Institution: University of Hull

Unit of Assessment: 11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

The Department of Computer Science and Technology is part of the Faculty of Science and Engineering. The Department's research is organised within three Research Groups (RGs):

Dependable Intelligent Systems (DEIS)

Healthcare Informatics and Robotics (HIR)

Virtual Augmented Reality and Simulation (VARS)

Each RG has dedicated laboratory space with facilities to support research by academic members of staff, research associates, postgraduate research students, and visiting researchers. A Research Committee involving the Head of Department, Director of Research and RG Leaders and Postgraduate representatives develops and coordinates the research strategy in consultation with staff, and approves individual and group research plans. An annual review of research activities allows monitoring of progress, and informs supportive actions.

Under this simple and robust administrative structure we have established an inclusive, collaborative, and mostly heterarchical research environment where the **intellectual pursuit of knowledge** (the Academy) generates the **fruits of impactful research** for society: a model that stretches back to the ancient Academy of Plato and the Garden of Epicurus. We, informally, refer to this research environment as our academic garden, a place where impactful research ideas are nurtured. In the 2014-21 REF period we have produced innovative techniques that can improve the dependability of complex systems, including the intelligent, autonomous, connected and open cyber-physical systems of systems emerging in many areas of life. The results of this work are presented in the **BIOLOGIC impact case study** (**ICS**) authored by the DEIS RG. We have also produced novel virtual environments for training professionals that improve public health and emergency services. The results of this work form the **VETA ICS** co-authored by the VARS and DEIS RG. Our **impact** is **local** and **global** and includes transfer of research globally to the **automotive**, **aerospace** and **other safety critical industries**, the **green energy sector,** UK wind energy in particular, **over 150 hospitals worldwide,** and **a third of the UK's fire services**.

The transformation of the research produced by our research environment into enterprise is facilitated through the **Innovation Centres of the University.** They include **Knowledge Exchange**, through which two spinouts have been created to commercialise our research (Vertual and Lampada), and the AURA Innovation Centre (see later). Through AURA, we have the potential to orientate elements of our research toward the offshore wind energy industry (which is a crucial, fast-emerging element of our regional economy and wider international economies). The commercialisation of our research is also facilitated through links to C4DI, **a Hull-based technology incubator** creating much needed high-tech, high-value employment and business in the region. We have nurtured this kind of innovation so that we are embedded in an **international network** of universities, hospitals, fire services, software houses, SMEs and large engineering companies through which we transfer our research globally. The mechanics of our impact strategy and contributions to society and economy are explained in the two ICS and in 4.2.

1.2 Research and Impact strategy

The three departmental RGs have evolved from those submitted in REF2014:

- **Dependable Intelligent Systems (DEIS)** evolved from Dependable Systems (DS) to address the new challenges in the field of intelligent systems. It is led by Prof. Papadopoulos.
- **Healthcare Informatics and Robotics (HIR)** evolved from Intelligent Systems (IS) to provide a more specific application and technology focus to this group. It is led by Prof. Murray.
- **Virtual Augmented Reality and Simulation** (VARS) evolved from The Simulation and Visualization RG (SimVis) and is led by Warren Viant.

This evolution and partial changes in direction was partly caused by the unfortunate deaths of professors Jiang and Phillips, and the arrival of new leadership: Prof. Murray – currently HoD with interests in Robotics. Change was managed effectively and the groups built on their extant strengths and developed new research challenges. They also aligned further with the research priorities of the University and regional agendas.

The research and impact strategies of the department are knitted together within our **integrated research and impact strategy.** This has four interconnected layers as shown in Figure 1.

Fundamental Technologies Researched [L1]		Research Groups [L2]		Application Areas Targeted [L3]		Impact Cases [L4]
Model-Based Systems Engineering	(D)					
Probabilistic techniques	(D)					
Model Checking	(D)	DEIS (D)				
Software Testing	(D)		(D)	Automotive	[B]	
Metaheuristics for optimization	(D,H,V)		(D)	Aerospace	[B]	
Machine Learning	(D,H,V)		(D,H)	Manufacturing	[B]	BIOLOGIC (B)
Big data analytics	(D,H,V)		(D,H,V)	Offshore wind	[B]	
AI planning	(D,H)		(D,H)	Internet of Things	[B]	
Autonomy	(D,H)	HIR (H)	(D,H,V)	Health Services	[B,T]	VETA (T)
Sensor fusion	(D,H)		(D,V)	Fire & Emergency services	[B,T]	
Ambient Intelligence	(D,H)		(D,H)	Smart Agriculture	[O]	
Assisted Living Technologies	(D,H)		(H)	Inland security	[O]	Other Smaller Impacts (O)
Graphics	(V)		(V)	Education	[T,O]	
Image processing	(V)					
Simulation	(V)	VARS (V)				
Virtual Reality	(V)					
Augmented reality	(V)					

Figure 1: Integrated Departmental Research and Impact Strategy

Reading left to right, column **L1** shows the **fundamental technologies** that we research. Column **L2** shows the three **RGs** and, in between the two columns, how these RGs engage with fundamental technologies. Column **L3** shows the **application areas targeted** and, in between columns L2 and L3, how RGs relate to these areas. Finally, column **L4** shows the two **ICS** and, in between columns L3 and L4, the impact in each of the application areas. The **BIOLOGIC ICS** impacts on technologies that improve the dependability of systems, and the **VETA ICS** impacts on virtual environments for training professionals in the health and emergency services. The three

RGs have significant '**Other Smaller Impacts'** in areas including **inland security** and **education**, as our **research strategy** also supports effective collaboration beyond our department.

