artificial intelligence research in Northern Ireland

2019 report

matrix.

Northern Ireland Science Industry Panel

Artificial Intelligence Research in Northern Ireland and the Potential for a Regional Centre of Excellence

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Foreword by Dr. Robert Grundy, Chair of Matrix

There is no faster moving Science and Technology sector than ICT/Digital. The speed at which digital technology is developing is increasing exponentially as we find new ways to maximise the value of the data we produce.

Within this space, the field of Artificial Intelligence (AI) has evolved particularly quickly. The productivity and success of our whole economy depends increasingly on the quality of the systems and machines we build to support and drive it. We have become accustomed to the speed at which many technologies are being developed, but that pace is set to increase exponentially, largely driven by AI. Areas as diverse as healthcare, agriculture and finance are being transformed by its applications.

In 2016, Matrix published its Digital ICT Report, which identified four areas – software engineering, advanced networks and sensors, data analytics and cyber security – in which Northern Ireland was already, or had the potential to be, world class.

It also noted that five sectors which the panel had already identified as key drivers of the Northern Ireland economy - Financial Services (Fintech), Manufacturing, Public Services, Agriculture and Life and Health Sciences – would be particularly likely to benefit from the then-emergent discipline of Artificial Intelligence.

As a result of this observation, Matrix commissioned The Alan Turing Institute to undertake this review of AI capabilities in Northern Ireland.

It is crucial for Northern Ireland to fully understand its AI capabilities in order to realise its potential in this space and so the importance of this work by the team from The Alan Turing Institute cannot be underestimated. The observations made in this comprehensive report provide us with a strong base from which we can further develop our strengths and take full advantage of opportunities as they reveal themselves.

Dr Robert Grundy

Foreword by Tom Gray, Chair of the Review Panel

Roy Amara stated that "we tend to overestimate the impact of a technology in the short term, and underestimate the impact in the long run".

This has played out many times during the current "Digital Revolution", with skeptics - for good reason at the time - decrying the failure of the Internet or Mobile Technology or Cloud just before business and society has been utterly transformed by them.

The latest technology to be subject to Amara's Law is Artificial Intelligence and, sure enough, the AI advocates have been promising revolutionary advances for many years, with limited impact on people's daily work and leisure.

Except that, without anyone really noticing, AI has woven its way into everyone's lives - whether it's helping find your next favourite song or TV binge, protecting you from credit card fraud, controlling your heating, or helping you drive and park more safely. It's also getting better at selling you stuff you don't need, giving you news stories that reinforce your viewpoint, hacking your personal information and, perhaps, undermining democracy.

AI is here now - at least in the form of Machine Learning - and we're only starting to see the ultimate potential of the technology. I think we're at the stage of underestimating the ultimate impact, but it's possible to see the direction of travel.

Every nation and region is investing in Research and Skills to ensure that they, and their citizens, aren't left behind. And Northern Ireland should be no different.

As part of a series of activities driven by Industry and Government, the Turing Institute was asked to review NI's AI research capability.

I was honoured to Chair this Review on behalf of Industry and I was delighted to receive the findings that QUB and UU, taken together, would be the 6th most impactful AI research institute in UK. This is an achievement to be proud of and a strong foundation to build upon.

In addition, the report has highlighted complementary strengths across both universities - in Cyber Security, Medicine and Bio-informatics, for example - that will allow Northern Ireland to take a leading position in the development and application of AI.

At the moment, most commercial activity is based on applying mature techniques and, in NI, we have challenges around lack of skills and awareness amongst our companies, which must be addressed as a priority. The Turing Report was focused on Research excellence, and does not cover Skills or Application challenges, but we must ensure that any investment or activity is taken with this in mind.

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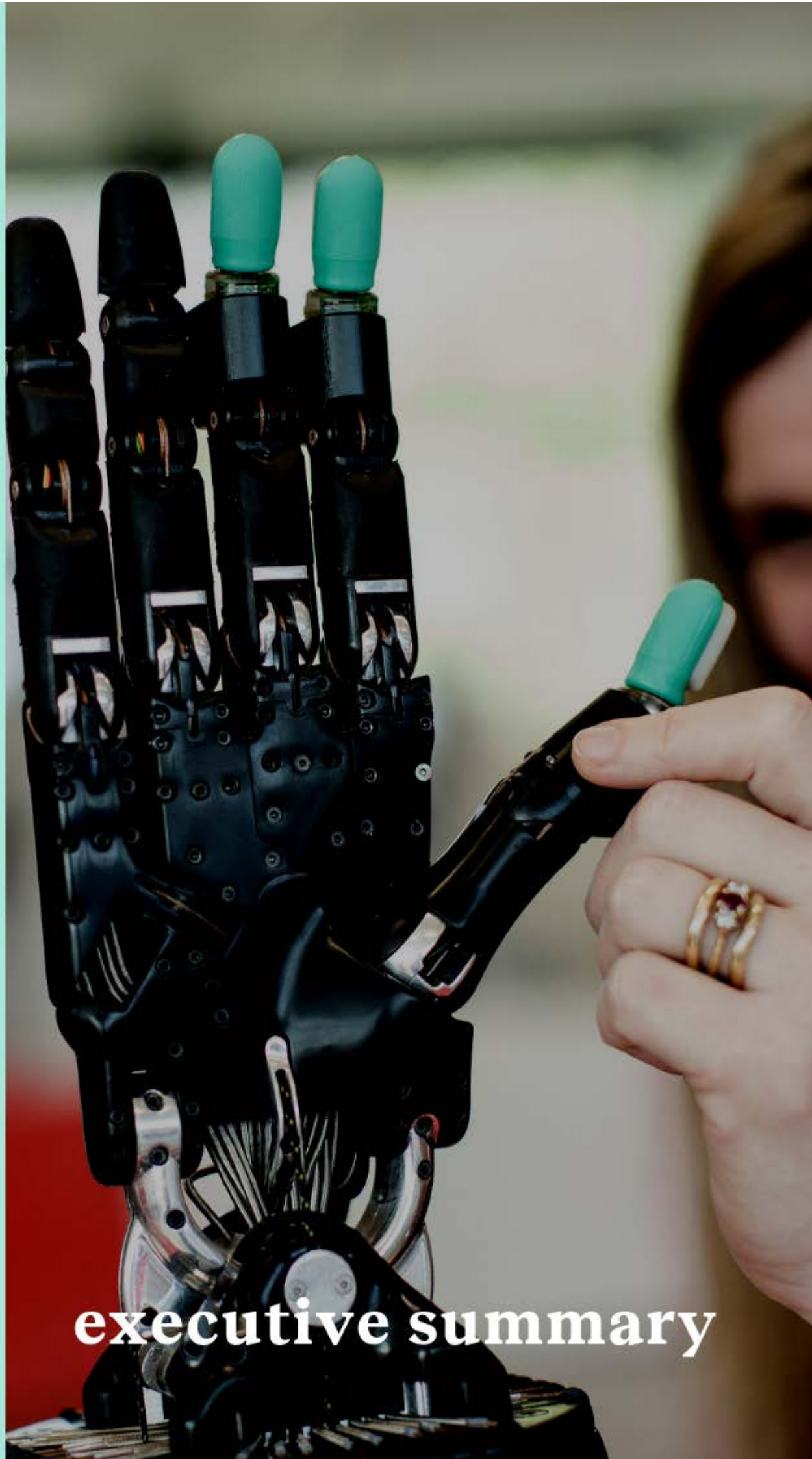
I welcome the findings of the Report and highlight the need for a single AI Centre of Excellence, which brings together the best of NI Research and Commercialisation, and provides a strategic focal point for NI AI activity - both internally and externally. Our goal should be to support local talent and commercial endeavour and to attract the best from other regions.

We can't underestimate the potential for AI, or the need for timely investment, proportionate to the potential impact of the technology and its application.

Tom Gray



executive summary

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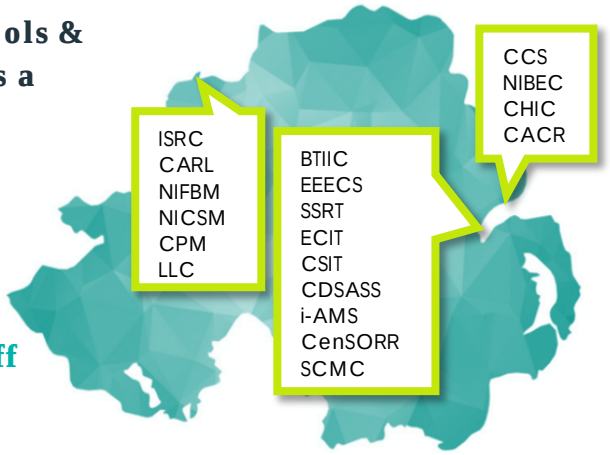
Northern Ireland – a centre of excellence in Artificial Intelligence research

UU & QUB have numerous schools & centres specialising in AI across a range of disciplines...

