EPSRC Engineering and Physical Sciences Research Council

ORCHID

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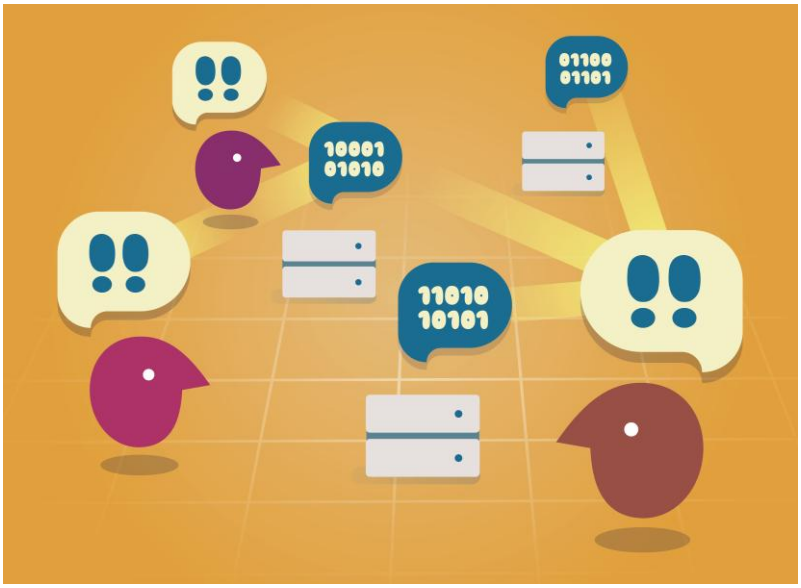
# Developing the science of Human-Agent Collectives




## END OF YEAR REPORT 2011

BAE SYSTEMS

SECURE

ACFR
AUSTRALIAN CENTRE FOR FIELD ROBOTICS

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# Introduction

ORCHID is an Engineering and Physical Sciences Research Council (EPSRC) Programme Grant that aims to establish the new science that is needed to understand, build and apply *human-agent collectives* (HACs) that symbiotically interleave human and computer systems to an unprecedented degree. The project involves a number of leading University groups: the University of Nottingham (Professor Tom Rodden), the University of Southampton (Professor Nick Jennings, Dr Alex Rogers and Dr Gopal Ramchurn), and the University of Oxford (Professor Steve Roberts). It has the following organizations as industrial collaborators: BAE Systems, Secure Meters and the Australian Centre for Field Robotics (ACFR). It also employs a Knowledge Transfer Officer, Dr David Nicholson, who is jointly funded by EPSRC and BAE Systems, and a project administrator (Angela Westley). The project receives advice from an Independent Scientific Panel (Professor Brian Collins (University College London), Professor Yolanda Gil (University of Southern California), Dr Thore Graepel (Microsoft Research Cambridge), Professor David Parkes (Harvard University) and Professor Alan Winfield (University of the West of England, Bristol)) and an Industrial Advisory Group (Dr Paul Vangasse, Dr Robert Johnston and Dr Simon Case (BAE Systems), Kaushik Ghosh (Secure Meters UK Ltd) and Professor Salah Sukkarieh (ACFR)).

The programme started on the 1 January 2011 and received £5.5M in funding from EPSRC. This was supplemented by £3.67M of additional investments: 24 PhD studentships provided by the partner universities at a cost of £1.35M; a £1M commitment from BAE Systems to an aligned programme to pull through the results of ORCHID into their corporate research programme and relevant Business Units; a £400k commitment from Secure Meters to a parallel programme in which they allocate a full-time engineer (Dr Ramachandra Kota) to pull through the results of ORCHID into their commercial activities; a £255k contribution in kind from BAE Systems and Secure Meters for their senior managers and scientists to fulfil their various research and advisory roles associated with ORCHID; a £320k contribution from ACFR to support engagement with their field robotics capability; and a £250k contribution from Southampton's Strategic Development Fund to co-fund two research fellows for three years each (Dr Victor Naroditskiy and Dr T Dong Huynh) and to interface with their University Strategic Research Groups. To date, the programme has funded some 12 research fellows and 5 PhD students. Further information of the spend to date and the staff employed on the project are provided in Appendix D.

In more detail, HAC systems embody a number of distinctive features that make it particularly challenging to engineer, control and predict their behaviour. Their global scale and decentralised nature means control and information will be widely dispersed among the large number of, potentially self-interested, actors with different aims and objectives (some of whom may be humans, others may be software agents). The various system elements will exhibit a range of availabilities (some actors may always be present, others only transiently). The collections of independent heterogeneous entities will need to be coordinated with individual agents that are agile enough to adapt their behaviour and action to the prevailing circumstances to best achieve their goals. The interaction in real-world contexts means uncertainty, ambiguity, and bias are endemic and so the agents need to handle information of varying quality, trustworthiness and provenance. Thus, techniques are required to provide an auditable information trail from the point of capture (a sensor or a human participant), through the fusion and decision processes, to the point of action, and the agents will have to reason about the trust and reputation of their collaborators in order to take the best course of action, as well as taking into account uncertainty regarding observations. Finally, in many cases, it is important that the collective action of the individually motivated actors results in desirable social outcomes (such as fairness, efficiency or stability). When taken together, these features of HAC systems require us to:

- understand how to provide *flexible autonomy* that will allow agents to sometimes take actions in a completely autonomous way without reference to their human owner, while at other times being guided by much closer human involvement in key decisions.
- discover the means by which groups of agents and humans can exhibit *agile teaming* and come together on an ad hoc basis in order to achieve a joint goal that none of the individuals can achieve in isolation and then disband once the cooperative action has been successful.
- elaborate the principles of *incentive engineering* in which the actors' rewards are designed in such a way that the actions that the participants are encouraged to take, when amalgamated, generate socially desirable outcomes.
- design and develop an *accountable information infrastructure* that can provide a step change in situational awareness by blending sensor and crowd generated content in a robust and reliable way, and developing mechanisms that allow its veracity and accuracy to be confirmed and audited.

The ORCHID team all share the ethos of undertaking excellent fundamental research in real-world contexts (“in the wild”) and are working closely with the Programme’s industrial collaborators to demonstrate and evaluate this fundamental work in the application domains of *energy systems, citizen science* and *disaster response.*

Given this background, this document reports on the project’s main achievements to date. More details are available on the project’s website (http://www.orchid.ac.uk) and all the documents listed in this report are available there or in the intranet (access available on request).

# Research Achievements

This research within ORCHID is split into five work areas, each of which is described in more detail in the remainder of this section. Each section describes the progress to date in that area and then outlines the high level plans for the coming year. More details of the work carried out are given in the Appendices: B lists all the deliverables produced and C the statements of work that were active in the reporting year.

To date, the project has produced 43 publications, 15 in journals and 26 in conferences and workshops (see Appendix A for the full listing). Of these, 4 are between more than one of the partners involved in the project, 19 involve an international co-author and 2 involve an industrial co-author.

In addition to those listed in this section, a number of research achievements relate to knowledge transfer activities and these are detailed in the section on Knowledge Transfer Achievements.

## Flexible Autonomy

### Progress against Objectives

This Work Area is led by Rodden and its initial objectives, as identified in the proposal, were:

> We will focus on the establishment of the key interactional principles between human and software agents that are needed to allow a sense of flexible autonomy to be established, monitored and amended in a context sensitive manner. These principles will be built into key mechanisms and reflected in the ways we represent and reason about these systems. Key objectives in establishing these principles are as follows. (i) The ***development of new presentation and interaction techniques*** to allow users to understand the actions of large collections of independent systems as they reason and act on behalf of users. (ii) The ***development of new control models and representations*** that allow dynamic and fluid interactive arrangements of agents and users. For example, allowing authority relationship between users and agents to change in different contexts and agents to work under varying levels of supervision. (iii) The ***development of techniques to recognise human activity*** to allow agents to reason about human interaction so they might exploit this understanding to augment and support the actions of users. (iv) An ***elaboration of the effectiveness of different styles of interaction*** and their role in HACs. For example, when should users give direct orders that agents must obey? When might users express their broad desire and allow these to be re-interpreted by agents? Under what circumstances should agents instruct users what to do and when should users be able to question them?

