Institution: University of Kent

Unit of Assessment: UoA 11: Computer Science

a. Overview Research in the School of Computing is sustained, managed and developed through its five research groups. Each staff member has a principal group membership; many also have secondary memberships. ECR and other appointments in the REF period are noted.

- **Computational Intelligence** (REF abbrev: I). *Primary staff:* David Barnes, Howard Bowman, Dominique Chu [2008 appointment], Alex Freitas, Colin Johnson, Luana Micallef (ECR), Peter Rodgers (Head of Group). *Secondary staff*: (Caroline) Ling Li (ECR), Fernando Otero (ECR).
- **Computing Education** (E). *Primary staff*: Sally Fincher (Head of Group), Michael Kölling, Ian Utting. *Secondary staff*: David Barnes.
- **Future Computing** (F). *Primary staff*: Antonis Alexandridis (ECR), Leon Chua [2013 appt], Michael Kampouridis (ECR), (Caroline) Ling Li (ECR), Matteo Migliavacca (ECR), Fernando Otero (ECR), (Benjamin) Kwang M. Sim (Deputy Head) [2012 appointment], Frank Wang (Head of Group) [2010 appointment]. *Secondary staff:* David Chadwick.
- **Programming Languages and Systems** (P). *Primary staff:* Fred Barnes, Olaf Chitil, Rogério de Lemos, Richard Jones, Stefan Kahrs, Andy King (Head of Group), Jael Kriener (ECR), Scott Owens (ECR), Simon Thompson, Peter Welch. *Secondary staff*: Eerke Boiten.
- **Security** (S). *Primary staff:* Eerke Boiten (Head of Group), David Chadwick, Theo Dimitrakos [2013 appointment], Julio Hernandez-Castro [2012 appointment]. *Secondary staff*: Andy King, Matteo Migliavacca (ECR).

The School is sited at both UK campuses of the university (Canterbury and Medway). The Future Computing group is based at Medway, and the others at Canterbury; as a part of our "one school" policy staff take part in activities at both, as appropriate. Each staff member's principal affiliation is to a research group at their site, and PGRs and RAs are based at their supervisor's site.

b. Research strategy ***Achievements 2008-2013.***

Academic impact and funding. The School of Computing delivers research with recognised academic impact in CS and, through its interdisciplinary work, in cognitive science, security and biosciences. Wider impact is delivered to users in industry and education, often through open source software. Since 2008 our funding sources have become more diverse: more than £1.4m comes from the European Commission, approaching the £2.2m received from EPSRC. The School has also gained funding for industrial collaboration, including 3 KTPs and 2 Royal Society Industrial Fellowships, and direct industrial funding (e.g. Oracle, Agilent). Interdisciplinary research centres, such as the Cyber Security Centre led by the School, give a platform for successful research bids.

Critical mass. Across the two campuses, the research groups have a critical mass of academic staff, of RAs and of funding, and support internationally recognised activity and publication. 29.1 FTE staff have been submitted to REF 2014, and 12.6 FTE of these have been appointed since 2008, including 7.4 FTE ECR. This shows an increase over the 26.7 FTE staff submitted in RAE 2008. The School has 12 staff who are Research Associates or Research Fellows.

New Research Capability. Taking advantage of staff retirements and recruitment, and in line with university research strategy, it has built new research capability at the Medway campus, forming the Future Computing group comprising 2 professors, 1 professorial fellow and 5 ECR lecturers.

Appointments. The vitality of research at the Canterbury campus has been ensured by making a number of appointments during the REF period. These range from early-career research fellowships identifying promising candidates immediately on PhD submission, through ECR lecturers who are building research reputations, to a chair awarded to a candidate with substantial industrial research experience. Alongside the new Future Computing research group at Medway, research groups at Canterbury have been consolidated into four larger units: Computational Intelligence, Computing Education, Programming Languages and Systems, and Security.

Computational Intelligence (Group I) .The Computational Intelligence group brings together interdisciplinary researchers on the interface of computer science, biosciences and cognition. The research can be broken down into modelling, novel computing paradigms and data analysis.

