



JRI for computational systems

The Northern Research Partnership: overview: The University of Aberdeen, the University of Dundee and the Robert Gordon University have joined together to establish a research partnership in engineering and related disciplines, known as the Northern Research Partnership.

The purpose of this partnership is to pool research strength in areas common to partner universities, and to exploit areas of complementarity. It is the first time that the institutions have agreed to go beyond collaboration on an ad-hoc basis towards a convergence of research priorities in the area of engineering research. This will enhance research performance of the participating groups in all partner universities by creating critical mass, and increase significantly the competitiveness of research groups in the region. The proposal mirrors the establishment of similar regional partnerships in Edinburgh and Glasgow.

Research activity is taken forward through four JRIs and one overarching joint research group:

- JRI for Civil Engineering (also to form part of the national Telford Institute)¹
- JRI for Computational Systems
- JRI for Energy & Clean Technologies
- JRI for Medical Technologies
- Non-linear and Complex Systems Group

The partner universities have also set up a common Graduate School to support and enhance research student activities.

The partner universities have selected members for the JRIs with a view to international excellence, applying stringent criteria relating to research grants and contracts income and RAE submissible publications. The partnership represents a cluster of research groups in the engineering area, comprising 135 researchers, 160 research assistants and 286 PhD students.

JRI for computational systems: Summary

The proposal is to establish a centre of excellence in computational science and informatics in the North East of Scotland, combining the complementary strengths existing within the Department of Computing Science at the University of Aberdeen (UoA), the Division of Applied Computing at the University of Dundee (UoD), and the School of Computing, at the Robert Gordon University (RGU). The proposed institute will deliver world-class research and technology transfer in a number of strategic areas likely to impact on the Scottish economy. It will have sufficient critical mass to compete with leading centres in Europe and North America.

Strategic case

¹ This JRI will also involve a researcher from the University of Abertay, Dundee.

Our case is based on the potential of a group of high quality researchers focussed into a number of sub-areas representing strength in depth. Existing activities at each of the partner institutions complement each other well (see below) providing us with an opportunity to create a research institute focussed on three critical areas of contemporary computer science: mobile, distributed and networked computation; the interface between humans and information technology; the role of intelligent systems within knowledge management and decision support.

Aims of the proposed JRI

The institute will perform basic and applied research in the following areas:

- Mobile, Distributed & Networked Systems
- Human-Computer Interaction
- Intelligent Systems

Mobile, Distributed & Networked Systems

The participants in this theme have a strong track record in the key areas of mobile applications, distributed systems and networks for extreme environments, with a natural and growing convergence between these areas.

In *mobile systems*, the group has a worldwide reputation in supporting mobile users. Its expertise ranges from data communications networks and mobile telecommunications infrastructures through wireless peer-to-peer networks to software provision for harnessing contextual information in mobile computing that provide a foundation for information retrieval in mobile scenarios. The group has a strong focus on user groups including a background in network access and use for older people and people with disabilities, with applications in remote learning, lifestyle modelling and inter-personal multimedia communication.

In *distributed systems*, the group has an internationally leading track record in both the formal theoretical specification of agent networks, and their practical application to new problems. From nonclassical modal logics for handling and reasoning about action and change in complex agent societies, to semantics for inter-agent communication protocols and argumentation structures, the theoretical base is broad and sound. That base has supported successful practical applications in diverse domains including models of federation and communication for information sharing and exchange, implementations of virtual organisations in Web and Grid contexts, and e-commerce applications (such as auction houses).

In *networked systems*, the group has global standing in its design and hardware implementation of network components and protocols that support robust communication in extreme environments. A particular strength is in systems for space craft, and its SpaceWire international standard has not only been adopted as a defining mechanism for communication between onboard components, but has also been deployed on many ESA, NASA, JAXA and commercial space missions.