At the **individual scale** we develop our staff with responsibility for research. These are talented, focussed and productive academics who have earned highly competitive posts, and we therefore enhance their potential. We ask them to be research *effective* rather than simply research active. This means 1) producing excellent research in appropriately high-profile and visible publications (with at least **one high quality publication per annum as lead or corresponding author** (with Open Access)); 2) producing **at least one high-quality grant application** at sector average or above to enable this research per annum, and 3) **earning funding for high quality postgraduate researchers** (at least one as lead supervisor every third year), and supervising them effectively to timely completion with high-quality publications to follow.

Our **impact strategy** builds on the effective partnerships we develop with research-users. We build their requirements into the design of research programmes to ensure delivery of their needs and robust impact. Our impact agenda has progressed considerably from REF2014 due to a clearer University-wider focus on impact and engagement.

The **Aura Innovation Centre** (AIC) recently opened at the Bridgehead Business Park on the outskirts of Hull. It is a £12M investment of University and European Regional Development Funding and provides space for large businesses and SMEs to access University research for collaboration and innovation, and in the offshore wind sector especially. It also houses dedicated Aura Innovation Managers, research labs and equipment that connect commercial users with university expertise to support shared activities, development and commercialisation (including projects supported by an £8M ERDF-fund of University-administered Sparkfund Innovation Vouchers and Research and Development grants).

The University Directors of Business Engagement and Enterprise support this infrastructure, as does a Knowledge Transfer Partnership (KTP) Champion and dedicated KTP support (that have supported Dethlef's successful KTP-application for data analytics, natural language processing and AI to aid management in Spencer's Engineering). Transparent university support also includes HEIF funding (through application with an external user), dedicated Impact Officers and Impact Accelerator Awards also support this agenda.

1.2.1 Dependable Intelligent Systems Research Group - Research and Impact Strategy

Since the 1990s the DEIS RG, led by Prof. Yiannis Papadopoulos, has been recognised internationally for innovative research on the engineering of dependable systems. The group is pioneering a novel syntheses of software engineering and bio-inspired technologies for the design, analysis, and operation of dependable intelligent systems. Model-based and AI techniques are exploited to assess and guarantee dependability properties, including safety and security of systems, communication, and data. Applications span from the engineering of safety critical transport systems, through geospatial simulation, and from the analysis of documents and social media to the synthesis of generative art.

A central vehicle and outcome of our work is the HiP-HOPS method and tools for design and analysis of dependable systems. The method offers a significant innovation covering the system engineering lifecycle, from intelligent allocation of safety requirements through automated dependability analysis to evolutionary optimisation of system architectures, the automated production of certification artefacts, and intelligent safety monitoring using agents. Over 200 papers on the theory and industrial application of this method have been published. HiP-HOPS is

widely recognized as contributing to the international state-of-the-art in the area of dependability. It is one of the first methods to have **automated** the production of safety analysis models such as **fault trees** and **FMEAs** in the 1990s, and to have **used AI metaheuristics** in model-based engineering in order to auto-explore trade-offs among dependability, performance and cost in the **design of dependable systems** in the 2000s. Within the period, HiP-HOPS made a significant turn towards AI, and advanced significant innovations - several of which are described in our REF outputs and cited in the BIOLOGIC ICS. They include:

- Pandora, an **algebraic framework** for the analysis of **temporal fault trees** and the prediction of dependability in dynamic systems. Pandora can analyse state-sensitive fault trees describing sequencing of faults and created from architectural models and state machines.
- Algorithms for **multi-objective optimization of the architecture and maintenance** of systems; the latter include optimization that exploits **condition monitoring data through analytics** to continually predict the **remaining useful life** of components (DREAM project, funded by EDF) .
- Evolutionary algorithms for automatic allocation of safety requirements as Safety Integrity Levels or Development Assurance Levels; these **automate** the implementation of modern automotive **safety standards** such as ISO 26262 and the ARP aerospace safety standards.
- Contributions to EAST-ADL (MAENAD EU project), and AADL - two **emerging languages** with dependability analysis and optimization capabilities for the design of automotive and avionics systems respectively.
- New Fuzzy **and** Bayesian concepts for **safety analysis under uncertainty** that are integrated into the HiP-HOPS method.
- Novel work that addresses emerging challenges in open, cooperative, autonomous cyber-physical systems. In the DEIS H2020 project, we pioneered the development of the **Digital Dependability Identities** (DDI) concept, a novel technology for run-time certification of cyber-physical systems, autonomous systems and open systems-of-systems, and we have created digital metamodels and tools which are available in the public domain. DDIs are executable specifications that can be used in **multi-agent systems for** safety monitoring and dynamic certification open system of systems at runtime.
- Development of SafeML – a method for predicting the accuracy of machine learning by using empirical statistical distance measures to measure distributional shifts between training datasets and real-time input data.
- Nature-inspired **algorithms capturing the social intelligence of Penguins**. This work has been applied in automotive design and received attention from the BBC and global media (see section 4.2)

The group has a long history of taking research solutions to European and global industry. In the period, our **impact strategy** focused on developing a **network of national innovation ecosystems** in Europe and Brazil though which significant global impact was achieved: novel commercial tools for system design and analysis, new spinouts, applications to several industries, wealth generation and the improvement of the dependability of technological systems. Further details on strategy and impact are given in the two ICS and section 4.2.

1.2.2 Healthcare Informatics and Robotics Research Group - Research and Impact Strategy

The HIR RG, led by Prof. John Murray, develops research into **cognitive** and **control systems** including robotics, machine learning and system security applications, plus decision support and

data mining in **telehealth**. The latter includes research on decision making and data mining from clinical data, machine learning and pattern recognition, and the pervasive intelligence provided by wireless sensor networks for telecare and other applications. Robotics work is evolving to provide advanced research into robot assisted telecare. In addition to academic research, HIR has developed a strong capability for product design and development for local industry.