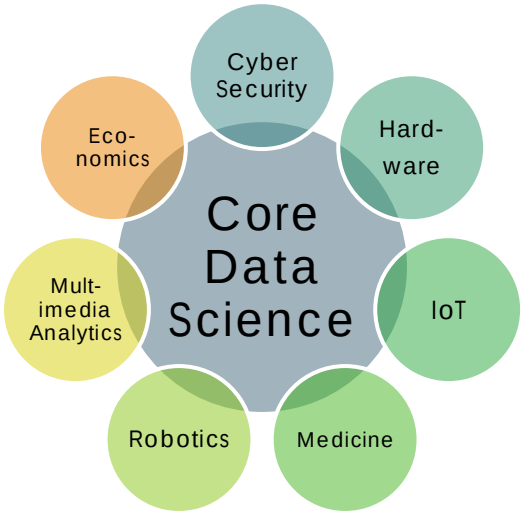


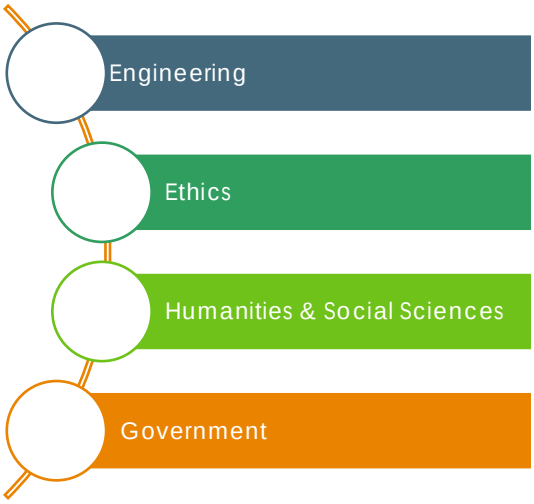
...in total they have over

150

permanent staff involved in AI research.

Northern Ireland has several major clusters of excellence in AI research....





...as well as some significant minor clusters of excellence.

Ulster and Queens Universities have also produced a number of successful AI spinouts...

Analytics Engines
intelesens RESPONSIVE HEALTHCARE
ActionSense
pathxl
EVENTMAP
performa
axial3D Patient data made real
ALMAC Diagnostics
anyVISION A BETTER TOMORROW
BRAINWAVEBANK
sonraí SECURITY
NeuroCONCISE
Nightingale ANALYTICS
HeartSine
DATACTICS™

Executive Summary

The potential contribution of Artificial Intelligence (AI) to economic progress has become increasingly recognised around the world and many countries and regions have formulated and implemented policies designed to support the development and use of AI. Many of these have taken the form of attempts to nurture 'AI Clusters' – conglomerations of highly active centres of research and commercial enterprises that interact synergistically to stimulate economic growth in the region in which they are clustered.

Many factors influence the success of such ventures, but some are critical. These include the presence of a critical mass of AI research excellence, typically located in universities, and a track record of successful interaction, collaboration and knowledge transfer between the research base and a vibrant industrial ecosystem comprised of large technology-oriented firms, e.g. multinationals; a rich mix of small and medium-size enterprises (SMEs) – established, early stage and spin-offs – that are focused on the delivery and provision of AI products, processes and services; intermediary organisations that specialise in knowledge transfer and the provision of AI-related services to industry; and an array of potential users eager to take advantage of AI-related technologies as they become available.

The main aim of this review was to explore the potential for the establishment of a regional centre of excellence (RCE) in AI research that could act as a 'growth pole' at the heart of an AI cluster within Northern Ireland – a centre that could draw upon AI research expertise located in Northern Ireland's two main universities, Ulster University (UU) and Queen's University Belfast (QUB), and adopt the mantle of a leading-edge player on a UK and world stage, networking with other globally recognised centres of excellence, such as The Alan Turing Institute, and interacting effectively with an industrial community in the region that is ready, able and willing to realise the promise of AI. Throughout this report, we shall refer to this Artificial Intelligence Centre of Excellence in Northern Ireland as AiCE@NI.

The headline finding of this review is that the basic ingredients exist for the establishment of an AiCE@NI that could act as an effective growth pole within a dynamic AI cluster.

Individually, UU and QUB are significant sources of AI research excellence. Collectively, they constitute a UK powerhouse. If the AI publications they produce are pooled, UU and QUB together would rank 6th in the UK in terms

of the number of publications produced to date during the current UK Research Excellence Framework (REF) timeframe (2014 – 2021)[6].

Across both universities, this review identified eight clusters of significant AI research excellence that we have labelled Major Clusters of AI Research Excellence. Research in these clusters stands comparison with leading-edge AI research across the globe. The separate clusters focus on Core Data Science (including theory, algorithms, methods); Cyber Security (including threat detection, cryptographic methods and surveillance techniques); Hardware (including High Performance Computing (HPC), scalable architectures and cloud computing); Internet of Things (including smart devices and their applications); Medicine (including health and well-being, clinical medicine, genomics, neurosciences and biosciences); Robotics (including autonomous systems and advanced manufacturing); Economy (including trade and fintech); and Multimedia Analytics (including computational vision, natural language processing (NLP), text mining and speech recognition).

These clusters are complemented by work conducted in four smaller Minor Clusters of AI Research Excellence. These focus on Government (including policy applications); Engineering (including civil engineering applications); Ethics (including fairness, transparency); and Humanities and Social Sciences (including digital humanities and social data science).

Collectively, the combined AI research base of UU and QUB is strong enough and broad enough to support the case for the constitution of a new AiCE@NI that could draw upon the expertise resident in both universities. Moreover, both universities have indicated that they would be enthusiastic partners in the creation of such a centre.

This review also found that both universities have impressive records of collaborating with firms (large and small), emphasising the importance of knowledge transfer and encouraging spin-offs. The AI sector in Northern Ireland, as elsewhere, is expanding rapidly from a small base and demand for AI related products, processes and services is commensurate. AI NI, a community group established in March 2018 to allow individuals and organisations interested in AI to interact and participate in workshops, panel

[6] Figures on the collective publication performance of QUB and UU were provided by Elsevier and are based on a review of publications included in journals included in the AI sub-category of the All Science Journal Classification Scheme (ASJC).

discussions and other events, now has over 1,000 individuals registered as members.

Firms active in the AI sector in Northern Ireland appear confident in their ability to satisfy the increasing demand for AI, subject to the availability of skilled staff, and they are keen to expand the interaction between industry and academia on the education, research and technical assistance fronts. Ensuring an adequate 'skills pipeline' is a priority for many firms and there is an evident willingness to work with academia to evolve customised training courses and even Master's programmes.

There was also a desire for a better 'shop window' that would allow firms in many sectors a clearer view of the 'research offer' presented by the academic sector. Many firms had established contacts with academic sources of expertise on an informal, ad hoc basis in the past, but lacked an overview that would allow them to make more informed choices when seeking assistance and collaboration partners. This has resulted in a situation whereby many firms collaborate either with UU or with QUB, but not with both.

The establishment of a new AiCE@NI would fill a gap that currently exists in the AI innovation ecosystem in Northern Ireland. High calibre research expertise exists in a multitude of institutional locations within UU and QUB, but it is not always visible to the industrial community. A new AiCE@NI would act as a 'one stop shop' offering a clear conduit to this know-how.

To fulfil industry expectations, it is clear that any new AiCE@NI would also have to have a broad mission statement, offering 'translation services' at low to medium Technology Readiness Levels (TRLs) that facilitate knowledge transfer from the research base to industry, and more focused 'industry services' at higher TRL levels, e.g. contract research for SMEs and facilities for testing and piloting prototypes.

The clear aspiration of industry, however, is for a strong association with an institution with a world reputation as a leading-edge research institute – one which could satisfy all the demands of local industry and act as a magnet for foreign direct investment (FDI) in the region that would accelerate the growth of the regional economy.