The work within this section focuses on integration between users and agents. To date, this work has tended to trial the user-side of the work on applications (in conjunction with the applications work area). In particular, the progress against these objectives has mainly focused on the exploration of new presentation techniques. Specific progress is as follows:

(i) The **development of new presentation and interaction techniques** has progressed through work at Southampton and Nottingham exploring how best to embed agent interaction within a range of applications. This has included:

a. Nottingham and Southampton developing and testing an interface for an agent-based approach to battery management. This has focused on providing a bookable interface where users can select a time slot for a particular appliance (in this case a washing machine) to run. Users are presented with differential tariff prices for running the machine that draw upon the agent system exploiting the scheduling of appliance use and a local battery to smooth energy use in the home. The system is being developed to be deployed and used with a number of homes.

b. The exploration at Southampton of using a mark-up interface to annotate captured energy information. The developed system presents users with a graphical presentation of total energy consumption through the day. Users may annotate particular peaks of energy use with the particular device or appliance they believe has drawn the increase in energy use. A range of agent systems can then draw upon this annotated data.

c. Development and deployment at Nottingham of a network of energy monitoring systems in 28 homes for 3 months. The aim of this is to assess people's interaction with the monitoring infrastructure and a browser allowing exploration (Fischer, Pantidi). This study has particularly focused on how ecology of different devices might be used in tandem to present information and activity to users. This has included the use of social media (twitter), messaging (SMS) and an integrative browser interface. This exploration has linked with Southampton and fed into the development of a joint integrative activity focusing on switching tariffs based on data drawn from energy monitoring systems.

(ii) The exploration of **new control models and representations** has featured within the majority of explorations to date. This has been complemented by the development of a number of coordination applications. This has included:

a. The development at Nottingham of a simple experimental framework for situational awareness that provides three distinct interfaces to control the activities involved. The broad scenario is based on searching for a virtual truck that is deemed to be shedding radioactive material. This consists of three interfaces. A driver interface that directs the truck presented on a map interface, a coordinator interface that has a range of readings presented on a map and can request new readings. Finally, a set of mobile phone interfaces where users can see requests to take a reading at a given locations. Using this interface a mobile user can go to the given location and take a new sensor reading, which is uploaded to the systems.

This work has established the groundwork to allow this work area to focus on a series of deployments with real world users in 2012. The information from these deployments will allow us to explore (iii) the development of ***techniques to recognise human activity***. Comparison between the assessments of different deployments will allow us to focus on (iv) elaborating the ***effectiveness of different styles of interaction***.

## Key Aims for 2012

The work until now has focused mainly on the development of novel interface approaches often embedded with specific applications. Work for 2012 will focus on deploying these applications and understanding the effectiveness of different techniques in use. The emphasis of the work thus shifts to consider the other key objectives in this work area. In particular:

(i) The **new presentation and interaction techniques** developed will, through a combination of the assessment of existing interface and the development of new approaches allow the team to focus on broader integrative discussions. This will take the form of:

a. A series of fieldwork studies exploring the effectiveness of different interactional approaches (they will include an agentSwitch deployment and the Battery study). These will be complemented by a range of other mini-ethnographies or lab based studies.

b. An exploration of language and communication between users and autonomous agents through a PhD at Nottingham working jointly between ORCHID and the English department.

c. Hosting of a workshop jointly with the AI and HCI communities to explore and elaborate the interactional issues involved in human-agent collectives.

(ii) The exploration of **new control models and representations** will be driven through a series of deployments of emerging frameworks. This will include

a. The deployment and trialling of the simple scenario based around the location of a truck with radioactive material. This activity will focus on trialling these with a collection of users in different locations.

b. The deployment and trials of a number of focused tasks based on simple small scale situational awareness scenarios. These will allow real-time experiments with human-agent collectives in near real world settings.

(iii) The **development of techniques to recognise human activities** will draw upon existing work by exploring the activity recognition possibilities using the combination of data derived from experiments and trials. These will be driven by the needs of the specific application being used as a vehicle for the work.

(iv) The **elaboration of the effectiveness of different styles of interaction will result from** a number of integrative workshops drawing together the lessons learned from each of the distinctive trials involved and upon the deployment and study of a significant event engaging the public. This is currently focusing on a pervasive gaming experience ideally to be deployed at the igfest event in Bristol.

# Agile Teaming

## Progress against Objectives

This Work Area is led by Rogers and its initial objectives, as identified in the proposal, were:

> We will focus on the development of key mechanisms and formalisms to deliver the agile teaming described above and how these are made available to users. Key objectives in establishing these mechanisms and formalisms include the following. (i) The ***development of new metaphors and design guidelines*** that enable effective teams to be formed by interleaving humans and agents such that they can work collectively toward a particular task, while fully exploiting the specific advantages and constraints of both parties. (ii) The ***development of mechanisms and algorithms*** that allow humans and agents within a group to effectively coordinate their activities and actions to collectively maximise their utility. (iii) The ***integration and demonstration*** of these approaches within exemplar applications within the domains of energy systems and disaster response.

To date, the progress against these objectives is as follows:

(i) The **development of new metaphors and design guidelines** has progressed through work at Oxford developing Bayesian approaches to identify and detect teams within groups of interacting entities, and work at Southampton developing the notion of coalition-types to address the need to scale existing approaches:

a. Ebden (Oxford) has developed a novel approach to Bayesian nonnegative matrix factorization to identify overlapping communities within social networks. This has been evaluated on a number of real-world datasets including observations of bird interaction in collaboration with the Department of Zoology. The approach is currently being extended to identify the classification behavior of Galaxy Zoo volunteers, and has led to a number of insights that improve the way in which Galaxy Zoo filters and fuses the multiple conflicting opinions from volunteers.

b. Rahwan (Southampton) has begun work addressing the computational complexity of existing coalition formation algorithms that currently preclude their use within the large-scale setting envisioned in ORCHID. In particular, his technique exploits similarities between agents to form a reduced number of agent and coalition types. State-of-the-art clustering techniques are then used to group similar agents into a single cluster, and one can control how similar the agents need to be in order to be placed into the same cluster. This, in turn, controls the trade-off between run-time and solution quality.

c. In addition, initial work has begun to explore the parallels between these two approaches, with initial observations made at the Agile Teaming Workshop (28 November 2011) focusing on similarities between the algorithms used to maximize posterior probability in the Bayesian approaches and utility in the coalition formation approaches. In particular, recent work on coalition formation over sparse networks (Dr. Maria Polukarov) shows strong parallels with the work identifying overlapping communities and represents an ideal area for future collaboration.

(ii) The **development of mechanisms and algorithms** that allow humans and agents to coordinate activities has progressed within a setting in the domain of disaster response where multiple UAVs provide live situational assessment imagery to first responders at the scene of a disaster.

a. The max-sum algorithm, with a novel utility function, has been applied to this setting and evaluated in simulation. This work has led to algorithmic developments for settings where the outcomes of joint actions are stochastic and/or uncertain. In particular, multi-arm bandit approaches have been applied to balance exploration and exploitation when joint actions are stochastic (Delle Fave, Dr. Ruben Stranders, and Tran Thanh), and the max-sum algorithm has been extended to partially ordered settings to address utility functions described by probability distributions (Delle Fave and Stranders).

b. Furthermore, interaction with the Flexible Autonomy work area has started with the work of Wu who is developing new decision-theoretic models to formally represent problems involving interaction between people and agents. His model takes input of human information, such as working schedules of the near future, and outputs a plan that balances the control between agents and human operators. To date, these approaches are computationally hard and lack scalability, and thus, a line of work will address the challenge of finding approximate solutions to tackle real-world applications. Initial work in this space is tackling the same disaster response setting as modeled above.

c. This work has been augmented by that of Jacob Selmes, a PhD student funded by the Complexity DTC, who started in October 2011 and is continuing the development of the max-sum algorithm in this setting.

