Informatics at Edinburgh

Edinburgh's School of Informatics is the leading informatics department[1] in the UK and is home to international research leaders in all of its six research institutes. With 21 full professors, 200 academics and researchers, 200 Doctoral students and graduating around 140 Masters students per year, Informatics at Edinburgh is a vibrant research community acting as a hub for research activity in Scotland, the UK, Europe and worldwide. With a growing research income of over £10m per year Informatics at Edinburgh provides a unique research environment with the potential to transform our understanding in basic research and to support the development of radical new technologies for industry.

Research

Informatics' vision is to develop a new discipline where the study of computation, cognition and communication transcends the usual boundaries of artificial, computer-based, systems and natural, biological, systems. Our research is carried out within 6 *Institutes*, which provide a home for rich interdisciplinary interactions that are developing this new science:

- Laboratory For Foundations Of Computer Science
- Institute For Adaptive And Neural Computation
- Centre For Intelligent Systems And Their Applications
- Institute For Communicating And Collaborative Systems
- Institute For Computing Systems Architecture
- Institute Of Perception, Action And Behaviour

Researchers are members of one or more Institute; this helps to develop cross-specialism working. The work of the Institutes is summarised on the accompanying sheets.

Informatics is rapidly evolving and we expect new research areas to be explored and new groupings to emerge as the discipline develops. To allow for this, we have established **Research Programmes**; some of these may eventually become Institutes.

- **Software Engineering**. Applies a wide range of methodologies and techniques to software engineering problems: empirical studies; applications of AI techniques, computer science, mathematics, and cognitive science.

- **Bioinformatics**. Includes research within Informatics, Biology and Biomedicine. It investigates a wide spectrum of problems at a variety of levels of detail. For example: understanding gene regulation and embryo development; analysing genetic variation; understanding the forces that shape gene and genome evolution; understanding of the development and functioning of specific neural structures.

- **System Level Integration**. This programme works on new forms of system, integrating transduction, computation and communication on a single chip. The design, analysis and correct implementation of SLI devices presents new research challenges, and the programme brings relevant expertise within Informatics to bear on selected problems in the area.

- **Processes, Events And Activity**. Representing and reasoning with and about plans, processes, events, activity and behaviour is a common theme that is being explored by almost all Institutes within Informatics and in related areas within the University using a wide range of approaches and techniques. This collaboration is to help exchange of ideas between the various groups and approaches.

- **Reasoning**. This Programme promotes interaction between all the researchers in the School of Informatics at the University of Edinburgh studying reasoning. This covers both automated and interactive tools for the mechanisation of reasoning and investigations into the reasoning of human and other animals.

- **Music, Minds And Machines (M3) Group**. An interdisciplinary group that meets regularly to discuss the interaction of music with scientific disciplines such as Artificial Intelligence, Acoustics, Psychology, Cognitive Science and Linguistics.

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[1] Informatics at Edinburgh was the only department rated 5*A in its category in the 2001 Research assessment exercise.

Wider Collaboration

We are the focus for many national and international collaborative research ventures. For example:

- **Edinburgh-Stanford Link**. Sponsors activities with the Centre for the Study of Language and Information (CSLI) at Stanford University. The funding, provided by Scottish Enterprise, is for five years. The activities will encompass basic and strategic research; training and technology transfer in speech and language processing.

- **Interdisciplinary Research Collaboration In Dependability (DIRC)**. DIRC is developing effective solutions to the challenging problems concerning the dependability of large, complex systems by studying the interactions of people, technologies and institutions. Its six-year programme involves collaboration with social, cognitive and computer scientists drawn from Edinburgh, Lancaster, Newcastle, York and City Universities.

- **Interdisciplinary Research Collaboration In Advanced Knowledge Technologies (AKT)**. Is developing integrated methods and services through the knowledge lifecycle of capture, modelling, reuse, publishing and maintenance - services taking knowledge from cradle to grave. Its six-year programme draws together groups from the Universities of Edinburgh, Southampton, Aberdeen, Sheffield and the Open University.

Within Edinburgh, Informatics serves as a hub for interdisciplinary research. Informatics' researchers collaborate with colleagues in all the other Colleges in the University and have long-established collaborations with many of the individual Schools.

- **Human Communication Research Centre**: an interdisciplinary research centre bringing together theories and methods from several formal and experimental disciplines to understand better how people communicate with each other and with machines.

