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The ALADDIN Project: Agent Technology to the Rescue

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ALADDIN

autonomous learning agents for decentralised data and information networks

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Autonomous Learning Agents for Decentralised Data and Information Networks

- Received £5.5M funding (plus £1M in kind)
  - Started 1st October 2005
  - Duration 5 years (3 + 2)
- Funded manpower:
  - Research Fellows: 600 person months
  - Programmers: 100 person months
  - 1 lecturer
  - 13 PhD students (10 allocated, 3 unallocated)

The Team

University Team

- Professor Nick Jennings (Director)
  - School of Electronics and Computer Science, University of Southampton
- Professor Erol Gelenbe
  - Department of Electrical and Electronic Engineering, Imperial College.
- Professor David Hand
  - Department of Mathematics, Imperial College.
- Dr David Leslie (Bristol)
  - Department of Mathematics, University of Bristol.
- Professor Steve Roberts (Oxford)
  - Department of Engineering Science, University of Oxford.

BAE Systems Team

- Deputy director (Andy Wright)
- Programme manager (Alan Gould)
- Technology transfer coordinator (TBC)
- Number of researchers (Dave Nicholson)

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Aims

- Develop techniques, methods and architectures for modelling, designing and building decentralised systems that can bring together information from variety of heterogeneous sources in order to take informed action
- Take total systems view on information and knowledge fusion and consider feedback between sensing, decision making and acting in such a system
- Achieve these objectives in environments in which:
  - Control is distributed.
  - Uncertainty, ambiguity, and bias are endemic.
  - Multiple (self-interested) stakeholders with different aims and objectives are present.
  - Resources are limited and continually vary during system's operation.
- Demonstrate applicability in domain of disaster management

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Conceptual Underpinning

- System composed of autonomous, reactive, and proactive components
  - Actors or agents
- Individual actors
  - Make best use of what information is available
  - Flexible and agile in their decision making
  - Cognizant of fact they are operating in a multiple actor environment
  - Adaptive to their environment
- Multiple actor systems
  - Need to deal flexibly with interdependencies
  - Initiate and respond through interactions to achieve individual and collective aims

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Technical Approach

- Building Individual Actors
  - Information fusion
  - Inference
  - Decision making
  - Machine learning

Principled combination

Total systems view

Demonstrable applicability

- Building Multi-Actor Systems
  - Multi-agent systems
  - Game theory/Mechanism design
  - Mathematical modelling of collective behaviour

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Research Foci

- Fundamental
  - Basic research on how individual actors can act and interact to achieve goals in autonomous fashion by utilising feedback between sensing, decision making & acting.
    - Decentralised decision making
    - Decentralised (information) fusion methods
  - Flexible and agile social interactions in highly dynamic and open systems
- Systems Research
  - How to develop DDIS architectures that are robust, flexible & scaleable
  - Focus on information architectures.
- Demonstrators
  - Build software demonstrators to illustrate potential, cohesiveness and effectiveness of the developed techniques and architectures

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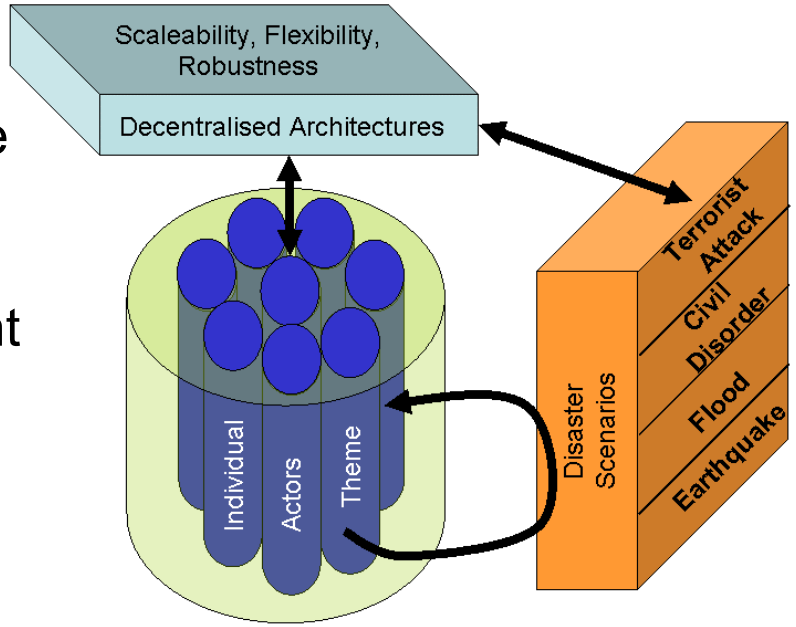
Research Objectives