(iii) The **integration and demonstration** of this work above has been carried out both within a simulation environment and within live flight tests performed in conjunction with the Australian Centre for Field Robotics (ACFR).

a. With regard to the former, a Java simulation environment was engineered incorporating models of the UAV and the interface used by the first responder to select tasks, and an implementation of the max-sum algorithm developed above to coordinate the UAV. The demonstrator was shown at the ORCHID all hands project, and will be demonstrated at AAMAS 2012.

b. With regard to the later, a PhD student exchange was performed with ACFR, and Francesco Maria Delle Fave spent February 2011 to May 2011 working to deploy the max-sum coordination algorithm developed above on the UAV that the ACFR use for trials. Three successful flight tests were performed (see the videos at http://www.orchid.ac.uk/max-sum-uavs/) and the description of the system and trials was accepted for presentation at ICRA 2012 (see publications list).

## Key Aims for 2012

While the work described above will continue into 2012, there are two additional aims that will be addressed in future work:

(i) Initiate collaboration with Nottingham: Resource for Nottingham within the agile teaming work area starts in 2012, and a key aim is to initiate collaboration in this work area. Brainstorming at the agile teaming workshop suggests that the initial aim will explore how to elicit preferences from human collaborators, and how the limitations of doing so will potentially impact the choice and design of the coalition formation algorithm that must be used (Hines + NPhD2).

(ii) Develop agile teaming applications within the smart grid domain: In conjunction with above, work will also be extended to cover the smart grid application domain. It is likely that this will be done through the analysis of coalition formation mechanisms within virtual power plants (Maleki), and also through collaboration with Dr. Meritxell Vinyals and Dr. Alessandro Farinelli, who are developing message passing algorithms to form coalitions across social networks to match electricity consumers with compatible consumption profiles. Vinyals will move to Southampton in June 2012, and this work will likely be demonstrated within the agentSwitch demonstrator which will consider collaborative purchasing options between coalitions of electricity consumers (see Applications for more details).

# Incentive Engineering

## Progress against Objectives

This Work Area is led by Roberts and its initial objectives, as identified in the proposal, were:

> We will focus on the development of mechanisms and methods of approach that provide a means of influencing the behaviour of individual actors (humans and software agents) and groups, where there is no direct means of controlling the internal workings of the participants. In particular, the key initial objectives for this work are as follows. (i) Evaluate a **principled value for information, action and strategy** to inform an agent's assignment of utility. (ii) Develop methods to **incentivise humans and agents to gather and utilize information and act** in uncertain, dynamic environments. (iii) Develop **methods by which communities and social networks and coalitions of humans and agents** can be analysed, tracked and forecasted. (iv) Determine **how and what (weak or indirect) control** needs be exerted over collectives of humans and agents to achieve global objectives by engaging in joint actions.

To date, the progress against these objectives is as follows:

(i) Evaluate a **principled value for information, action and strategy** to inform an agent's assignment of utility.

a. Developed incentive compatible framework for *value of information, action and strategy*, along with mechanisms for *active sampling* in communication poor environments. These approaches are tested in *human-in-the-loop* systems, such as *preference learning.* (Wharton, McInerney, Osborne)

b. Developed appropriate theory for the principled valuation of information from heterogeneous sources, particularly *soft* and *hard* information. Extended theory to optimize efficient fusion of such information. (Reece)

(ii) Develop methods to **incentivise humans and agents to gather and utilize information** and act in uncertain, dynamic environments.

a. Exploration and development of incentives and verification of information in referral based crowdsourcing and social networking. (Naroditskiy)

b. Combining both non-parametric and parametric physical models to predict human behaviour in a dynamic environment and incentivise them to reduce their energy expenditure. (Reece, Ghosh, Rogers)

(iii) Develop **methods by which communities and social networks and coalitions of humans and agents can be analysed**, tracked and forecasted.

a. Development of value of information theory for probabilistic social networking and community detection. (Psorakis, Ebden)

b. Initial investigations into *dynamics* of social networks and groupings. (Ebden)

c. Analysis of information value and coordination in large cohorts of weak decision makers in crowdsourcing (Zooniverse). Initial evaluation of feedback and weak control of agents. (Simpson)

(iv) Determine **how and what (weak or indirect) control needs be exerted over collectives of humans and agents** to achieve global objectives by engaging in joint actions.

a. Initial evaluation of feedback and weak control of agents. (Simpson)

b. Weak control and coordination of multiple agents using non-parametric models. (Calliess, Osborne)

## Key Aims for 2012

The work described above will continue into 2012.

(i) Evaluate a principled value for information, action and strategy to inform an agent's assignment of utility.

a. Development of methods for the inference of value and cost from censored observations, preferences and actions (Osborne).

b. Further evaluation of performance on energy, citizen science and situation assessment application domains (Reece).

(ii) Develop methods to incentivise humans and agents to gather and utilize information and act in uncertain, dynamic environments.

a. Joint work between Oxford/Southampton (Ghosh, Naroditskiy, Reece & Osborne) to exploit value of information research in incentive creation (links to (iv), weak control).

(iii) Develop methods by which communities and social networks and coalitions of humans and agents can be analysed, tracked and forecasted.

a. Investigation of links between adaptive mechanism design and graph properties.

b. Development of methods for tracking networks of agents and manipulating the interactions to achieve desired graph properties (links to iv, weak control).

(iv) Determine how and what (weak or indirect) control needs be exerted over collectives of humans and agents to achieve global objectives by engaging in joint actions.

a. Further development of weak control and incentives for crowdsourcing applications (e.g. Zooniverse), energy application and situation assessment using HACs.

b. Development of real-world scenarios and experiments with human-agent collectives. Interaction with Nottingham to build situation assessment / information gathering experiments to test algorithms on real HAC systems.

# Accountable Information Infrastructure

## Progress against Objectives

This Work Area is led by Moreau and its initial objectives, as identified in the proposal, were:

> We will focus on the establishment of the key principles underpinning an accountable information infrastructure, and on the design of its architectural foundations. Whereas provenance tends to be detailed, providing an explicit account of how information was derived, trust and reputation tend to be measures of the quality of such information. Given this, several approaches have been proposed to derive the latter from the former (cf. [Moreau, 2009]). However, their varied nature in terms of representation and size imply different techniques to gather, manage, reason over and query them. In particular, ORCHID aims to integrate them in a coherent manner in the accountable information infrastructure. To this end, key objectives include the following. (i) The **specification of the information infrastructure underpinning HACs**, including common data models, representations and APIs to share and access accountable information uniformly. (ii) The definition of **models for provenance/trust/reputation** of information and their source in HACs. Models and algorithms will also be designed to support crowd generated content, uncertain information, incomplete and conflicting provenance, and anonymity and pseudonymity for privacy concerns. (iii) The **design of accountability services**, for online and offline use, based on a decentralised, large-scale architecture for capturing and reasoning over provenance/trust/reputation. These will exploit and build upon existing cloud infrastructures. (iv) The development of **techniques to manage provenance/trust/reputation over variable timescales** with an emphasis on the computational and ethical issues that may emerge from long lived information.

