer excellent collaborative potential. It is also an area where we have strong leadership with 8 professors and 5 Readers supporting the early career researchers.

Interaction design is our most mature area, building on work started by Thimbleby and Blandford who are now at Swansea and UCL respectively but remain associated with the group as Visiting Professors. It has continued to grow, particularly through the UK Visual Analytics Centre, but also through a broadening of our portfolio in recognition of the complexity and diversity of emerging ways that people and technology interact.

Our work in visual analytics has a number of dimensions including the analysis and management of big data, ways of representing multiple levels of emergent relationships within complex data and collaborative decision-making. We are also exploring the integration of these with the use of techniques such as serious games for training scenarios in situations such as disaster management, where there is the need to manage and integrate complex visualisations into group processes *[Wong, Xu, Attfield, Ham, Fields and Passmore].*

In recognition of the rapid development of 'the internet of things' and the falling cost of technologies associated with areas such as haptics, robotics, augmented realities, affective computing and image processing, we are strategically strengthening our activities in these areas. In particular, we have an emerging strand of research associated with health and social inclusion (integrating with our algorithmic work in the medical fields) including rehabilitation robotics and sensor networks for health *[Augusto, Gandhi, Springett, Loureiro and Zivanovic]*. We have strands of work in the legal and ethical aspects of human-technology interaction *[Duquenoy]* and the use of augmented reality to support the teaching of software engineering *[Dafoulas and Saleeb]*. We have also taken the decision to centre much of our public engagement activity around this area as our research has obvious and appealing physical presence for promoting not only computer science but STEM areas generally *[Walker]*.

Our work in *networks and distributed systems* has traditionally focused on modelling and simulation in areas such as wireless handover, energy optimisation and security *[Aiash, Ever, Gemikonakli, Lasebae, Mapp, Trestian Vien and Nguyen]*. Our new laboratory infrastructure (described below), however, has enabled us to support a wider range of empirical activities including hardware development and physical measurement. Moreover, developments in other areas such as the internet of things and visual analytics has enabled us to develop research in broader aspects of distributed systems such as sensor networks, cloud infrastructures and distributed multimedia systems *[Ghanem, Loo, Mostarda, Sakellari, Shah and Zhou].*

The next phase of our strategy is already underway. It involves further growth across STEM areas, albeit at more modest levels within computer science, but accompanied by a carefully managed development of the environment. Inevitably growth in staff numbers is leading growth in funding

and doctoral numbers. Whilst research income has more than doubled since REF 2008, through increased numbers of grants, we need to set our aspirations higher. We are starting to see significant increases in the size of grants, and also in our capacity to manage significant collaborative programmes (details below). We intend being in a position within two years where more than 90% of staff in computer science are carrying out research at a level commensurate with this submission or better, from our current position of 75%, with an environment capable of supporting further improvements in quality as the large number of ECRs we have recruited start to develop their own research programmes.

The final part of our strategy will then be to build upon this robust computer science research base, developing areas closely allied such as mathematics and engineering. This will require the development of additional collaborative networks, with seed funding being released as the mature areas of computer science become largely self-sustaining. Adding mathematics and engineering research to the environment, however, will also enhance the opportunities for computer scientists to develop exciting new areas at the interfaces. Our technical infrastructure (both physical and people) has already been developed to support these initiatives, and further staffing is already planned and committed to ensure we develop breadth without dilution of the support for the existing computer science base.

c. People, including:

i. Staffing strategy and staff development

As noted above, our research strategy is an essential part of our overall academic strategy, similarly our staffing strategy for research underpins our academic provision generally. Fundamental to this is that we have recruited academic staff who are (or have the potential to be) excellent teachers as well as researchers, and we have not recruited core staff on research-only contracts at any level. This is vital if our drive for excellence in research is to be sustained, and the strategic objectives of the University met. This requires very careful management of workloads, to ensure equality and to help all staff develop across a diverse set of roles. We will start by outlining our general practices regarding research, then detail the specific actions we take for ECRs, as we have recruited significant numbers of these during the period.