In this regard, the unanimous opinion across industry and academic representatives participating in this review was that a new AiCE@NI would benefit enormously from a formal link with The Alan Turing Institute and the members of the Turing network. Benefits accruing to Turing were also envisaged in terms of an expanded geographical reach and the opportunity for it to enhance its overall socioeconomic impact via increased interaction

with a new centre operating as a hub within an expanding AI cluster in Northern Ireland.

The main recommendation emerging from this review, therefore, is for the Northern Ireland authorities to act quickly to develop an Action Plan that would allow major stakeholders in the region firstly to commit to a new AiCE@NI, and secondly to explore formal links to The Alan Turing Institute that would add value to the proposition.

introduction

1. Introduction

In 2016, the Digital ICT Report[7] prepared by MATRIX, the Northern Ireland Science Industry Panel, identified four areas – software engineering, advanced networks and sensors, data analytics and cyber security – in which Northern Ireland is already, or has the potential to be, world class. It also noted five key industry sectors in Northern Ireland that were likely to benefit from AI developments, namely Financial Services (Fintech), Manufacturing, Public Services, Agriculture and Life and Health Sciences. The report concluded with a recommendation that Northern Ireland should establish a Research Institute in Data Analytics.

Subsequently, the Department for the Economy (DfE) in Northern Ireland commissioned The Alan Turing Institute to undertake a review of Artificial Intelligence (AI) capabilities in the region and examine the case for the establishment of a new AI Centre of Excellence in Northern Ireland (henceforth termed AiCE@NI).

Figure i. Industry sectors in Northern Ireland most likely to benefit from AI developments

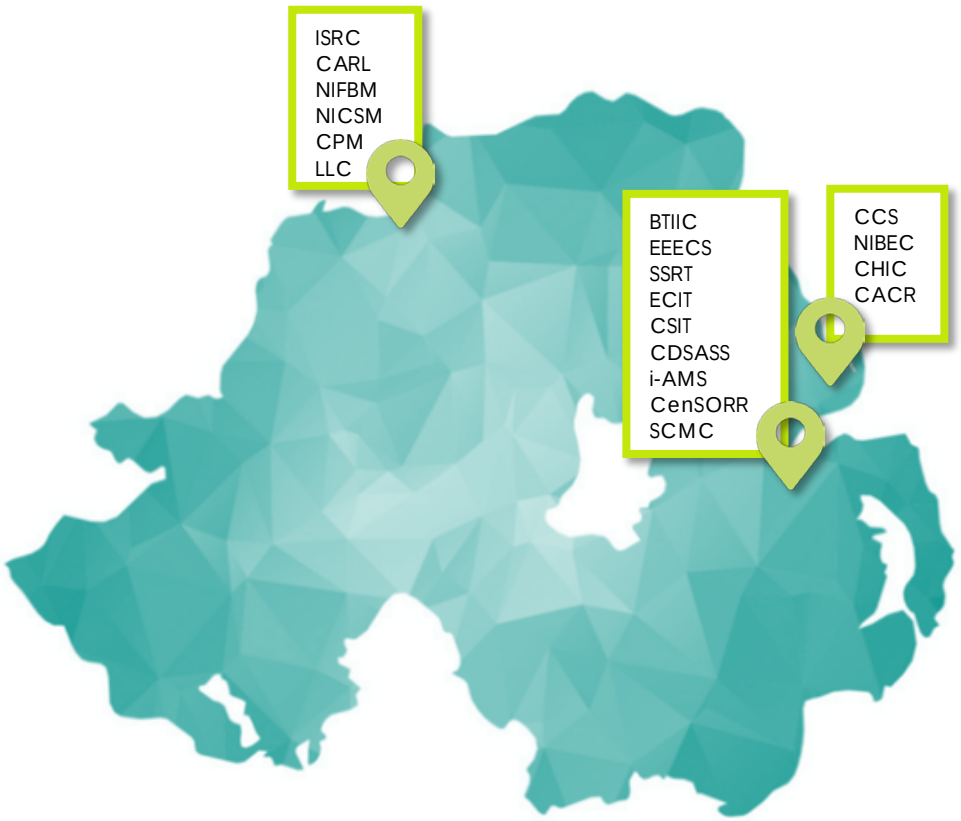
[7] https://matrixni.org/reports/2016-digital-ict/

1.1 Objectives

The main objectives of the review were to:

- Evaluate overall levels of regional academic-commercial research excellence within the AI sector and the role played by public sector research institutes;
- Determine how the research conducted by public sector research institutes meets the needs of local businesses in both Northern Ireland and the UK;
- Assess Northern Ireland's capacity to establish a Regional Centre of Excellence in Artificial Intelligence linked to the UK's Alan Turing Institute, all within the context of the development of a thriving AI cluster in Northern Ireland;
- Suggest policy actions likely to support the future development of the AI sector in Northern Ireland.

Figure ii. The academic research AI landscape in Northern Ireland



1.2 Expectations

The research was expected to feed into future sectoral policy in Northern Ireland by helping to:

- Provide an overview of the academic and commercial AI sectors in Northern Ireland;
- Assess the quality, sustainability, relevance and impact of existing research activity;
- Identify key areas of great academic and commercial potential that could be a focus for future policy support in Northern Ireland;
- Identify opportunities for improved collaboration between public sector research institutes and the private sector;
- Identify priority areas for investment in research and research infrastructure;
- Explore the fit between planned research in Northern Ireland's public sector research institutes and AI-related elements of current UK policy, e.g. the UK Industrial Strategy[8], the Industrial Strategy Challenge Fund[9] and the AI Sector Deal[10];
- Inform decisions about the establishment of a regional Centre of Excellence in AI as part of The Alan Turing Institute network, again in line with current UK policy thinking[11];
- Identify possible structure(s) for a new regional Centre of Excellence;
- Identify the future support requirements of AI stakeholders in Northern Ireland and policy actions that could meet these needs.

[8] https://www.gov.uk/government/policies/industrial-strategy
[9] https://www.gov.uk/government/collections/industrial-strategy-challenge-fund-joint-research-and-innovation
[10] https://www.gov.uk/government/publications/artificial-intelligence-sector-deal/ai-sector-deal
[11] https://www.gov.uk/government/speeches/artificial-intelligence-from-alan-turing-to-the-industrial-strategy

1.3 Methodology

The approach adopted involved a review of key documentation and an intensive round of structured interviews with key stakeholders associated with the development and use of AI in Northern Ireland. In total, discussions were held with approximately 80 representatives of the public sector, universities, firms and other bodies.

The interviews were structured around the main issues of interest:

The excellence of indigenous AI capabilities and research. Lines of questioning here focused on the scale, scope and quality of existing activities in NI, with a particular focus on similarities and differences between the perceptions of quality held by supply- and demand-side representatives. Commercial potential was also explored;

The needs of local and UK industry. The focus here was not only on perceived needs, but also on how well these had been and might be met by local actors. Again, an effort was made to understand whether or not the perceptions of the supply-side and demand-side actors were in alignment or not;

The prospects for a regional centre of excellence in AI linked to the Turing Institute. The aim here was to explore the arguments for and against the development of a regional centre of excellence within the context of an emerging AI cluster and evaluate the evidence underpinning these arguments;

Possible configurations for a regional centre of excellence. Alternative configurations for a potential new centre of excellence were explored with interviewees;

Policy needs and recommendations concerning the future development of a strong AI cluster in NI.

Other methodological details, e.g. those concerning the formulation of assessments of research excellence in the academic community, are described in relevant sections of the review.

1.4 Definitions

Due to the complex and multi-faceted nature of the field, there is no single generally accepted definition of Artificial Intelligence (AI). According to the Engineering and Physical Science Research Council[12]:

"Artificial Intelligence technologies aim to reproduce or surpass abilities (in computational systems) that would require 'intelligence' if humans were to perform them. These include: learning and adaptation; sensory understanding and interaction; reasoning and planning; optimisation of procedures and parameters; autonomy; creativity; and extracting knowledge and predictions from large, diverse digital data."

We have adopted this definition for the purposes of this review and have included, amongst others, fields of specific interest to MATRIX[13], namely:

- Machine Learning;
- Deep Learning;
- Advanced Analytics;
- Behavioural and Emotion Analytics;
- Cognitive Analytics;
- Predictive Analytics;
- Natural Language Processing (NLP).