- *Modelling*: *D. Barnes* and *Chu* are experts in applying computation to investigating the modelling of gene expression, and work with bioscientists to develop computational models of biological systems behaviour. *Bowman*, *Johnson* and *Li* have examined models of human attention, creativity, emotions and reasoning. This research has focussed on modelling cognition supported by EEG data provided by Psychologists, and Monte Carlo methods have revealed new insights for detecting neural markers of conscious activity.
- *Novel Computing Paradigms*: *Johnson* and *Otero* apply biological metaphors to computation, and research new computational methods such as genetic algorithms and swarm intelligence in areas including data analysis, music technology and bioinformatics.
- *Data Analysis*: *Freitas* and *Otero* have developed novel techniques for data mining that use the results of inter-disciplinary research to find solutions to computationally expensive problems, predominantly in the area of hierarchical classification. These are applied to biosciences and data in the area of aging. *Micallef* and *Rodgers* develop new algorithms for information visualization to explore data within complex systems, and these have been applied in areas such as business planning, transport, bioscience and medicine.

Computing Education (Group E). The group takes as its focus the teaching and learning of computer science. Its work falls into two main areas: the design and development of tools to support novice learning of object-oriented programming, and multi-institutional – and often multi-national – investigations of educators' approaches and attitudes to practice.

- *Kölling* and *Utting* create environments that support novice learning of Java, and have built two world-leading systems: BlueJ, aimed at first year university students, and Greenfoot, for secondary school students; the latter is the subject of a REF impact case study. Research on resource uptake and innovation diffusion in educator communities underpins this work.
- *Fincher* and *D. Barnes* undertake empirical, qualitative studies that investigate how, when, and with what evidence educators change their teaching practice. These studies often involve multiple sites to demonstrate general applicability.

Future Computing (Group F). The Future Computing group was inaugurated in 2010 and targets next generation computing paradigms. To do this requires a multi-disciplinary approach, bringing together members with a breadth of backgrounds. The group's work is supported by a Brain Computing / Cognitive (BC2) Lab coordinated by *Li*. The BC2 Lab supports interdisciplinary research with the schools of music, sports and pharmacy.

- *Chua*, *Li* and *Wang* research brain computing. *Li* has used the BC2 lab to gather EEG data for a study of seasonal affective disorder and *Chua* and *Wang* have shown that *Chua's* memristors can provide a radically new way to construct neural networks..
- *Migliavacca, Sim, Wang* and *Chadwick* work on complementary aspects of grid, cloud and distributed computing, including middleware, foundational technologies and resource allocation, composition and brokering.
- *Migliavacca*, *Otero* and *Wang* have developed new search-based approaches to computation, such as ant colony optimisation methods for predicting protein function.
- *Otero*, *Kampouridis* and *Alexandridis* work in computational economic modelling, applying these search-based approaches to financial and economic data.

Programming Languages and Systems (Group P). The group focuses on the specification, design and implementation of computer systems, from the very large to the very small, and characterized by the interplay between theory and practice. It has three main research themes: verification and dependability; memory management; and program development.

- *Verification and dependability*: *Owens* has developed memory models for Power multi-processors and a usable programmer's model for x86 multiprocessors, with the aim of influencing the C11/C++ standard. *Kahrs* has developed foundational proof techniques for rewriting, which in turn underpin work on program correctness. *Boiten's* research is concerned with the relation between state-based and behavioural specification methods.

King and *Kriener* have developed techniques that apply abstraction to automatically diagnose flaws in existing programs. *de Lemos* has applied verification at the architectural specification level to assure dependability. Funded by NCR, he has applied work on artificial immune systems to anomaly detection in ATMs, leading to the award of patents.

- *Memory management*: *Jones'* work has focused on garbage collection on multicore systems, including understanding the overheads placed by concurrent applications on runtime systems, reducing memory overheads in real-time systems, and exploring locality.
- *Program development*: *Thompson* has developed the Wrangler refactoring tool for Erlang, which is the subject of a REF impact case study. His team has also demonstrated how to verify the correctness of refactorings, and developed techniques for users to define new refactorings. *Chitil* has explored how contracts - expressing requirements for functional programs - interact with laziness. *Welch* and *F. Barnes* have shown how to develop concurrent programs that are correct by design. Their work is applicable both to programs written in conventional parallel languages and those coded in occam-pi, of which *Welch* and *F. Barnes* are the principal architects. This is the subject of another impact case study.