Since 2008 we have gradually been moving staff in computer science away from the conventional post-92 University workload model, based upon teaching with remission for research, to a situation where all staff have a balanced workload comprising teaching, research and administration in approximately 40:40:20 ratios. In addition, we have adjusted our teaching models to ensure that most staff get either two clear days each week for research or blocks of time, depending on their preferences and the courses being taught. One of the ways this has been achieved is through the creation of a junior post of academic assistant. The Computer Science Department currently has ten assistants and they support staff in their teaching across areas such as laboratory supervision and staffing help-desks for support with assignments, but also act as research assistants providing *ad hoc* support such as carrying out experimental and technical work or supporting research events including conferences and technical meetings. These junior staff are typically registered for research degrees, and the University is implementing a new staffing structure that ensures there is a career path for them through to full academic positions. They are managed centrally within the school by a senior member of staff who ensures that their development as researchers is considered alongside their development as teachers.

Throughout all of our staffing policies, equal opportunities are carefully considered, in line with the University policy on equality and diversity: the university no longer has a compulsory retirement age, all staff are offered opportunities to engage in research, and we ensure that breaks in activity for any reason (such as maternity/paternity, compassionate leave, career breaks or illness) are managed sensitively. All staff are able to benefit from the University's sabbatical policy, entitling them to be seriously considered for a 12 month break every seven years of service. In practice, however, the school is usually able to facilitate breaks less formally through careful workload management. The ethnic and linguistic diversity among our staff gives us considerable strengths in international collaborations. We are keen to promote staff in recognition of their achievement; during the REF period 4 staff have been promoted to Professor (*Gao*, *Gemikonakli*, *Huyck* and

Karamanoglu) and 3 to Reader (*Belavkin*, *Loureiro* and *Raimondi*). These promotions alongside our newly recruited 4 Professors (*Albrecht, Ghanem, Nagarjan* and *Zhou)* and 1 Reader (*Augusto*) ensure strong leadership across all three areas.

Many ECRs are also new to teaching, and we take great care to ensure that the pressures of teaching do not cause major discontinuities in their research, as our decision to appoint them is accepted as a commitment to support the transition from ECR to an independent academic career. Most ECRs will be required to attend our Postgraduate Certificate in Higher Education to develop teaching skills, with a reduced teaching load to facilitate this, and many continue to complete the full Masters programme (MEd). The programme includes research training such as doctoral supervision skills, grant writing and research project management. It is very unusual for an ECR to be given a module (course) to lead in the first year, and he or she will typically join a team on an existing module taking tutorials and supervising laboratory sessions, possibly contributing some lectures in their specialist areas where appropriate. This means the individual does not need to get heavily involved in academic administration in the first year, and workloads can be adjusted easily if someone needs more time to adapt to the teaching role without hindering their research. It also provides flexibility to ensure that networks can be developed and sustained, and we always honour commitments such as conference attendance or overseas visits previously planned (even if these are of several weeks duration). We also encourage new staff, including ECRs, to continue involvement such as research student supervision at their previous establishments where practicable and in the interest of the student.

All new members of staff have a full induction programme and are allocated a research-active mentor who can help them with University systems for supporting research. Because we do not operate formal research groups, we take great care to ensure that all new staff are introduced to a variety of colleagues with related interests and that they are invited to all of our seminar series (see below). We also ensure that all new computer science staff have regular, informal, contact with the Dean, Deputy Dean and their Head of Department (all of whom are in this submission): this helps them feel valued and supported, but also ensures they can contribute to our strategic development through the input of their prior experience, reflections and ideas. This is important, because we want to create an environment where new staff feel empowered to develop quickly, where status is not a barrier to excellence, and where we learn from each other regardless of status. Most of our new staff, including ECRs, come from strong research groups both nationally and internationally, and one of the attractions they find at Middlesex is that we recognise their value and excellence from the outset. We also help new staff to plan career progression from the beginning, so that we align our expectations with theirs. Our flexible structures benefit us here, as we are able to allow younger staff to lead sub-areas of research as soon as they are ready, without having to restructure group configurations and without the administration and overheads that accompany resource management of formal groups. This, we believe, is central to our success in attracting and retaining research excellent staff in a highly competitive market.