To date, the progress against these objectives is as follows:

(i) Through our leadership of the W3C (World Wide Web Consortium) Provenance Working Group (Moreau, co-chair) we have set the foundations for a standardized data model for provenance and API to produce it. Concretely, draft specifications were published about the PROV data model, the PROV ontology, and the PROV Access and Query mechanism. These are core building blocks for the accountable information infrastructure. In parallel, with the W3C activity, we have developed a JSON representation of provenance, to be used in ORCHID Web-applications. For details, see deliverable 4.2. This work is contributing to preliminary objectives **(i) specification of the information infrastructure underpinning HACs and (ii) models for provenance/trust/reputation**.

(ii) We have developed a crowd-sourced application (Huynh, Stranders, Ramchurn), for collaborative editing of building evacuation routes, CollabMap. This application is provenance-enabled, which allows the exact provenance of any CollabMap data to be recorded, queried and displayed. The CollabMap application is being rolled out, and will collect real-life provenance traces, to be used in further investigations.

(iii) With the rest of the ORCHID project, we have contributed to the agentSwitch joint application, identifying potential provenance-based scenarios for this application. Taking a user's perspective, Fischer and Rodden have developed mock-up screenshots of how provenance and trust information can be exposed to users. The agentSwitch architecture incorporates a provenance service, a core-member of the family of accountability services (preliminary objective (iii) **design of accountability services** )

(iv) We have initiated research activities to analyse provenance graphs, aiming to characterise their information content, so as to be able to infer provenance, represent it efficiently, and predict future behaviour based on past experience. Ebden and Roberts have developed algorithms to infer missing edges, whereas Keshavarz has designed a preliminary framework for provenance graph traversal and processing. These activities are addressing preliminary objectives (iii) **design of accountability services** and (iv) **techniques to manage provenance/trust/reputation over variable timescales**.

## Key Aims for 2012

In the coming year, the aim is to consolidate the architectural design, implement it and deploy it in agentSwitch, so as to produce real-life provenance, which can then be analysed by our nascent algorithms, and exposed to users in novel ways. Concretely, our objectives are:

(i) Pursue our W3C standardization activity, refining specifications, and pushing them through to the standardization pipeline. It is hoped that some of these specifications will be nearing the 'candidate recommendation' stage. Furthermore, we will seek to get the JSON serialization a formal status in the PROV working group.

(ii) Complete the roll-out and evaluation of CollabMap, and create a catalogue of provenance traces, as a potential test suite for future algorithm designs.

(iii) Design and undertake a user study aiming to understand if and how users can interact with provenance, trust and reputation information. Some of that user study will be short-term based on agentSwitch, some of it is likely to be longer term, potentially requiring a different application, exploiting provenance in different ways.

(iv) Continue the design and implementation of provenance graphs algorithms, and their evaluation over real data we collect, and where possible, in applications we deploy to users. As algorithms mature, we will seek to expose them, as part of the ORCHID accountability services family.

# Applications

## Progress against Objectives

This Work Area is led by Ramchurn and its initial objectives, as identified in the proposal, were:

> The specific objectives are as follows. (i) **Define vignettes that generate use-cases for HAC systems** that reflect the level of maturity of the developed HAC technologies. Through outreach exercises (workshops, symposia, and other domain-specific forums) and our various advisory groups, the vignettes will be enriched and enhanced. This may include looking outside the initial exemplar domains of energy systems and disaster response as new opportunities present themselves. (ii) Develop a **methodology for the construction of HAC systems** that can be used by researchers and practitioners that combines all the constituent components into a coherent overarching framework. (iii) Design applications that both **collect domain data** from deployments and **simulate challenging domain-specific problems** with high fidelity. Initially, user applications with rapid up-time will be developed that permit the collection of sizeable datasets with regards to user behaviour and system performance and, in the long term, act as vehicles for evaluating ORCHID technologies 'in the wild'. In addition, simulations will be designed to contain an extensive set of use-cases, coupled with a benchmarking framework. (iv) As technologies mature from other work areas, they will be **evaluated in both real-world settings (through user trials) and simulation platforms**, feeding back new datasets and requirements. (v) Construct demonstrators to **showcase HACs to domain experts** and to **obtain feedback** from the public, academics and policy makers that will help identify new requirements and highlight the associated ethical issues.

To date, the progress against these objectives is as follows:

(i) **Definition of vignettes that generate use-cases for HAC systems**: two vignettes were defined for the domains of energy and disaster management domain. During the course of the year, opportunities for a new top level exemplar were identified and taken up. This covers the area of citizen science and specific contacts have been established with the Zooniverse consortium. In more detail:

a. The use-case for the energy domain revolves around the deployment of smart meters in the domestic sector. Interactions between humans and their agent hinges on the automation of appliance scheduling, home heating controls, and energy contract selection. With respect to the latter, significant joint effort between Southampton and Nottingham has been devoted to the development of the agentSwitch application. The latter is a web-based service that allows users to find out the best contract to switch to, using predictions of their energy production (using techniques developed by the Oxford partners) in and using the uSwitch API to query for contract specifications (e.g., from EDF, eON, or British Gas). agentSwitch also allows users to find out ways in which they could reduce their electricity costs by shifting their appliance usage or by grouping with other homes to buy energy in groups. Such features will be developed to test appliance monitoring algorithms (by Parson) and agile teaming algorithms developed in the agile teaming work area (by Rahwan) in particular. Provenance graphs (from the accountable information architecture work area) developed for agentSwitch (by Huynh) will also help enhance users' trust in the application through the development of interface elements to represent them (with Nottingham's input).

b. The use-case for the disaster management domain involves the development of the CollabMap crowdsourcing application that involves requesting users for information about their environment in order to build high resolution evacuation maps. In this application, a strong element of provenance was implemented to track user performance, which in turn spawned the development of a django-based provenance service.

c. Citizen-science work has involved developing the Zooniverse Labs (similar to Google labs) platform so that machine learning algorithms and predictive models developed within ORCHID can be plugged in to improve human performance in galaxy identification tasks.

(ii) **Develop a methodology for the construction of HAC systems:** this objective is being addressed by three key activities:

a. The development of the agentSwitch application for energy contract selection focuses on the aspect of **human-to-agent task delegation** where humans have to trust their agent to perform some tasks and provide them with information about their own energy usage with a view to minimizing energy usage costs. In this work, the methodology articulates the main steps towards building an application where humans delegate sensing, prediction, and search tasks to the agent, while humans decide to delegate critical decisions to choose specific contracts to the agent.

b. The development of the CollabMap platform focuses on crowdsourcing as a mechanism to harness human intelligence and knowledge in order to improve mapping tools. The methodology of HACs in this context involves defining the **workflows for human input** at various stages and points within such workflows where machine learning and statistical tools can help improve the trustworthiness of the data generated. The methodology also defines the integration of provenance services in tracking user actions in the system.

c. The deployment of preference learning algorithms within the Zooniverse Labs project defines the use of **machine learning for human task performance analysis** and to determine the best tasks to ask them to perform.

(iii) **Design applications that both collect domain data from deployments and simulate challenging domain-specific problems with high fidelity:** This objective has been fully met in the development of:

a. the agentSwitch application (integrating data collection platforms built into more than 40 homes in Nottingham and Southampton utilizing different meters from CurrentCost and AlertMe), as well as the Chamberlain houses deployment of Secure smart meters and heating controls.

b. The CollabMap platform was publicly released towards the end of 2011 and generated hundreds of data points from tasks performed by users. This data may be used as test data for trust mechanisms developed in the flexible autonomy and agile teaming work

areas. Moreover, the workflows and incentive mechanisms used in the deployment will be used as benchmarks for mechanisms developed in the agile teaming work area.

c. The Zooniverse labs platform will collect data about human task performers and the performance of machine learning algorithms in task selection.