Security (Group S). The Security Research Group is an integral part of the University's recently established inter-disciplinary Cyber Security Research Centre, led by *Boiten*. Recent research proposals and projects in this centre span Schools including Sociology, Law and Engineering.

- *Chadwick* has led the development of the PERMIS open source access control infra-structure, partly within the £1m EU TAS3 project; this work is the basis of an impact case study. Innovations include attribute aggregation in federations, exceptional access handling, delegation and cloud security. He has also worked with professionals on security aspects of law and healthcare. With *de Lemos* (group P) he has developed mechanisms for autonomic security, by self-reconfiguration of networks in anomalous situations. *Dimitrakos*, through his industrially based research, investigates security and privacy in contemporary computing systems, including cloud, SaaS, PaaS and the internet of things.
- *Boiten* leads the EPSRC CryptoForma network (2009-2015), which investigates the application of formal methods to cryptographic protocols. He has developed new notation for reasoning about asymptotic behaviour, essential to modern cryptography. *King* obtained a Royal Society Industrial fellowship where he developed reverse engineering methods using program analysis techniques so that security experts can find software vulnerabilities.
- *Hernandez-Castro* has been successful in the development and analysis of RFID security protocols, including a cryptanalytic attack on a recent standard protocol. He also works on steganography and data leakage protection, and also participates in CryptoForma. *Migliavacca* has developed information flow control methods for event processing systems.

Inter-group collaboration. Research groups do not work in silos: there is substantive collaboration between groups. Apart from joint group membership, this is exemplified by:

- Joint PhD student supervision: applying self-adaptive systems to security (groups P, S); cognitive systems and EEG (groups F, I).
- Co-investigators in funded research projects: EPSRC project on refactoring and evolutionary computing (groups I, P); detection of robots in online chess (groups P, S).
- Joint participation in research projects: visualisation of multicore distributed systems (groups I, P); security in cloud computing (groups F, S).

Strategy from 2014 onwards.

Groups. We will sustain our existing groups, providing continuity of research activities, and we will recruit the right staff to achieve this. Some 25% of our submitted FTE staff are early career researchers, reflecting our commitment to sustaining the research base. We plan to form a second research group at Medway in **Computational Economics and Agent-Based Systems**, led by *Sim*. Key members of this new group include *Otero* (data mining & knowledge discovery), *Kampouridis* (computational finance) and *Alexandridis* (computational economics). The School is taking a number of actions to support this new group, including a computing cluster being built to test models in typical cloud environments and providing start-up funds for new members. The group will collaborate with the Kent Centre for Finance and HEIs in the UK, Europe and the USA.

Research funding. We will continue to increase and broaden our research funding, with a target for awards of £1.3m per year by the end of 2016, 30% above the £1m worth of funding awarded in 2013. For PGR students, we aim to stabilize numbers at about 50, with a greater proportion of external funding. We will continue to target the EPSRC for research support. We also plan to extend our cross-disciplinary work with bids to the MRC, Leverhulme Trust, BBRSC and funders for multi-disciplinary work in cyber security. We will further develop external collaboration by targeting Horizon 2020 calls from the EU, including ERC, STREP and Marie Skłodowska-Curie Actions, building on the increased expertise in the School as a result of greater success in gaining EU funding since 2008.

Collaboration. We will extend our collaboration with other schools through the University's interdisciplinary research centres, and leverage this collaboration to participate effectively in new national and international initiatives, e.g., in PGR supervision and cyber security. Evidence of the latter comes from Kent's partnership in two of the projects coming under the aegis of the second GCHQ/EPSRC Academic Research Institute, established in 2013 to conduct research into automated program analysis and verification. Within the School, inter-group collaboration will continue, e.g. in "big data", a focus for all the School's research groups as noted below.