HIR has earned several research grants in the period. An Innovate UK project with **METIS Aerospace** and **Teledyne E2V** focused on the **detection** and **identification of drones** in restricted airspaces, and included the deployment of the technology at high profile sites such as Heathrow and Gatwick Airports. HIR have secured grants through Innovate UK- and SBRI-funded initiatives to work closely with the **UK Home Office and Border Force** on developing scanning technologies for the **detection of illicit firearms** and other illegal concealments (such as drugs and laundered money). This work led to three funded projects with the main Parcel Force and Border Force distributers, the **Centre for Applied Science and Technology** (CAST), and the UK Home Office. These projects developed machine learning algorithms for incorporation into X-Ray systems. As a direct consequence of this research we delivered a high-profile workshop at the British Machine Vision Conference in 2019.

HIR has a long running project collaboration with **QinetiQ** and the Ministry of Defence on logistical routing systems using graph databases for the supply of resources in “the last mile”. This project is also being developed commercially for sale to QinetiQ. In addition to “last mile”, there are wide ranging applications of this work in humanitarian aid and mainstream freight logistics.

HIR has collaborated with **iMonSys ltd** and **Network Communication Systems ltd** on developing a series of low-cost **wearable and portable digital devices,** and software, for healthcare monitoring. The devices can monitor Temperature, HR, ECG, PPG, SPO2, BP, respiration, and Heart Sound on demand and continuously. Benefits to society include enabling an aging population to live independently with confidence, promoting general public self-healthcare, and enhancing patient-doctor communication. Successful prototypes led to a KTP project to create an intelligent hand-held non-intrusive **vital-sign monitoring device** (NVSM) for use in many sectors of the care industry for the ageing population. This device will allow users to predict and prevent clinical incidents, or to limit their severity.

1.2.3 Virtual Augmented Reality and Simulation Research Group - Research and Impact Strategy

The VARS RG, led by Warren Viant, focuses on the application of **augmented** and **virtual reality**, **simulation** and **visualization** to genuine end-user problems, and on the creation of the new tools, techniques and theory needed for their construction. Its strengths in underpinning these technologies stem from work on algorithms for modelling, simulation and rendering, and from expertise in building, validating and using innovative display modalities. These strengths combine to offer discipline-leading applications in **radiotherapy, medical practice** and **emergency service training**. The strategy to underpin a sustainable future for this group involves delivering evidence-based, fundamental research that is grounded in the real world of users’ needs and aspirations.

An exemplar of this approach is the team’s theoretical framework on high-precision and efficient **geometric reconstruction of the human vascular system**, which has established a theoretical basis for a range of applications from vascular modelling to the 3D printing of human organs. An ellipsoid fitting algorithm, popularly referred to as Li’s algorithm (Li is member of VARS), has been used in a wide range of applications including MIPAV and a US Patent image segmentation (Ref.

US8275182B2). The research has generated several high-quality papers in prestigious graphics journals including ACM Trans., On Graphics, IEEE TVCG, and Graphics Forum.

Continuing the reconstruction theme, the team has a longstanding collaboration with Dundee Dental Hospital and Dundee University on a Wellcome Trust funded project **analysing maxillofacial growth using 3D medical image analysis**. Accurate and robust 3D volume and surface land-marking has been developed to measure the external changes in soft tissues using CT, MRI and photogrammetry imaging modalities.

Throughout the REF assessment period the team has collaborated extensively with **Vertual Ltd**, on the creation of the VERT product range for **radiotherapy training** (See VETA ICS). Technology transfer is not limited to VERT, but includes several other projects, including the i-BIT project, where virtual reality and video games combine to provide a potential **treatment for amblyopia** (lazy eye) in children. In collaboration with Nottingham University and NHS Trust, the team have secured both Wellcome Trust and Innovation UK support for Industrial funding, completing two successful sets of clinical trials. An NIHR commercialization grant has been submitted to productise the research.

Further medical applications have been developed. An **orthopaedic surgical training system**, to build key procedure-specific navigation skills, has been produced in collaboration with Northern Lincolnshire and Goole NHS Foundation Trust. The prototype aided the training of junior orthopaedic surgeons positively. An assessment tool to measure and analyse the driving habits and reaction times of older drivers with chronic heart failure, was developed in collaboration with Hull and East Yorkshire NHS Trust.

Finally, the team's extensive experience in VR and systems led to the development of VIC and LIMA software applications in conjunction with Humberside Fire and Rescue Service (HFR) and North Staffordshire Fire and Rescue Services (NSFRS). These applications are used to deliver advanced **training for multi-level emergency incidents** (See VETA impact case) in more time- and resource-efficient ways.

1.2.4 Future Research and Impact Strategies

We plan to expand the successful areas of our research further, and strengthen the academic, innovation and industrial networks that we cultivate internationally.

Fundamental research will be directed to solve problems in the **off-shore wind industry** which is of increasing importance to the Humber region and the UK. We will do this through the AURA innovation centre and our links to the ORE Catapult. Our focus will include the **intelligent planning** of offshore **operations and maintenance**, and the development of maintenance techniques using **drones** and **underwater robots**. We will expand our work on the DREAM project with EDF. We also work closely with the **£7M EPSRC Aura Centre for Doctoral Training in Offshore Wind Energy and the Environment** (with partner universities Sheffield, Durham and Newcastle). This DTC (2019-27) supports this fast-growing wind energy field and its associated technical and environmental challenges. Dethlefs is a Co-I for the DTC, and CST staff supervise two PhD projects. HIR's work on **healthcare informatics** is also growing and is expected to create significant impact through KTP projects and work with local companies on developing **digital health monitors**.

The collaboration between DEIS and VARS has yielded new promising results in the area of **virtual environments** with applications to **digital art**, **education** and **art therapy (see TIMAEUS project)** - which we plan to strengthen further.