(iv) agentSwitch, CollabMap, and Zooniverse labs are, or will be, evaluated in the real-world in user trials (in the first half of 2012), thus meeting **objective (iv)**. These will also act as demonstrators for HACs thus meeting **objective (v)**.

## Key Aims for 2012

The next steps in WA5 will involve a combination of further development of the three core applications, moving from an implementation of basic elements of HACs to more integrated deployment of state-of-the-art research in other work areas. More specifically, the key objectives are to:

(i) Deploy interfaces, predictive models, incentive mechanisms, and optimization algorithms within agentSwitch that would showcase the full potential of HACs. In particular, this will involve implementing within live systems, algorithms to predict energy usage, to select the best contract for electricity, and identify ways in which users could save on their energy costs. Moreover, users should be able to track the information sources that generate the suggestions given by the agent using a provenance service. Results of the deployment and evaluation will be fed back to other work areas.

(ii) Deploy novel incentive mechanisms (incentive engineering work area) and trust models (from accountable information architecture) within workflows used for crowdsourcing using the CollabMap framework. Through user trials, we aim to define the key mechanisms to allocate tasks to users and therefore develop a methodology for the specification of incentive mechanisms in crowdsourcing applications. Results of the deployment and evaluation will be fed back to other work areas.

(iii) Deploy provenance services and machine learning techniques (from incentive engineering) within the Zooniverse labs to improve task performance and accuracy of reports from users. Results of the deployment and evaluation will be fed back to other work areas.

(iv) Demonstrate the applications of HACs at conferences and in public events as well as at the all hands meeting to obtain feedback and generate new requirements for these applications (see Knowledge Transfer Achievements for details).

(v) Generate new requirements for the other work areas given the feedback on the applications and on the challenges faced in deploying technologies in the real-world.

(vi) Explore new applications that may require either extending the current application platforms or building new ones in order to test those research outputs that cannot be demonstrated with the current platforms or because such research outputs are likely to add to the methodology of HACS in ways that were not expected initially and require different environments to be evaluated.

# Knowledge Transfer Achievements

## Progress against Objectives

The Knowledge Transfer activities, led by Nicholson, identified the following communities in the proposal as the beneficiaries for the ORCHID work:

- Academic communities
- Industrial beneficiaries
- Policy makers and the general public.

### Academic knowledge transfer

(i) An ORCHID PhD student from the University of Southampton (Francesco Maria Delle Fave) visited ACFR for three months to transfer ORCHID technology into successful UAV flight trials. This work formed the basis for a joint conference publication.

(ii) ORCHID researchers engaged with the EPSRC-funded SUAAVE project on some overlapping research objectives associated with agent collaboration. This resulted in a joint publication with the SUAVVE project team based at the University of Ulster.

(iii) ORCHID research at the University of Oxford is bridging academic departments to the benefit of new Citizen Science experiments and analysis. Specifically, knowledge is being transferred between the Pattern Analysis & Machine Learning Group in the Department of Engineering and the Astrophysics Group in the Department of Physics.

(iv) Academic researchers from ORCHID and Horizon Digital Economy Research participated in a joint workshop at the University of Nottingham in July 2011 on the subject of future energy systems (25 attendees across the projects).

(v) ORCHID research was presented at the high-impact NIPS 2011 workshops on Machine Learning for Sustainability (energy disaggregation and the smart grid) and Decision Making with Multiple Imperfect Decision Makers (Zooniverse classifier combination).

### Industrial knowledge transfer

(i) The University of Southampton teamed with BAE Systems Advanced Technology Centre (ATC) to prepare a MOD Centre for Defence Enterprise (CDE) proposal. If it is successful this bid will secure £70K spin-off funding to re-purpose ORCHID's CollabMap platform for Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) applications.

(ii) BAE Systems ATC was awarded £35k funding under the MOD's SEAS DTC extension programme to investigate the application of ORCHID technology for mixed-initiative operations in the defence autonomous systems context (i.e. missions carried out by teams of unmanned vehicles and human operators)

(iii) BAE Systems ATC has aligned the research of one of its sponsored EngD students at the University of Bristol to study HAC system designs and concepts in the context of defence and security applications.

(iv) ORCHID researchers worked with BT to develop The Energy Quiz (www.energy-quiz.org); an online quiz intended to data mine common misunderstanding in energy comparison through a game like interface.

(v) ORCHID researchers supported the Agent Framework (AF) Workshop hosted by BAE Systems Defence Intelligence business at their Yeovil office in November 2011. BAE Systems is developing the AF as a mechanism for rapid exploitation of ORCHID research.

(vi) BAE Systems has transferred an ORCHID technology, Nonnegative Matrix Factorisation for overlapping community detection, into a bespoke tool (Information Finder) for ingesting documents and performing social network analysis. This work involved exchange visits between BAE Systems and the University of Oxford.

(vii) BAE Systems has provided an integrated vehicle health monitoring dataset to the University of Oxford to facilitate transfer of its Variational Bayes Classifier Combination technique into BAE Systems Maintenance and Through-Life Support business area.

(viii) Secure Meters provided top-up international funding for an ORCHID project student at Southampton. Sasan Maleki started in this position on 1st June 2011 and is investigating the agile teaming of renewable generators within virtual power plants in the smart grid.

(ix) i2O Water provided top-up international funding for an ORCHID DTA studentship at Southampton. i2O Water is a Southampton based company that is a world leader in the instrumentation and monitoring of water distribution networks. The subject of the studentship is disaggregation of water consumption and leakage from water pressure measurements within local water distribution networks. This represents a first extension of the ORCHID application domain of smart grids to the more general setting of smart infrastructure.

(x) MBDA provided an EPSRC CASE studentship award to Southampton to investigate the application of decentralized coordination algorithms within systems of unmanned autonomous vehicles. The studentship starts in October 2012 and recruitment is in progress, with the intention that the successful candidate will focus on the application, deployment and demonstration of the coordination algorithms developed within the agile teaming work area.

(xi) Initial meetings have taken place between the ORCHID and Horizon Knowledge Transfer Officers with a view to organizing joint events and exposing ORCHID's research outputs to Horizon's industrial partners (> 100).

### Policy makers and general public knowledge transfer

(i) A number of press releases have been issued in popular journals and on a public web site to promote ORCHID's interim achievements:

| | | |
|---|---|---|
| 01/11 | Computer Weekly | Smart grids will need smart agents |
| 03/11 | New Scientist | Smart-grid 'stockbrokers' to manage your power |
| 05/11 | New Boundaries | Coordination in a crisis |
| 09/11 | The Economist | Bidding for Volts |
| 14/11 | ECS News Release | ORCHID contends for TechWorld University Excellence title |
| 01/12 | ECS News Release | CollabMap crowdsourcing software for evacuation plans |

(ii) ORCHID presented a poster and demonstrations at the TechWorld event organized by UK Trade & Investment (UKTI), held in London during November 16-17, 2011. This event was attended by representatives of many of the project's intended beneficiaries from government, charities and NGOs, and the ORCHID material was positively received.

## Key Aims for 2012

Knowledge Transfer opportunities are expected to increase in 2012 as ORCHID continues to develop and mature its technologies and embed them in demonstrators that showcase their applicability. The key aims for 2012 are:

### Academic knowledge transfer

(i) The Universities of Southampton and Nottingham have led a joint proposal to organize a workshop on Human Agent Interaction at the AAMAS 2012 conference. The aim is to ensure its success and promote HAC research within the international academic community. More generally, there is an aim to expose ORCHID research to a wider and more diverse set of academic areas than has hitherto been the case (i.e. to step outside the traditional multi-agent systems and machine learning communities). Several academic groups will be starting work in 2012 on a new programme, Autonomous and Intelligent Systems (AIS), funded by EPSRC and industry. This has overlapping interests with ORCHID in the areas of trusted decision-making and human-machine interaction. ORCHID will therefore aim to engage with AIS to identify areas of knowledge transfer and research collaboration between academic groups.