- Techniques to balance acting and information gathering in
  - dynamic, uncertain, multi-actor environments.
- Techniques for decentralised fusion of inter-related information
  - that is uncertain, incomplete, imprecise and ambiguous.
- Machine learning algorithms relevant to
  - dynamic, multi-actor environments that are uncertain and incomplete.
- Coordination mechanisms that
  - enable collectives to plan and act collaboratively to achieve common goals.
- Methods for modelling and predicting global behaviour
  - given local behaviour of individual actors.
- Agent mechanisms that
  - ensure desirable global properties emerge given local actions and views
- Decentralised information architectures that are
  - robust, scaleable, and flexible in their operation.

Research Themes

- Individual Actors (Lead: Hand; Deputy Roberts)
  - Design of actors that can perform effectively in dynamic uncertain and multi-actor environments
- Multiple Actors (Lead: Gelenbe; Deputy: Leslie)
  - Way in which individual actors can interact in flexible ways to achieve individual and collective goals
- DDIS Architectures (Lead: Nicholson)
  - Development of efficient and effective system architectures
- Applications (Lead: Jennings)
  - Development of disaster management demonstrators



Multiple Actor Theme

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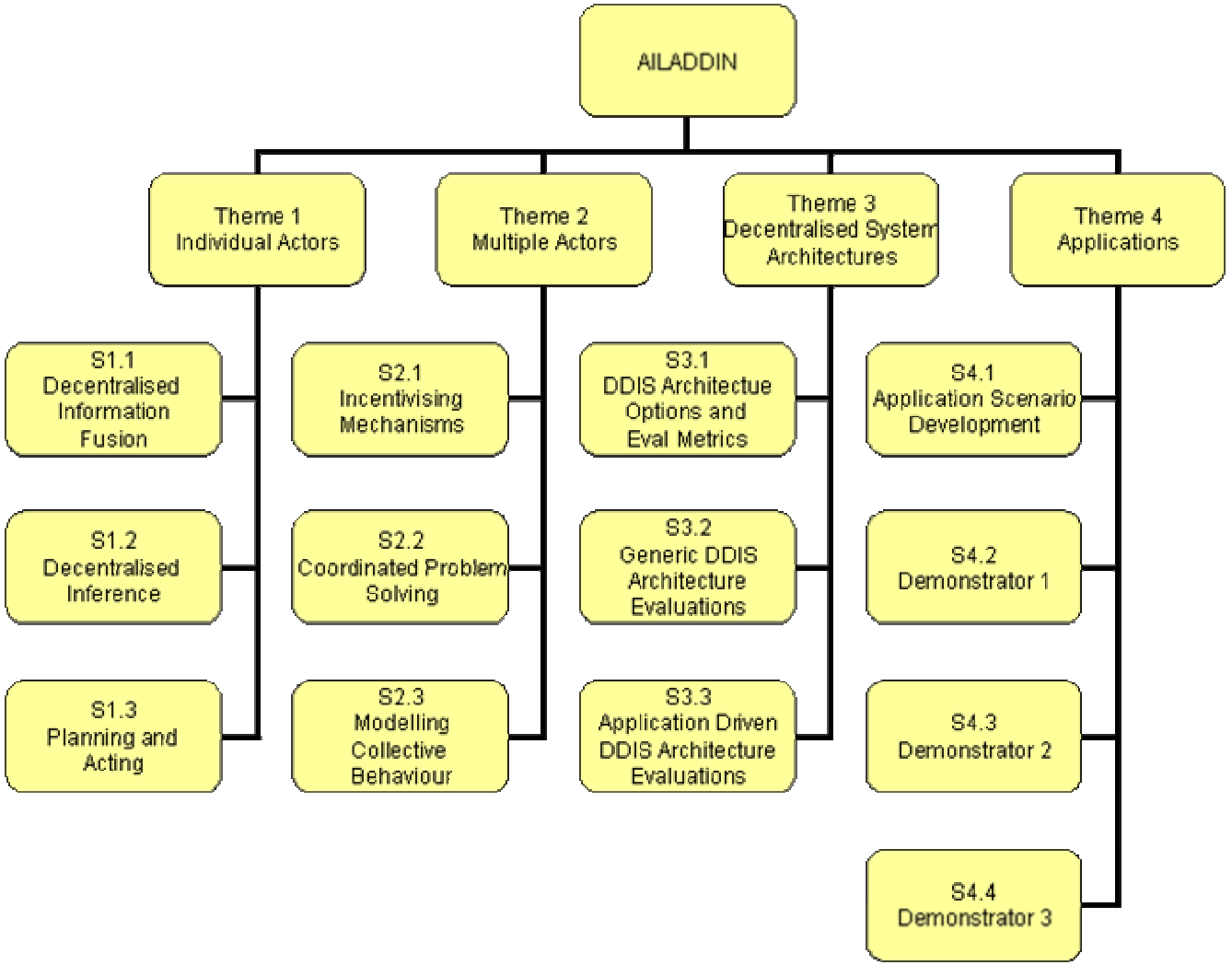
Theme Structure