The School operates four seminar series relevant to this submission. All staff are kept free of teaching to attend the main School seminar programme, which is intended for a general, technical, audience, and has a mixture of prestigious external and internal speakers, including for 2013 Mike Paterson, Iain Stewart and John Harrison from INTEL. All new staff will be asked to present within their first term, as this increases their visibility and facilitates collaboration. Most staff will also be able to attend the seminar programme in their specific area, but many also manage to attend across all four seminar series. This serves to ensure that all staff are aware of the breadth of activity across the school and are able to participate in activities around their specific area of interest. The Interaction Design Centre has a longstanding weekly seminar series, frequently organised around visits of international partners, and often extending to half-day or whole-day events on particular themes. It also organises various workshops, such as the prestigious 2 week UKVAC summer school funded by the US and UK governments, which provide an excellent opportunity for our staff and research students to work alongside international experts on current research challenges. There is a theoretical computing and AI series, initially intended as a reading group to support research students in studying the more complex mathematical literature, but now a strong weekly seminar series with regular invited speakers and also social activities to ensure

that the many new staff in this area feel welcomed and supported. The networks and distributed systems area has developed its seminar series around workshops, typically half-day, with invited speakers or visiting research groups forming part of an informal exchange programme, or sessions around new equipment within our laboratories. All of these series have been able to evolve to meet specific needs and preferences of staff, maintaining their character and vitality through local coordination. They are, however, administered and centrally funded by the school, supporting events, international visitors and occasional longer-term visits where possible.

The University has a number of specialist functions to assist staff in research activities, and we ensure that all staff are aware of these, and also that staff in the centre are informed of the arrival of new staff, their areas of interest and any immediate help they may require (for example, if a conference is being organised or a grant application already underway by a new member of staff). We are fortunate that the current Director of Research at University level, Professor Dick Comley, is also a computer scientist and included in this submission. The specialist functions offered by the Research and Knowledge Transfer Office (RKTO) include support for contracts and grant applications including all legal and IPR issues, and a specialist unit for assisting academics to manage the development of impact through routes such as spin outs and channels for knowledge transfer. It also manages the formal committee structures for research, including those for the governance of research policy and research degrees, procedures for our ethics committees and responsibility for all policies and procedures relating to good scientific practice and compliance with the concordat on research integrity. The RKTO also facilitates access to a variety of external information sources and contacts, such as understanding of the latest European funding policies and the priorities of national agencies, and has an excellent research intelligence dissemination system for ensuring all staff are aware of funding and other opportunities, and collaborative bids across the institution are initiated and facilitated.

The School is also very active in running technical staff development events. Whenever new facilities are added, all staff are invited to training events to ensure they feel empowered to utilise these, and also to create networks of interest. The recent acquisition of a cloud server, for example, to support the work of *Sakellari* and *Ghanem*, was supported by an additional £10,000 specifically for training, so that existing academic and technical staff felt empowered to use the facilities alongside new staff, immediately starting the process of building human networks around new technology.

Our staffing strategy is firmly focused on full-time staff, rather than utilising part-time or visiting academics, as this is essential for our long-term strategy. The exceptions are *Bornat* (phasing his retirement, but still very much part of our community); *Ham* and *Mostarda*, who were both full time until recently, but have developed partnerships in Korea and Italy respectively and are currently spending a period each year overseas with contracts allowing them to return to Middlesex full time when their projects finish. For *Mostarda*, this has enabled him to obtain funding (through Camerino University, one of our partner institutions) from the Italian government to work on the PASS project, developing a sensor-enabled environment supporting assistive technology for the elderly: an area that integrates well with *Augusto's* work in the UK. Regular staff exchanges with Camerino are an example of the way that seminars in networks and distributed systems have developed around such group activities. *Aiash* and *Vien* have been appointed initially on fixed term contracts to cover these absences, but both are ECRs and hence add to our research capability as well as providing teaching cover. *Walker*, who is also 0.5FTE at Nottingham, was appointed here specifically to help with public engagement in science through his media activities as part of our STEM development agenda, but is bringing together research activities from robotics, sensors and interaction design around the development of new public engagement opportunities, stimulating new research as well as disseminating our existing work.