A new area of expansion is **smart agriculture**. With Fraunhofer IESE we work on delivering technologies for safe collaborative deployment of autonomous vehicles and smart implements in smart agriculture. Fraunhofer has strong links with the advanced German industry in the area, so our aim is to become a link in a bilateral and mutually beneficial technology transfer from which the UK can prosper. This area of research will benefit from our work on robotics, dependability and other disciplines in the university.

Our long-term emphasis on research ethics is demonstrated by our approach to the increasingly important area of **Dependable AI**. Given the implications of the vulnerable world hypothesis that sees the history of scientific progress as also bearing the risk that one technology (such as nuclear weaponry) could devastate humanity, we apply a similar cautious approach to advances in AI, where investment and development accelerates. While dependability is paramount, the difficulties of safety assurance are significant and encompass system learning, autonomy, and high uncertainty in open systems. There is a grand technology challenge here, and the implications for industry and society are enormous. We will intensify our efforts towards Dependable AI and the safety of machine learning and deep learning, and undertake further research on the concept of executable DDIs that can address the safety and security of autonomous systems and open systems of systems.

1.2.5 Cooperation in our research environment

Our research environment allows and enables cooperation and the **cross-fertilization** between RGs. This is evident in the **VETA ICS** where VARS provided research and expertise on virtual environments while DEIS provided research and expertise on safety critical systems, communication protocols and digital learning (for details, please see the ICS).

Similarly, DEIS is collaborating with HIR on applications of machine learning and robotic applications, in particular on dependable **Multi-Robot Systems** (MRS), where a new large EU grant called SESAME (Safety and Security of MRS) was won in 2020. Neil Gordon, of DEIS, is also doing related work on digital learning and education that also informs virtual environments. His HEA report on Technology Enhanced Learning was used by institutions across the world that include the NHS and, more recently, it influenced the Chinese government response to COVID19 in education.

VARS and DEIS also collaborate on digital art and various aspects of philosophy and its intersections with science. Applications of this work are becoming increasingly impactful: TIMAEUS is **a digital art studio environment** that enables the creation of personalised, 3-dimensional virtual sculptures. TIMAEUS has been applied in fields ranging from **art therapy** to **education on literature and philosophy,** with examples given in by the Virtual Digital Stoa and the Alternative Virtual Odyssey projects.

1.3 REF2021 vis-à-vis REF2014 : quick comparison

REF2014 was the first time that Hull Computer Science was submitted to UoA11. We returned **14 staff** and **ranked 47th**. The panel ranked us **5th** nationally for the impact of our research.

Our REF strategy was to improve the quality of our outputs and to sustain our high-ranking Impact. In REF2021 we return a smaller number of **11 staff,** but this smaller submission is mostly due to changes in internal University processes. The 'Academic Careers Framework' allows staff to make their primary contribution in areas where their skills are most suited and beneficial. Staff submitted to this REF are located primarily in the 'Research Domain' (although all staff make teaching contributions).

Our total research income fell from **£2,105,015** (REF2014) to **£1,510,455** (REF2021) but therefore remains approximately the same per FTE submitted. This income was supplemented by PhD funding from Doctoral Training Centres based at the University (from where we have funded PhD students). Our commercialization and knowledge exchange activities add to the income figures above. Overall, there is evidence that we return **higher-quality outputs** and **sustained our impact** from 2014: In addition, the total number of **PhDs** awarded in the period increased from **24** (REF2014) to **28** (REF2021) with an increase per FTE submitted.

2. People

2.1 Staffing strategy and staff development

Since 2014 the Department has welcomed several early career lecturers and a new professor. It has also seen the promotion of existing staff, based on their research leadership. New staff are supported by University PhD scholarships where possible, with early career staff given additional weighting (and an established mentor for supervision) in the campus-wider studentships competition). Targeted PhD studentships, plus research funding are used to pump-prime collaborative research in strategic fields across the Department and University. To foster and develop the research culture, research and enterprise activities form part of the Department's workload model (typically 30-40% of time for 'Research Domain' academics). Research activities such as Research Postgraduate supervision, grant submission and management, and research output submissions are included in the calculation of workloads.

The University's **Staff Development Strategy**, in accordance with the **Concordat to Support the Career Development of Researchers**, recognises and promotes personal and career development at all stages to enhance the lifelong learning of staff. We encourage researchers to identify and attend events in the annual career development programme, and the University offers nationally-recognised courses for researchers that are run in-house. Research project supervisors are encouraged to use them, along with their associates and students. The **Researcher Development Framework** (RDF) is a detailed competency framework that maps out the skills required to be a successful researcher. Research staff use the RDF to plan their own development in conjunction with appraisal and review discussions. In addition, each research group provides development activities and peer reviews of research plans and project outlines.

The University of Hull is a member of VITAE (Careers Research and Advisory Centre (CRAC)), which supports researcher's professional development at all stages. Hull has held the HR Excellence in Research Award since 2012 and its practices align with the principles of the European Charter for Researchers and Code of Conduct for Recruitment. Our Staff Development Team provides opportunities for researchers to extend their skills with formal courses, self-guided online training, and informal mentoring and group activities.

The Faculty supports research leadership by providing **Advance HE Research leaders training** onsite to 10 colleagues in alternative years. Of the recent cohort, six have now taken on significant leadership roles. The Faculty also supports the participation of women colleagues in the Aurora leadership programme. To date 22 women have completed this programme, many of whom have gone on to undertake significant leadership roles.

Staff are encouraged to participate in the Faculty-run **Mentoring Schemes**. Twelve staff have completed Advance HE mentor training and can deliver specific, target-oriented mentoring (where mentees outline the support they want (e.g. promotion)). Less formal, more general supportive

mentoring relationships between colleagues are also encouraged and cover all aspects of academic careers.

Grant writing skills are developed through the Grant Writing Challenge, whereby university Research Development Managers and senior colleagues guide a cohort of early career academics through a structured, six-month series of sessions to produce a competitive grant application. ThinkWrite Grant- and article-writing workshops are also held annually.

