Institution: King's College London

Unit of Assessment: Computer Science and Informatics

a. Overview

Informatics at KCL comprises a unique combination of research in robotics; autonomous agents; planning; software modelling; applied logic; wired and wireless communications; algorithms and bioinformatics and signal processing. These areas were brought together to respond to emerging challenges in ICT and society.

Informatics comprises the following groups addressing different aspects of ICT in the future society:
Centre for Robotics Research (CoRe): Distributed sensing, perception, control, dexterous manipulation, reconfigurable mechanisms, learning and cognition for the fusion and interpretation of sensor signals, haptics and human-robot interaction;
Centre for Telecommunications Research (CTR): Telecommunications and signal processing with applications to mobile networks and systems, audiovisual communications and applications in biomedicine and the connected society.
Software Modelling and Applied Logic (SMAL): Domain specific programming languages and embedded languages, specification and programming environments, software modelling, automated verification and software analysis techniques, security, real time response and safety-critical systems, logic and analysis of complexity;
Agents and Intelligent Systems (AIS): Multi-agent architectures, complex networked systems, inter-agent collaboration and negotiation, communities of agents and adaptive agent behaviours;
Planning: Automated strategic planning and decision-making, modelling and solution of decision problems, planning with time and metric resources, management of uncertainty and plan-based learning;
Algorithms and Bioinformatics (AB): Organisation, distribution and management of Massive Data, randomised algorithms, approximation algorithms, string algorithms, heuristics, meta-heuristics and optimisation methods.

b. Research strategy

In 2010 a new strategy for Informatics was formed, based on the initiative of bringing Artificial Intelligence, Robotics, Software Systems, Algorithms and Telecommunications into one department in order to facilitate the collaborations necessary to address some of the major Information and Communication Technology (ICT) challenges emerging today.

In 2008 the Department of Computer Science consisted of 3 research groups: Algorithm Design, Logic and Theory of Computing and Software Engineering. As part of a strategic reorganisation within the School of Natural and Mathematical Sciences, the Department of Informatics was formed in 2010 by the merger of Computer Science with the Centre for Bioinformatics and two groups from Engineering: the Centre for Robotics Research (CoRe) and the Centre for Telecommunications Research (CTR). With these additions, Informatics has significantly expanded and diversified, at the same time building on the areas of strength submitted in RAE 2008. CTR brought 8 staff and has been further strengthened by 3 new posts. There has been a major strategic expansion in Robotics and AI, including 12 new posts, across AIS, Planning and CoRe. The formation of both the AIS and Planning groups has taken place since 2010. The loss of the Centre for Research on Evolution, Search and Testing (CREST), which featured strongly in the 2008 submission, led to a restructuring in which Software Engineering was combined with Logic and Theory of Computing, in order to better exploit shared interests in formal verification, security and formal modelling. This new group has been enhanced by the recruitment of 5 new staff. Algorithms and Bioinformatics is based on the pre-existing Algorithm Design group, with an increased emphasis on its strong research in bioinformatics. The group was supported by a new post in 2013.

The strategic objective pursued by the Department has been to bring together a diverse collection of groups in Computer Science and Engineering, under a broad interpretation of Informatics, investing in enhancing excellence within the groups while emphasising integration between them. In doing this, Informatics has cohered around a collection of areas of expertise that together

address some of the major modern challenges in the future Information Society.

The Research Groups

Research in Informatics is coordinated within 6 research groups, as identified above.

CoRe (8 members, Group Leader: Lakmal Seneviratne): CoRe pursues fundamental as well as applied research in four closely interlinked research strands: Intelligent Mechanisms; Sensing and Perception; Computational Intelligence and Machine Learning and Robot-Human- and Robot-Environment-Interaction. Across these research strands, CoRe engages in the creation of metamorphic, reconfigurable as well as soft robot mechanisms, new approaches to locomotion and bi-manual control and miniature force and tactile sensing technology, together with new insight into neuroscience, advanced fuzzy control methods, and machine learning for robotic skill acquisition and imitation, and pattern recognition techniques. CoRe impacts on a wide range of applications in industry, healthcare and society.

CTR (11 members, Group Leader: Hamid Agvhami): Telecommunications research in the decades ahead will be marked by integration of billions of smart mobile and heterogeneous devices, into the Internet of Things (IoT), to form the information infrastructure of a modern society capable of supporting health, smart cities, energy, transportation and environment systems. CTR activities are focussed on providing advanced information processing, communication and networking solutions, as well as reference architectures and models underpinning the IoT, along with applications in biomedicine and the connected society.

SMAL (10 members, Group Leader: Maribel Fernandez): The group works on modelling and engineering of software systems, and applications of logic and mathematics to computer science, information and software security, and multi-agent systems. The major themes within the group are: software modelling, developing environments to support the specification and verification of complex systems, security, building innovative programming languages and language workbenches, and constructing logical models for multi-agent systems and the semantic web, using spatial, temporal, non-monotonic, multi-modal and description logics.

AIS (7 members, Group Leader: Simon Miles): The focus within AIS is on distributed artificial intelligence and automated reasoning. The major areas of research are in multi-agent systems, argumentation, normative systems, complex systems, machine learning, market-based control, uncertainty, and data provenance. The group leads research into modelling of arguments, provenance, and norms, and the development of reasoning over these in practical systems, in particular in healthcare and clinical research, in economic marketplaces, in analysis of social networks, and in aerospace applications.