Research strategy and operations in the school are managed by the Research and Enterprise Committee (REC) that meets termly and is comprised of Director of Research and Enterprise (DoR)(chair), Heads of Research Groups (HoGs), Head of School, Director of Postgraduate Studies (Research), a junior member of academic staff, and the School Administration Manager. It reports to the Faculty Research and Enterprise Committee, and the University Board for Research and Enterprise, and liaises with the Stakeholder Panel and the School's Management and Strategy Groups. Staff set research goals for the coming year in annual meetings with the DoR and HoG. These, in turn, feed into Group plans and the School Research Plan, agreed by the REC.

The Computational Intelligence Group will continue to emphasise cross-disciplinary, collaborative work. Our research plans in the forthcoming period include:

- In the area of systems biology, we will continue work to understand the thermodynamic limits of computing in living cells. We will analyse data from systems pharmacology and the systems biology of ageing using new probabilistic data mining techniques.
- Neurological modelling work will use EEG data to study the relationship between conscious awareness and attention, and will be applied to forensics, such as lie detection.
- Our visualization efforts will examine the communication of risk, as well as hybrid text and visualization methods for categorical data.

The Computing Education Group's plans extend existing work and also develop a new direction.

- The group will extend its work in researching early programming environments to include development of a new programming interaction design, intended to make program source more readable, and program manipulation easier.
- A new research direction will come with the collection and provision of quantitative data of programming learners within the 'Blackbox' project. This will provide a large-scale dataset (100,000s of users, 100s millions of interaction events) of Java programs created within the BlueJ programming environment. This will support data-driven research investigations at an unprecedented scale; to fully exploit this the group will collaborate with other CSEd groups..
- The group will continue to conduct qualitative studies with educators to assess, *inter alia*, how such quantified knowledge may be used to advance computing education.

The Future Computing Group will continue to explore unconventional computing paradigms strengthened by recent staff appointments and funding success. It is planned that staff in computational economics and multi-agent systems will form the nucleus of a new research group in that area, based at the Medway campus, and working on automated negotiation and intelligent techniques for financial engineering. Our future plans include:

- Continuing to work on the impact of the memristor in unconventional computing, such as the memristor as a novel implementation of synthetic synapses in neural networks.
- Examining Big Data storage/communication, and agent-based cloud/distributed computing.

- Investigating automated negotiation and intelligent techniques for financial engineering.

The Programming Languages and Systems Group will consolidate recent staff appointments and funding success in both verification and concurrency. The overall aim will be to sustain impact by working with government agencies and industrial organisations, and releasing research results as open source systems. The group will also set the goal of publishing in the most prestigious venues, as well as ensuring the widest visibility for its results. Our future research focus will be:

- To investigate how concurrent languages can be extended to better support correctness-by-design, and explore how to systematically verify compilation.
- To investigate memory management for many-core and other emerging computer architectures; and low-energy virtual machines.
- Through underpinning foundational work in the semantics of rewriting systems, functional programs and binary programs, the group will develop novel semantically-based tools for program development, refactoring, tracing and security fault diagnosis.
- To leverage mechanical verification technology to justify refactorings, program analyses and end-to-end compilation.
- To devise fault-tolerant architectures for dependable systems.

The Security Research Group will continue to expand its interdisciplinary and fundamental research into cyber security. Future research efforts will be directed at:

- Fundamental studies in binary malware analysis, logics and methods for cryptographic protocol verification.
- Developing steganalytic techniques that target current video steganography tools, as well as investigating network steganography and steganalysis.
- Addressing cyber crime in all its incarnations, including financial and identity theft, cyber bullying and child pornography.
- Security analysis and practical solutions for application areas such as cloud computing, healthcare, event processing, low-power devices and RFIDs.

Big data will be a **cross-cutting theme** for our research in the coming period. Group I will explore the concept of “big context”, i.e. the role of context in big data, as well as looking at big data in application areas, e.g. gene function analysis in systems biology, data mining and visualization. Group S will look at the security aspects of large (meta-)data sets ("behaviour" data), e.g. analysing these to find anomalous behaviour, and also considering problems of privacy and (de-) anonymisation. Group F will focus on cloud-based approaches to big data, while Groups P and E will work on large data sets gathered from system behaviour (e.g. Erlang distributed systems, JVM memory management) and quantitative educational research, through the Blackbox project.

c. People, including: i. Staffing strategy and staff development

Staff recruitment. It is School policy to recruit permanent staff whose research performance and prospects will ensure that they can contribute fully to the School’s research activity. Since Sept. 2010 the School has appointed two professors (Wang, Sim), one professorial fellow (Chua) and five early-career lecturers (Alexandridis, Li, Migliavacca, Kampouridis, Otero) to build research capacity in the Medway-based Future Computing Research Group, partially supported by strategic investment funding made available by the University.