Conference costs and academic visits are supported by a £250k Research Support Fund from the Faculty. This is temporarily suspended through the pandemic, but normally covers one conference per annum, with additional awards if an impressive case is made. Recipients must demonstrate appropriate results from previous awards for subsequent awards to be considered. The scheme especially encourages applications from early career academics, those retuning from parental or sickness leave, and others seeking a return to research. The scheme can make extra provision for parents with dependents if required. It also provides support specifically targeted at PDRAs for activities reaching beyond the funded grant that employs them – to allow them to further their personal research profiles from their PhD research, or a previous, or potential, Post-doctoral position. The university recognises the crucial importance of **celebrating contributions and success**. In 2017 the Faculty introduced **annual research awards** to recognise research and engagement activities. Seven categories stretched across all career stages, roles and collaborations, as well as leadership. These events are catered and build excellent research culture.

Facilitating **international collaboration** is another key element of our strategy for staff development. The Faculty support a Visiting Research Fellow Scheme to attract visiting researchers for a two or three day visit (at minimum), to include at least two engagement events for staff and early career academics/postgraduates. Visiting staff are also appointed using support from other funding sources. During the period, international visiting staff appointments included:

- **Ramin Tavakoli** (2019) Professor, Nuremberg University, on safety of machine learning.
- **Adnan Kiani** (2017) Associate Professor, Lahore University, on safety of AI and agents for runtime assurance of dependability.
- **Joxe Unanue Aizpurua** (2016), Lecturer at Mondragon University, Spain, on HiP-HOPS extensions for maintenance planning.
- **Youcef Gheraibia** (2015 and 2020), Researcher, University of Setif, Algeria, on Penguin-inspired metaheuristics for optimisation of autonomous cars.
- **Weixin Bian** (2018), Associate Professor, Anhui Normal University, China, on human-computer interaction, and fingerprints biometric based authentications.
- **Jin Zhu** (2017), Professor, Tongji University, China, on wearable sensors for healthcare.
- **Bing Zhang** (2017), Associate Professor, Yanshan University, China, on indirect blood pressure prediction model.
- **Jiadong Ren** (2017), Professor, Yanshan University, on healthcare data science.
- **Xintao Ding** (2017), Professor, Anhui Normal University, China, on deep learning for object recognition.
- **Qian Wang** (2016), Associate Professor, Yanshan University, on software security.
- **Jianwei Ma** (Feb 2016), Professor, Henan University of Science and Technology, China, on assistive living robots under ambient intelligence.

2.2 Research students

2.2.1 Support structure and training

The goal of our postgraduate research training is to nurture and develop PhD students into good scientists who have a good grasp of **epistemology:** the theory of the nature of knowledge and its justification. We argue that students who have thought about the fundamentals of science find it easier to complete a PhD and write a quality thesis. We therefore supplement our PhD programme with **epistemological seminars**.

In six tutorial-style seminars, we convey a **historical perspective** on scientific research starting from a Platonic definition of knowledge as justified true belief. We then cover topics on the **nature of knowledge and truth**, on **scepticism**, **logic** and **proof**, on **empiricism** and **induction,** as well as on **falsification** and the **hypothetico-deductive method**. To foster an appropriately-rounded scientific ethos, we also focus on the importance of research ethics and the centrality of **testing contrary to** predictions **of a hypothesis**. This training helps to form sceptical, independent researchers who challenge their own positionalities and develop clear understandings of what constitutes a rational basis for a scientific hypothesis. Students understand how to put forward **credible scientific hypotheses** and how to use the scientific method to either disprove them (**falsification**) or, through evidence, increase the **Bayesian belief** in their validity.

We are expanding our access to PhD programmes. An increasing number of postgraduates are funded through the China Scholarship Council and, as above, we also play a role in managing and supervising PhD students in the EPSRC AURA CDT. The University PhD scheme awards clusters of connected projects on strategic themes that face key challenges and research debates. Computer Science staff are involved with several clusters. For example, Dethlefs brings her skills to supervising PhDs on clusters addressing 'Offshore Wind', 'Living with Water' and 'Sensing the Water Environment'. All PhD students are funded at national UKRI rates.

Our research students are supported by a supervisory team of at least three academics including a primary supervisor. The supervisors offer advice and focus, monitor progress, and ensure that training requirements are met. PhD programs are structured with a clear set of goals and deliverables. These are formally reviewed in six PhD Panel meetings over the course of the programme; each with mandatory and discretionary deliverables. A University-level institute, the Doctoral College (DC), ensures that students and staff use best practice. The DC and library have on-campus, purpose-built facilities with 24-hour access for research students and their supervisors. All supervisors attend the relevant DC training courses and research students must complete the **Postgraduate Training Scheme (PGTS)** run by the DC, which enables students to graduate with certificated evidence of their research and transferable skills. Modules equip new researchers with a skills 'toolkit', including writing and specific research and employability skills, research ethics, and communication and networking skills.

An **annual 'PhD Experience' conference**, organised by students, is hosted by the DC. The University also offers regular **PGR Writing Retreats** to PGR students for more focused and productive writing experiences. Bi-weekly PGR seminars are delivered by PGR students supported by staff, allowing the PGR students to share their research and gain transferable skills. In addition, the students run their own Postgraduate Forum to foster social activities and networking. Participation in national meetings and international conferences is expected, supported by a Faculty Research Support Fund (RSF) (see above).

The research environment is enhanced by virtual social communities over **Discord**, **Teams**, and social media such as Facebook. These provisions have been enhanced in the context of the **COVID-19 pandemic,** as have all our online services. An innovative online Graduate Virtual Research Environment has assembled the collective stories of researchers and research students across the University, enabling students to access over 200 short videos illustrating individual research achievements and advice on all aspects of the journey.