Planning (6 members, Group Leader: Maria Fox): The group works on building planning systems and modelling languages for temporal and metric planning. The major areas of focus are in temporal modelling and reasoning, management of metric resources, planning with concurrent and synchronised behaviours and integrating planning with the controllers of robotic systems. The group leads research into representing and planning for mixed discrete-continuous planning models. The group has a particular focus on applications of planning and the transfer of domain-independent planning technology into a range of practical applications, including remote vehicle task planning, planning for future energy systems and resource-constrained transportation planning.

AB (7 members, Group Leader: Costas Iliopoulos): The key research themes of the group are string algorithms and their applications, the analysis and search of massive networks, and bioinformatics. Research in the group on string algorithms involves designing provably efficient algorithms for processing sequences of symbols. Research in bioinformatics aims to use computational methods to enhance understanding of the importance of specific molecules in pathological conditions, and in the development of a comprehensive view of disease network dynamics. The aim of research on analysis and search methods for networks is to develop fast, distributed algorithms for discovering structural properties of massive networks, based on the analysis of random graph processes.

Vision

Over the next decade and beyond, there will be increasing demand for both physical and virtual intelligent infrastructure to support the systems on which we are increasingly dependent in all aspects of life. These systems include the physical infrastructure supporting healthcare, energy, transport safety and security, and the virtual worlds of the cloud and the connected society. The

vision of the Department of Informatics is to be at the centre of developments in designing and realising the future intelligent computer systems and machines that will supply this infrastructure, making some of the transformative inventions that will lead these developments. The combination of strengths now within Informatics provides the right mixture of scientific and engineering technical expertise and background to initiate some of the fundamental advances underpinning future intelligent, autonomous and massively distributed systems. Deployment of physical robots in sectors such as health, requires advances in the intelligent co-operation of dexterous manipulators and sensors, key areas within CoRe, and biomedical imaging, speech and audio signal processing, key areas within CTR. Long-term autonomy requires advances in modelling, real-time response and software security**,** key areas within SMAL. Advanced control and decision-making, both single- and multi-agent, are the focus of AIS and Planning. The challenges of Massive Data require advances in random algorithms and optimisation methods, the focus of AB. The Internet of Things, which will support the autonomous organisation of interoperable virtual objects in the future connected society, is the focus of CTR. Tailoring the architecture of the internet to support future communication patterns and content consumption, requires advances in both network capacity and transmission quality, to support multimedia over internet and advanced content distribution schemes. These are key areas in CTR, integrating with research on graphs, complex networks, data mining and analysis of massive data sets in AB and AIS.

Addressing these challenges requires expertise that cuts across groups, inspiring collaborations and synergies between them. Informatics is working to build an environment that facilitates cross-cutting collaborations, both in theoretical and applied research. At the same time, Informatics recognises the importance of enabling highly focussed research within specialised areas, and building the expertise and mass within its areas of strength to ensure that world-leading specialised research can flourish.

Future Plans

Following a period of strategic realignment, Informatics plans to cohere around the 6 research groups now established, and concentrate on building its reputation for excellence in both research and industrial engagement in, and across, these areas. Through College-level reorganisation and the 21 new academic appointments made since 2009, Informatics has brought together excellent individuals, who are leaders in their research communities, and provided them with team-building resources. By focussing on groups that address complementary problems, Informatics has positioned itself to make substantial contributions in key emerging areas. Informatics plans to contribute to defining future intelligent systems and providing advanced solutions to the new problems in communications, distributed intelligence and automation, physical autonomous robotics and intelligent information processing. To do this, Informatics will drive both academic research and impact in these areas, building on existing collaborations between CoRe and CTR; CoRe and Planning; AB, AIS and CTR; AIS and SMAL, and encouraging further inter-group collaboration. Targets will include:

1. Increasing cross-cutting project-funding from the research councils. Proposals combining agent-based systems with green communications in cognitive radio, and microwave imaging with Nuclear Quadropole Resonance for explosive detection, are already in progress;
2. Increasing engagement with non-academic partners providing opportunities to field technology Links are being established with new partners such as Schlumberger Ltd, BSkyB and Broadcom;
3. Improving existing laboratory facilities, in order to facilitate specialised research and attract the best researchers.
4. Increasing collaboration with other departments and institutes within the College. KCL provides a rich context for interdisciplinary research, particularly in War Studies, Digital Humanities and the Schools of Medicine, Dentistry and Biomedical Sciences, where research objectives are already aligned with those of Informatics and strong collaborations with Informatics are already in place.

c. People, including:

i. Staffing strategy and staff development

Of the 24 Category A staff submitted to Computer Science and Informatics in RAE 2008, only 12 remain in this submission, yet staff numbers have increased to 49 (including the addition of 11

early-career researchers: Pissis, Black, Musial-Gabrys, Magazzeni, A. I. Coles, A. J. Coles, Liu, Howard, Mahmoodi, Sastry and Zschaler). 46 of these 49 are submitted. This increase has been achieved partly through reorganisation (13 posts) and partly through new appointments (21 posts). All 21 new academic appointments have been directly focussed on building strengths in the critical areas supporting the outlined research strategy, and have been focussed on building capacity in the 6 groups outlined above.

