UNIVERSITY OF LIVERPOOL

Department of Computer Science

OUR RESEARCH

2018

Contents

Introduction

Welcome to the Department of Computer Science at the University of Liverpool.

Since it was established in 1983, our department has grown into a vibrant environment, investigating key topics for developments in computer science and building a strong international reputation for research in Artificial Intelligence (AI) and Algorithms.

In 2014 we became one of the top 10 computer science departments in the UK after 97% of our research was rated as world leading and internationally excellent in the Research Excellence Framework.

We produce high quality publications, all of which stem from the research of our dedicated staff who continually publish their results in top-rated journals and present their work at national and international conferences.

Over the years, we have built strong working relationships with a number of local, national and international partners and have established inter-disciplinary collaborations with departments across the University's three faculties.

We enjoy close collaboration with the Department of Electrical Engineering and Electronics, together with whom we form a school. The school plays a key role in the University's Digital research theme that aims to transform society and industry through the generation, communication and application of data across science, health and humanities subjects.

Our outstanding reputation has enabled us to build a strong community of PhD students, who work on a wide range of topics aligned with specialised research groups within our two core areas of research, Algorithms and AI.

We hope that this overview will provide you with an insight into the important research we have been working on, as well as the applications of our research and inter-disciplinary collaborations we are involved in and look to build on within our future plans.

Professor Katie Atkinson -
Head of Department of Computer Science.

ONE. Artificial Intelligence

Our Artificial Intelligence researchers focus on the theory and practice of building intelligent systems within four core areas of artificial intelligence.

Data Mining and Machine Learning

centres on the fundamental problem of extracting algorithms, decision supporting information, and knowledge from data, natural language text, images, or videos.

It employs a broad range of techniques, and focuses on three core areas:

Natural Language Processing: aims to provide principled solutions and is applied across a wide range of areas including automated sentiment classification and social media analysis.

Sequential Decision Making: studies methods that allow an agent (an intelligent system) to make decisions over time, particularly focusing on systems with many agents. We apply our research to complex application settings such as large scale urban traffic control and multi-robot coordination in autonomous warehouses, building on techniques from reinforcement learning, decision-theoretic planning, and deep learning.

Data Mining and Analysis: includes time series analysis such as keyboard typing pattern authentication and mechanisms for achieving secure data mining over encrypted data. One of our main focuses is to develop semantic representations of raw data (images, videos and natural language text), which can be used for further applications such as visualisation and natural language processing.

Knowledge Representation and Argumentation

Knowledge Representation and Argumentation is dedicated to representing information about the world in a form that a computer system can utilise to solve complex tasks, such as driving a car or diagnosing a medical condition. This group has three main areas of focus.

Intelligent Information Systems: investigates how information can be retrieved from structured but incomplete or heterogeneous data sets, which are growing at an enormous rate.

The techniques we use come from computational logic, artificial intelligence, and databases to develop appropriate query languages and algorithms for processing queries. Ontologies are one of the main tools for providing access to such data. We design ontology languages and algorithms for developing, maintaining, and deploying ontologies.

Foundations of Multi-Agent Systems: uses methods from computational and philosophical logic to explore multi-agent systems and develop logics in which their behaviour can be specified. We also develop algorithms which check whether a given system meets its specification.

Argumentation: develops formal models and languages, and explores the complexity of argument-based decision making in a broad range of models. A major application of our argumentation research is in law.

Robotics and Autonomous Systems

focuses on the ability of machines to act intelligently within society. Autonomous systems can perceive their environment, for example through sensors on a robot, situated in a building within an Internet of Things (IoT) scenario, or by monitoring electronic services and information sources. Based on this knowledge, agents make decisions to perform actions that are directed to achieving a specific aim such as autonomous vehicles and smart devices, as well as social and industrial robots.

Our research portfolio focuses on two main areas:

Verification of robot and autonomous systems: analyses the specification and behaviour of autonomous systems such as social robots and autonomous vehicles to understand and verify how they behave within real world scenarios.

Collaborative Knowledge Sharing: addresses the evolution of knowledge representations (ontologies) in individuals and populations, where no prior agreement exists over the underpinning language. This is necessary in diverse and evolving knowledge-rich environments such as disaster/relief scenarios, or the use of mobile devices. This research addresses questions such as how agents adapt their ontologies when interacting with their environment, and how this knowledge can evolve when the environment changes.

Many of our research activities in robotics are located in our smARTLab, a state-of-the-art robotics laboratory that includes two large experimentation facilities, one of which can be used for experimentation with UAVs and UGVs.