The group also boasts two successful spinout companies that bridge the three areas. The first is Calico Jack Ltd., which provides multi-agent solutions to telecommunications operators including Orange, France Telecom and most recently, Wanadoo. The company values its interactions with academia, freely licensing a version of its platform for academic use (which has been employed in projects at both Aberdeen and Dundee), contributing to the EU

Network of Excellence in Agent Based Computing, and providing a host environment for student placements and PhD work. The second is STAR-Dundee, which provides development and test equipment for organisations developing spacecraft using SpaceWire technology. It too retains strong links with academia, both in its design cycle and its international customer base.

Challenges

It is at the points of synergy between the sets of expertise available at the three sites that the most exciting opportunities for tackling new challenges occur:

- i. With an increasing need for networked subsystem autonomy and responsiveness in extreme environments such as space and subsea, the reasoning and interactive capabilities of agents would be coupled with robust communication protocols to provide for platforms that are not only reliable, but also able to respond to unexpected failures. The group is uniquely positioned to capitalise on its skills in this new emerging area.
- ii. As ubiquity of computing resources increases, virtual organisations will increasingly become heterogeneous, mixing electronic agents with human agents. With such ubiquity comes a need for interaction mechanisms that are sensitive to the contexts in which they are to be employed. With the group's track record in building and testing such virtual organisations a new opportunity presents itself for integrating models of users' context into the ubiquitous network in which applications are embedded.
- iii. Information exchange presents a well-known and relatively well-understood list of problems, but that list is greatly extended and complicated when the transfer of information is between representatives of different organisations with complex networks of vested interests and organisational responsibilities. The background of the group makes it uniquely well positioned to examine the use of agent systems in large-scale distributed information seeking, management and fusion in such virtual organisations, and to do so from both a theoretical point of view (harnessing the work in formal representation) and an application-oriented point of view (building on experiences with eScience and Grid computing in particular).
- iv. The communication structures employed by networks of scientists in both the natural and physical sciences are constructed from complex, dynamic relationships that can be modelled by virtual organisations reflecting the social complexity of practices in these disciplines. The structured exchange and development of ideas can be represented through practical models of disputational exchange. This enables research into appropriate structures to support enhanced transfer of information and resources in eScience and eSocial-Science domains.

The proposed grouping would make use of both its close relationships with relevant companies and industries to ensure that commercial opportunities are identified and exploited where appropriate. There are also, almost inevitably, strong opportunities for interactions between the Mobile, Distributed & Networked Systems Theme and the others in the JRI. The HCI theme includes strong natural language processing competence and range of user-centred development approaches that might contribute to interactions with users in mobile contexts. The Intelligent Systems theme includes strong expertise in modelling users and communications structures that might be valuable in the development of agent systems and Grid infrastructure components and middleware.

Human Computer Interaction

The participants in this theme have a strong record in innovative approaches to improving Human Computer Interaction (HCI) over a range of applications and challenges. The group

has developed innovative design methodologies, including work on visual perception and visual coding, the quantification of user mental models and creating new tools for usability engineering. Additionally, novel research has been conducted on context sensitive mobile computing and learning systems. Two of the partners have specialised in investigation of quantitative methods, and the third partner has explored new qualitative methods in this field; bringing them together will produce a very useful combination of these approaches.

The participants between them have worked both on Natural Language Processing and Natural Language Generation, and are in an excellent position to integrate these technologies with more conventional HCI methods and exploit them in realistic applications. We have explored a number of aspects of both multimodal input to computers and multimedia output. Bringing our skills and experience in these areas together will make for a rich mix.

Members of the group are deeply committed to multidisciplinary working, and between us have established good working partnerships with colleagues in biology, medicine, psychology, education, therapy, rehabilitation, art and design. This wide range of contacts and established goodwill will be inherited by the proposed JRI. In the field of HCI, we are separately expert in developing assistive systems for people with speech, hearing, language, visual and literacy problems, and also are developing systems specifically for the older population. We have established that systems developed for people with disabilities have the potential to be useful for all of us, and particular for users in unusual or stressful environments.