At Canterbury, the School has appointed a Research Lecturer [modelled on the RCUK Academic Fellowship] (Owens), a Lecturer in Security (Hernandez-Castro), a professor (part time with industry) (Dimitrakis) and two Early Career Research Fellows (Kriener, Micallef).

Workload and staff support. The School's workload-allocation model (WAM) proactively supports research activity: research-active staff are given a substantial baseline time allocation (450 hrs) to pursue their research; this is increased by attracting additional resources, producing outputs and funding applications, as well as service to the discipline (editing, conference organisation, reviewing etc.). The School has a budget for research-related travel and smaller items of equipment, and this is complemented by a similar Sciences Faculty fund. Research-active staff are

strongly encouraged to take study leave to gain access to new ideas and foster external collaborations; 12 staff have taken a total of 11 years study leave during the REF period..

Staff are supported in developing research grant applications at school and university level. Research groups provide early feedback on research ideas expressed as “one pagers” that encapsulate the essence of a research programme in a single page. The school and the university’s Internal Peer Review processes give formalised feedback at a later stage in development. Research Services support staff in developing applications through the Grants Factory workshop series, department-based surgeries and one-to-one mentoring. Kent Innovation and Enterprise provides complementary support for enterprise activities such as KTP.

Career Development Support. Newly appointed staff serve a probationary period, and during this they are assigned a senior academic in the school as probation supervisor. Staff will also have a mentor, a senior member of the School in the same research area. The probation supervisor has the formal role of supervising the appointee’s progress through probation, whereas the mentor provides more informal advice and strategic support. The School limits the load on new staff: in their first year the teaching load is reduced by 50%, and in the second by 25%. The university provides a range of Staff Development courses, and discussion of staff training needs is an integral part of the University’s appraisal process. Staff from the school are also supported in attending external courses, e.g. at the Royal Society. The School monitors progress in promotions, ensuring that staff are not overlooked in the process, and given appropriate opportunities by the school.

PGCHE. All newly appointed early-career academic staff undertake the Postgraduate Certificate in Higher Education (PGCHE), which includes two modules focussed on research and PGR supervision. It is also a forum for new researchers to interact; this is complemented by the Early Career Researcher Network that provides formal workshops and informal networking opportunities.

Research training. All research groups host a regular research seminar series. This allows PhD students to practice research presentation skills in a supportive environment, and students and staff can discuss research ideas and ideas for research grants; external speakers are also invited regularly. Groups also coordinate staff research plans, and responses to potential research opportunities. Research staff are also encouraged to develop teaching skills, and given opportunities to deliver classes, seminars and ‘guest lectures’. The School supports PGR and research staff to take the University’s Associate Teacher Accreditation Programme (ATAP) - a 30 credit course based on a subset of the PGCHE, and research staff teaching is regularly observed as a part of the School’s peer observation of teaching. In order to gain experience of administration and management in the department, new staff members are co-opted to school committees for short periods. All PGR training provided by the Graduate School is also available to research staff.

Personal Research Fellowships. Research fellowships have been held by a number of staff members of the School, who are encouraged to apply for these for individual career development as well as in support of the school: EPSRC Postdoctoral Fellow (*Gomez*, 2006–9), Royal Society Industrial Fellow (*Rodgers*, 67% fellowship over 2010–13; *King*, 50% fellowship over 2008–12), RCUK Academic Fellow (*Cowell*, 2007–9; *Chu*, 2005–8), Marie Curie Fellowship (*Chua* 2013–15).

International Staff Appointments. The school seeks to recruit the best candidates internationally, and during the REF period the School has appointed 11 research assistants and 4 academic staff from Argentina, Brazil, China, Germany, Greece, Iraq, Malta, Singapore, Spain, Tunisia, and USA.