Our (contract) research staff and technical staff are equally important to our strategy. Research staff are primarily allocated to specific projects, although the School has a fund it uses to retain excellent individuals between contracts, providing job security and promoting long-term developments. This fund is also used to enable appointments to be made prior to the formal start-dates of projects, facilitating a more efficient recruitment strategy. We have invested heavily in the

10 academic assistants noted above, who act as junior RAs. Researchers and technicians have access to the full range of development opportunities available to academic staff including seminars and research events, plus all workshops organised centrally by the University. The School technical team includes ten dedicated computer science staff, all of whom are highly skilled. Two of these have PhDs and three are currently completing a research degree. In line with our general strategy, we do not separate out research technicians, as all of our staff support areas of research, several of them co-author research publications and are included in project teams.

ii. Research students

The strategy for research students is to recruit them only to areas of existing strength: we do not use them to develop new areas. Like research funding, our numbers of students and doctoral completions lag behind the growth in academic staff, but both show significant signs of increasing as we would expect. We have also managed to reduce the average time for completion to well below 4 years for full time students, reducing the overall numbers of students in the system, but increasing completions to 52 in the period, 10.4 per year compared to 4.2 in RAE208.

The University runs a research student training programme that conforms to the Vitae framework. This is supplemented by an extensive programme of school events. These range from informal training in new technologies, such as the new cloud servers mentioned above, to two week full-time programmes in using the R language environment and the residential Visual Analytics Summer School. Students are also required to attend a range of internal seminars and encouraged to take the opportunities offered at other London University seminar programmes. Students have the same access to funds for conference attendance to present papers as academic staff, with the emphasis being on quality of papers rather than quantity, and most students will be able to attend at least one top international conference during their three years. Attendance at national-level conferences is also supported to provide experience where appropriate. The School also runs a highly successful annual conference for research students across science and technology, with a formal call for papers, reviewing process and printed proceedings, with more than 40 papers presented in four parallel streams last year.

All supervisors must undergo a formal training course, provided by the RKTO, and the supervisory team (typically two people) must contain experience of successful supervision. ECRs will thus be coupled with experienced supervisors who will mentor them through the process as well as ensuring excellent supervision for the student. The School enforces strict limits on the numbers of students supervised, 6 per person, and also takes into consideration the supervisor's track record on time for completion. A small team of highly experienced staff are on hand to help with the occasional problems that students have where they feel the need to talk through issues with someone outside of their direct supervision team, typically when they feel 'stuck', and this has helped with our completion rates.

Students are monitored via a formal six monthly process, but they are integrated into project research teams so that there are many other less formal review points built into programmes such as presentations at project meetings, contributions to publications or participations in partner visits. Part time students are required to attend the University regularly: for some this is intensive blocks, for others it may be weekly evening meetings. Our decision to locate research students centrally within the Computer Science building in a well-resourced Graduate Centre aids informal monitoring, as senior staff regularly drop in and have discussions with students, identifying issues early, and before they become problems.