CoRe: As a key part of the merger that formed Informatics, 6 roboticists: Althoefer, Seneviratne, Dai, Nanayakkara, Lam and Spratling joined the Department from the Division of Engineering, bringing expertise in sensing, automation, reconfigurable mechanisms, non-rigid body mechanics and learning, fuzzy control, neurocomputing and vision. The coexistence of Robotics and AI within the same department provides an ability to address intelligence and control in a coherent and integrated way that is not possible in many other institutions. We have since sought to strengthen Robotics, and the bridge with Artificial Intelligence, with the appointment of 2 further lecturers: Howard and Liu.
CTR: Also as part of the merger, Agvhami, Cvetkovic, Friderikos, Kosmas, Nakhai, Nallanathan, Said and Shikh-Bahaei, joined the Department from Engineering, bringing the long-established Centre for Telecommunications Research into Informatics. Between 2009 and the present, 3 other posts have been added: the Professorial post of Dohler, appointed in 2013 to lead research in broadband wireless design and the Internet of Things, and the junior posts of Mahmoodi and Sastry.
SMAL: This group was formed by integrating the previous Logic and Theory of Computing group with the previous Software Engineering group, bringing Fernandez, Kurucz, Lano, Rodrigues and Overill into the new Informatics. Reinforcement of strengths in software and security have been realised through 5 new appointments: Chockler, Tratt, Urban, Vigano and Zschaler, in formal verification, programming language design, security logics, theorem-proving and model-driven development. The specialisms within SMAL complement the AIS focus on argumentation and reasoning, and the Planning focus on model-based reasoning and verification.
AIS: Luck and Miles brought multi-agent systems research to Informatics. The Professorial appointment of McBurney was made in 2010, resulting in a group of 4 (Luck, Miles, McBurney and Keppens). The group has since been further enhanced by the appointments of Black and Modgil (argumentation theory) and Musial-Gabrys (complex social networks).
Planning: To form a bridge between AI and Robotics, a new group in AI Planning was created with the strategic recruitment of 6 staff, over two phases. The first phase established the group with the appointments in late 2011 of Fox, Long and A. I. Coles. To achieve sustainability and stronger integration with AIS and SMAL, this was reinforced by the appointments of A. J. Coles and Magazzeni, and the fixed-term professorial appointment of Geffner.
AB: This group, formed from the Algorithm Design Group and the Centre for Bioinformatics, brought together Cooper, Crochemore, Iliopoulos, Radzik, Steinhofel and Tsoka. It contains expertise in: string algorithms, combinatorial optimisation, network optimisation, random structures and algorithms and bioinformatics. The group has been strengthened by the new appointment of Pissis.

Research Organisation
While research groups organise their own subject-specific meetings and activities, the Department has put in place mechanisms to foster activity across groups and awareness of activity and achievements within groups. These include: monthly Department Colloquia; Advanced Research Seminars; pump-priming funding for inter-disciplinary initiatives, Informatics Online news, a blog and facebook page and a twitter feed. There is also a programme of public Inaugural Lectures run by the School.

Mechanisms for supporting early career staff include: start-up funds, pump-priming funding, peer feedback on proposals, differential loading, and priority in the allocation of PhD student scholarships. All new staff appointed since RAE 2008 receive a start-up fund, to be spent at their discretion. The Department also makes pump-priming funds available (by application) to support the initiation of new activities whose duration is intended to outlast the funding. To encourage staff to apply for external research funding, and raise success rates, the Department provides

encouragement and mentoring in the process of writing grant applications. The Peer Feedback process, which is open to all staff at all levels, consists of a programme of regular constructive feedback meetings, in which colleagues come together as their other commitments allow, to read and comment on draft proposals.

The allocation of teaching is typically limited to no more than two modules per year per staff member, and newly appointed staff are given lighter loads to enable them to develop their research. The normal probationary period is 3 years, during which time they are carefully mentored by a more senior academic and regularly appraised against an agreed set of targets for their research career development.

As a means of providing time to focus on research in order to open up new directions or to undertake more substantial activities, every member of research active staff is entitled to apply for sabbatical leave after 6 years. In the assessment period, 10 members of staff (Crochemore, Cooper, Dai, Fernandez, Iliopoulos, Kurucz, Seneviratne, Steinhofel, Althoefer, Cvetkovic) have been granted sabbatical leave. Cvetkovic is spending his sabbatical at Stanford and Berkeley, supported by an EPSRC grant (EP/K034626/1). Staff in receipt of full fellowships are exempted from teaching, but are encouraged to participate as their time allows. In the period, A. J. Coles has been an EPSRC Postdoctoral Research Fellow, Urban an Emmy-Noether Fellow from the German Research Council (equivalent in prestige to a Royal Society Fellowship), and Black, Howard and Zschaler were in receipt of competitive Fellowships prior to taking up their posts.