1.5 Structure

Following this introduction, the review is structured into three sections:

- Section 2 focuses on academic and industrial capabilities and links;
- Section 3 focuses on the case for the establishment of a new AiCE@NI;
- Section 4 contains the conclusions and recommendations emerging from the review.

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[12] https://epsrc.ukri.org/research/ourportfolio/researchareas/ait/

[13] https://matrixni.org/current-work/artificial-intelligence/

In addition, Appendix 1, prepared in conjunction with the DfE in Northern Ireland, contains an overview of UK policy relevant to AI; and Appendix 2 contains a list of all discussion partners in Northern Ireland in the public and private sectors.

academic and industrial capabilities and links

2. Academic and Industrial Capabilities and Links

2.1 The Academic AI Landscape

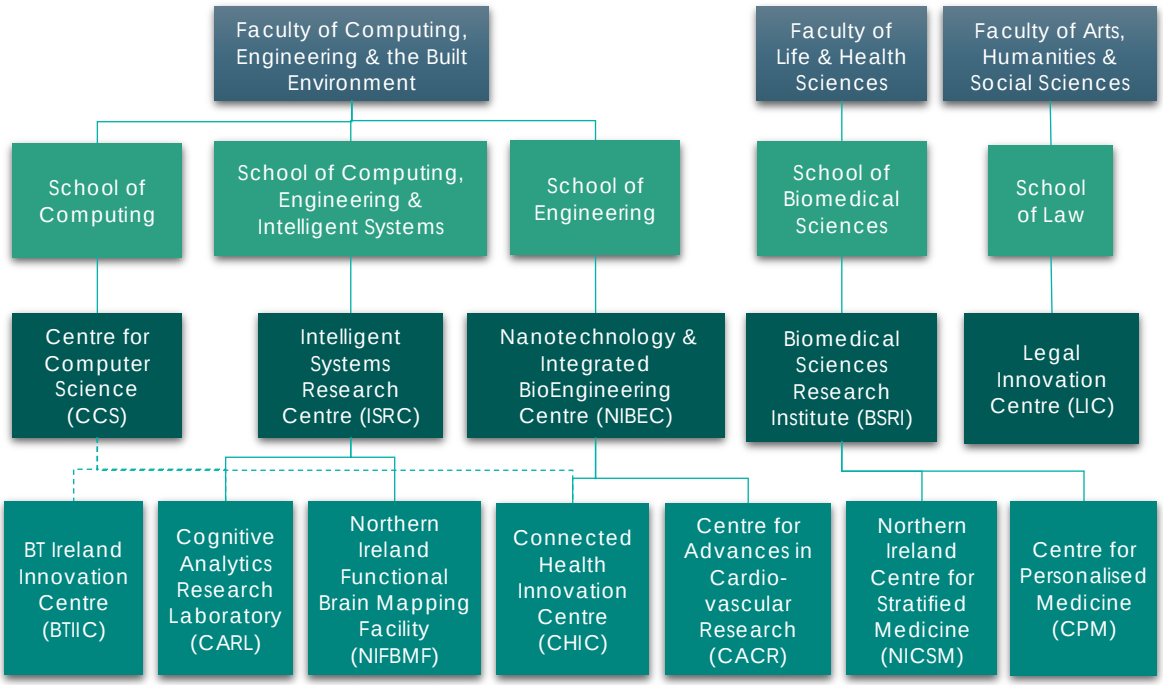
Academic AI capability in Northern Ireland is concentrated in its two main university institutions: Ulster University (UU), which has campuses in Belfast, Jordanstown, Derry/Londonderry and Coleraine; and Queen's University Belfast (QUB). In this descriptive section of the report, web-based data and other publicly available documents are complemented by material provided by the two universities to provide an overview of AI activities in Northern Ireland that is not readily available elsewhere.

2.1.1 Ulster University

Ulster University (UU) is home to the largest computer science grouping on the island of Ireland and the 14th largest in the UK. AI has been the main focus of research in Computer Science at UU for over 25 years. UU has developed expertise in Data Analytics both in terms of machine learning algorithms and the application of analytical techniques across a diverse range of domains. Recent investments include: £11m in the Centre for Stratified Medicine; £5m in the Functional Brain Mapping facility; €4.5m in MIDAS (Meaningful Integration of Data, Analytics and Services); and £1m in Capital Markets Collaboration. In Dec 2016, €8.6m was also invested in the Centre for Precision Medicine (CPM), which uses data analytics to improve clinical decision-making and patient safety.

The main research groups involved in AI at UU fall under three Schools located within the Faculty of Computing, Engineering and the Built Environment: the School of Computing, Engineering and Intelligent Systems (CEIS), which is located in Derry/Londonderry; the School of Computing, which is located in Belfast and Jordanstown; and the School of Engineering. Other centres of research expertise can be found in the School of Biomedical Sciences in the Faculty of Life and Health Science and the School of Law in the Faculty of Arts, Humanities and Social Science. Figure 1 shows the main centres of AI expertise within these Faculties and Schools (shaded areas). Overall, UU estimates the total number of permanent staff involved in AI research to be approximately 100.

Figure 1. Principal Centres Involved in AI Research at UU



Intelligent Systems Research Centre (ISRC)

The Intelligent Systems Research Centre (ISRC) is located within the School of Computing, Engineering and Intelligent Systems at the Magee campus in Derry/Londonderry. The centre is organised into cross-disciplinary teams. The ISRC currently has around 75 researchers with a total budget in excess of £20m. ISRC's over-arching and distinctive research focus is bio-inspired AI. The aim is to harness developments in our understanding of natural computational (biological and social) systems for the next generation of AI technologies. ISRC's external collaborators include Professor Steve Furber, leader of the EPSRC-funded spiNNaker project at the University of Manchester.

ISRC research is structured around six themes:

- **Computational Neuroscience and Neuromorphic Engineering.** Modelling cellular and network level brain function to create biologically inspired algorithms and hardware;
- **Cognitive Neuroscience and Neurotechnology.** Intelligent signal and image processing to understand brain dynamics, structure and function and develop ways to restore, maintain and enhance cognitive function;

- **Cognitive Robotics.** Robotic technologies with human-like sensing capabilities for seamless interaction, with applications in assistive devices, tactile sensing and robot control;
- **Intelligent Data Analytics.** Applying bio-inspired paradigms for AI and scalable computing to complex, challenging data analytics problems;
- **Spatial Computing and Future Human-Computer Interaction.** Developing new contexts for computing through wearables and technology everywhere;
- **Cyber Security and Web Technologies.** Secure, intelligent technologies able to deliver context aware knowledge and actions in real-time.