To foster a dynamic international environment, we actively promote student exchange. We host **students from the University of Angers in France** annually, and send our students to France in reciprocal arrangement. In the period we have also hosted two PhD students from the University of Catania (**Federica Merlo** and **Cristina Romano**) and several MSc students from China: **Dong Yang** (2016) worked on the development of a wearable heart rate monitor; **Peng Zhu** (2015), developed a multi-functional vital sign monitor, which has received the IET Highly commended award. **Hangyang Ye** (2017) investigated respiration estimation for wearable devices. **Tianqi Fan** (2018) developed a prototype smart digital stethoscope which contributed to a KTP project.

A major challenge for doctoral students is maintaining consistently good **mental health** – something that our research environment takes very seriously. The university provides dedicated services and CST supervisors are encouraged to be extra vigilant and proactive. The PhD can be an isolating and difficult experience, and the pressures to perform, compete and excel can be high. To help students deal with these pressures, reflect on own expectations, anxiety and stress, and build resilience, we also introduce them, though seminars, to the timeless wisdom of ancient **Stoicism** and encourage them to study the writings of **Seneca** and **Epictetus** as well as modern stoics such as scientist-turned-philosopher Massimo Pigliucci. The informal feedback from students has been overwhelming positive; we are currently discussing ways of applying this approach more widely.

The University's response to the Covid-19 pandemic included funded extensions for PhD students (and PDRAs if needed), support with IT and workstation equipment for researchers working off-campus, and additional Research Culture and Community seminars to sustain the research environment while normal university conditions were suspended.

2.2.2 Student Outcomes and Awards

The Department has awarded **28 PhD** and **3 MSc by Research** degrees in the period. At census point, there were **24** registered postgraduate research students.

Several of our PhD students have received distinctions and awards:

- **Koorosh Aslansefa**t, supervised by Papadopoulos, has received the "Best Poster Award at Global Offshore Wind 2019" from RenewableUK, and the prestigious "Leslie H. Paddle Scholarship" in the international IET Postgraduate Student Award competition in 2020 for his PhD work which is funded by EDF Research London.
- **Declan Whiting**, supervised by Papadopoulos, is part-time PhD and software engineer in local company APD. He won the "Young Engineer of the Year" in the International Critical Communications Awards 2019 thanks to his work on automating analysis of security threats in HiP-HOPS.
- **Joyjit Chatterjie**, supervised by Dethlefs, was sponsored by Microsoft Research and Deep-Mind to present research at the "Tackling Climate Change with Machine Learning" workshop at the 33rd Int'l Conf. on Neural Information Processing Systems in Vancouver. He received

the IEEE "Young Researcher Award" during the Int'l Conf. on Automation, Computation and Technology Management (ICACTM), London, April 2019.

- **Annika Schoene**, supervised by Dethlefs, was selected for a competitive internship programme at IBM Research UK in 2017. She has received travel grants from NeurIPS and AAAI and has been sponsored to attend the Machine Learning Summer School in 2019, and the Brains, Minds and Machines Summer Course at MIT in 2020.
- **Quan Qi**, supervised by Li, received the best student paper award at the 2018 Int'l Conf. on Automation and Computing (ICAC 2018).

More than **50% of student research output** is the result of **collaboration with industry.** Many research students work on projects that contribute to developments with European and global industry, e.g. on HiP-HOPS and the design languages AADL and EAST-ADL. We take additional care to sustain clear and productive lines of communication with industrial sponsors and to involve them in project design, progress and, where appropriate, supervision.

2.3 Equality and Diversity

The University of Hull is committed to equality of opportunity and to respecting diversity for both staff and students. To support this, and to raise awareness about equality and diversity, training ranging from online modules to bespoke training packages are offered by the University's staff development team. All staff interviewing PhD applicants, researchers and other academics must have completed the required training. The Department has a Staff Development Officer to ensure that training is taken up. As part of our efforts to improve the working environment, the Department will be part of a Faculty-wide application for silver Athena SWAN award in 2022-23. This will include:

- Implementation of a supportive Staff Performance and Development Review (appraisal) process that recognises that a suitable work-life balance is underpinned by equality of opportunity for all staff, and a transparent workload allocation where workload is monitored for bias (gender, race, disability), and where workload is proportional to FTE (so part time staff are not disadvantaged).
- A flexible working policy that acknowledges family life, with key meetings within 9.00am-3.00pm.
- Annual staff appraisals that ask specifically about career progression so colleagues less likely to self-advance are encouraged to apply at the same rate as others
- The requirement for Leadership roles in the department to be advertised openly with all staff having the opportunity to contribute
- Equality, Diversity and Inclusion, and Health, Safety and Wellbeing, are standing agenda items on all formal meetings.
- The requirement that all staff will undertake unconscious bias training and Equality and Diversity training
- The aim to work towards a 50/50% gender ratio for invited speakers in departmental seminars

These aims already inform our practice. **45% of our staff are ethnic minority and/or women**. Female academic staff (Sharvia and Dethlefs) have been fully supported in the REF period in balancing work and family life with the provision of **multiple and extended maternity leaves** and related support in the time preceding and following such leaves. Both are submitted to the REF.