Challenges

Our aim is to pioneer a number of new developments in HCI, building on the work we have done so far, and exploiting the power of pooling our knowledge and skills and working as a team. We propose four new areas of research, which we would address within the joint research institute:

- i. **Innovative Approaches to User-Centered Development of HCI**
This will start with achieving a better understanding of the psychological processes underlying human information processing, reasoning and uptake of information presentation. New methodologies in user modelling, requirements elicitation and evaluation will be developed. Qualitative methods will include use of observer participation, long-term partnership with potential users, and interactive drama. Quantitative methods will include devising new ways to capture and quantify user mental models for interface design.
- ii. **HCI & Natural Systems**
We will develop systems applying natural language processing to HCI for people with disabilities, including natural language processing and generation. We will also investigate HCI issues which arise in developing adaptive systems, e.g. in the domain of learning. Included in this work will be studying brain-computer interfaces. We will also explore HCI issues in wearable, ubiquitous, invisible computing, environments that respond to our presence and our actions, and issues which arise from involving multiple input modes and multimedia output. An immediate application area for this work will be systems for people with disabilities, older people, and people in unusual or high stress environments, although many of the technologies have significant potential for wider applications.
- iii. **Affective & Social Computing**
Affective computing is computing that relates to, arises from, or deliberately influences emotions or other non-strictly rational aspects of humans. We will investigate affective natural language generation, and also the introduction of

emotional effects in speech synthesis. Affective computing introduces new challenges in user modelling (e.g. the modelling of affective state), but also underpins many real applications, for instance those involving the use of language to motivate or persuade. The wider social aspects of interacting with computers are receiving increasing attention, and we will explore this emerging new field in HCI, which has applications in computer-based interviewing, agent computing, and robotics.

iv. **Visualisation & Visual Communication Systems**

Our work on visualization for biomedical, communication, and educational purposes has shown that this is a powerful new application of computers whereby they begin to augment our powers to think, imagine, and be creative. Again, work in this area builds on an understanding of human psychological behaviour, and will be guided by theory, with the research process based on the development and evaluation of a range of exemplary applications. Potential applications in this area include supportive environments for people with special needs, advanced decision support environments, and visual systems to support and enhance social interaction.

Intelligent Systems

The proposed group contains academics from the University of Aberdeen's knowledge technologies group, the University of Dundee's computational sciences and interactive digital media groups and RGU's knowledge-based systems and computational intelligence groups. These researchers cover the topics of knowledge, computation and digital media that are central to Intelligent Systems. Modern society makes vast quantities of information available to decision-makers. The development of reliable and ubiquitous computing makes it possible to collect data and events across large systems and organisations, such as the health service, transport systems and multinational corporations. Monitoring equipment and microcontroller technology provide the capacity for control of complex industrial processes. Technological advances in genetic analysis such as micro-arrays are making available vast biological data sets for analysis and interpretation. The Web has made the possibility of reusing existing knowledge sources in a different context, a tantalizing prospect.

All of these areas give rise to difficult decision-making problems posing problems of immense complexity. Typical features of such problems are complex interaction of constraints, combinatorial explosion in solution space, multiple and conflicting objectives, non-deterministic outcomes, the use of predictive simulations to evaluate outcome, incomplete or poorly structured knowledge, noisy or missing data, and operation in a distributed environment.

Intelligent systems have long been applied to such problems. Persistent themes of this research are: knowledge representation, acquisition and refinement, knowledge discovery, experimental design, grammar acquisition, statistical modelling, parameter optimisation, comparison of intelligent algorithms and the appropriate selection for particular problems, self-adapting systems, integration between algorithms and human decision-making in mixed-initiative systems, and frameworks for applying techniques to new problems.