Visitors. Since 2008 the School has hosted visiting lecturers / researchers from Brazil (10), China (4), India (2), Japan (2), Portugal (1), UK (1) and USA (4) for periods of 2-12 months. Collaboration with Brazil is particularly strong: all these visitors had Brazilian government funding. 5 came from the University of Saõ Paulo (USP): of these 3 were PhD students co-supervised by *Freitas*.

Equality and diversity. The University of Kent has joined and is committed to the principles of the Athena SWAN charter. The school has created a working group which has already begun the work to enable an Athena SWAN School award submission to follow success at University level. The

School has reviewed procedures and has introduced: more support for staff seeking promotion, monitoring of application and success rates at promotion, representation of a wide range of staff on panels and committees, a review of invitations to speakers to visit Kent, and female representation on appointments panels. The European Commission has awarded Kent the HR Excellence in Research award for its implementation of the UK Concordat to Support the Career Development of Researchers; the University is also a member of Stonewall's Diversity Champions scheme. All new members of staff who declare a disability are offered a disability assessment on arrival, so that their needs can be met. The University provides a flexible working regime for staff who are carers, and those living with long-term illness.

ii. Research students

Recruitment. The number of PGR students admitted and total funding support are shown below. The majority of PGR admissions in 2011 are non-EU students: to help to increase international recruitment (*inter alia*) the School has appointed a marketing and communications officer. After a dip in 2008 and 2009, these have increased substantially since. We aim to recruit around 15 students per year in years 2014 to 2016. Support here comes from school and university scholarships and EPSRC GTA funds; one panel, with male and female members, interviews all applicants for support to ensure equity in selection.

	2008	***2009***	***2010***	***2011***	***2012***	***2013***
MScR/PhD entry	0 / 8	0 / 8	3 / 14	1 / 12	2 / 9	0 / 13
Support + fees	£342k	£343k	£364k	£447k	£352k	£455k

Supervision. Each research student is allocated a supervisory team, comprising a primary supervisor and a supervisory panel that includes two members of staff with related research interests. In order to act as supervisor, members of academic staff must be approved as "supervisory chairs" by the University Board for Research and Enterprise; they may co-supervise while awaiting approval. The University uses an online system available to students, supervisors and administrators to record and monitor the PGR supervision process. Students typically meet their supervisors weekly, and they record a monthly meeting in the online system. Formal progression rests with the entire supervisory panel, chaired by the Director of Graduate Studies, and which occurs at least every academic year. Students submit a "mini-thesis" surveying their research area at the end of year 1 and a detailed thesis plan at the end of year 2.

Support and achievement. PGR students have received best paper awards at ICLP'11, SOUPS 2008 and EvoBio-2008 and external funding from ACM SIGPLAN (POPL, PLDI, ISMM,) and ACM SIGSAC (DIM), an Endeavour Research Fellowship from the Australian Government and an EC CERN Doctoral Scholarship. A number have received (competitive) Microsoft Research Internships and ISC2 awards for their security research. Research students have access to a travel budget, to attend national or international conferences in their research area; since 2008 the School has funded all such requests to present research papers when support from other organizations has not been available. Each research student is given a desk and computer for their exclusive use throughout their registration. Each year the School funds an "outward bound" weekend for the first year students, establishing cohort cohesion. Students are given all assistance to fulfil their potential, in liaison with the University's Disability and Dyslexia Support Service as appropriate.

Training. Within the School, technical training for research students is primarily provided by their supervisors. In their first year PGR students attend weekly research training sessions led by a senior academic within the School. At progression points, the School runs targeted sessions on both academic and administrative matters. All research students are expected to attend both their research group seminars and School seminars, and to participate themselves by presenting their research. Students also present their research at an annual student-organised "poster fair" and at Research Fairs organised by the Sciences Faculty and the Graduate School. The School offers the opportunity for PGR students to teach undergraduates, supported by teacher training provided by the School, and also ATAP if the student wishes. The Graduate School offers a Researcher Development Programme providing generic transferable skills training to PGRs and PDRAs.