Informatics has an active programme of visiting appointments. During the assessment period we have hosted some 80 visitors, for stays lasting over a month, from companies and universities from around the world. Of regular academic appointments, 25 out of 49 staff are international, with 12 from the EU, and 13 from outside the EU. In addition, we continue to seek visiting fellowships, and have hosted two Royal Society Newton Fellowships (Tischler and Puglisi), three Marie Curie Fellowships (Miller, Bertolissi and Velez), a Commonwealth Fellowship (Rahman) and a Fulbright Fellow (Sklar). Moreover, Cooper was awarded a “Japan Society for the Promotion of Science” (JSPS) Invitation Fellowship, one of only nine such awards in the UK for 2011-12.

The internal allocation of studentships (EPSRC DTA funds and internally-funded teaching assistantships) takes into account the need to support new staff, so that new staff are prioritised over others where the quality permits, subject to regulations for supervision.

Academic staff are appraised annually. The appraisal process is not directly linked to the promotion process, but it is a clear opportunity for advice on career development to be sought and given. The College has also established a programme of career development for researchers (post-docs). Finally, the College and the Department expects all new lecturers to complete its Postgraduate Certificate in Academic Practice (PGCAP) as part of their preparation as effective university teachers and educators. King’s has an Athena Swan Bronze Award, and Informatics is working with the School’s Equality and Diversity Committee towards a Silver application.

ii. Research students

PhD students in Informatics are funded from a variety of sources including EPSRC, EU and industry. A number of overseas students are funded by competitive government scholarships or by their employers. Since 2008, 14 graduated students have been sponsored by industry, through CASE studentships (e.g. BT and Vodafone), and Mobile VCE core 4 and 5 research programmes. Such students work closely with their industry sponsors – those supported by Mobile VCE were each assigned an industrial mentor, submitted monthly progress reports (reviewed by industrial programme leaders), and regularly presented their work to industrial partners, receiving feedback and technical steering to ensure research remained relevant to the industry.

Informatics accepts about 30 new PhD students per year, with a typical population of about 120. PhD students are located in open-plan office space close to academic staff and laboratory space. There is a Staff-Student Liaison Committee for research students, held once per semester, chaired by the post-graduate student tutors. The tutors provide pastoral support and help to resolve any

conflicts that could affect students' work. PhD students are encouraged to engage with their broader research communities: Informatics provides generous travel support. All students may apply once per year for funds to attend an international conference, with further funds available from supervisors and the Graduate School.

Training of research students is delivered in a three-tiered framework. King's Researcher Development Unit (part of the College's Graduate School, and the London hub for Vitae) provides generic skills training for effective researchers (with around 300 modules in its programme), and a dedicated PGR careers advisor. School training includes induction, the School's Research Day, and training modules specifically relevant to the disciplines within the School. Departmental training includes inductions, Departmental Colloquia and seminars, and student presentations, as well as a large range of taught courses drawn from our extensive portfolio of MSc modules spanning departmental research. Training is also provided on entrepreneurship.

Progress monitoring revolves around key milestones, at 9 months (a Departmental requirement additional to School and College requirements) to ensure adequate progress to move to the second year, and at 15-18 months to upgrade from MPhil to PhD, with an upper limit of 48 months for completing a PhD. In addition, monitoring requires reports every 6 months from students and supervisors (starting after 3 months), including information on training received and planned, with online reports reviewed by PGR Tutors in order to determine any further action needed. Informatics has two PGR tutors who are jointly responsible for monitoring progress and providing pastoral care.

New postgraduate supervisors must attend appropriate supervision skills training and include an experienced supervisor on the supervisory team. The Graduate School at King's has its own dedicated website for support of research students and supervisors, with information on national, College and School guidelines and regulations, and the Department also maintains dedicated internal web pages for PhD and discipline-specific resources. Academic supervisors provide a high level of support and guidance for all students. The efforts of Dai (CoRe), Iliopoulos (AB), Nakhai (CTR) and Althoefer (CoRe) in student supervision were rewarded with the Supervisory Excellence Award for the School, in 2009, 2010, 2011 and 2012 respectively.

d. Income, infrastructure and facilities

Income reflects the strategic priorities of Informatics, and is organised here under the following cross-group headings: Robotic Capability; New Technology Platforms; Autonomous Reasoning; Security; Software and Verification; and Health and Bioinformatics.

Robotic capability: Informatics has numerous projects relating to different aspects of autonomous robotics, including the EU-funded *Application of Dexterous Hands for Deboning Operation* (ECHORD), *Topological Motion Synthesis for Dexterous Manipulation* (TOMSY), *Developmental Pathway towards Autonomy and Dexterity in Robot in-Hand Manipulation* (HANDLE) and *Dexterous Assembler Robot Working with Embodied Intelligence* (DARWIN), which study the replication of dexterous in-hand movements with a variety of hands including an anthropomorphic artificial hand. The project *Cost-driven Adaptive Factory based on Modular Self-contained Factory Units* (COSMOS) is concerned with self-adaptive control strategies for the automation of manufacturing environments. STIFF-FLOP (coordinated by Informatics) addressing stiffness-controllable manipulators for robot-assisted, minimally invasive surgery. Informatics is also a core partner in SINTELNET, the European Network for Social Intelligence. In addition, Informatics holds EPSRC-funded projects, EP/I028765/1 REINS, investigating human-robot interfaces, EP/I028773/1 *Impedance Control on Uncertain Objects,* EP/E012574/1 *Investigation and Development of a new class of mechanisms*, EP/F031394/1 *Creating Physical Structure from Disarray*, the EU-funded *Architectures of light duty vehicles for urban freight transportation* (V-Feather) and two ICUK-funded projects: *Development of an anthropomorphic robotic hand* and *Exploration of a novel wheeled-legged robot and compliant metamorphic structure for lunar exploration*.