The Intelligent Systems grouping brings together, from three institutions, researchers with a well-established international reputation in Knowledge Technologies: discovery and representation, capture, refinement, re-use and transformation. Our significant activities in this area include data and text mining, image understanding, knowledge bases and constraints, ontological modelling and their transformation and subsequent use in intelligent systems. The group has a strong international reputation in Machine Learning encompassing: self-adapting and biologically-inspired systems, grammar acquisition, experimental design and parameter optimisation. Our significant activities in this area include evolutionary algorithms, inductive

logic programming, Bayesian probabilistic models, graph and combinatorial algorithms, and particle swarm optimisation and their use to build intelligent systems.

The grouping has a wealth of experience in developing intelligent systems for tasks that have highly-demanding requirements including multi-objective optimisation, non-linear constraints, learning and inference from image data, complex knowledge representations, computational complexity and distributed knowledge bases. Our expertise has been refined on a wide range of real-world application areas including medicine and healthcare, bioinformatics, pharmaceuticals, planning and scheduling, image analysis, surveillance and engineering.

Challenges

The proposed research institute offers an exciting opportunity for internationally-leading work in developing advanced intelligent systems. The grouping will be uniquely positioned to address a number of key challenges.

i. **Opportunistic Systems**

A well-established principle of computing is ‘divide-and-conquer’ – complex problems that defy solution are split up into more tractable problems. The group’s combined experience in knowledge modelling and adaptive systems will allow the development of Opportunistic Systems. These automate ‘divide-and-conquer’ by recognising parts of problems that can be solved, where to acquire problem-solving knowledge and how to integrate solved sub-problems into a solution of the original problem.

ii. **Semantic Web**

Knowledge arises in a wide variety of forms and representations from highly formalised ontologies to case bases to probabilistic graphical or grammatical models derived from adaptive search. Advanced Intelligent Systems require the ability to combine ensembles of discovered knowledge containers in order to support decision-making. These systems will increasingly consist of autonomous intelligent components sharing and recombining knowledge. The group’s strengths across a very broad range of knowledge technologies coupled with leading-edge work in extending representations for rules and constraints provide an excellent foundation for high-quality work in knowledge fusion.

iii. **Multi-Faceted Decision Support**

It is often the case that intelligent components of decision support systems can be applied in a number of different ways within the same application area. Typical modes include information, advice, decision-making, training and mixed-initiative aid. The challenge here is to promote re-use of advanced technical components while matching the context and objectives of a particular mode of application. A promising direction is to use techniques of knowledge capture to elicit context and objectives into a formalism that can be used to specify a decision-support system constructed from available components. These might for example be discoverable web services with customisable interfaces. Our expertise in knowledge capture and decision-support systems provides a very strong platform for addressing this challenge.

iv. **Knowledge Discovery**

A key challenge during search is to use the knowledge one has gained during the search to date to decide where best to search next. The knowledge gained during a search may also build into a model that can be interpreted by experts or used to construct an ontology. The strengths of the grouping in this area position the group well to meet this challenge by combining an understanding of complex algorithms, learning and inference from various data sources, and advanced knowledge modelling.

There are strong opportunities for interactions with the other themes in the proposed institute. The Mobile, Distributed & Networked Systems theme contains expertise that strongly relates to our themes of component-based advanced intelligent systems operating across communications networks. The Human Computer Interaction theme contains expertise which will ease the process of knowledge elicitation from users and also improve the effectiveness of intelligent components interacting with human decision-makers.

Knowledge transfer

The participants in the proposed JRI already have extensive external links and partnership arrangements which the JRI will be able to build upon. Dundee's existing collaborators include BT, Calico Jack Ltd, Department of Health, European Space Agency, IBM, GlaxoSmithKline, Japanese Space Agency, Microsoft, NASA, NCR, Scottish Executive and Scottish Power; Aberdeen has established links with BT, IBM, Rolls Royce, WNI Oceanroutes. Intelligent Applications Ltd, Aerospace & Marine International, the Macaulay Institute, and the Simpson Maternity Hospital (Edinburgh); Robert Gordon University has relationships with GlaxoSmithKline, AstraZeneca, BP, Reuters, BT, BAE Systems, Agilent Technologies, and the NHS. One of the key challenges for the JRI is to engage with these existing collaborators to secure their participation in its activities, and to ensure that pathways exist for commercialisation of research outputs.