Student representation. The Graduate Staff-Student Liaison Committee meets every term: all PGR students are encouraged to attend. Two students are elected as Research Postgraduate Student Representatives and raise any issues both at SSL and Postgraduate Board of Studies (Research). One of these representatives sits on the Faculty Graduate Studies Committee.

d. Income, infrastructure and facilities

The **School's research budget** funds generic IT infrastructure, suitable specialised kit, staff/PGR travel funding, fees for 'open access' journals and access to research publications. The School Administration Manager and her team provide grant administration services, complementing the work of Research Services and the Faculty Research Support Officer. Kent Innovation and Enterprise support consultancy, KTP and other activities.

The **technical computing infrastructure** for the School is a balance between Unix servers and regularly updated desktop and laptop facilities linked by fixed and wireless (eduroam) networks. The School provides shared file-store for projects, web services for researchers' web presence and hosting services for web domains (e.g. greenfoot.org). It also provides projects.cs.kent.ac.uk, a repository supporting external collaboration for Kent-based research projects. There are also more specialized resources, such as clusters supporting research projects (e.g. CoSMoS, RELEASE) and themes (e.g. computational economics). Sun Microsystems have donated a 128 core server for research and teaching, and Cisco a videoconferencing system to support remote working.

Equipment and resources. The department has a typical spend of some £130k/annum on equipment, spent on the rolling replacement of desktop / laptop machines for staff and maintenance of the research cluster and RAID array storage. This is augmented by particular investments, such as £50k spent on two clusters of machines and high-resolution EEG kit to support the BC2 Lab at the Medway campus. The infrastructure is supported by a 3 person technical team who provide day-to-day support, system management and general technical advice. The library spend for 2012-13 is £115k; this supports book purchase and periodical bundles including ACM Digital Library, IEEE/IET, Science Direct, Springer Link, and Wiley Blackwell.

Research funding, consultancies and professional services. Research funding during the REF period has become more diversified: it has more funding from the EU (FP7, Marie Curie), with £2m of awards from 2007 to groups P and S. EPSRC remains a major funder at close to £2m, supporting all research groups except E, whose principal funding of over $1.2m is from Oracle. The School also has 2 Royal Society Industrial Fellows, and support from JISC (£250k) and Agilent (£50k). The bulk of the remainder is from three KTPs. Notable recent awards include:

- Two EPSRC awards for Automated Program Analysis and Verification work in King's team, in the 2nd Academic Research Institute for Cyber Threats, 2013-16, total £516k. [Group S]
- European Commission FP7 awards for supporting work in Thompson's team on property-based testing of web services (PROWESS: grant no. 317820, 2012-15, £441k) and multi-core programming with Erlang (RELEASE: grant no. 287510, 2011-14, £352k). [Group P]
- EC Marie Curie Fellowship, Leon Chua, totalling €309k for two years, 2013-15. [Group F]
- An EPSRC Discipline Hopping Award to Freitas, with pharmacy (2012-14, £104k). [Group I]
- Oracle have awarded a total of some $1.2m to Kölling's team over the REF period for their work on the novel pedagogical programming environments BlueJ and Greenfoot. [Group E]

e. Collaboration and contribution to the discipline or research base

Collaborations include: FP7 consortia: Belgium, France, Germany, Greece, Italy, Netherlands, Spain, Sweden; EPSRC partners: Aston, Birmingham, Bristol, Brighton, City, Imperial, Sheffield; Joint papers: Australia, Brazil, China, Egypt, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Poland, Spain, Sweden, Switzerland, the UK, USA and Vietnam.

Much of the School's work is interdisciplinary. Work with psychology (*Bowman, Li*) focusses on computational modelling of cognitive processes: modern brain imaging techniques enable plausible models of cognition to be constructed, underpinned by experimentation. Work with biosciences (*Chu*, *Johnson*) has a number of strands including computational evolution of cell signalling networks and modelling a gene expression pathway in *E. coli*. Work with legal experts and health-

care professionals has addressed data privacy and security (*Chadwick*). Joint work with pharmacy is supported by an EPSRC Discipline Hopping Award (*Freitas*). The School has been instrumental in setting up and running university research centres in computational biology, cognitive science and systems and cyber security. The school runs a joint research seminar with Kent Business School at Medway, and also joined an initiative on digital identity with social sciences researchers. We lead the EPSRC Network CryptoForma, uniting cryptologists and software engineers.