The robotics equipment in the lab includes: e-puck robots, Turtlebot II robots, an octocopter, nanocopters, a custom-built telepresence robot, KUKA youBots, an optitrack motion capturing system, and a fleet of small robots including Surveyor Blackfin, Scribbler, LEGO NXT and custom-built platforms based on Raspberry Pi and Arduino processors.

Verification has been applied in safety-critical applications, such as air traffic control systems, for many years, and is becoming increasingly important for the development of autonomous vehicles and robots.

We work on a wide spectrum of topics within this area, such as investigating the computational complexity of verification problems and developing verification algorithms using techniques from automata and game theory. Recently, we have used formal verification techniques to understand the behaviour of autonomous robotic systems for use in nuclear, offshore, and outer-space environments.

A Case Study: Autonomy and Verification Lab

In the near future we can expect to see fully autonomous vehicles, robots and software. Whilst these technological advances have the potential to benefit society, improve safety, efficiency, and even happiness, many people are concerned about their control, safety and reliability.

Our research has helped to develop new, world-leading techniques for not only designing these systems to be transparent in their decisions but also to be able to verify that they always make the `right' decisions. As such, the techniques we have developed can be used to address not just safety issues, but also ethical considerations.

Collaborations and funding

Our work has led to wide collaboration and impact with a number of local, national and international partners who offer expertise and facilities to assist us in producing leading research. Our research has also enabled us to secure valuable UK government funding of £2 million to develop robotics and Artificial Intelligence (AI) for use in extreme environments. Our collaborations include:

Centre for Autonomous Systems Technology is part of the University of Liverpool who provide us with expertise in Engineering, Psychology and Law. The Virtual Engineering Centre provide us with expertise and facilities to allow for modelling, analysis, simulation, and visualisation using high-performance computers.

RAIN (Robotics and Artificial Intelligence for Nuclear) is led by the University of Manchester, it includes experts in robotics and nuclear engineering from a number of UK Universities and the UKAEA's Remote Applications in Challenging Environments (RACE) centre. It also incorporates key partners from the nuclear industry, international partners and a range of SMEs across the UK. RAIN will develop innovative technologies that address the challenges posed by the entire nuclear industry from decommissioning and waste management to fusion, plant life extension and new build. It aims to become an international centre of excellence in Nuclear Robotics.

ORCA (Offshore Energy Asset Integrity Management) is led by Heriot-Watt University and aims to use autonomous robotics to revolutionise how the offshore energy sector assesses, repairs, and improves assets such as wind turbines, oil rigs and pipelines. Using advanced robotics and AI techniques can significantly improve both safety and efficiency in this sector.