The University of Dundee component of the JRI already has experience creating successful spin-out companies; specific examples being: Calico Jack Ltd, (incorporated in 2002 and currently employing 4 staff) and Star Dundee Ltd, (also incorporated in 2002 and employing 7 part-time staff). Applied Computing also accommodates a pre-incubator, the Greenhouse, jointly funded by Scottish Enterprise Tayside and the University of Dundee, which provides fully equipped offices and support services for staff and students who wish to explore establishing a company. This experience will be invaluable to the proposed JRI, and it is anticipated that awareness raising sessions on commercialisation opportunities will be held for all academic participants in the JRI; these are likely to include site visits and presentations from individuals with responsibility for commercial activities within the Dundee spin-outs. Participants within the JRI also have experience of other forms of knowledge transfer; for example, Applied Computing at UoD has a 3 year KTP funded contract in collaboration with NCR, while RGU has one involving Aberdeen's Marcliffe Hotel. There are also several examples of patents arising out of the research activities of JRI staff.

Between them, the three institutional groups within the JRI have strong contacts with other research organisations, at national, European and international levels. Participation in European networks is especially strong, with membership in recent years of the following: MONET, KDNet, OntoWeb, AgentLink. Involvement with international standards bodies is another important activity which the proposed JRI will seek to develop further; current links include: W3C (Web Content Accessibility Guidelines, RuleML, Rule Interchange Format, Semantic Web Best Practice & Deployment) and ETSI – European Telecommunications Standards Institute.

To facilitate knowledge transfer and commercialisation activities, the proposed JRI will establish an industry forum to communicate the activities of its research themes and to identify future strategic opportunities.

Exemplars of Research Opportunities

Activities at the intersection of the three research themes within the JRI will allow the communities at the participating institutions to contribute to some of the Grand Challenges¹ of

Computing. One of these is the need for scientific principles, engineering methodologies, and software tools to support the development of ubiquitous computing. It is expected that over the next 5-10 years, smart systems will become increasingly embedded within people's lives raising many issues including system reliability, trust, and privacy. We must be able to model such systems and their interactions, as well as ensuring that our engineering solutions scale to the potentially huge number of such devices which will interoperate. Integration of activities across the JRI will allow us to contribute to this challenge: data communications, infrastructure and protocols (Dundee), formal theoretical specification of agent networks (Aberdeen), models for trust and argumentation in agent systems (Aberdeen, Dundee), information management in mobile scenarios (Robert Gordon), mechanisms for information provenance (Aberdeen), human-computer interaction (Aberdeen, Dundee², Robert Gordon), complexity (Dundee), adaptive systems (Aberdeen, Robert Gordon). Another significant computational challenge is presented by so called "memories for life" – i.e. the personal collections of digital material now routinely assembled by individuals. Such collections are set to grow in the coming years with the inclusion of additional data including TV viewing histories, medical prescription details, learning materials, etc. We believe that the JRI can make real progress towards the goal of helping people manage and use information better by contributing expertise in several key areas: information retrieval (Robert Gordon), autonomous software agents (Aberdeen, Dundee), human-computer interaction (Aberdeen, Dundee³, Robert Gordon), natural language processing (Aberdeen⁴, Dundee), intelligent decision support (Aberdeen, Robert Gordon), image processing (Dundee, Robert Gordon), machine learning (Aberdeen, Robert Gordon). These example grand challenges illustrate how there is a real need for pooling of resources and expertise to make a successful contribution.

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