3. Income, infrastructure and facilities

3.1 Income

The Department has attracted numerous funded Research Projects during the REF period, with **research spend at £1.51m**. As above, this figure does not include income from the commercialization of research and the Postgraduates registered in Computer Science and funded by the DTCs based at the university. Our research income is increasing but remains modest, but the return on this capital measured as volume and quality of research output and economic and social impact is high. The main funded projects are listed below:

- **DEIS** (2017-20) Papadopoulos-PI: Digital Dependability Identities for cyber-physical systems with Siemens, General Motors, et al., EU H2020.
- **DREAM** (2018-21) Papadopoulos-PI: Integrating sensor data, reliability models and AI techniques to optimise maintenance in wind farms, EDF London.
- **MAENAD** (2011-14) Papadopoulos-PI: Design of fully-electric vehicles developing EAST-ADL with Volvo, Fiat, Continental, et al., EU-FP7.
- **TextMine** (2019-21) Dethlefs-PI: Natural language processing on documents to inform decision making, KTP with C. Spencer Ltd.
- **KBGen** (2018-19) Dethlefs-PI: Web-data mining and representation as knowledge graphs, Stanford University AI spin-off Diffbot.
- **TELFP** (2013-14) Gordon-PI. Technology Enhanced Learning and Flexible Pedagogy, HEA.
- **Autonomous Last Mile Resupply** (2018-20), Murray-PI, QinetiQ – DSTL.
- **ProTEcTME**: Proposal based exTEnsible Threat detection fraMEwork (2018-19) Murray-PI. InnovateUK.
- **Adaptive Real-Time Scanning for novel detections of illicit items**. (2019) Murray-PI, InnovateUK.
- **SKYPERION** - Autonomous and Intelligent UAV Detection (2018) Murray-PI, Innovate UK.
- **Digital Stethoscope for Health Monitoring** (2017-2018) Cheng-PI, NCS ltd.
- **Vital sign monitor** (2015-17) Cheng-PI, iMonSys ltd.
- **WT Seed Award in Science** (2017-19) Ma-PI, 3D analysis of maxillofacial growth in patients with cleft lip and palate, Wellcome Trust.

3.2 Infrastructure and Facilities

The Department hosts three dedicated research laboratories (one for each research group): a robot laboratory, Hull Visualization Environment (HIVE), and a 3D-printing and Fabrication Lab. Since 2014, the department has invested over **1m** in the **renovation of the research labs** and the **creation of** the new **3D printing lab**.

Hull Immersive Visualization Environment (HIVE) is Yorkshire and Humber's premier centre for virtual reality practice and research. HIVE was established in 2002 as a SRIF-funded initiative designed to leverage the quality and quantity of multi-disciplinary research, and it is managed by a full-time member of staff. Facilities include a large rear-projected stereoscopic 'workwall' with head-tracking capability for collaborative projects, a CAVE-like display, a range of fixed and portable stereoscopic immersive systems, and force-feedback displays.

The department also has access to **Viper** - the University of Hull's £2.1M High Performance Computer (**HPC**) which began operation in 2016. Viper is one is among the most powerful

academic HPC resources in the UK, and the top performing in the North of England. Based on the latest Intel Omni-Path interconnect, Viper has approximately 5,500 Intel Broadwell CPU cores and includes high memory nodes with 1TB RAM, dedicated GPU nodes and visualisation nodes. VIPER is supported by a team of HPC system specialists which include software support engineers.

4. Collaboration and contribution to the research base, economy and society

4.1 Collaborations and contribution to research base

DEIS has active collaborations with many of the leading groups in the area of Dependability. We work closely with **Fraunhofer IESE** (Institute for Experimental Software Engineering, Peter Liggesmeyer) and **Fraunhofer IKS** (Institute for Cognitive Systems, Mario Trapp) on various topics of Model-Based Safety Analysis (MBSA), including the concept of DDIs for runtime certification of autonomous cyber-physical systems.

The DEIS group works closely with the **University of Nuremberg** (Kolagari), the **Royal Institute of Technology** (Törngren) and **Volvo** (Lonn) on the **EAST-ADL** automotive design language. We have published metamodels, model-transformations and tools for dependability analysis and optimisation of designs in EAST-ADL.

DEIS also works with the Software Engineering Institute at **Carnegie Melon University** (Feiler) on the **AADL** avionics design language. We have published algorithms and tools for HiP-HOPS analysis of AADL specifications. Together with the **University of São Paulo** (Masiero and Oliveira), **MDS Sistemas** and **Embraer,** we co-develop concepts for automated safety analysis of product lines applicable to avionics systems.

We have a long-established cooperation with the group of Antoine Rauzy, currently in **Trondheim,** who is famous for authoring the **ALTARICA** language and tools. We co-develop MBSA techniques, co-supervise PhDs, and founded the International Symposium on MBSA. Papadopoulos is member of the Steering Committee of **IMBSA**, has co-chaired IMBSA'17 (Trento), IMBSA'19 (Thessaloniki), and edited the Springer LNCS proceedings.

We are instrumental in developing the field of **dependable control within IFAC** and co-founded **IFAC DCDS** (Dependable Control of Discrete Systems). Papadopoulos is steering IFAC-DCDS, sits in two **IFAC committees** TC 1.3 on discrete-event and hybrid systems, and TC 5.1 on manufacturing plant control, and the IFAC AMEST WG on maintenance. He has organized and chaired special tracks on Dependable Control at: IFAC World Congress, Toulouse, 2017; IFAC DCDS, Cancun, 2015; IFAC SAFEPROCESS, Paris, 2015.

Papadopoulos has given a number of keynotes and invited talks including: keynote at the Lorentz Centre on "Safety of Future Systems", Leiden, 9-13 April 2018; keynote at IFAC-DCDS 2015 on "Intersections of philosophy, logic and biology in design", Cancun, May 27-29, 2015; keynote at 7th IEEE Conference on Intelligent Computing and Information Systems on "Metaheuristics for the design of safety critical systems", Cairo, December 12-14, 2015; keynote at Automotive System Safety Europe, "Darwin, Penguins, and ISO 26262", Berlin, November 28-30, 2016.

Dethlefs, working on machine learning and computational linguistics, has been **area chair for ACL**, the leading conference in computational linguistics, for the "Generation" area in 2019 and for the "Dialogue" area in 2020. She was area chair for "Dialog Processing and Dialogue Systems – Multimodal Interfaces" at COLING in 2016. Dethlefs was **guest editor** of a special issue on "Machine Learning for Multiple Modalities in Interactive Systems and Robots" in **ACM Trans on**

Interactive Intelligent Systems (2015). She has given a keynote at the "Let's Discuss - Learning Methods for Dialogue" workshop at NIPS 2016.