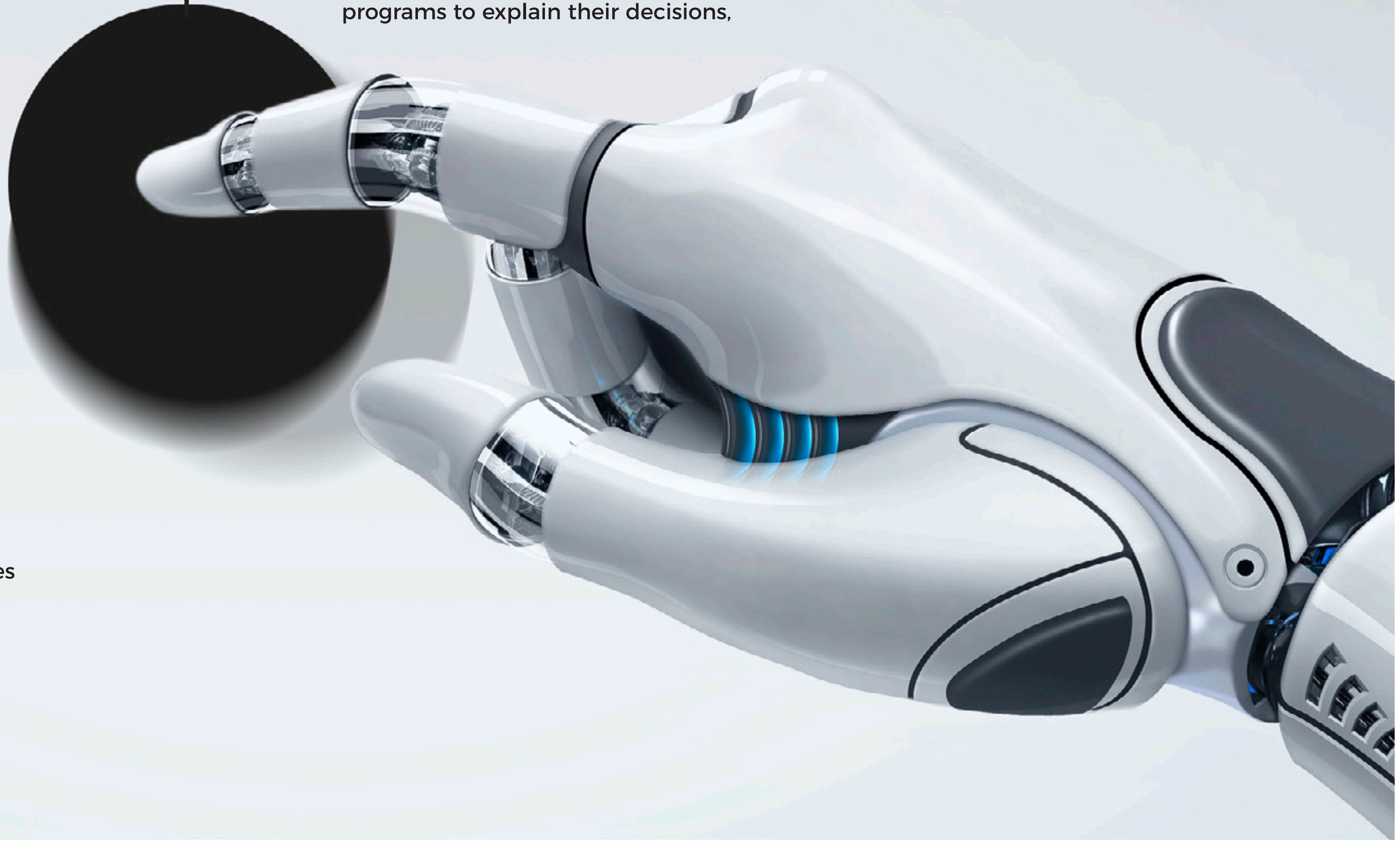
FAIR-SPACE (Future AI and Robotics Hub for Space) is led by the University of Surrey and involves experts from a number of UK universities and the space sector.

B Case Study: Artificial Intelligence and Law

We have developed a knowledge engineering methodology which can represent legal cases as a formal model and can be turned into an executable program that uses automated reasoning to decide the outcome of legal cases.

The methodology is based on techniques from the field of computational models of argument. This aims to capture argument-based reasoning as a formal model and enable arguments to be automatically generated and evaluated by algorithms to determine which are justified and why. A key feature of this approach is the ability of the automated argumentation programs to explain their decisions, which is a key concern for developing trust in the technologies by the end users.

The methodology developed has been applied to three key legal domains well known in AI and Law and has yielded a 96% success rate in replicating the human judges' decisions and reasoning. A collaborative project with Weightmans LLP is now underway to investigate how the methodology can be applied to cases in current domains that the company conducts its work in and further produce a useable tool for decision support in future cases. We have a number of other industrial collaborations funded by Innovate UK in which we are applying AI in legal work.



TWO. Algorithms

Understanding algorithms and their efficiency significantly affects our lives today due to automatic methods applied in many on-line systems for decision making such as banking, stocks, prices in markets, weapons applications and security. Our Algorithms researchers are organised into three groups that focus on designing and analysing algorithms for many applications of Computer Science.

Algorithms, Complexity Theory and Optimisation (ACTO) is focused on a key practical algorithmic question: "What can be efficiently computed?" In particular ACTO works on:

- Fundamental questions about what can be computed in principle (computability theory)
- What amount of computational resources such as time and space are required to perform those computations (computational complexity theory), and in the heart of those questions
- The broad area of algorithms, optimisation, data science and their various applications.

A core element of ACTO's research is the study of the notion of algorithms and abstract models, and a particular emphasis is placed on the development of optimisation models and theoretical techniques for analysing these models. We also work on the design of new algorithms for various mathematical abstractions, as well as applications of innovative algorithmic ideas.

We are involved in several interdisciplinary projects, such as the University's Leverhulme Centre for Functional Materials Design, and are open to new collaborations on algorithmic and complexity aspects for various computational problems that appear in other areas, including chemistry, physics, biology, economics and engineering.

Economics and Computation (ECCO) is focused on research in Algorithmic Game Theory, which is at the interface of economics and computation. It looks at situations with strategic users and aspires to explain and provide guarantees for their strategic outcomes (known as equilibria). We also have industrial collaborators, such as Stratagem Technologies, a UK-based company that predicts the outcomes of sporting events. Our core research topics are:

Auctions and Mechanism Design: looks to design mechanisms that achieve some desired outcome, such as designing an auction that maximises an auctioneer's profit. We also look at cost sharing mechanisms, to decide how the cost of some system outcomes should be shared among users, for example, Google's main source of revenue comes from sponsored search auctions that decide what sponsored adverts are shown next to the search results.