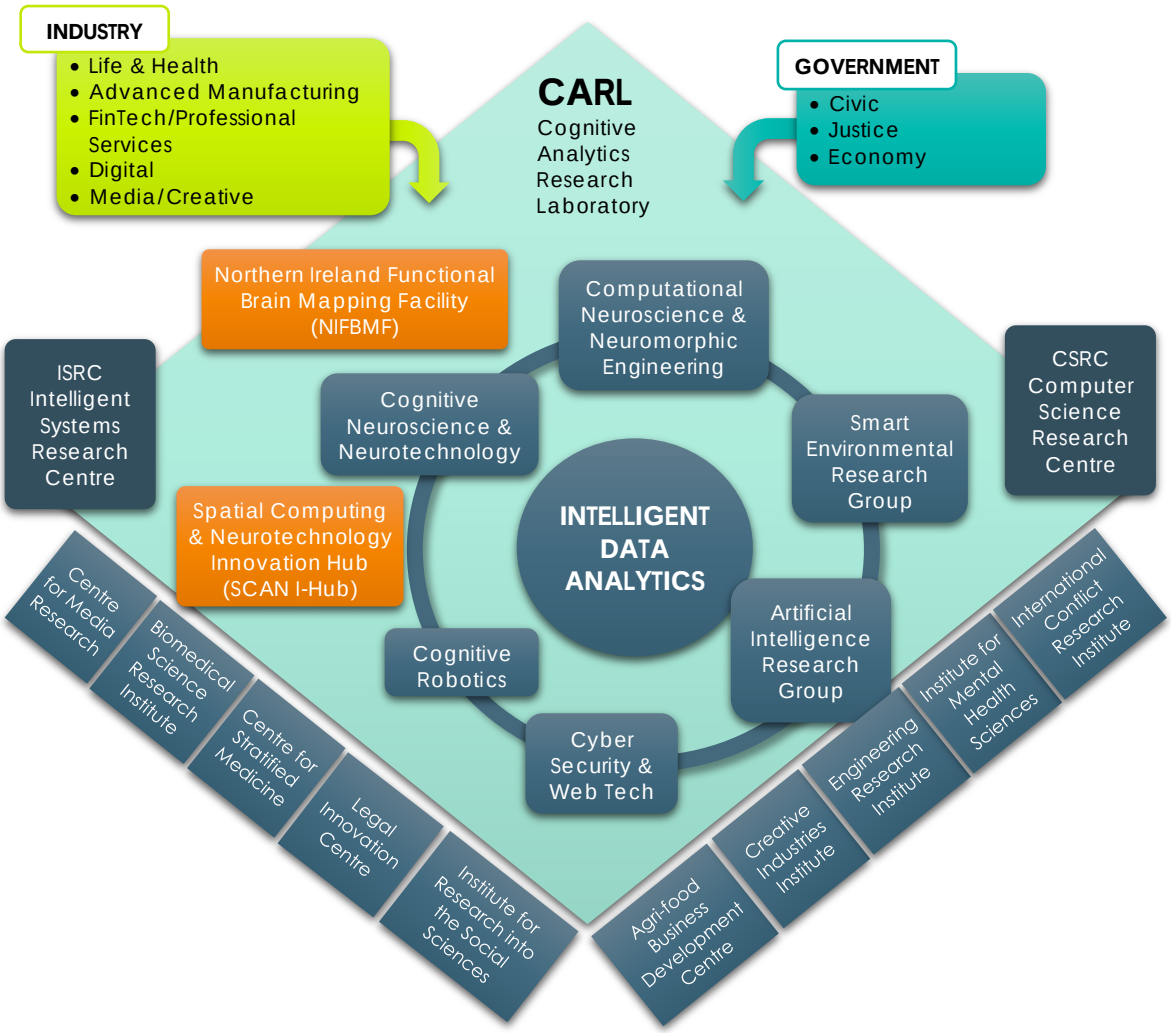
Key people: The director of ISRC is Professor Damien Coyle. His research interests include computational intelligence/AI, bio-signal processing, computational neuroscience, neuroimaging, neurotechnology and brain-computer interface (BCI) applications. He has won two international awards for AI research, was a Royal Academy of Engineering/Leverhulme Trust Senior Research Fellow, a Royal Academy of Engineering Enterprise Fellow and is currently CEO of NeuroCONCISE Ltd., the UU spin-out company he founded to develop AI-enabled wearable technology, which won the inaugural IET and E&T Innovation of the Year Award in 2018.

Cognitive Analytics Research Lab (CARL)

ISRC hosts the Cognitive Analytics Research Lab (CARL), which is also linked to the Centre for Computer Science (CCS). UU launched CARL in 2017 with an investment of £4m to create 12 new full-time research posts. The aim is to draw upon machine learning and AI expertise across the whole of the university and consolidate it in one centre with an emphasis on applications relevant to a diverse range of domains. CARL was established after extensive consultations with industry and civic stakeholders in Northern Ireland. These ensured that its vision took into account the region's economic and social challenges. CARL's key focus is the application of research in cognitive analytics in a number of areas including: healthcare, fintech, advanced manufacturing, media and energy.

Figure 2 shows how CARL links across the university and taps into expertise and data from multiple UU institutes and initiatives.

Figure 2. CARL in a UU Context



Key people: CARL is led by Professor Liam Maguire, currently Executive Dean of the Faculty of Computing, Engineering and the Built Environment. Professor Maguire's research focuses on data analytics and machine learning, especially of bio-inspired approaches. He is a Fellow of the Institution of Engineering and Technology and a chartered engineer with an extensive network of colleagues in the digital and engineering sectors in Northern Ireland.

Northern Ireland Functional Brain Mapping (NIFBM)

ISRC also hosts the Northern Ireland Functional Brain Mapping (NIFBM) Facility, a joint investment between UU and InvestNI, which possesses the only magnetoencephalography (MEG) brain imaging system in Ireland. Current projects include: a Brain-Computer Interface (BCI) operated hand exoskeleton-based neuro-rehabilitation system for movement restoration in paralysis and extraction and modelling of Alzheimer's disease data for patient stratification using a novel integrative, multiplex network approach.

Key people: NIFBM is led by Professor Girijesh Prasad. His research interests include data engineering, brain modelling, brain-computer interfaces and neuro-rehabilitation, assistive technology.

Centre for Computer Science (CCS)

The Centre for Computer Science (CCS) consists of two research groups focusing on Pervasive Computing and AI and two affiliated Innovation Centres.

Within CCS, there are three main AI research themes:

- **Semantic data analytics:** including text analytics (extraction, summarisation, information retrieval, sentiment analysis); video/image analytics (face recognition/verification, event recognition, anomaly detection, biometrics); and spectra analytics;
- **Data science and analytics:** including supervised and unsupervised machine learning-based classification systems and ensemble methods; big data analytics and decision-making with uncertainty methods to address real world problems, including satellite data exploitation with an emphasis on anomaly/change detection for hazardous analysis and risk resilience; sentiment analysis for opinion mining and cyberbullying detection; and sensor fusion for activity/event recognition in smart environments;
- **Knowledge engineering:** including knowledge representation (Knowledge Base and Ontology), Reasoning (Probability/Uncertainty), and Intelligent Decision Support with applications in safety and risk analysis, urban planning, agri-food and land management, health care, situational awareness.

Key people: The director of CCS is Professor Chris Nugent. His research interests include development and evaluation of technologies to support ambient assisted living, activity recognition and behaviour modelling.

BT Ireland Innovation Centre (BTIIC)

In November 2017, BT opened a new £28m Innovation Centre in Belfast. In partnership with UU, BTIIC will conduct research at the intersection between Artificial Intelligence, the Internet of Things and Telecommunications. Further details are included in Section 2.3.1, which considers UU's links with industry.

Key people: The UU BTIIC team is led by Professor Sally McClean, a Professor of Mathematics in the School of Computing. She has research interests in Mathematical Modelling, Applied Probability, Multivariate Statistical Analysis,

and applications of Mathematical and Statistical methods to Computer Science, particularly Databases, Tele-communications, Cloud and Sensor Technology

Nanotechnology and Integrated BioEngineering Centre (NIBEC)

The Nanotechnology and Integrated BioEngineering Centre (NIBEC) represents a consolidation of research groups, associated with advanced material types used in medical devices, electronics, photonics, tissue engineering, nanotechnology, microfluidics, sensors, MEMS, optical and environmental devices. The centre is based within the Engineering Research Institute (ERI) and is host to a number of research groups and centres.

One group within NIBEC, the Healthcare Sensor Systems Group, utilises AI and machine learning concepts in the development of diagnostic algorithms. Expertise in machine learning has been developed through numerous projects that have been successfully completed in NIBEC over the last 24 years (Prime ECG-cardiac mapping; defibrillator algorithms; heart arrhythmia recognition and blood analyser point of care diagnostics). AI research has also underpinned the development of new algorithms that are leading the way to a set of new spin-outs following the success of algorithm-based companies such as Heartsine and Intelesens.

Key people: The Healthcare Sensor Systems Group is led by Professor James McLaughlin, the Director of NIBEC. He has over 30-years research experience in the area of integrated sensors and the development of smart algorithms based on real-world data for predictive and accurate decision making within healthcare. Building on their 3rd place in the $10m Qualcomm Tricorder Xprize Competition, his team has been responsible for the development of a range of machine learning enhanced platforms that provide mobile, IoT-based sensor solutions that prioritise user-friendliness and clinical relevance. Current work focuses on next generation CMOS image sensors with associated AI and their application to lateral flow, molecular and remote sensing.

The Connected Health Innovation Centre (CHIC)

CHIC sits within NIBEC and CCS and has health science at its core. It has been funded by InvestNI for £8m for a period of 5 years to support industry driven research within the Connected Health sector. CHIC currently has over 30 companies (national and European) as members and supports 18 Research Fellows/Associates. Key foci for the research are Vital Signs Sensing Development, Integrated Care, Assisted Living, Point of Care Diagnostics and Healthcare Analytics.

Key people: CHIC is led by Professors James McLaughlin and Chris Nugent.

The Centre for Advanced Cardiovascular Research (CACR)

Also situated in NIBEC, this centre conducts research in the field of medical devices, nanotechnology and bio-molecular science applied to critical cardiac care, and research aimed at identifying methods to improve diagnostic and therapeutic clinical needs, with an emphasis on medical instrumentation through clinical trials.