New Technology Platforms*:* Informatics holds a substantial portfolio of research in development of new platforms for wireless and mobile communications, social networking, radio access and signal processing. Research into speech and audio technologies in EP/D053005/1 *Robust Syllable*

Recognition in the Acousic-Waveform Domain and EP/F001142/1 *Perceptual Sound Field Reconstruction and Coherent Emulation* are leading to a paradigm shift in automatic speech recognition and a new multichannel audio technology. The Strategic Partnership grants EP/G062420/1 *Green Radio*, and EP/D052769/1 *Optimising Resource Efficiency in Future Mobile Communications,* are designing new ways to support cognitive radio access and resource-sharing. The project EP/I000054/1 *Robust Intelligent Lamp Post (ILP) Sensor Networks for Energy Efficient Transportation Systems* aims to develop radically new strategies and protocols for the supply of both energy and data communications along existing power transmission lines used by Intelligent Vehicle and Transport Infrastructures. Work on EP/K024914/1 CD-GAIN: *Content Delivery Using Graph-based Analysis of Interest Networks* is focussing on providing new platforms, using social networks, for supporting video over Internet.

Autonomous reasoning: Informatics holds projects funded by EPSRC and EU-FP7 in this area. In 2011 the Planning group was awarded two projects (EP/J012157/1 and EP/J012211/1) from the EPSRC "Autonomous and Intelligent Systems" call, which was co-funded by 9 industrial partners, to investigate aspects of autonomous deliberation, planning and control. Other EPSRC funding in this area includes EP/G023360/2, *Automated Modelling and Reformulation in Planning,* and participation in the multi-institutional EP/I031650/1, *Autonomic Power System*. A. J. Coles held EP/H029001/2, a post-doctoral fellowship *Maximising Efficiency of Resource Usage Under Uncertainty in AI Planning*, which completed in 2013. EU FP7 funding includes PANDORA, a collaboration between 4 European universities, addressing long-term decision-making autonomy in an underwater vehicle, and CONTRACT, providing assurances for behaviour for eBusiness. In 2013 CoRe and Planning were awarded an EU FP7 Integrated Project, SQUIRREL, aimed at integrating planning with the metamorphic hand, for use in automating domestic tidying-up tasks. The industrially-funded UAVs (BAE Systems Defence Technology Centre) project, *Norm and Organisation-based Practical Reasoning*, ran from 2009-2011.

Security: In addition to the CONTRACT and BAE Systems-funded DTC work mentioned above, Informatics holds an EU-funded project, *COunterfeit PHarmaceuticals Interception using Radiofrequency MEthods in Realtime* (CONPHIRMER), aimed at creating a portable sensor for distinguishing genuine medicines from fakes without removing them from their packaging. A Government Home-Office-funded project on NQR & NMR detection of explosives (CONTEST), and a Wellcome Trust-funded project *Radiofrequency Methods for the Non-invasive, Non-destructive Detection and Qualitative Analysis of Counterfeit, Fake Substandard Medicines*, successfully completed in 2010 and 2013 respectively. Informatics has on-going collaborations with War Studies and participates in projects on *Strategy and the Network Society* (Office of Naval Research), on *Access Control in dynamic information management and exchange for Command and Control applications* (European Office of Aerospace Research and Development), on *Bayesian Networks for Digital Forensics* (Innovation China UK), and on *Evidentiary Reasoning for Crimes* (Nuffield Foundation).

Software and verification: Informatics has held a number of EPSRC-funded grants in software modelling and search*:* EP/G03012X/1 *Higher-Order Refinement Techniques for Model-driven Architecture,* and *Software Engineering by Automated Search*, in collaboration with Daimler Chrysler, IBM UK Labs and Motorola Ltd., EP/F059442/2 *Slicing State-based Models*, in collaboration with Motorola Ltd., EP/F010443/1 *Automated Cluster-Breaking*, and the Platform Grant *Crest: Centre for Research on Evolution, Search and Testing*. In addition, in programming languages research, EP/K01790X/1 *Composing Language Runtimes* (COOLER), the Oracle-funded *Heterogeneous Interactive Development Environments* and The Deutsche Forshungsgemeinschaft (DFG)-funded *Nominal Isabelle.* Informatics held the Royal Society-funded *Dependent types for nominal terms*, and EP/D501016/1 *CANS: Computational Applications of Nominal Sets* (held jointly with the University of Cambridge).