- **National e-Science Centre**. Established to lead, stimulate and sustain the development of e-Science in the UK, to contribute significantly to its international development and to ensure that its techniques are rapidly propagated to commerce and industry. Edinburgh won the national competition to host this centre because of its strength in Informatics combined with a long-standing track record in High Performance Computing.

- And other internationally recognised groups and centres:

Centre For Speech Technology Research
Centre For Neuroscience
Centre For Functional Imaging Studies
Institute For System Level Integration
The Edinburgh Virtual Environment Centre
Edinburgh Parallel Computing Centre
Centre For Forensic Statistics And Legal Reasoning
Language Technology Group

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Laboratory for Foundations of Computer Science

www.lfcs.inf.ad.ac.uk

The Laboratory for Foundations of Computer Science develops mathematical theories for modelling and reasoning about computational systems and concepts of all kinds. These theories guide the creation of algorithms, methods and notations to support the design and analysis of real-world systems. LFCS covers the full range of research and development activity from fundamental work to the creation of prototype software tools and their application.

Research Challenges

Complexity and Analysis of Algorithms. This group has made groundbreaking contributions to randomised algorithms, with applications in statistical physics and combinatorial enumeration, and major contributions in finite model theory with applications to the design of database query languages. Achievements include the award of the Goedel Prize to Jerrum and Sinclair.

Concurrency and Distributed Systems. This group works by making foundational innovations, applying them to real-world problems, in collaboration with industry, and disseminating the techniques in software tools that have large international user communities. The disseminated techniques have strongly influenced the direction of research in this area internationally.

Application areas include: safety-critical systems; performance in active networks; protocols for distributed systems. Tools include: PEP (a Petri net tool); the Model Checking Kit; the Edinburgh Concurrency Workbench; and the PEPA Workbench.

Semantics and Type Theory. This group works on foundational connections between mathematics, logic and computation, including work on category theory, logic and type theory. It has consistently provided international leadership in establishing the agenda for research in this area. Current topics include: categorical and logical foundations of higher-order abstract syntax; categorical frameworks for programming language semantics; axiomatic domain theory; realisability models of computation; modelling computational features such as control, state and mobility; variations on logical relations; game semantics; and linear logic.

Achievements include seminal work in axiomatic domain theory, foundations of higher-order abstract syntax, the theory of logical relations, game semantics and full completeness results in linear logic. Work on highly expressive type theories has formed the basis for an influential range of proof assistants. These systems are in wide use and have been applied to verification tasks in real systems e.g. distributed garbage collection and verification of reactive systems.

Specifications, Programming Languages and Software Engineering. This group is concerned with the specification, implementation and engineering of software systems. There is expanding activity to study code mobility and "global computation", covering aspects of construction of such systems as well as their specification and analysis. The software engineering activity has grown out of an interest in assuring system dependability and in object-oriented modelling and development, with current work focusing on product-line architecture and the role of domain-specific representations.

Achievements include: type systems for resource-bounded computation, which have been applied by researchers in Stanford and UPenn to the analysis of cryptographic protocols; the novel concept of architectural specifications, for specifying the modular structure of systems under development; and an account of behavioural equivalence yielding new proof methods for behavioural specifications.

Databases. The school has recently committed to building up its strength in databases. Two years ago Peter Buneman, a leading database researcher, was hired with the purpose of building up a world-class Database Research Group. Recently Stratis Viglas (University of Wisconsin) and Wenfei Fan (Bell Laboratories) were hired from two of the strongest database research groups in the world. With their arrival, the group is now by far the strongest database group in the UK and is poised to compete with the top database groups in the US. Aided by funding from the Royal Society, the UK Engineering and Physical Sciences Research Councils and funding under the EU FP6 DELOS project, the database group has good resources to support the development of broad research group. The group currently has six core members and, with anticipated funding of approximately 2m Euros, is expected to grow to at least twelve in the coming year.

The group has close links with the National e-Science Centre, and it was instrumental in Edinburgh's successful bid to host the National Data Curation Centre. The research activity of the centre is closely linked to the research activity of the group. The group has established research links with IBM and Bell Laboratories, and is developing links with scientific database work, notably with the European Bioinformatics Institute.

Institute for Adaptive and Neural Computation

www.anc.ed.ac.uk

The Institute studies adaptive processes in both artificial and biological systems. It encourages interdisciplinary and collaborative work drawing on the traditional disciplines of biology, particularly neurobiology, cognitive science, computer science, mathematics and statistics. The main areas of research are in *artificial learning*, *bioinformatics* and *neuroinformatics.*

Artificial Learning. This group concentrates on developing statistical models of data and algorithms to learn from data. Applications of this work include the classification of astronomical objects and modelling neural spike trains in studies of the brain.