Key People: The Director of CACR is Professor Omar Escalona, who leads a team drawn jointly from UU and the Royal Victoria Hospital Belfast and Craigavon Hospital.

Biomedical Sciences Research Institute (BSRI)

The Biomedical Sciences Research Institute (BSRI) hosts two research centres relevant to this review.

Northern Ireland Centre for Stratified Medicine (NICSM)

Research in this centre aims to identify how genes or patterns in the levels and states of molecules, or subtle differences in medical images, could be used to create robust clinical decision-making tests for a range of degenerative diseases. Based in the Clinical Translational Research and Innovation Centre (C-TRIC) on the Altnagelvin Hospital site in Derry/ Londonderry, NICSM was established in 2013 following an award of £11.5m from the European Union Regional Development Fund, InvestNI, the Northern Ireland Public Health Agency, ILEX and UU.

NICSM is in the process of creating a biobank and associated database that are to be linked to patient data. They will contain the whole genome sequences, proteomic data and other 'omic' data of 7,000 people with degenerative disease. As contract research for Genomic Medicine Ireland, NICSM C-TRIC is currently aiming to recruit 200,000 people in total from Northern Ireland (i.e. 10% of the population).

Key people: The director of NICSM is Professor Tony Bjourson. His research interests include genomics based personalised medicine in cancer, autoimmune disease and pharmacogenomics. Professor Bjourson also leads the recently established Centre for Personalised Medicine (see below).

The Centre for Personalised Medicine (CPM)

Established as a consequence of €8.6m received from the EU INTERREG VA Programme, this is a cross-border collaboration between academic partners (UU, NUI Galway, University of the Highlands and Islands, Letterkenny Institute

of Technology), public healthcare providers (NHS Highland, Western Health and Social Care Trust, NI Clinical Research Services) and healthcare services companies (Healthcare Analytics Ltd, Clinisent, Randox, Optum). The objective is to create a research-led environment for personalised clinical decision-making.

Key people: The director of CPM is Professor Tony Bjourson (see above).

Legal innovation Centre (LIC)

The Legal Innovation Centre (LIC) is a collaboration between UU Law School, law firms in Northern Ireland and the ISRC. It is an inter-disciplinary research group that brings together academics from Law and Computer Science to explore computational law, a branch of legal informatics focused on the automation of legal analysis to streamline the delivery of legal services. Current research includes the extracting facts from prospectuses of firms going public.

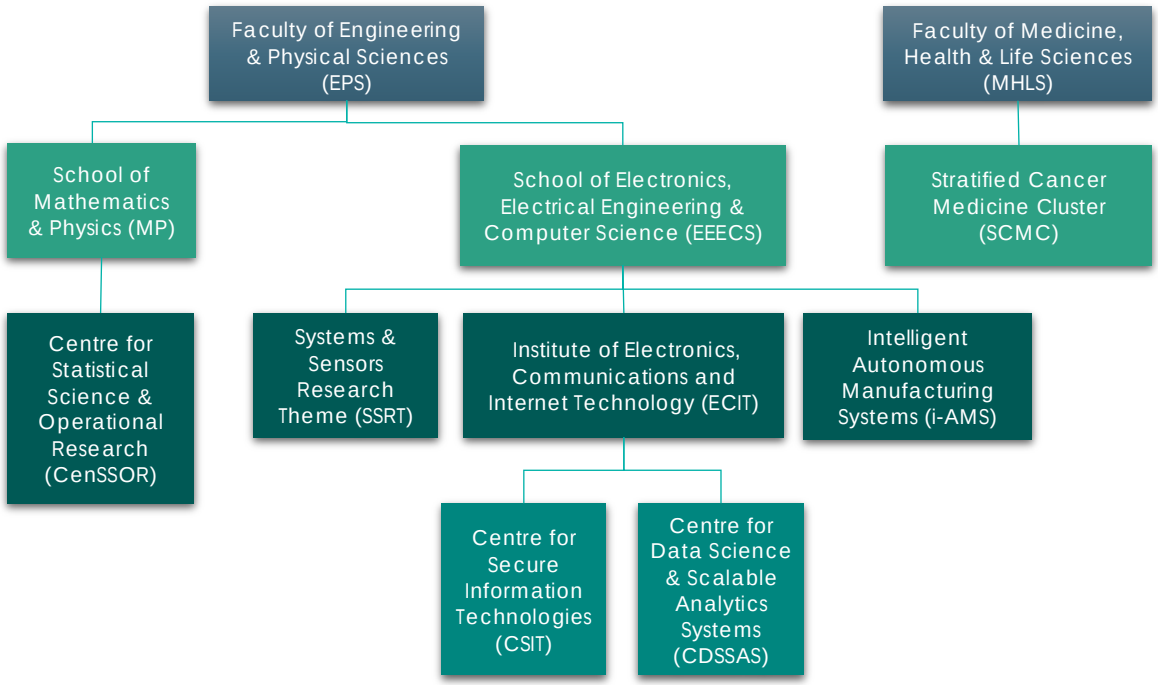
Key people: LIC is led by Professors Eugene McNamee (Law) and Kevin Curran (School of Computing). Curran's research interests include ambient intelligence and virtual worlds, cyber security, encryption, and ambient intelligence.

2.1.2 Queen's University Belfast

Research is conducted across a range of Faculties and Schools in QUB. Figure 3 shows the main centres of activity in the university (shaded areas). Within the Faculty of Engineering and Physical Sciences (EPS), a cluster of centres can be found in the School of Electronics, Electrical Engineering and Computer Science (EEECS), while the Centre for Statistical Science and Operational Research (CenSSOR), which focuses on statistical methods for the analysis of complex systems, is located in the School of Mathematics and Physics (MP).

Significant AI-related research focusing on applications of AI in healthcare is also undertaken in the Stratified Cancer Medicine Cluster (SCMC), which falls under the aegis of the Faculty of Medicine, Health and Life Sciences (MHLS). Smaller pockets of research activity can be found in the Schools of Biological Sciences, Natural and Built Environment and Chemical Engineering (not depicted in Figure 3). Overall, QUB estimates the total number of permanent staff involved in AI research to be approximately 50.

Figure 3. Principal Centres Involved in AI Research at QUB



School of Electronics, Electrical Engineering and Computer Science (EEECS)

Research in AI in the School of Electronics, Electrical Engineering and Computer Science (EEECS), located within the Faculty of Engineering and Physical Sciences, constitutes a core disciplinary activity and a central focus of work in a Systems and Sensors Research Theme (SSRT), a Global Research Institute, the Institute of Electronics, Communications and Information Technology (ECIT), and a Pioneer Research Programme, Intelligent Autonomous Manufacturing Systems (i-AMS).

Key people: The research director of EEECS is Professor Vince Fusco. His main research interests include wireless communications, autonomous vehicles, IoT, satellites, healthcare imaging and sensors.

Systems and Sensors Research Theme (SSRT)

The Systems and Sensors Research Theme, led by Professor Roger Woods, covers the capture of information through sensors, clever embedded systems to enhance processing at source, the creation of new algorithms to process information from a rich range of data sources, and approaches to extract information intelligently from these data for decision-making purposes. There is a strong application focus across the complete range of research activities and two spin-off companies, EventMAP Ltd. and Analytics Engines Ltd., have been created.

Key people: The research director of EEECS is Professor Roger Woods. His research interests include computing systems architectures, particularly those involving Field Programmable Gate Array (FPGA) technology, innovative telecommunications hardware platforms and acceleration of Big Data analytics. He is Founder and Chief Scientist of Analytics Engines, which provides scalable business data platforms for data analytics and management and won the 'ITLG Emerging Technology Award 2013' at the Global Technology Leaders Summit in the USA.

Institute of Electronics, Communications and Information Technology (ECIT)

The Institute of Electronics, Communications and Information Technology (ECIT) is the Global Institute located in EECS. It was established in 2004 as a research anchor for the Northern Ireland Science Park, with initial funding of over £37m. It is host to two centres that perform AI research: the Centre for Secure Information Technology (CSIT) and the Centre for Data Science and Scalable Computing (CDSSAS).