Health and Bioinformatics: Informatics has developed collaborations with other units at King's, including Primary Care and Public Health Sciences with Medicine and with the Institute of Psychiatry, in areas of agent-based computing, provenance, bioinformatics and decision support. These activities are supported by several projects, addressing software and hardware engineering

and agent-based computing challenges in electronic health records through projects including *Electronic Health Records for Clinical Research* (EHR4CR, EC IMI), *Translational Research and Patient Safety in Europe* (TRANSFoRm, EC), *Dynamic Nutrition Behaviour Awareness System for the Elderly* (Diet4Elders), *Trials in Databases* (Medicines & Healthcare Products Regulatory Agency), PEARL – *Influences on Psychosocial Health in Early Adulthood* (Wellcome Trust); addressing bioinformatics through MAARS – *Microbes in Allergy and Autoimmunity Related to Skin* (EC), *Community Structure Detection in Complex Networks* (Leverhulme Trust); advancing the field of medicine authentication through MAQUETTE (Wellcome Trust); and addressing robotic surgery through the KCL Medical Engineering Centre at St Thomas's (Wellcome Trust, EPSRC). The Robotic capability projects mentioned above are fundamental to applications of robotics in Health. Informatics also holds EPSRC projects on the design of algorithms for networks and bioinformatics applications: EP/J006300/1 *Random walks on computer networks*; EP/D00232X/1 *Amorphous computation, Random Graphs and Complex Biological Networks;* and EP/D062012/1 *Stochastic Local Search Algorithms for Structural Proteomics.*

Infrastructure:

Space at the Central London Strand campus is highly constrained, so it is impossible for all academic members of staff in Informatics to be co-located. However, Informatics has achieved a logical organisation that works well. Staff are distributed over 2 floors and PhD students are located as close as possible to their supervisors, research facilities and co-students. The floors are close together in the Strand Building, and the organisation of staff offices follows the structure and alignment of research groups.

Following the merger in 2010, a strategic initiative by the College, to improve integration of staff in the new Department of Informatics, resulted in the move into modern refurbished accommodation (with investment of over £5,000,000) on the 6th floor of the Strand Building. With the growth in the Department that has occurred since then, the 1st floor of the same building was allocated to the Department. SMAL and CoRe are located there, with plans for CTR to move there in early 2014, and AIS, Planning and AB are located on the 6th floor.

CoRe is equipped with a specialised laboratory for the manufacture and testing of flexible and metamorphic manipulators, sensors and soft robots, including medical and rehabilitation devices, designed within the group. The laboratory also contains three high resolution rapid prototyping machines, a CNC machine, and numerous mobile robots, robot manipulators, hands and mechanisms, primarily for use by CoRe, but increasingly also for related activities elsewhere, for example in Planning and AIS.

The CTR is equipped with several laboratories. The Flexible Radio Lab comprises a number of highly capable software defined radios and RF measurement equipment in order to experiment with technologies for radio adaptation such as dynamic spectrum access and cognitive radio. Other RF and microwave equipment includes a vector network analyser (VNA) and a dielectric probe kit, which is used to measure dielectric properties of materials mimicking human tissue for biomedical applications.

The Audio Lab comprises an ESMONO sound acoustic isolation room, the second largest in the UK, diffuser panels, specialist software packages and a large number of studio reference loudspeakers and microphones. It provides researchers with a complete platform to experiment under well-controlled conditions in different areas of audio research, including psychoacoustic testing, acoustical beam-forming and room acoustic simulation. The lab was equipped with EPSRC support (EP/F001142/1), and additional investments from the School. The lab supports the work of the CTR on optimal sound field capture and rendition for accompanying video transmission and mobile entertainment applications. Further EPSRC support (EP/H049665/1) equipped the lab with dedicated audio-video recording facilities supported by StreamPix software.

The Multimedia and Signal Processing Lab features equipment funded by CISCO and Texas Instruments, and provides hardware and software facilities for the design and testing of multimedia communication over wireless and IP networks.

King's IT Services provides computing services to the whole College, administering the College computer network, and around 1,500 PCs. The Department runs its own local computing network, with 1Gb managed networking throughout the infrastructure, and 10Gb networking between servers, enterprise-grade storage facilities (90TB), and 5 computing labs for staff and students, with Departmental systems support consisting of 5.5 FTE computing officers. In addition, the School of Natural and Mathematical Sciences provides a high performance computing facility of several Linux clusters with shared storage and high performance networks able to deliver 56 Gb per second. Over the REF period there has been a £800K College investment in HPC for Informatics.

Library resources for Informatics are included in the Maughan Library. Staff also have access to the central libraries of University of London and the libraries of other University of London colleges. All researchers thus have access to a broad range of journals, abstracting and bibliographic services, including all of the major relevant resources (e.g. ACM/LNCS/IEEE) (with an estimated £70K per annum spent exclusively on engineering and computing journals in addition to more general packages such as Science Direct), many of which are supplied electronically.

Informatics has strong administrative support, with 5.5 FTE administrative staff, including support for research management and event organisation. In addition, the School provides an additional 7 FTEs providing support across 4 departments, and there is also a dedicated research support officer for the School, as well as central support for research grant preparation and monitoring from the central Research Grants & Contracts Office.

Informatics has been seeing a steady increase in external funding since 2008. Over the REF period, a total of £30,856,357 has been awarded. This is roughly double the research income in the RAE 2008 period (which was £16,703,790). The table shows the amounts of the live awards held in Informatics in each year over the 6 years since the RAE. It can be seen that a high level of income has been maintained and, despite occasional fluctuations, is on an upward trend.