## Industrial knowledge transfer

(i) Generate spin-off funding for targeted exploitation of specific ORCHID technologies into the collaborating industrial partner's application environments.

(ii) Co-organise an event with the Horizon project to expose ORCHID technology to a larger number and a broader range of industrial organisations.

(iii) Engage with the Technology Strategy Board's Knowledge Transfer Network (KTN) to share ORCHID's achievement with a cross-section of business, academic, and technology organisations.

## Policy makers and general public knowledge transfer

(i) Ensure ORCHID's demonstration platforms (agentSwitch, CollabMap, Energy Quiz, and Zooinverse) are promoted through local schools, radio, press and social networks, as a means of engaging, informing, and educating the public about HAC capabilities.

(ii) Showcase ORCHID at the UK Young Scientists and Engineers Fair (The Big Bang), held in Birmingham's NEC during March 15-17, 2012. This event attracts school groups and families, offering an excellent outreach opportunity for the project.

(iii) In March 2012 the RCUK's Energy Programme is sponsoring an 'Energy zone' in the 'I'm a Scientist Get me Out of Here!' science engagement event. ORCHID aims to support this event by nominating a PhD student from its research team to participate.

(iv) Initial contact will be made with the policy-making organisations identified by the proposal, i.e. the Carbon Trust and the Disasters Emergency Committee, with an aim to understanding how ORCHID can support their respective requirements in future energy systems and disaster response via the provision of new research data.

# Summary

ORCHID has had a successful first year in terms of assembling a high quality team of researchers and students, in terms of starting to identify and make progress on some of the key challenges associated with our vision for human-agent collectives, and in terms of initial successes with a wide-range of knowledge transfer activities. This activity has produced a good number of published outputs, several prototypical HAC systems have been planned and implemented, and good working relationships have been established between the different research teams. The project held a very successful All Hands Meeting (3-4 October 2011) that allowed all the researchers to meet together for the first time, and for the Independent Scientific Panel and the Industrial Advisory Group to provide input into ORCHID's direction. The work proceeded broadly in line with the areas identified in the initial proposal, although the new application area of citizen science was identified as one where ORCHID could make a significant impact.

For the coming year, the key challenges include deepening the collaboration between the research teams, developing more encompassing demonstrations that capture richer illustrations of the interactions involved in human-agent collectives, and further broadening the scope of the knowledge transfer activities.

# APPENDIX A — PUBLICATIONS

The project produced the following publications; the following markings are used to denote publications that:

*: are between more than one of the groups involved in the ORCHID project
+: involve an international co-author
#: involve an industrial co-author
++: were shortlisted or won a best paper award


- Fischer, J.E., Flintham, M., Price, D., Goulding, J., Pantidi, N. and Rodden, T. Serious Mixed Reality Games. Position paper accepted at the workshop on Mixed Reality Games. *ACM Converence on Computer-Supported Cooperative Work*, 2012. Seattle, WA, USA.
- Fischer, J.E., Pantidi, N., Bedwell, B., Colley, J. Rennick Egglestone, S. and Rodden, T. Living with energy monitoring: implications for designing interactive information ecologies. In submission to *Journal of Transactions on Computer-Human Interactions (ToCHI)*. *Special Issue on Sustainable HCI through Everyday Practices* (expected 2013).
- + Chalkiadakis, G., Markakis, V., & Jennings, N. R. (2012) Coalitional stability in structured environments. *Proc. 11th Int. Conf. on Autonomous Agents and Multi-Agent Systems*.
- *, + Delle Fave, F. M., Rogers, A., Xu, Z., Sukkarieh, S. and Jennings, N. (2012) Dynamic decentralised task assignment for teams of unmanned aerial vehicles. *Proc. IEEE Int. Conf. on Robotics and Automation (ICRA)*.
- * Osborne, M. A., Roberts, S. J., Rogers, A., & Jennings, N. R. (2012) Real-Time Information Processing of Environmental Sensor Network Data. *ACM Transactions on Sensor Networks* **9** (1).
- Miller, S. J., Ramchurn, S. R., & Rogers, A. (2012) Optimal decentralised dispatch of embedded generation in the smart grid. *Proc. 11th Int. Conference on Autonomous Agents and Multi-Agent Systems.*
- Pryymak, O., Rogers, A., & Jennings, N. R. (2012) Efficient sharing of conflicting information in large decentralised teams. *Proc. 11th Int. Conference on Autonomous Agents and Multi-Agent Systems*.
- Simpson, E., Roberts, S. J., Psorakis, I., & Lintott, C. (2012). Bayesian combination of weak decision makers. In *Decision Making with Imperfect Decision Makers* Springer
- Stein, S., Gerding, E. H., Robu, V., & Jennings, N. R. (2012) A model-based online mechanism with pre-commitment and its application to electric vehicle charging. *Proc. 11th Int. Conference on Autonomous Agents and Multi-Agent Systems*.
- + Stein, S., Williamson, S., & Jennings, N. R. (2012) Decentralised channel allocation and information sharing for teams of cooperative agents. *Proc. 11th Int. Conference on Autonomous Agents and Multi-Agent Systems*.

- Stranders, R., Tran-Thanh, L., Fave, F. D., Rogers, A., & Jennings, N. R. (2012) DCOPS and bandits: Exploration and exploitation in decentralised coordination. *Proc. 11th Int. Conference on Autonomous Agents and Multi-Agent Systems*.
- + Szczepanski, P., Michalak, T., & Rahwan, T. (2012) A new approach to betweenness centrality based on the Shapley value. *Proc. 11th Int. Conference on Autonomous Agents and Multi-Agent Systems*.
- + Teacy, W. L., Chalkiadakis, G., Farinelli, A., Rogers, A., Jennings, N. R., McClean, S., & Parr, G. (2012) Decentralized Bayesian reinforcement learning for online agent collaboration. *Proc. 11th Int. Conf. on Autonomous Agents and Multi-Agent Systems*.
- Tran-Thanh, L., Rogers, A., & Jennings, N. R. (2012) Long-Term information collection with energy harvesting wireless sensors: a multi-armed bandit based approach. *Journal of Autonomous Agents and Multi-agent Systems*.
- Voice, T., Ramchurn, S. D., & Jennings, N. R. (2012) On coalition formation with sparse synergies. *Proc. 11th Int. Conference on Autonomous Agents and Multi-Agent Systems*.
- + Guo, M., Naroditskiy, V., Conitzer, V., Greenwald, A., & Jennings, N. R. (2011) Budget-Balanced and Nearly Efficient Randomized Mechanisms: Public Goods and Beyond. *Proc. of the 7th Workshop on Internet and Network Economics,* 158-169.
- Parson, O., Ghosh, S., Weal, M. and Rogers, A. (2011) Using hidden Markov models for iterative non-intrusive appliance monitoring. In: *Neural Information Processing Systems workshop on Machine Learning for Sustainability*.
- Simpson, E., Roberts, S. J., Smith, A., & Lintott, C. (2011) Bayesian Combination of Multiple, Imperfect Classifiers. *Proc. 25th Annual Conference on Neural Information Processing Systems (NIPS)*.
- McQuillan, A., Aigrain, S., & Roberts, S. J. (2011). Statistics of Stellar Variability from Kepler - I: Revisiting Quarter 1 with an Astrophysically Robust Systematics Correction. *Astronomy and Astrophysics.* Online publication doi: 10.1051/0004-6361/201016148.
- + Tran-Thanh, L., Polukarov, M., Chapman, A. C., Rogers, A., & Jennings, N. R. (2011) On the Existence of Pure Strategy Nash Equilibria in Integer-Splittable Weighted Congestion Games. *Proc. of 4th Int. Symposium on Algorithmic Game Theory,* 236-253.
- + Stein, S., Gerding, E. H., Rogers, A., Larson, K., & Jennings, N. R. (2011) Algorithms and mechanisms for procuring services with uncertain durations using redundancy. *Artificial Intelligence* **175** (14) 2021-2060.
- Stranders, R., Ramchurn, S. D., Shi, B., & Jennings, N. R. (2011) *CollabMap: Augmenting Maps using the Wisdom of Crowds*. *Proc. 3rd Human Computation Workshop*.
- Psorakis, I., Roberts, S., Ebden, M., & Sheldon, B. (2011) Overlapping community detection using Bayesian non-negative matrix factorization. *Physical Review E* **83**(6), 066114.
- + Stefanovich, N., Farinelli, A., Rogers, A., & Jennings, N. R. (2011) Resource-Aware Junction Trees for Efficient Multi-Agent Coordination. *Proc. Tenth International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2011)*, 363-370.