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Individual Actors Theme

- Decentralised Information Fusion
  - Techniques to combine temporal information for multiple highly heterogeneous sources in presence of significant degrees of uncertainty
  - Utilise Bayesian perspective for information fusion at multiple levels
- Decentralised Inference
  - Construct decentralised inference techniques that take into account both external information sources and information from multiple actors in uncertain & dynamic environments
  - Use Bayesian approach
- Planning & Acting
  - Achieve objectives in challenging environments
  - Use reinforcement learning and stochastic dynamic programming to balance information seeking with acting

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Requirements

- Fuse information obtained from its environment in order to form a coherent view of its world that is consistent with other actors
  - Derive techniques for the decentralised fusion of inter-related information that is uncertain, incomplete, imprecise and ambiguous.
  - Techniques to combine temporal information for multiple highly heterogeneous sources in presence of significant degrees of uncertainty.
- Make inferences over this world view to predict future events
  - Derive inference techniques for the prediction of events based on inter-related information that is uncertain, incomplete, imprecise and ambiguous.
  - Derive techniques that combine temporal information in the presence of significant degrees of uncertainty to provide probabilities of potential future outcomes.
- Plan and act on its conclusions in order to achieve its objectives given these predictions.
  - Derive methods capable of achieving objectives in environments that are dynamic uncertain and incomplete
  - Understand how individual actors can act and interact to achieve goals in autonomous fashion by utilising feedback between sensing, decision making & acting.

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Multiple Actors Theme

- Incentivising Mechanisms
  - How to structure interactions so individuals are incentivised to behave in way that leads to desirable system properties
  - Use game theory and mechanism design
- Coordinated Problem Solving
  - How to form agile teams to tackle particular niches as and when they are needed
  - Use markets and auction theory to cope with unexpected resource allocation situations
- Modelling Collective Behaviour
  - Mathematical models of agent behaviours and emergent system properties resulting from the above technology
  - Use multi-dimensional Markov processes

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Requirements

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- Structure the interactions of the autonomous actors such that overall system exhibits certain sorts of desirable properties
  - Derive techniques to balance acting and information gathering in dynamic, uncertain, multi-actor environments.
  - Develop machine learning algorithms relevant to dynamic, multi-actor environments that are uncertain and incomplete.
- Coordinate the problem solving of multiple actors when the system is operational
  - Develop methods for modelling and predicting the global behaviour given local behaviour of the individual actors.
  - Develop agent mechanisms that ensure desirable global properties emerge given local actions and views
  - Develop coordination mechanisms that enable collectives to plan and act collaboratively to achieve common goals.
  - How to form agile teams to tackle particular niches as and when they are needed.
- Model and simulate interactions of multiple actors in order to determine macroscopic behaviour of overall system based on microscopic behaviour of the participants.
  - Mathematical models of agent behaviours and emergent system properties resulting from the above technology

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Decentralised System Architectures Theme