Key people: The director of ECIT is Professor Dimitrios Nikolopoulos, who is an expert in system software for large-scale computing and new computing paradigms. His research interests include scalable computing systems for data-driven applications. He is the recipient of a Royal Society Wolfson Research Merit Award, the NSF CAREER Award, the DOE CAREER Award, the IBM Faculty Award, and the SFI-DEL Investigator Award. He has Best Paper Awards from some of the premier IEEE and ACM conferences in his field.

Centre for Secure Information Technology (CSIT)

CSIT is the UK's National Innovation and Knowledge Centre (IKC) for cyber security. CSIT is one of seven UK 'Innovation and Knowledge Centres' established through a 2008 EPSRC funding call and was awarded a Queen's Anniversary Prize for Higher and Further Education. Its aim is to enable the commercialisation of ideas in an area of research strength.

CSIT's AI-related research areas include cryptographic systems, malware detection, intrusion detection and prevention, and frameworks for software systems and network security. CSIT is involved in coordinating a number of EU H2020 Research programme and has extensive links with international research groups in cyber security.

CSIT has a strong focus on the commercial exploitation of cyber security innovations. This is reflected in its collaborations with regional and international companies, including Allstate, BAE, Chemring, Cisco, GCHQ, IBM, Infosys, Intel and Thales. CSIT's ambition is to be the nucleus for an

emerging Belfast cyber cluster and to establish a global innovation hub for cyber security.

Key people: CSIT was founded by Professor John McCanny, FRS and is now led by Professor Maire O'Neill. Her research interests include hardware security and applied cryptography.

Centre for Data Science and Scalable Analytics Systems (CDSSAS)

CDSSAS undertakes research concerning the collection, storage, processing, querying, extraction, integration and analysis of heterogeneous forms of big data. Its AI research is mainly concentrated within two related thematic areas:

- **Cognitive Signal Processing and Data Science:** has a focus on the application of visual analytics, multi-modal signal processing and machine learning to recognise human activity in in video and in general anomaly detection;
- **Data Science:** has a focus on developing advanced data analytic algorithms, with applications in biomedical and financial data, and in data analytics in web-mining, including social media and graph mining.

CDSSAS has been part of major UK collaborations funded by UK research councils, including the flagship EPSRC/DSTL University Defence Research Centre (2013-2018).

Key people: CDSSAS is led by Professor Neil Robertson. His research interests include machine learning and deep learning for image/visual analytics, with expertise in face recognition. He is also a co-founder of AnyVision, whose main customers are in defence and security.

Centre for Intelligent Autonomous Manufacturing Systems (i-AMS)

The Centre for Intelligent Autonomous Manufacturing Systems (i-AMS) is a Pioneer Research Programme within EEECS that conducts interdisciplinary research on applications of AI in advanced manufacturing. It collaborates with regional industry partners in areas such as process monitoring, control and optimisation, time series prediction and in-line sensor characterisation. i-AMS's research is centred on three main thematic areas:

- **Virtual Sensing, Prognostics and Virtual Factory Simulations:** applications of big data and advanced data analytics for real-time assessment of machine performance, tool health and energy consumption, fleet level information sharing and integration to deliver

enhanced process monitoring and real-time fault detection. Research goals include zero-defect manufacturing and integrating data driven modelling of complex manufacturing systems to deliver comprehensive virtual factory models;

- **Flexible Automation and Robotics:** developing adaptive multi-robot/machine control, self-reconfiguration and self-calibration systems; capturing, modelling, predicting and anticipating human-robot interactions; designing distributed control and path planning algorithms to deliver flexible and safe multi-robot and human-robot collaborative working environments;

- **Autonomous and Intelligent Decision Making: design** of intelligent supervisory control and autonomous, real-time decision support systems able to respond to dynamically changing operating requirements and take account of enhanced situational awareness provided by virtual sensing, prognostic models and virtual factory model predictions. Applications include optimal decision making for maintenance scheduling, quality control and production planning. There is also interest in developing methodologies to capitalise on production flexibility to reduce energy consumption and/or deliver demand response services to the power system.

Key people: The director of I-AMS is Professor Sean McLoone. His research interests include automated optimisation and control using machine learning and AI algorithms, with a focus on engineering applications such as in smart-grid and advanced manufacturing informatics.

Centre for Statistical Science and Operational Research (CenSSOR)

CenSSOR is a research cluster within the School of Mathematics and Physics. CenSSOR research relevant to this review includes analytical methods that combine statistical, operational research and data mining techniques. Applications include fraud detection and capital market abuse, predictive maintenance in manufacturing processes, personalised medicine and healthcare planning. CenSSOR is also involved in the development of highly efficient algorithms.

Key people: The director of research for CenSSOR is Professor Adele Marshall. Her research interests include Survival Analysis, Bayesian Modelling, Data Mining, Markov Modelling, Stochastic Models, and Longitudinal Data and Analytics.

Stratified Cancer Medicine Cluster (SCMC)

The Stratified Cancer Medicine Cluster (SCMC) is involved in the application of data analytics to cancer research. Its research is focused on enabling precision medicine and modernising public health through approaches that involve computational genomics, digital imaging (through the Cancer Research UK Digital Pathology Accelerator led by Prof Manuel Salto-Tellez), actionable analytics and health economic/administrative data analysis (through the Administrative Data Research Centre (ADRC) led by Professor Dermot O'Reilly). Innovations in machine learning, actionable analytics, digital imaging and data 'integromics' have led to the development of high-throughput platforms for biomarker discovery and therapeutic development.

Health Data Research Wales-Northern Ireland (HDR Wales-NI), a partnership between QUB and the University of Swansea, is one of only six substantive sites of Health Data Research UK (HDRUK), the newly formed national health data science institute for the digital world. HDR Wales-NI is involved in the application of data analytics to address challenges in precision medicine and population health.

SCMC is a partner in the recently announced Science Foundation Ireland (SFI) Centre for Research Training in Genomics Data Science. It is also in active discussions with SFI on the potential for an all island AI initiative, and with Genomic Medicine Ireland (GMI) concerning potential collaborative projects.

Spin-outs that are exploiting SCMC's research include computational genomics applied to new treatment predictors (Almac Diagnostics) and computational vision algorithms for advanced digital pathology (PathXL, now owned by Philips). Sonrai Analytics – a spin-out from QUB involving personnel with roots in SCMC – is a partner in PathLAKE, the Warwick University led HDR UK digital pathology programme.

Key people: Professor Mark Lawler is Dean of Education for Medicine, Health and Life Sciences and holds a Chair in Translational Cancer Genomics at the Centre for Cancer Research and Cell Biology. He leads HDRUK's cancer data research strategy, building on programmes such as the MRC-CRUK funded Stratified Medicine in Colorectal Cancer Consortium, a pan-UK coalition (University of Oxford, QUB, University of Leeds, University of Birmingham, Kings College London, University College London, University of Aberdeen) to drive precision medicine in this common cancer. Professor Lawler is QUB's Principal Investigator and Co-Director of HDR Wales-NI, where he leads the Enabling Precision Medicine Theme. This will form a linked information network to comprehensively capture, interrogate and accumulate data at scale. He is

also leading the proposal for an All Island Interdisciplinary Programme on Data Driven Research to Enhance Human Health (iDATA-HEALTH) and is the NI lead on the HDRUK-Turing DTP proposal.

2.2 Academic Areas of Strength

This section looks at academic performance and assesses areas of strength in AI for each university. In the first instance, AI publication performance is considered at an institutional level. Secondly, research strength is assessed in different AI-related technical areas and clusters of AI research excellence are identified. Finally, commentaries are added on significant developments within each of the universities that aim to build on strengths.

The assessments of AI publication performance at an institutional level are based on the results of analyses of the AI publication performance of UK institutions during the current UK Research Excellence Framework (REF) timeframe (2014 – to date).

At the request of the review team, Elsevier provided two analyses of the AI publication performance of UK institutions over the UK REF timeframe commencing 2014[14]. Both were based on data contained in Scopus, the largest abstract and citation database of peer-reviewed literature, and analysed via the use of SciVal, a proprietary tool of Elsevier. The first analysis was based on a search of publications in the 216 journals included in the AI sub-category of the All Science Journal Classification Scheme (ASJC). The second analysis provided by Elsevier drew on a broader set of publications than those contained in the AI sub-category of the ASJC, though the data set was limited to publications dating from 2014 to 2017[15].