Achievements include: development of novel graphical frameworks that provide a revolutionary new way of understanding stochastic models of information processing; development of Gaussian process models for prediction which are computationally simpler than the standard Bayesian neural networks and, in combination with support vector machines, underpin kernel-based predictors which are now the method of choice for many machine learning tasks; development of the Generalised Topographic Mapping, a new probabilistic method for modelling data which improves substantially on the widely used and influential self-organising map by providing a principled statistical basis for this algorithm.

Bioinformatics. Bioinformatics can be broadly defined as the storage, manipulation and analysis of biological information via computer science. Edinburgh is a world-leading centre for research in biological, biomedical and informatics and currently hosts one of the largest and best groups of researchers in bioinformatics in the UK. A major focus of bioinformatics research within ANC is exploring the genetic basis of brain structure and function. The model in this work is the fruit fly *Drosophila* because of its behavioural complexity yet small size. The studies comprise a multi-level analysis of behaviour and underlying neural circuitry of *Drosophila*, and is one of the first studies to combine experimental and informatics-based approaches to the study of a whole organism at subcellular, cellular and supracellular levels. This could lead to new therapies and a deeper understanding of the function of the brain. A key building block in this programme is the development of a sophisticated database infrastructure to support the basic science. This is an important contribution to the expansion of the Bioinformatics Research Programme (http://www.anc.ed.ac.uk/Bioinformatics).

Neuroinformatics. Neuroinformatics encompasses three research activities: (i) the mathematical and computer modelling of brain function and brain development; (ii) th**e** development and use of tools to support computer modelling studies and to store and manipulate neuroscience data at all levels; (iiii) the development of novel types of computation inspired by knowledge of how real neural systems operate.

Achievements include: novel computational theories of the functioning of the basal ganglia which are changing the way in which we understand and treat motor disorders; the first formalisation of the concept of neurotrophism into a theory of the development of nerve connections which links neuroanatomy with underlying biochemical processes; development of a novel theory of word recognition constrained by the neuroanatomy of the cerebral cortex; leading an international team in developing the NEOSIM simulation framework for neural processes, planned as the basis for the next generation of the internationally recognised neural simulators NEURON and GENESIS; investigation and application of advanced computational techniques for analysis and visualisation of fMRI datasets.

The EPSRC/MRC funded **Doctoral Training Centre in Neuroinformatics** provides for the funding of 50 PhD studentships, with 10 students entering the programme each year. These 4-year studentships enable students from the physical/mathematical/computer sciences to acquire training in neuroinformatics before embarking on their research project. The Centre is attached to the Institute for Adaptive and Neural Computation and collocated at the Forrest Hill site. (http://www.anc.ed.ac.uk/neuroinformatics)

Centre for Intelligent Systems and their Applications

www.cisa.inf.ed.ac.uk

CISA undertakes basic and applied research and development in knowledge representation and reasoning.

Research Challenges

Knowledge lifecycle: In our globalised world, knowledge management needs "joined up" engineering which links the various stages in use of knowledge (from acquisition to decommissioning) and enables us to support these in concert. Through projects like the AKT-IRC we are developing a modern knowledge lifecycle together with the theories needed to understand it.
Model integration: Models are used to manage processes and enterprises. Choosing the appropriate model is key to success in managing knowledge but coordinating different kinds of models poses significant challenges. Through projects like AKT and I-X we are building the frameworks necessary to develop and share different types of problem-specific model through common underlying representations.
Agent-based engineering: It is hard to build a multi-agent system and predict accurately what its behaviour will be. The nub of the problem is that agent systems cannot depend on the integrity of their environment or the reliability of the other agents with which they must interact. In a range of projects we are bringing engineering precision to "soft" concepts like negotiation, argument and belief revision in order to understand how macro-behaviours of multi-agent systems emerge from the behaviour of individual agents.
Planning and activity management: We are exploring representations and reasoning mechanisms for inter-agent activity support. Applications include crisis action planning, command and control, space systems, manufacturing, logistics, construction, emergency procedural assistance, help desks, and a myriad of other planning activities.
Intelligent Interfaces: We are researching and developing intelligent multi-modal interfaces which can provide support to user tasks, languages, locations and capabilities. Projects such as GhostWriter, O-Plan and I-X are a basis for this work. Applications include multi-lingual and cell phone support for maintenance and for emergency procedures.