Evaluation and Computation of Equilibria: focuses on the strategic behaviour of users and their sub-optimal outcomes when exposed to different environments. We quantify the loss of system quality that the strategic behaviour causes and ways to mitigate those effects.

In order to predict the outcomes in strategic environments we need to be able to compute or approximate their equilibria. In particular, we develop efficient algorithms for computing equilibria, which are invaluable for automated decision making.

Social Choice: combines individual preference to reach a collective decision, for example a committee electing a leader using a voting system. We have proposed a new voting system called 'majority judgment' that brings many advantages over traditional voting systems.

Networks and Distributed Computing Group focuses on algorithms, combinatorial structures, natural processes and complexity analysis in networks and distributed systems. We use mathematical modelling, formal design and simulations within four main areas:

Central Network Protocols: covers basic network processes including data integrity, connectivity and communication, network testing and coding methods. We are interested in wired infrastructure, optical networks, wireless and mobile networks, and more recently in sensor networks, IoT and large-scale distributed systems, including cloud systems.

Network Discovery, Dynamic Topology, and Fault Tolerance: encompasses communication and computation in networks with unknown, partially known or unstable topology of connections. The main emphasis is on ad-hoc and temporal networks as well as networks populated by mobile agents (robots).

Natural Processes, Stabilisation, and Simulations: covers complex natural processes that require accurate mathematical modelling, elements of formal analysis and simulations, for example abstract models of population protocols, chemical networks, and crystal formation, as well as more specialised models of spiral and scroll waves as non-linear dissipative patterns. Some key application areas are in medicine and technology.

Our research on algorithms also spans other interests covering High Performance Computing which includes GPU computing, programmable matter, efficient scheduling methods, complex network analysis and visualisation.

C

Case Study: Leverhulme Research Centre for Functional Materials Design

In 2017 the University launched the new Research Centre for Functional Materials Design following a £10 million award from the Leverhulme Trust. The aim of the centre is to drive the design revolution for functional materials by fusing chemical knowledge with state-of the-art computer science to develop a new approach to the design of functional materials at the atomic scale. The Centre is housed in the University's Materials Innovation Factory (MIF), which is a facility and a concept of operation designed to catalyse and fuel innovation, by maximising the effective use of shared scientific infrastructure. The MIF is a newly purpose-built facility with one of the highest concentrations of automated equipment in the world for materials chemistry.

The University has an internationally leading position in chemistry, computer science and modular, functional materials design. Together these groups create an excellent interdisciplinary working environment for tackling complex problems in computational chemistry and designing functionally interesting systems through close collaboration with a team of leading computer scientists, including experts in algorithms, network communication, game theory, complexity theory, artificial intelligence, machine learning and robotics.

Our vision is to create a radical new design capability through four interacting themes in computational and experimental design, intelligent automation, and in knowledge exploitation. In its early years, the Centre will build dialogue and understanding between the disciplines, for example to develop state-of-the-art computer science algorithms for chemical structure prediction problems. As the Centre evolves, we will exemplify this capability through discovery of exciting new functional materials, such as synthetic enzymes, but these will exit the core Centre for further application-specific development, to retain our capability focus. The core output of the Centre will be a Materials Design Engine – that is, an integrated set of hard and soft tools to transform how we design materials in the future, rather than the development of specific materials for applications.

This Centre will develop an entirely new approach for materials design that will empower leading researchers to address the global challenge of discovering transformative functional materials. Within this research project we will train a cohort of more than 80 leaders to propagate this vision in the future, and into new research areas. In this context our major goal is to make sure that the Centre will be internationally recognised as a beacon of research leadership that has produced the people, the thinking, and the tools to transform our ability to position atoms and molecules for function. Moreover we expect that this Centre will be recognised as a key enabler for a sustainable future, driven by fundamental scientific research.