2008-9	2009-10	2010-11	2011-12	2012-13
£9,321,367	£9,625,383	£11,340,178	£12,075,432	£10,992,691 (plus ~ 1.4M in new grants awarded but not yet in the system)

The expenditure picture is also very encouraging. The research spend for Informatics in the REF period is £10,474,856, which is almost three times the spend in the RAE 2008 period (£3,640,511).

Informatics has had significant success in engaging with companies and organisations, by providing consultancy, acting as project partners, and by direct application of research results. All groups are engaged in these activities, as detailed in the REF3a Impact Template. To assist in the promotion and support of these activities, Informatics has a Technology Innovation Fellow who devotes 5% of his time as part of a network of academics supporting the promotion and identification of innovation through research and its subsequent impact (with associated funding for innovation activities). In the REF period Informatics has filed 17 patents.

e. Collaboration or contribution to the discipline or research base

Informatics has been involved in a number of major research initiatives in line with its strategic goals. CoRe has made important contributions to the development of robotic systems, including novel sensors and sensing techniques, haptic feedback techniques, novel mechanisms and the related kinematics, manipulation and object handling and locomotion of soft robotics. A feature that distinguishes CoRe from other Robotics groups in the UK is its focus on flexible medical instruments, manual dexterity and in-hand manipulation of complex objects. The group has pioneered 3 generations of the anthropomorphic hand, a four-fingered hand with a folding palm, enabling a high degree of dexterity in manual tasks such as folding cardboard. A range of miniaturised flexible instruments and haptic feedback techniques have also been developed, for use in in-vitro surgery, dentistry and tumour-detection. The autonomous stiffening and relaxing of flexible robotic devices enables new locomotion methods and opens the way for many novel

surgical and other applications. These areas are being researched in collaboration with both academic and industrial European partners, through EU FP7 projects, for example: Shadow Robotics, Unilever Research, Yasakawa Electric Company and Ford Motor Company. CoRe also has strong links with the King's medical school and Guy's and St Thomas' hospitals.

The Planning group is dedicated to the development of AI Planning systems, modelling languages and applications. It is known for fundamental research in temporal and mixed-discrete continuous planning. The group has developed 6 automated planning systems, freely available on sourceforge, that are in wide general use as benchmarking planners both in the international research community and in a small, but growing, industrial user community. These systems have been used for prototyping by industries in transportation logistics (MAERSK) and mission planning (BAE Systems Ltd, SciSys Ltd). The group specialises in temporal and numeric planning and plan-based robot control, and has developed domain-independent modelling languages to support applications in future power systems, mobile robot path and task planning and adaptive tracking. The group works with a large number of UK and European universities and companies on its EPSRC and EU-funded projects. Members of the group collaborate with leading universities worldwide: for example, the universities of Genoa (Fox), Copenhagan (Coles), del'Aquila (Magazzeni), NASA Ames (Fox and Long), MIT (Fox and Long). It collaborates closely with SciSys Ltd (Long) and Schlumberger (Fox and Long). It also has research collaborations in Australia (NICTA) and the US (Monterey Bay Aquarium Research Institute (MBARI), where Fox was Adjunct Researcher from 2010-2013).

Strong industry links ensure that Informatics research remains at the forefront of the field of wireless communications and sensing. Kosmas is currently Vice President and CTO of MediWiSe – a bioengineering company developing novel wireless medical modalities for medical diagnostics and intelligent monitoring. Dohler is founder, former CTO and now with the Board of Directors of Worldsensing, a wireless M2M and instrumentation company. Through Mobile VCE, the CTR was also involved in the UK-China Science Bridges projects, which were concerned with R&D on 4G Wireless Mobile Communications. This collaboration (2009 to 2012), involved 10 UK universities, Mobile VCE, 6 Chinese universities and 7 Chinese companies. The CTR has driven start-up activities to establish the Mobile VCE Core 5 Green Radio programme. The CTR also coordinates the ICT-ACROPOLIS Network of Excellence: a research project considering coexistence technologies such as Cognitive Radio and Dynamic Spectrum Access with the objective of integrating the best researchers to solve related issues in such technologies. In this role the CTR is directly involved in numerous collaborative works. Members of the CTR are engaged in a large number of individual projects, involving international collaborations with leading research institutions. These include collaborations of Cvetkovic with the University of California, Berkeley, Harvard University, Stanford Research Institute (SRI International) and AT&T Shannon Laboratory; Nakhai with Southeast University, China, and University of Bologna, Italy, Nallanathan with MIT, Princeton University, California Institute of Technology, National University of Singapore and Beijing Bell Labs Alcatel-Lucent amongst others; Shikh-Bahaei with the University of California, UCLA, Harvard, Nokia, Anritsu and Texas Instruments; Mahmoodi with F5 Networks; Kosmas with the University of Wisconsin-Madison, and South University of Science andTechnology, China and Sastry with BBC R&D, Last.fm, Blackberry, MIT and others.