- + Rogers, A., Farinelli, A., Stranders, R., & Jennings, N. R. (2011) Bounded Approximate Decentralised Coordination via the Max-Sum Algorithm. *Artificial Intelligence* **175** (2) 730-759.
- + Armour, W., Karastergiou, A., Giles, M., Williams, C., Magro, K., & Zagkouris, S., et al. (2011). A GPU-based survey for millisecond radio transients using ARTEMIS. *Proc. of ADASS XXI.*
- + Calliess, J., Lyons, D., & Hanebeck, U. D. (2011). Lazy auctions for multi-robot collision avoidance and motion control under uncertainty. (*Technical Report No. PARG-11-01*). Oxford: University of Oxford
- + Chapman, A. C., Rogers, A., Leslie, D., & Jennings, N. R. (2011) A unifying framework for iterative approximate best-response algorithms for distributed constraint optimisation problems. *The Knowledge Engineering Review* **26** (4) 411-444.
- Fave, F. D., Stranders, R., Rogers, A., & Jennings, N. R. (2011) Bounded Decentralised Coordination over Multiple Objectives. *Proc 10th Int Conf on Autonomous Agents and Multi-Agent Systems*.
- *, +, # Chalkiadakis, G., Robu, V., Kota, R., Rogers, A. and Jennings, N. (2011) Cooperatives of Distributed Energy Resources for Efficient Virtual Power Plants. Proc. *Tenth Int. Conference on Autonomous Agents and Multiagent Systems*, 787-794.
- Fox, C. W., & Roberts, S. J. (2011). A tutorial on variational Bayesian inference. *Artificial Intelligence Review.* Online publication doi: 10.1007/s10462-011-9236-8.
- Gibson, N. P., Aigrain, S., Roberts, S. J., Evans, T. M., Osborne, M. A., & Pont, F. (2011). A Gaussian process framework for modelling instrumental systematics: application to transmission spectroscopy. *Monthly Notices of the Royal Astronomical Society,* 419(3), 2683–2694.
- + Karastergiou, A., Roberts, S. J., Johnston, S., Lee, H., Weltevrede, P., & Kramer, M. (2011). A transient component in the pulse profile of PSR J0738?4042. *Monthly Notices of the Royal Astronomical Society*, 415(1), 251-256.
- + Lyons, D., Calliess, J., & Hanebeck, U. D. (2011). Chance-constrained Model Predictive Control for Multi-Agent Systems. *arXiv*.
- Macarthur, K. S., Stranders, R., Ramchurn, S. D., & Jennings, N. R. (2011) A Distributed Anytime Algorithm for Dynamic Task Allocation in Multi-Agent Systems*. Proc. Twenty-Fifth Conference on Artificial Intelligence (AAAI) 701-706*.
- Papakonstantinou, A., Rogers, A., Gerding, E. H., & Jennings, N. R. (2011) Mechanism Design for the Truthful Elicitation of Costly Probabilistic Estimates in Distributed Information Systems. *Artificial Intelligence* **175** (2) 648-672.
- Pryymak, O., Rogers, A., & Jennings, N. R. (2011) *Efficient Sharing of Conflicting Opinions with Minimal Communication in Large Decentralised Teams*. *Proc. IJCAI Workshop on Link Analysis in Heterogeneous Information Networks*.

- Psorakis, I., Roberts, S. J., Ebden, M., & Sheldon, B. (2011). Overlapping Community Detection using Bayesian Nonnegative Matrix Factorization. *Physical Review E*, 83(6).
- + Rahwan, T., Michalak, T., Elkind, E., Faliszewski, P., Sroka, J., Wooldridge, M., & Jennings, N. R. (2011) Constrained Coalition Formation. *Proc. 25th Conf. on AI (AAAI)* 719-725.
- + Rahwan, T., Michalak, T., & Jennings, N. R. (2011) Minimum Search to Establish Worst-Case Guarantees in Coalition Structure Generation*. Proc. Twenty Second International Joint Conference on Artificial Intelligence (IJCAI)*, 338-343.
- Stein, S., Payne, T., & Jennings, N. R. (2011). Robust Execution of Service Workflows using Redundancy and Advance Reservations. *IEEE Trans. on Services Computing* **4** (2) 125-139.
- # Reece, S., Roberts, S. J., Nicholson, D., & Lloyd, C. (2011). Determining intent using hard/soft data and Gaussian process classifiers. *Proc. of the 14th International Conference on Information Fusion.*
- + Gerding, E. H., Robu, V., Stein, S., Parkes, D., Rogers, A., & Jennings, N. R. (2011) Online Mechanism Design for Electric Vehicle Charging. *Proc. 10th International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS 2011)* 811-818.

# APPENDIX B — DELIVERABLES

| Date delivered | Deliverable | Title | Type | Author |
|---|---|---|---|---|
| 16/08/2011 | D5.1 | Report on developing new algorithms for coalition formation with constraints | Report | T Rahwan |
| 07/11/2011 | D5.2 | Report on applying hard/soft data fusion algorithms to energy management settings | Report | S Reece |
| 07/11/2011 | D5.1 | Report on learning and inference in systems of mixed humans and agents | Report | S Reece |
| 07/11/2011 | D1.1 | Knowledge Transfer Strategy Report | Report | D Nicholson |
| 11/11/2011 | D5.1 | Report on applying online mechanism design to the energy domain | Report | S Stein |
| 11/11/2011 | D5.2 | Report on applying decentralised task assignment algorithms to disaster management settings with limited communication | Report | S Stein |
| 14/11/2011 | D3.1 | Verification in referral-based crowdsourcing | Report | V Naroditskiy |
| 23/11/2011 | D5.1 | Scenarios for agent-assisted home energy management | Report | J Fischer |
| 30/11/2011 | D5.2 | Applying newly developed coalition formation algorithm to the energy domain | Report | T Rahwan |
| 06/01/2012 | D2.2 | Investigation of HAC formation within energy applications | Report | M Ebden |
| 06/01/2012 | D5.2 | Non-intrusive appliance monitoring using iterative application of hidden Markov models | Report | O Parson |
| 12/01/2012 | D2.1/3 | AAMAS Paper 'Optimal decentralised dispatch of embedded generation in the smart grid' | Paper | S Miller |

# APPENDIX C — STATEMENTS OF WORK

All research undertaken in the project is covered by a statement of work. In this section, the statements that were active at some point in the report period are listed.