D

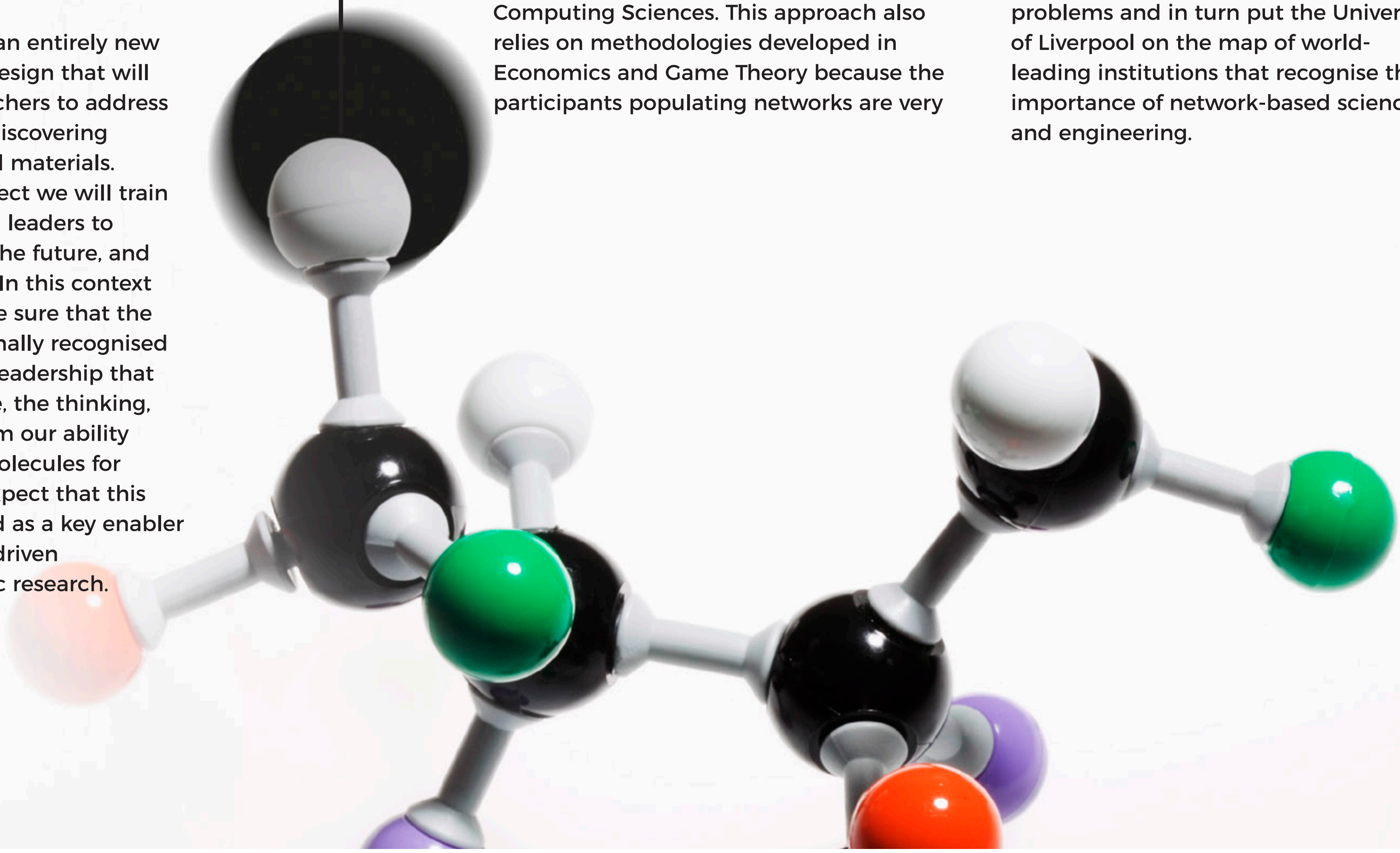
Case Study: Networks Sciences and Technologies (NeST) Initiative

The main purpose of this initiative is to establish a well-founded and vibrant environment that will provide a vehicle for stimulating inter-disciplinary applications of foundational research in network sciences and technologies.

Networks are naturally embedded in biological, chemical, physical and digital systems, economy, social relationships and many human made complex structures such as the Internet. A network-based approach to modelling, understanding and processing of surrounding environments has a strong foundation in Mathematical and Computing Sciences. This approach also relies on methodologies developed in Economics and Game Theory because the participants populating networks are very often autonomous and interested in achieving their own particular goals.

As a result of this, apart from high quality foundational research explorations, the NeST initiative targets knowledge exchange, including interdisciplinary research activities that will involve academics from our University, national and international University partners, industry partners and members of the public.

NeST aims to stimulate interdisciplinary projects based on network research and engineering, to create a critical mass for large projects targeting challenging problems and in turn put the University of Liverpool on the map of world-leading institutions that recognise the importance of network-based sciences and engineering.



For more information about our research and collaborations, please visit:

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