Technologies

Streamlining theory for use. We produce "lightweight", pragmatic versions of theoretical systems which retain all of their formal integrity and most of their computational power but which have been adapted to suit standard styles of engineering.
Fitting our systems to industrial processes. For example, all current volumes of the Yellow Pages for British Telecom have an improved layout produced much more rapidly and flexibly through our knowledge-based layout language and algorithms.
Building applications which are used profitably. The RAF Logistics Expert Provisioner, based on our research, is claimed by the RAF to save £30 million per year by preventing over-ordering of spare parts for aircraft.
Making the world a safer place. We have developed systems for advising on hazardous waste disposal and providing medical advice in distant lands.
Shaping engineering standards. We had a key role in producing the NIST Process Specification Language standard.
Publishing in areas which matter to other disciplines. We have publications in mathematics, psychology, education, bioinformatics, simulation and environmental sciences as well as in the applied AI literature.

Institute for Communicating and Collaborative Systems

www.ics.inf.ed.ac.uk

ICCS is dedicated to the pursuit of basic research into the nature of communication among humans and between humans and machines using text, speech, and graphics, and the design of interactive dialog systems. Applications include natural language processing, information retrieval and presentation, education, musical analysis, and instruction.

Research Challenges

Natural Language Processing. The work of this group ranges from theoretically-oriented computational linguistics through to language engineering. The main sub-themes of research consist of natural language understanding and generation; data-intensive linguistics; and spoken dialogue systems. The group has an established track record of building tools which are firmly based in theory and which have been widely adopted throughout the world.

Achievements include: the first theory of grammar to integrate syntax, information structure, and compositional semantics, constituting the most successful contemporary account of coordination and intonation structure, with applications to wide coverage parsing and applications in spoken language technology (CCG) and the first NL-based tool to support model-checking hardware verification using temporal logic (PROSPER). The Language Technology Group's language engineering software tools (which have been licensed to around 8,000 users world-wide in industry and academia) include the LT-TTT tools for processing large bodies of text. Work with the Centre for Speech Technology Research has developed concept-to-speech generation techniques, linking work on discourse generation with CSTR's widely used Festival speech synthesis system. The recent establishment of the new Chair in Speech Technology and the subsequent appointment of Professor Steve Renals strengthens this work.

Human Communication in Practice. This group studies natural language communication and dialogue, human computer interaction, and the role of external representations (e.g. maps, diagrams, notations, visualisations, video) and artefacts (e.g. tools for communicating, recording and processing information) in mediating human communication and action.

Achievements include: groundbreaking work contrasting the semantics of diagrammatic and linguistic notations predicted the outcome of studies that found significant interactions between students' cognitive styles and the graphical or verbal external representations they used. The same approach has been used to model the impact of diagrams and algebras on shared practice in software engineering for dependable systems. Research in support of the design of computer-based detection tools for breast screening has revealed how annotation practices have evolved to make the judgements of individual radiologists accountable and how this helps maintain individual and team decision-making performance. Other work on the dynamics of small group communication successfully predicted impaired discussion when group members share access points to a desktop conferencing system. IBM is using data derived from predictive user modelling of physically disabled users' typing in developing accessibility tools. An opportunistic text generation system for personalised information delivery (ILEX) was one of the first such systems to be made accessible over the Web. Other achievements include the XML processing component of the MATE Workbench for standoff annotation of structured linguistic data, including continuous speech; a simplified form of SGML that was a significant input into the design of W3C international standard XML; and the first schema validator for XML, now being used by the NHS.

Institute for Computing Systems Architecture

www.icsa.inf.ed.ac.uk

ICSA is primarily concerned with the architecture and engineering of future computing systems. Its fundamental research aims are: to extend the understanding of the performance and scalability of existing computational systems; to improve the characteristics of current systems through innovations in algorithms, architectures, compilers, languages and protocols; to develop new and novel architectures and to develop new engineering methods by which future systems can be created and maintained.

Research Challenges

Architecture in the Small. This group has strengths in many aspects of the production of architectures particularly targeted at system-on-chip embedded systems. There is activity in basic architecture (asynchrony, reconfigurability and processor-memory interaction), design methodology (hardware software co-design), and specification, verification and validation. This work involves close interaction with industry, active collaborators including: ARM, Cadence/Tality, Hitachi, Lucent, Philips, Sharp, TRW Lucas Aerospace, Xilinx and Siroyan. Research is coordinated with three other Scottish universities via the Institute for System Level Integration (Sect. 2.5).