- Architecture Options and Evaluation Metrics
  - Examine potential options for information architectures and how we can evaluate the options
- Generic Architecture Evaluations
  - Evaluate architecture options in terms of:
    - physical architecture,
    - architecture topology, and
    - dynamic operational characteristics
  - Use Monte Carlo studies
- Application-Driven Architecture Evaluations
  - Evaluate in the context of specific applications

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Requirements

- Determine range of issues and variables that govern possible architectures and determine how these options can be compared and contrasted
  - Construct decentralised inference techniques that take into account both external information sources and information from multiple actors in uncertain & dynamic environments
  - Derive decentralised information architectures that are robust, scaleable, and flexible in their operation.
- Evaluate options to determine relative merits in varying circumstances
  - Examine potential options for information architectures and evaluate in a quantitative manner
  - Evaluate architecture options in terms of:
    - physical architecture,
    - architecture topology, and
    - dynamic operational characteristics
- Derive measures and, where possible, representative baselines against which the performance of new methods can be determined in an objective manor from both a local and systems perspective.

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Applications Theme

- Develop abstract model of disaster scenarios & assess existing mechanisms for disaster management
- Apply DDIS techniques, models, and architectures in software simulators
  - Algorithm for Robocup Rescue Simulation
  - Develop software demonstrators to integrate and evaluate DDIS technologies

Requirements

- Picture Compilation
  - Provide common operational picture in short space of time to allow resources to be distributed quickly and effectively.
  - Maintain consistent picture from disparate, confused overlapping, and partial info sources
  - Compile a common picture to help with the prioritisation and the communication.
- Coherent Decision Making
  - Allow independent units to make good decisions despite the lack of central guidance, and lack of information about access routes.
  - Allow independent units to coordinate on a local level, and authorities to coordinate on a global level.
- Resource Management
  - Manage resources over a large geographical distribution when communication between them will be minimal and erratic.
  - Allow independent units to communicate effectively to provide the correct resources where they are needed most given the damaged infrastructure like roads
- Resource Prioritisation
  - Prioritise resources where they are needed most.
  - Use limited resources effectively globally and locally.
- Understanding System Behaviour
  - Simulate interactions of multiple actors in order to understand macroscopic behaviour of system.
  - Ensure objectives of system as a whole are satisfied using suitable architectures, and techniques for information sharing and resource management.

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Robocup Rescue

- Provides a framework to capture disaster scenarios
  - mainly for earthquake but applicable to:
    - Terrorist attack
    - Civil disorder
    - Can be extended for floods
- Realistic simulation of events (fire, traffic, collapsed buildings, blockades on roads)
- Allows the creation of custom-made maps
- Extensible JAVA API allowing the implementation of various communication, coordination, and information fusion mechanisms.
- Allows tuning of uncertainty on various parameters
- Real-time analysis

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Robocup Rescue Demo 3D
Robocup Rescue Demo 2D

Application Requirements

- Picture Compilation
  - Provide a common operational picture in a short [illegible] of time to allow resources to be distributed quickly and effectively.
  - Maintain a consistent picture from disparate, [illegible] overlapping, and partial sources of information.
  - Compile a common picture to help with prioritisation and the communication.
- Coherent Decision Making
  - Allow independent units to make good decisions despite lack of central guidance, and lack of information [illegible] access routes.
  - Allow independent units to coordinate on a local level, and allow authorities to coordinate on a global level.

Application Requirements

- Resource Management
  - Manage resources over a large geographical distribution [illegible] communication between them will be minimal and erratic.
  - Allow independent units to communicate effectively to provide the correct resources where they are needed most given the [illegible] infrastructure like roads
- Resource Prioritisation
  - Prioritise resources where they are needed mo[illegible]
  - Use limited resources effectively globally and l[illegible]
- Understanding System Behaviour
  - Simulate interactions of multiple actors in order to understand the macroscopic behaviour of the system.
  - Ensure the objectives of the system as a whole are satisfied using suitable architectures, and techniques for information sharing and resource management.

The Promotional Video

Aladdin video

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Conclusions

- Exciting & challenging research agenda
  - Bringing together number of disciplines to produce end-to-end solutions to complex problems
- Fundamental research in basic techniques for individual and multiple actor systems
- Systems research on how to combine distinct components
- Demonstrations of technologies in disaster management scenarios