| Commenced | Researcher/PhD student | Title | Work Area and Packages* | Location |
|---|---|---|---|---|
| 01/03/2011 | Jan Calliess | Bayesian regression models with physically informed and structural priors | WA2 : WP3. WA5 : WP1, WP2, WP3 | Oxford |
| 01/03/2011 | Mark Ebden | Decentralised Formation of Collectives under Uncertainty | WA2 : WP1, WP3 | Oxford |
| 01/04/2011 | Joel Fischer | Human Issues with Human-Agent Collectives | WA1 : WP1, WP2, WP3. WA5 : WP1, WP2 | Nottingham |
| 01/09/2011 | Greg Hines | Algorithms for Human-Agent Coalition Formation | WA2 | Southampton |
| 01/05/2011 | T Dong Huynh | An Architecture for Provenance and Trust | WA4 : WP1, WP2, WP3. | Southampton |
| 01/10/2011 | Sasan Maleki | Coalition Formation for Distributed Energy Resources | WA2:WP1, WA5:WP2 | Southampton |
| 01/03/2011 | Victor Naroditskiy | Incentive Engineering in HACs | WA3 : WP1, WP2 | Southampton |
| 01/05/2011 | David Nicholson | Knowledge Transfer | All | KTO |
| 01/10/2011 | Michael Osborne | Efficient Bayesian Algorithms for Human-Agent Collectives | WA3 : WP3. WA4 : WP6. WA5 : WP2, WP3. | Oxford |
| 01/08/2011 | Nadia Pantidi | Understanding HACs in the real world | WA1 : WP1, WP2, WP3. WA5 : WP1, WP2, WP3, WP5 | Nottingham |
| 01/03/2011 | Talal Rahwan | Algorithms for Coalition Formation and Agile Teaming | WA2 : WP1, WP3. WA5 : WP2, WP3 | Southampton |
| 01/03/2011 | Steve Reece | Scalable Hard/Soft Data Fusion | WA3 : WP1. WA5 : WP1, WP3, WP4 | Oxford |
| 01/03/2011 | Seb Stein | Robust Coordination Mechanisms in Dynamic Settings | WA2:WP3, WA5:WP1, WP2, WP3 | Southampton |
| 01/09/2011 | Ruben Stranders | Decentralised coordination in multi-agent systems | WA2:WP1 | Southampton |
| 01/11/2011 | Long Tran Thanh | Efficient Learning and Motivating under Uncertainty in Human Agent Collectives | WA2 : WP1. WA3 : WP1 | Southampton |
| 01/10/2011 | Feng Wu | Decision-Theoretic Planning for Flexible Autonomy | WA1 : WP1, WP2. WA5 : WP1, WP3. | Southampton |

| *Work Areas | Work Packages |
|---|---|
| WA1 Flexible Autonomy | WP1 Flexible forms of control and influence, WP2 Awareness and attention in HACs, WP3 New forms of agency |
| WA2 Agile Teaming | WP1 Decentralised coordination under uncertainty, WP2 Human agent interaction in coordination, WP3 Integration and demonstration |
| WA3 Incentive Engineering | WP1 Decentralised inference and control, WP2 Bayesian Games and weak control, WP3 Inference over dynamic collectives |
| WA4 Accountable Information Architecture | WP1 Accountable information infrastructure, WP2 Provenance Model and reasoning, WP3 Architectures for Provenance/Trust, WP4 Representing human actions in crowdsourcing, WP5 User exploitation of accountability info, WP6 Trust and information fusion models |
| WA5 Applications | WP1 Defining scenarios, WP2 Energy systems applications, WP3 Disaster management applications, WP4 Monitoring of new application areas, WP5 Study of ethics and privacy issues |

# APPENDIX D — PROJECT MANAGEMENT DATA

## Spend Profile

| | | ORCHID | |
|---|---|---|---|
| | | Total Budget | Spend to date |
| Directly incurred | Staff | £2,266,281.00 | £282,330.39 |
| | Travel | £435,046.00 | £87,230.32 |
| | Equipment | £24,500.00 | £8,672.17 |
| | Other | £402,626.01 | £21,519.24 |
| | Sub total | £3,128,453.01 | £399,752.12 |
| | | | |
| Directly Allocated | Investigators | £550,420.00 | £81,475.27 |
| | Estates | £587,349.00 | £82,777.61 |
| | Other | £41,135.00 | £1,412.06 |
| | Sub total | £1,178,904.00 | £165,664.94 |
| | | | |
| Indirect costs | Indirect costs | £912,839.55 | £33,644.36 |
| | | | |
| Exceptions | Student Maint | £339,108.00 | £9,530.50 |
| | Student Fees | £85,362.00 | £15,537.47 |
| | Sub Total | £424,470.00 | £25,067.97 |
| | | | |
| | Total 100% (includes directly allocated costs) | £5,644,666.56 | £624,129.39 |

## Staff Employed on Programme

| | Oxford | Nottingham | Southampton | Start date | End date |
|---|---|---|---|---|---|
| PI | | | Nick Jennings | 01/01/2011 | 31/12/2015 |
| CI | | | Luc Moreau | 01/01/2011 | 31/12/2015 |
| CI | | | Alex Rogers | 01/01/2011 | 31/12/2015 |
| CI | Steve Roberts | | | 01/01/2011 | 31/12/2015 |
| CI | | Tom Rodden | | 01/01/2011 | 31/12/2015 |
| Project Administrator | | | Angela Westley | 07/03/2011 | 06/03/2016 |
| Knowledge Transfer Officer | | | Dave Nicholson | 05/05/2011 | 04/05/2014 |
| Researcher | | | Gopal Ramchurn | 01/01/2011 | 31/12/2015 |
| Researcher | | | Seb Stein | 01/01/2011 | 31/03/2014 |
| Researcher | | | Talal Rahwan | 01/01/2011 | 31/03/2014 |
| Researcher | | | T Dong Huynh | 12/05/2011 | 11/05/2014 |
| Researcher | | | Victor Naroditskiy | 01/04/2011 | 31/03/2014 |
| Researcher | | | Feng Wu | 01/10/2011 | 30/09/2014 |
| Researcher | | | Greg Hines | 01/09/2011 | 31/08/2014 |
| Researcher | | | Long Tran Thanh | 01/11/2011 | 31/10/2014 |
| Researcher | | | Ruben Stranders | 01/09/2011 | 29/02/2012 |
| Researcher | | | Muddasser Alam | 01/10/2011 | 30/09/2011 |
| Researcher | Steve Reece | | | 01/01/2011 | 31/12/2014 |
| Researcher | Mark Ebden | | | 01/01/2011 | 31/12/2013 |
| Researcher | Mike Osborne | | | 01/10/2011 | 30/09/2014 |
| Researcher | | Joel Fischer | | 01/04/2011 | 31/03/2014 |
| Researcher | | Nadia Pantidi | | 01/08/2011 | 31/07/2014 |
| PhD Student | | | Sasan Maleki | 01/10/2011 | 30/09/2014 |
| PhD Student | Jan Calliess | | | 01/10/2011 | 30/09/2013 |
| PhD Student | | Wenchao Jiang | | 26/09/2011 | 25/09/2014 |
| PhD Student | | Daniela Dybalova | | 01/10/2011 | 30/09/2014 |
| PhD Student | | Robert Spencer | | 26/09/2011 | 25/09/2014 |
| Associated Researchers*<br><br>Associated PhD Student* | <br><br>Ashley Wharton<br>Edwin Simpson<br>Rob McInerney | Derek McAuley<br>Brian Logan<br><br>James Colley | Maria Polukarov<br>Enrico Costanza<br>Siddhartha Ghosh<br>Francesco Delle Fave<br>Sam Miller<br>Oliver Parson<br>James McInerney<br>Amir Sezavar Keshavarz<br>Matteo Venanzi<br>Oleksandr Pryymak<br>Obaid Malik<br>Jacob Selmes | | |

*Associated researchers and PhD students are those who have provided support to the project but are not directly funded by ORCHID.

HUMAN-AGENT COLLECTIVES

DISASTER RESPONSE

SMART GRID

CITIZEN SCIENCE


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