The school and University have invested heavily in PhD studentships (fees and maintenance), typically 7 per year for computer science during the period, in addition to the funding for academic assistants, who are also undertaking research degrees. In recognition of the number of ECR staff recently recruited, the university has agreed to increase this significantly to 12 for 2013-4. In all cases our approach is to support only students in areas where we already have excellent research and high-quality supervision capacity.

d. Income, infrastructure and facilities

The major developments that have taken place in the period have been the result of strategic

planning and investment, supported by strong governance and quality processes at all levels. Following the RAE in 2008, and the development of the plan for STEM, the School has benefited from sustained investment but also a focused estate strategy as the institution moved towards the current situation with all of its UK provision based upon a single campus at Hendon. All of the income associated with the RAE was returned to the School, either directly or through PhD studentships managed centrally. The School took the decision not to use this substantial increase in income (approximately £500,000 p.a.) to invest in permanent academic staff as this would constrain growth after an initial cash injection, and ultimately lead to a position that was at best slowly declining. Rather we worked with the University to establish an additional, planned, long-term strategy for investment in staffing from existing core funds, with the additional RAE funding supporting growth in infrastructure, additional support for existing and new research areas and, critically, investment in high-risk ventures. A few staff were recruited on these funds to overcome immediate budget constraints, but were moved across to core funding within a year.

This investment fund managed locally enabled us to establish our collaborative aspirations, as staff were able to request resources to plan ventures such as EU applications. In particular, the School invested both time and money in visits to the US to develop the UKVAC and to run the first summer conference, resulting in the UK consortium being established. As a result of this investment our access to EU and other international funding has increased substantially, and we have developed an excellent network of partners around the world. This investment is now starting to show returns. For example, the successful bid to lead the £13.5m VALCRI EU project in Visual Analytics for Criminal Intelligence, is by far the largest project Middlesex has managed. The fund has also been used to support all staff in hosting meetings and exploring speculative ideas, both internally and externally.

Research income for the period is approximately £3.6m. This is a significant increase over the £1.6M submitted in RAE2008. Even with the 140% increase in category A staff, we have managed to increase the spend per FTE. Given the time lag between the appointment of new staff, particularly ECRs, and the flow of money through the accounts, we expect research income to increase substantially. The value of approved grants on our books is rising rapidly, with £2.5M added last year, £5.2M still under review, and newly appointed staff are already starting to attract significant funds. For example, *Augusto* has recently been awarded approximately €400,000 as part of a large FP7 grant and *Martin* has won his first EPSRC grant, £100,000, to work on infinite domain constraint satisfaction problems. As noted above, we have also accessed funding overseas by enabling staff to take fractional appointments in other institutions e.g *Ham* with the Korean Atomic Agency and *Mostarda* with Camerino in Italy.

The University policy of consolidating activities on the single campus at Hendon has brought tremendous benefits for our research, as the opportunity was taken to reflect the strategic importance of enhancing research in computer science and STEM generally within our estate strategy. As well as general infrastructure developments such as the consolidation of library facilities enabling access to more than 40000 journal titles, typically electronically, this has resulted in a complete redesign, and reconceptualization, of our laboratory provision, complete with new equipment and infrastructure. In 2008, we opened a new £40m science block, bringing together biosciences, computer science and psychology, with the specific goal of developing synergy between the subjects (as can be seen in this submission). This included a new suite of five observation laboratories clustered round a central control room, equipped with remote control cameras and lighting to support the Interaction Design Centre, and a new eScience grid facility and specialist facilities for medical measurement, imaging and analysis. In 2011 a further new building, costing £80m was opened to support all aspects of design and media. This includes professional standard TV and sound studios and production facilities, used by our computer vision researchers and interaction designers, and also modern manufacturing facilities. The latter is central to the development of robotics and embedded systems, as we now have full capabilities to construct major mechanical systems (such as the world's largest ever delta robot recently exhibited in the Tate Modern, 'Fearful Symmetries'). In 2012, with the creation of the new School of Science and Technology, the University took the opportunity of a final relocation exercise to completely reconfigure and re-equip all of our remaining laboratories alongside the development of four new

Computer Science laboratories. This enabled us to create 5 dedicated laboratories for robotics, embedded systems and physical computing, equipped with professional standard NI instrumentation, re-equip 4 laboratories with state of the art networking facilities including VOIP systems, and create facilities such as a sensor area networking lab. A capital grant of £240,000 allowed us to invest in a 3D printer capable of prototyping components with blended materials for haptics, robotics and interactive systems. The School also took the opportunity to create a private fibre network linking every School facility across the campus, and hence improving the integration of our facilities, including the development of a Blade Server facility costing £60,000 to support distributed systems research, whilst retaining complete control over the infrastructure.