SMAL researchers established the field of *search-based software engineering* and made significant advances within the REF period, funded by EPSRC and Industry as noted above. With the departure of Harman in 2010, this work has continued with advances in the design of programming languages, in collaboration with Oracle and JP Morgan, and software engineering methods, aimed at improving software comprehensibility and reliability through modelling. SMAL was one of only two UK groups (with Cambridge) recognised as an INRIA associated team, and was funded by INRIA to develop a new visual modelling tool in collaboration with their Bordeaux centre. Within SMAL, these areas of research are combined with theoretical investigations using the techniques of applied logic. The group has advanced the understanding of the expressive power of different logics and the complexity of reasoning systems, within the frameworks of type theory, category theory, rewriting systems and truth maintenance systems. The group collaborates with the Universities of Cambridge, Liverpool, Oxford, Imperial College and Birkbeck, as well as with international groups based at the Universities of Marseilles, Bordeaux, Venice, Pisa, Porto, Lugano,

ETH Zurich, TU Munich, the Alfred Renyi Mathematical Institute Budapest, Technical University of Catalonia, ORT Uruguay and University of Brasilia, with support from EPSRC, EU, the Royal Society, the Brazilian CAPES and the US via the EOARD.

In AIS, research into multi-agent systems, virtual organisations and trust, provides the essential foundation for developing future software agents and agent communities. AIS has contributed advances in normative systems, negotiation and inter-agent collaboration required to support the development of future autonomous internet agents. This activity has included international standards activity, with Miles participating in the W3C Provenance Group through 2011 and 2012. Advances in multi-agent systems within AIS are underpinned by theoretical work in argumentation, agent modelling and complex networks. A major application of agent-based systems developed by AIS is in Health, and AIS is involved in collaboration, through EU-funded projects, with AstraZeneca, Tunstall Healthcare, Roche and other pharmaceutical companies. Through the SINTELNET (European Network for Social Intelligence), AIS collaborates with the Universidad Politecnica de Madrid, Université Paul Sabatier and ISTS-CNR. AIS collaborates in the development of agent-based healthcare provision with the Primary Care and Public Health Service department at King's.

AB combines work in the design of randomised algorithms, optimisation techniques, heuristics and meta-heuristics, with specialised string and sequence-matching algorithms to establish a powerful suite of techniques for managing complexity. Its research on string algorithms involves designing provably efficient algorithms for processing sequences of symbols, working on the combinatorial structure of sequences. Their international academic collaborations, supported by grants from Royal Society, LMS and EPSRC, include France (Rouen, Paris East, Bordeaux), Italy (L'Aquila, Palermo, Padova), Germany (Karlsruhe Institute of Technology, Heidelberg Institute for Theoretical Studies), Greece (University of Athens, Athens Bio-Academy of Sciences, Patras, Thessaloniki), Switzerland (ETH), USA (CMU, Georgia Tech), Canada (MacMaster University, Fields Institute, Simon Fraser University), Israel (Bar-Ilan, Haifa), Australia (University of Western Australia, Curtin University), Japan (Kyushu, Fukuoka) and Korea (Seoul). The only UK-funded project in computational science under the Samsung Global Collaboration GRO programme is "*Fast, Low-Cost Methods to Learn Structure of Large Networks*", held by Cooper and Radzik.

Staff are extremely well represented on the major journals in the areas of focus. For example, Editor-in-Chief roles include: Journal of Discrete Algorithms (Iliopoulos), Knowledge Engineering Review (McBurney), Transactions of Emerging Telecommunications Technologies (Dohler), AI Communications (Fox). In addition, Informatics is well-represented on the editorial boards of the top journals, including Information Processing Letters (Vigano), IEEE Transactions of Signal Processing (Cvetkovic); ACM Transactions on Adaptive and Autonomous Systems (Luck); IEEE Transactions on Robotics (Dai); ASME Journal of Mechanisms and Robotics (Dai); Theoretical Computer Science (Crochemore); LMS Journal of Computation and Mathematics (Fernandez); Artificial Intelligence (Fox); IEEE Transactions on Wireless Communications (Nallanathan). There are about another 30 examples which are not included for reasons of space.
Staff feature regularly as programme and executive conference chairs, for example: the 12th International ACM SIGPLAN Conference on Principles and Practice of Declarative Programming, 2010 (Fernandez), 24th Association for the Advancement of AI (AAAI) 2010 (Fox); Wireless Advanced 2010 (Shikh-Bahaei), 36th ASME International Conference on Mechanisms and Robotics, 2012 (Dai), 24th Annual IEEE Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) (Agvhami), and many others. The international standing of our staff has additionally been recognised in the REF period by 14 Best Paper awards and many invitations to present keynote talks at top conferences in the areas of specialism, including: 3rd International Symposium on Mechanism Design for Robots (Dai); 2nd ASME/IFToMM Conference on Reconfigurable Mechanisms and Robotics (Althoefer); 24th International Conference on Automated Planning and Scheduling, 2009 (Fox); 12th Programming and Languages Conference, 2012 (Fernandez); 15th Conference on Developments in Language Theory, 2011 (Crochemore); 13th International Symposium on Problems of Redundancy in Information and Control Systems (Cvetkovic) and the 2013 Design of Medical Devices Conference (DMDEUR2013) (Althoefer). Finally, Informatics has 8 academic members of the EPSRC College.