Achievements include: first demonstration of operating system managed virtual hardware; invention of the circlet; invention of the micronet architecture for scalable asynchronous system design; and a novel clustered VLIW architecture based on queue register files. The last three are being exploited in collaborations with Xilinx, Sharp and Hitachi, and Siroyan respectively. O'Boyle holds an EPSRC Advanced Research Fellowship to further his work on optimising compilation for embedded systems.

Architecture in the Large. This group studies the structure and performance of high-performance architectures and networks for parallel and distributed computing systems, targeting information grids for applications including multimedia communication, medical imaging and neural simulation. As well as architecture design, there is a strong focus on novel modelling and simulation techniques, and the formal description and analysis of high-level distributed systems architectures. There is significant interaction with the work of the Edinburgh Parallel Computing Centre (Sect. 2.7).

Achievements include: a novel large-scale Internet simulator exploiting HPC, in collaboration with Cisco; an innovative tool combining simulation and visualisation of parallel computer architectures, which has been downloaded to over 1000 sites and forms the basis of a distributed version developed by Mitre; development of a provably best synchronisation scheme for compiler-parallelised programs; pioneering unification of loop and data transformations within a new framework; development of an exact analysis for memory coherence, eliminating the need for hardware support; and the novel application of notions from process algebras to a tool for analysis of distributed commit protocols.

Institute of Perception Action and Behaviour

www.ipab.inf.ed.ac.uk

This institute investigates how to link, in theory and in practice, computational action, perception, representation, transformation and generation processes to external worlds-- whether it is the physical world or another computational environment. Research activities include computer vision, mobile and assembly robotics, statistical machine learning and sensorimotor control, music perception and visualization.

Research Areas and Groups

We have various focus groups and research areas within the institute.

Mobile & Assembly Robotics: Currently the focus of our research concerns is finding more principled support for the familiar intuitive general guidelines of behaviour-based robotics, and exploring its use in the hybrid version of behaviour-based robotics we use in assembly work (a hybridisation of classical planner and behaviour-based plan interpreter), with special emphasis on the sensor fusion problem. The Mobile Robotics Group share a broad approach to AI which tries to understand intelligence through the construction of agents which live autonomously in the real world, using non-symbolic-logical tools: `behaviour-based' architectures, neural networks, genetic algorithms, ethology and control theory.

Machine Learning and Computational Motor Control: This group focuses on a highly inter-disciplinary agenda spanning statistical machine learning, formal learning theory, learning in connectionist systems (artificial and biological); robotic, humanoid and biological motor control, and on the sensory side, multimodal cue integration and attentional strategies. The group aims to exploit the recent advances in machine learning and apply it to the domain of adaptive control of high dimensional sensorimotor systems while also trying to understand biological motor control through development of complex multi DOF biomimetic systems.

Computer Graphics, Visualisation and Virtual Reality. Current and recent work is in the areas of level of detail (LOD) in graphics display, particularly in virtual environments. Visualisation: We have support from British Telecommunications plc to look at visualisation of very large data sets. We are concerned with visualisation and navigation techniques and work with colleagues in Psychology, Centre for Neuroscience and the Human Communications Research Centre. Virtual Environments: In addition to the graphics work, we are working on navigation within virtual environments in co-operation with Edinburgh Virtual Environment Centre (www.edvec.ed.ac.uk).

Machine Vision Unit. The Machine Vision Unit researches the transformation of raw signals into a symbolic representation, whether through initial investigation, an intermediate stage or (mainly) a final interpretation of the signal data into human concepts. Much of the research uses distance data acquired from a laser-stripe range finder.

Achievements include: the development of algorithms which enabled the first real-time internal model learning in a high DOF, compliant humanoid robot,; the first guaranteed ellipse finding algorithm; design and construction of the first hand-held range sensor and the cheapest consumer-oriented range sensor; the first demonstration of a biomimetic robot interacting with its conspecific animal; biomimetic robotic models of crickets and horseshoe bats, and a novel model of active and passive movement imitation mechanisms, all leading to testable neurobiological predictions; generalised Push-Stability Diagrams of Brost to include objects of arbitrary curved outlines; a force controlled compliant robot for performing assembly-like operations with generality of location, orientation, and dimension; and efficient metrics for perceived level of detail in graphics display.