Our substantial investment fund has also enabled us to provide specialist equipment to support new staff in moving on-going research to Middlesex: *Loureiro*, for example, was given a fund of £100,000 to recreate the ROBIN rehabilitation robotic system he had developed at Reading: this was immediately rewarded by a grant from DSTL for £173,000 for research into the use of haptic devices for relief of phantom limb pain. An investment of £40,000 was made on a sensor network facility to support the work of *Mostarda* and *Augusto,* and a new cloud server also costing £40,000 has been installed to support the work of *Sakellari* and *Ghanem* during their transition to Middlesex. We have strengthened our technical staffing, and developed the high-level skills and knowledge we require to support these developments. We are currently developing a technical structure that makes explicit the research roles of technicians in Computer Science, and also offers career paths to academic careers for those who so desire.

Administrative support for research is shared between the RKTO (supporting grant applications, legal services, budget management for projects, reporting requirements etc) and the School office for day-to-day support. Support for major events (conferences, summer schools, start-up meetings) is available centrally, but we often choose to employ senior research students or our academic assistants for this, as it helps them develop confidence and skills in such matters as negotiating with senior academics, planning projects and exploring areas outside of their narrow fields of study. It also helps them develop networks, and often results in invitations to visit other institutions.

In 2011 we decided that our strategy for collaboration needed closer integration with mechanisms designed for local interaction and public dissemination. We developed a channel for promoting our research services as consultancy and created a School Innovation Centre, deliberately located off-campus in a modern development with easy access and a large shop-front. This was fully funded by the University for a two-year start-up period and is already starting to demonstrate considerable success. Locally, for example, our interaction design expertise has been used as part of the project coordinated by the nearby RAF museum in Hendon to raise the remains of the Dornier Aircraft, funded by Wargaming.net (£75,000). We have created the Interpretation Zone and associated augmented realities at the Cosgrove site. The centre has also attracted international business, and we were one of the consultants advising Macy's of New York on their rebranding project in the area of interactivity in retailing. The centre is developing into an important aspect of our environment, both by attracting potential collaborations and also by acting as a showcase for our capabilities to the wider community.

e. Collaboration and contribution to the discipline or research base

Collaboration is fundamental to our research strategy. The nature of our work often requires teams with a blend of expertise and methodological skills, frequently drawn from several disciplines. For example, medical imaging research is carried out by teams including computer scientists, biomedical scientists and clinicians. Similarly the visual analytics area draws upon collaborations with geographers, intelligence analysts and psychologists. Internal collaboration is particularly strong within the new school, but also spans most other areas of the institution. External collaboration with academic and industrial partners, both within the UK and abroad, is a very strong component of our approach, enabling us to participate in a broader range of projects and access significant funding streams. As noted above, we invest heavily in expanding our collaborative base.

Visual Analytics offers the best illustration of this strategy in practice. The UK Visual Analytics Consortium was initiated by Middlesex as a way of enabling us to collaborate with projects being