Collaborations with users informing activity and strategy. The School has long-term links with a number of IT companies, including IBM, Oracle, Influential Software and Erlang Solutions. Some of these serve on the School's Stakeholder Panel that advises the school *inter alia* on research policy and practice. Oracle / Sun have helped to shape the research programme in teaching of programming to beginners (Greenfoot / BlueJ) by providing $1.2m funding (2008–13) as well as supporting research in multicore computing through an equipment donation. *Dimitrakos* bridges academia and industry (BT), and in his position on ENISA's expert group on Cloud Security and Resilience he advises the EC and its member states. De *Lemos'* work with NCR has led to two patents of a fault prediction mechanism for ATMs being granted during the REF period. Two Royal Society Industrial Fellowships give staff access to 'real world' scenarios and data that have resulted in changes of research direction, new applications and new funding sources (e.g. GCHQ).

Joint research projects in FP7 bring together researchers and industrial users. In ProTest, Wrangler was used in a long-term industrial case study, informing its design; with RELEASE and PROWESS, FP7 funding in this area amounts to £1.2m. In collaboration with the Swiss Ministry of Defence, the core components of PERMIS have been hardened for use in a military application (with a value of €1.8m). The School supports making these and other systems Open Source, thus allowing users to contribute to and sustain projects in the longer term. Joint work with GCHQ forms part of the GCHQ/EPSRC Research Institute in Automated Program Analysis and Verification.

Academic leadership. Notable distinctions include: ACM Distinguished Scientist (Fincher, Jones), ACM Distinguished Educator (Kölling), Java Champion (Kölling), IEEE Comp. Soc., Chair UK / RoI Chapter (Wang), UK principal expert X.500 standards mtgs. (Chadwick), Founding member, Computing at Schools, (Kölling), Steering Ctee. of the ACM/IEEE Computing Curriculum 2013 (Fincher), ACM SIGCSE award for Outstanding Contribution to CS Education (Fincher, Kölling), Chair of BCS/CPHC Distinguished Dissertations Panel (Thompson), Board Member and Director for the Assoc. of Logic Programming (King), IFIP WG 11.2 member (Hernandez-Castro), Chair of IFIP WG11.11 (Dimitrakos), ENISA expert group on Cloud Security and Resilience (Dimitrakos).

Peer reviewer for organisations in Australia (ERA: Jones); Belgium, Chile (Hernandez-Castro); Czech Republic (Rodgers); France (Thompson); Hong Kong (Freitas); Netherlands (Boiten, Thompson); and UK, including EPSRC Peer College (Chadwick, Freitas, Jones, Thompson).

Invited keynotes: 34, including ACM SIGCSE 2010, ISICA-2008, FSNC 2011, WorldCIS-2012.

Journal editorships: 36 including Formal Aspects CS, Jnl. Functional Programming, Computing, CS Education (editor-in-chief), International Jnls of Data Warehousing and Mining, Applied Meta-heuristic computing, Natural Computing, HOSC, IEEE Trans. Cybernetics, IEEE Trans. Systems, Man and Cybernetics (Pt. C), Intelligent Data Analysis, Trust Management Journal (Ed in Chief).

PhD examinations: 65+ in total; 5 India, 30 in Europe, including University of Nijmegen, Carlos III Madrid, Complutense Madrid, Milan, TUM, INRIA, Open University Netherlands, Potsdam; the rest in the UK, including Imperial College (4), Cambridge (2), Nottingham (3), York (4), Edinburgh.

Conference / Programme chairs: Refinement Workshop 2008, 2009, 2011, 2013 (Boiten); MIST 2009, IEEE STA 2011, IFIP CMS 2012 (Chadwick); IFIP Trust Management 2009, 2012, 2013, IEEE ECOWS 2010, ERCIM STM 2008 (Dimitrakos); ISMM 2008, ECOOP 2014 (Jones); PPDP 2012 (King); Diagrams 2012 (Rodgers); Erlang Workshop 2009, PEPM 2012, CUFP 2012, 2013 (tutorials) (Thompson); CSC 2012, CICN 2011 (Wang).