Manzoor, working on multi-agent simulation, **co-organised** the Multimodal Spatial Role Labelling Workshop at **CLEF-2017** in Dublin, and gave a **keynote** at the GeoSim workshop at **ACM SIGSPATIAL** (2018) on "Distributed Scalable Geospatial Simulation".

Gordon, working on digital learning, is member of the British Computer Society Ethics, the Green IT specialist group and the Horizons in STEM Higher Education committees. He chaired and hosted the conference "**Horizons in STEM Higher Education Conference"** in 2018.

Cheng, working on health informatics, was awarded the "Highly Commended Award" in the Measurement category of the **IET Innovation Awards** for his work with sensors and monitors in 2019. Cheng is serving as **associate editor of IEEE Access**. He was guest editor of a special issue on "Data-Enabled Intelligence for Digital Health" in this journal.

Ma, working on health informatics, has given invited talks at the **7th IEEE/ACM Conf. on Big Data, Applications and Technologies** on "Multi-modal deep-learning approach to the early prediction of mild cognitive impairment conversion to Alzheimer's" in 2020 and the **3rd Int'l Conf. on Deep Learning Technologies** on "Hybrid deep-learning and morphometric analysis for early diagnosis of Alzheimer's disease" in 2019.

Murray, working on robotics, has impact on inland security and collaborates with the MoD, QinetiQ, the Home Office and Border Force. He won several grants and organised a workshop at the **British Machine Vision Conference** on "Object Detection and Recognition for Security Screening", in 2019.

All submitted staff are active in editorial boards of journals, IPCs of int'l conferences, reviewing papers and research proposals, and serve as external examiners of research theses.

4.2 Contributions to economy and society

VETA and BIOLOGIC's impact is emblematic of our research influence on local and global economic and social impact in several dimensions: the generation of wealth, employment, improvements of dependability of technological systems, and the enhancement of public medical and emergency services.

Our impact on society stretches further. HiP-HOPS and the EAST-ADL have achieved wide impact through **technology transfer to industry and commercialisation**. Commercial tools include HiP-HOPS (commercialized by the University) and Safety Designer, the latter commercialized together with ESI GmbH (a German SME). Metacase (a Finnish SME) have co-developed with us an EAST-ADL tool in Metaedit+ with capabilities for HiP-HOPS safety analysis. Through HiP-HOPS, EAST-ADL and software tools and industrially funded projects, our research has been taken up by several global corporations which include **Toyota, Honda, Volvo, Fiat, Jaguar Land Rover, Continental, Honeywell, Embraer, DNVGL, Deepwater Horizon and EDF**.

The influence on technology of our work in the field of dependability goes much further. Safety Architect by **All4Tech** (France) is a safety analysis tool that draws heavily from HiP-HOPS. **Embraer** are developing and using their own **Fault Tree Generator** inspired by HiP-HOPS. **Component Fault Trees** (CFTs), a well-known technology invented by **Fraunhofer IESE**, effectively provides a visualisation of concepts proposed by HiP-HOPS. The direct influence of HiP-HOPS is also acknowledged by **Siemens** and **Fraunhofer** in the BIOLOGIC ICS. All these tools have generated wealth, increased productivity and improved he dependability of systems.

DEIS has also done work that simulates the **social intelligence of Penguins,** and developed its application to automotive systems. The BBC and other global media have reported this research, including a BBC article on "Hungry Penguins Keep Car Code Safe" and other articles run by the Electronic Engineering Journal on "Robot Penguins Zap Cyber-Threat!", the Automotive IQ on "Philosophical penguins show the road to safety for smart cars" and by the Daily Mail who published an article claiming that the new research helps to 'spot hackers'.

DEIS work on machine learning and natural language processing techniques for document analysis has been taken up nationally by **Spencer Ltd.,** and internationally by **Stanford University AI spin-off Diffbot.**

VARS work on **virtual environments** has global impact and forms the core of the VETA ICS. New aspects including **treatment for amblyopia** in collaboration with Nottingham NHS Trust, and work on **orthopaedic surgical training** that is maturing and expected to be applied in hospital care in the near future.

HIR work on **inland security** (in collaboration with **METIS**, **Teledyne**, **QinetiQ**, **UK Home Office** and **Border Force**) has yielded applications ranging from the detection of drones in restricted airspaces, to scanning technologies for the illicit detection of firearms.

HIR work on **wearable and portable digital devices** is being taken up by UK industry, specifically local companies including **iMonSys ltd** and **Network Communication Systems ltd**.

Our main influence on **international standards** is through **EAST-ADL**: a design language with growing impact in the automotive industry, and used by Volvo, Scania, Continental, Bosch, Fiat and General Motors among others. Tools Metaedit+ and HiP-HOPS are official EAST-ADL supporting tools. Papadopoulos sits in the board of the **EAST-ADL association**, a body responsible for the maintenance and evolution of the language.

DEIS work on DDIs has created digital metamodels and tools which are currently available to the community through the DEIS Github repository. An association has been formed to convert DDIs into a standard for expressing executable dependability models for autonomous and open systems. **Siemens** and **AVL List** already use this work (see BIOLOGIC ICS).

In collaboration with members of the Swedish and German committees of ISO-26262 and Fraunhofer IKS, we work on improvements of the new automotive (**ISO-26262**) and aerospace (**ARP-4761**) safety standards (see BIOLOGIC ICS).

Among other things, the innovations that arose from our research have benefited the regional economy. Two Hull-based spinouts, Vertual and Lampada have been formed to commercialise a stream of state-of-the-art, research-driven products. Their commercialisation creates high-tech employment training computer science students, and raising the high-tech business capability of the region.