organised through the US VAC, funded by the Department of Homeland Security. We created a consortium, at the request of the UK and US governments, as a vehicle through which all such transatlantic collaborations involving visual analytics could be channelled. Contacts made through this activity also led to Middlesex leading a €3.5m project, Crisis, on visualisation in security and crisis management with partners including Linköping University in Sweden, the University of Iceland, the West Midlands Police and British Transport Police. It also led to our involvement in the EPSRC Ideas Factory – Detecting Terrorist Activities: Making Sense (EP/H023135/1) led by Hankin at Imperial, with partners including Southampton, Leeds, LSE, Salford, Liverpool, Cranfield, Dundee and Surrey. The €13m VALCRI project (mentioned above) builds upon CRISIS, but includes new academic partners such as the University of Konstanz, Leuven University, TU Vienna, City University, and also the Pacific Northwest National Laboratory in the US, providing access to the American security community. A team, comprising the Advanced Technology Centre at BAE Systems, the Interaction Design Centre at Middlesex University, the Department of Air Transport at Cranfield University, and MASS Ltd, a leading Electronic Warfare operational support and training organisation has recently been awarded another grant, £195k from the Defence Human Capability Science & Technology Centre, to research the integration and visualisation of multiple source information to support decision-making by military personnel.

In the area of algorithms, in addition to strong internal collaboration, medical imaging related activities have been carried out with UCL (*Tizzard*, EP/E031633/1), and also Fudan, Tsinghua and Fuzhou Universities and the General Navy Hospital Beijing, China. *Belavkin* was PI on a grant, *Evolution as an Information Dynamic System* **(**EP/H031936/1), with partners at Manchester, Keele and Warwick, and a new grant of approximately £500,000 has been awarded by the BBSRC led by life sciences at Manchester. *Raimondi* has been awarded a grant (EP/K033921/1) to work on *Verification of resource-bounded multi-agent systems* with colleagues at Nottingham. *Clark* is working with the University of Duisburg-Essen, on the XMF/XModeler toolset to support new types of language engineering.

Many of our collaborations are interdisciplinary in nature. For example, *Belavkin* is working with natural scientists on mathematical models for evolution. *Barn* is working with social scientists at Royal Holloway on a project investigating the use of personalized mobile applications by young offenders and their youth workers. These interdisciplinary collaborations, and also collaborations with users of our research, such as clinicians, police forces and security agencies have ensured that our research is informed by practice and real need, rather than being curiosity driven alone. We are increasingly using Middlesex's overseas reputation and infrastructure to work with international users of our research: *Barn* and *Clark*, for example, have developed strong links with the software engineering research labs in India including the leading commercial research centre – the Tata Research, Design and Development Centre. Other collaborations with labs in India include Infosys and Accenture Labs where *Barn* and *Clark* have provided research input to product development activities. *Gao* and *Loomes* are working with clinicians in both Russia and China on medical imaging. *Kammemuller* has research collaborations with Microsoft Research at Cambridge. *Raimondi* has been collaborating via annual sabbatical visits with NASA on model verification since 2009.

Staff are encouraged to engage with colleagues externally through a variety of mechanisms. In 20012/13, for example, six staff were involved with Dagstuhl workshops, as organisers (*Clark)* or participants (*Attfield, Androutsopoulos, Xu*, *Raimondi* and *Martin*). Several members of staff hold visiting positions at other institutions. *Yang(X)*, for example, is a Visiting Professor at Reykjavik University, Iceland, a Guest Professor at both Harbin Engineering University and Shandong University, China. *Bornat* holds an emeritus position at Queen Mary. *Belavkin* is an Associate faculty member at the Center for Applied Optimization, University of Florida, USA. *Wong* was an International Visiting Research Scholar at Peter Wall Institute for Advanced Studies, University of British Columbia, Vancouver, Canada and *Kammemuller* was a Visiting Professor at University of Porto Allegre, Brazil. We have also established a residence scheme for practitioners wishing to collaborate on a regular basis with our staff on more applied aspects of our work, and currently have four designers in residence: Florian Dussopt, Michael Margolis, Nick Philips and Colin Payne, enabling us to use collaboration as a method of dissemination and public engagement.

The University is very supportive of staff engaging with the computer science community, and facilitates such engagement with resources were possible. The School sees this as a strategic priority for staff at all levels. *Loomes* and *Wong* are members of the EPSRC peer review college, whilst *Gao* and *Walker* are members of the AHRC peer review college. *Loomes* has also served for 7 years on the executive committee of CPHC, representing that body on the BCS Learned Society and Knowledge Services Board, BCS Research Committee and the UKCRC. He is also on the executive committee of the UK Deans of Science. *Yang(X)* is Vice-Chair of the IEEE CIS task force on Business Intelligence. *Springett* contributes to two COST actions, as vice chair of IC0904 and chair of a working group for 294.

Most colleagues are regular reviewers for research councils and other funding bodies, both on specific calls such as the EPSRC Grand Challenges in Health 2008 (*Gao*) and Data Intensive Systems – DAISY (*Wong*), and responsive mode submissions. A number of colleagues are reviewers for international research councils such as Czech Research Foundation and the Italian National Agency for Research and Academy Evaluation (*Primiero*), the Research Council of Norway (*Duquenoy*), Swiss National Science Foundation (*Yang*), Qatar National Research Fund *Nagarajarn*), National Research Foundation of South Africa, CHIST (*Wong),* and the National Science Foundation (*Loureiro*). All colleagues contribute to the wider international academic community though programme committee work for leading conferences (including CHI, ICSE, FASE, Rehabilitation Robotics and others) or as reviewers of leading journals. Since 2008, several colleagues have been guest editors of special issues including: Philosophy and Technology (*Primiero*); IEEE Transactions on System, Man, & Cybernetics: Part B Cybernetics (*Kotsia*); Future Internet Journal (*Mapp*); International Journal of Industrial Ergonomics (*Ham*); International Journal of Mathematical Modelling and Numerical Optimisation (*Yang*), Software and Systems Modelling (*Clark* and *Barn*) and Universal access in Information Systems (*Springett*). In addition to special issues, several colleagues occupy academic leadership positions as editors-in-chief of journals such the Journal of Ambient Intelligence and Smart Environments (*Augusto*) or as editors of top journals such as Biosystems & Biorobotics (*Loueiro*).

A number of colleagues have been invited keynote speakers at leading conferences. For example *Raimondi* was the recipient of a Best Paper award at ICSE 2008 and the paper subsequently presented as keynote talk at ISEC 2009. Other invited keynotes at conferences have included: NATO IST116 Conference on Visual Analytics in 2013 (*Wong*); the 5th International Conference on Human-centric Computing (HumanCom-12) (*Augusto*); World Wireless Research Forum, 2011 (*Ghanem*) and the 10th International Symposium on Experimental Algorithms (*Yang*). Recognising that practitioner communities are also vital for a research community, *Loureiro* was an invited speaker to The Italian Neurorehabilitation Group (IRNG) at Versilia Hospital, Italy and *Barn* was an invited speaker at the UK Enterprise Architecture Forum in 2013.

The research community at the School is supplemented by regular sabbatical or other visits from international researchers. Visiting Chairs include: Prof. Ann Blandford from UCL, Sue Thexton (Senior VP, BrightCove) and Prof. Harold Thimbleby from Swansea. Professor Penelope Sanderson from the University of Queensland visited *Wong* as part of her Royal Academy of Engineering Distinguish Visiting Fellowship. Currently, Dr Antony Moore from the University of Otago is also visiting the IDC. Dr Feng from the University of Technology in Sydney visited *Najarajan* to collaborate on their Australian Research Council joint project. Juan Botia Blaya, University of Murcia is working with *Augusto* on smart environments for dementia patients. Continuing with our strategy of developing the next generation of the international research community we have received a number of junior researchers embarking on their research careers. In the area of complexity theory, *Martin* was host to Antoine Mottet visiting from ENS Lyon. Sebastian Bittman from University Osnabrueck working on literate modelling visited *Clark* and *Barn. Raimondi* hosted 5 junior researchers from the Universities of L'Aquila and Warsaw to contribute to work on model-based verification. Consistent with some of the applied nature of our research, Prof. Vinay Kulkarni, Chief Scientist at Tata Research, Design and Development Center visited *Barn* and *Clark* to continue their research collaboration on model driven engineering.