The assessments of research strength in different technical areas and the identification of clusters of research excellence draw heavily on an approach that made use of 'multiple partial converging indicators'[16]. This involved a number of steps:

A series of technical areas were defined based on terms used by The Alan Turing Institute to describe activities within the field of AI (see Table 1);

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[14] These analyses were conducted by Elsevier on a *pro bono* basis.

[15] A description of the procedure used to define this dataset can be found at https://www.elsevier.com/?a=829143.

[16] Martin, B. (1996), 'The Use of Multiple Indicators in the Assessment of Basic Research', Scientometrics, Vol 36, No 3, pp 343-362 https://sci2s.ugr.es/sites/default/files/files/TematicWebSites/hindex/Martin1996.pdf

Table 1. Technical Areas

Defined using terms used by The Alan Turing Institute to describe activities within the field of AI

Technical Area	Description
Core Data Science	Including theory, algorithms, methods
Economy	Including trade and fintech
Ethics	Including fairness, transparency
Government	Including policy applications
Hardware	Including HPC, scalable architectures, cloud computing
Humanities and Social Sciences	Including digital humanities, social data science
Multimedia Analytics	Including computational vision, natural language processing (NLP), text mining, speech recognition
IoT	Including smart devices and their applications
Medicine	Including health and wellbeing, clinical medicine, genomics, neurosciences, biosciences
Robotics	Including autonomous systems, advanced manufacturing
Cyber Security	Including threat detection, cryptographic methods, surveillance techniques
Engineering	Including civil engineering applications

- Scale of research effort in each technical area was assessed via an analysis of data on staff numbers and their research activities. To complement material provided by each of the universities, university web pages were scoured and Google Scholar searches conducted to identify individual researchers and build a profile of their research activities. These profiles were then used to locate and count researchers within the Turing technical areas;

- The publication profiles of researchers in each of the Turing technical areas were enhanced by conducting analyses of Scopus data[17] to identify all publications produced by them that had been included in the Artificial Intelligence sub-category of the ASJC during the current REF period. False positives were excluded and information amassed on citations and journal impact factors to build qualitative assessments of the strength of research activity in each technical area;

- These assessments were supplemented by detailed reviews of publications selected by the universities themselves as representative of their research strength;

- They were also complemented by judgements formulated during the course of interviews with academic researchers from UU and QUB, and by interviews with industry representatives concerning their appreciation of the work conducted by their academic collaborators.

On the basis of the evidence collected via these steps, the technical areas were located in a 3x3 matrix describing scale of AI research activity in each technical area along one dimension and the density of high-quality AI publications in each technical area along the other dimension. These activity maps were then used to differentiate between major and minor clusters of AI research excellence in each university and across both of them:

- **Major Clusters of AI Research Excellence:** these are clusters of significant scale (medium to high levels of publication activity) producing significant amounts of medium to high calibre research (i.e. producing significant amounts of 3-4 Star research in REF2021 terms);

- **Minor Clusters of AI Research Excellence:** smaller-scale clusters (low to medium levels of publication activity) but still producing significant amounts of medium to high calibre research (3-4 Star research in REF 2021 terms)

[17] These analyses were conducted by the review team.

2.2.1 Ulster University

Institutional AI Publication Performance

Based on a search of publications in the 216 journals included in the AI sub-category of the ASJC, UU researchers published 257 papers in AI, making it 14th in the UK rankings in terms of number of publications. Twelve percent of UU's AI publications were in the top 10% citation percentiles in AI, and UU had a Field-Weighted Citation Index (FWCI) of 1.02[18].

In the analysis of Scopus data provided by Elsevier that drew on a broader set of publications than those contained in the AI sub-category of the ASJC, the results for UU were very similar to those described above: UU was 16th in the UK rankings in terms of number of publications and had a slightly higher FWCI of 1.06.

The main conclusion to be drawn from the perspective of this review is that the overall publication performance of UU is impressive in terms of its scale and breadth.

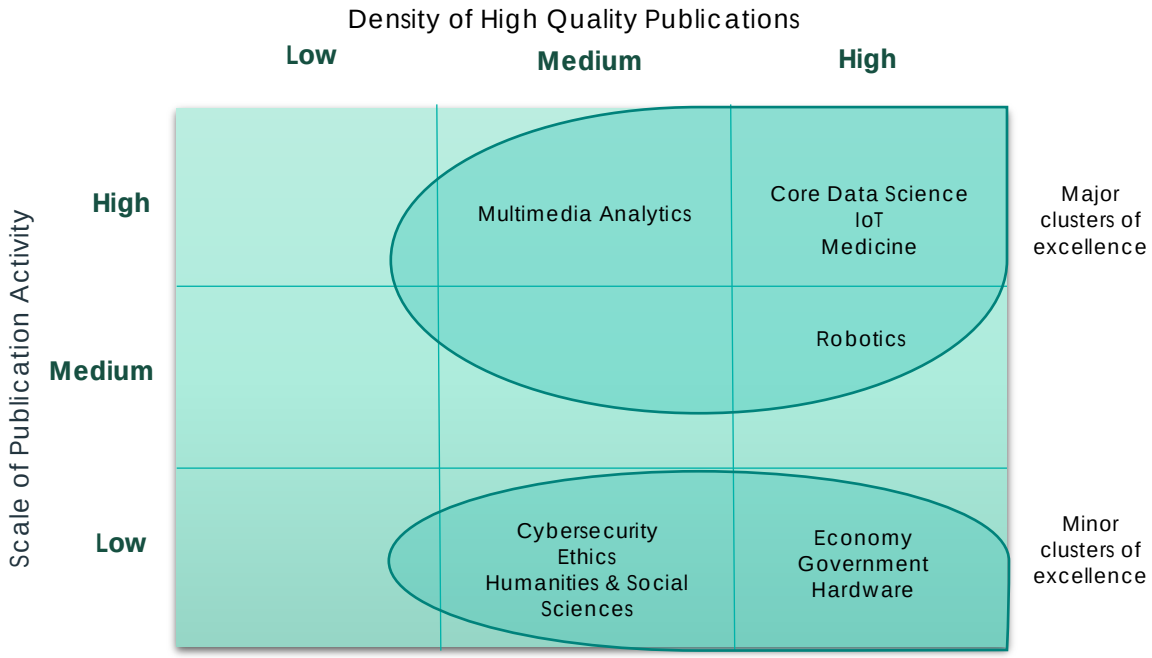
Clusters of AI Research Excellence

UU was ranked 48th overall out of 89 universities in the 2014 UK Research Excellence Framework results for the unit of assessment termed 'Computer Science and Informatics' (49th for quality and 25th for research power).

Our assessment of research strength in the current REF period in the narrower field of AI is depicted in Figure 4. This maps technical areas in a matrix depicting our assessments of the scale of research activity in each technical area along one dimension, and the density of high-quality publications in each technical area along the other.

[18] A Field-Weighted Citation Impact of greater than 1.00 indicates that the publications have been cited more than would be expected based on the world average for similar publications, for example a score of 1.10 means that the outputs have been cited 10% more times than expected.

Figure 4. Clusters of AI Research Excellence in UU



We identify eleven Clusters of AI Research Excellence: five Major Clusters of AI Research Excellence (Core Data Science; Internet of Things; Medicine; Robotics; and Multimedia Analytics) and six smaller Minor Clusters of AI Research Excellence (Economy; Government; Hardware; Cyber Security; Ethics; Humanities and Social Sciences).

Major Clusters of AI Research Excellence

Core Data Science

Liam Maguire (bio-inspired models for machine learning and AI); Sally McClean (Markov and semi-Markov models for optimisation of distributed database and cloud; anomaly detection, queuing management); Damien Coyle (bio-inspired models for machine learning and AI); Sonya Coleman (computational intelligence); KongFatt Wong-Lin (computational modelling and mathematical analysis of complex systems); Jun Li (formal logic, rule-based systems); Yaxin Bi (supervised and unsupervised machine learning-based classification systems and ensemble methods); David Glass (Bayesian inference, abductive reasoning, Bayesian networks, association rules); Jim Harkin (bio-inspired models for machine learning and AI); Martin McGinnity (machine learning); Hui Wang (methods); Darryl Charles (methods); Daniel Kelly (methods); Philip Morrow (methods); Ian Cleland (methods); Xuemei Ding (methods); Bryan Gardiner (methods); Glenn Hawe (ensemble methods); Junxiu Liu (spiking neural networks); Jose Santos (spiking neural networks); Mia Siddique (fuzzy logics) Jonathan Wade (spiking neural

networks); George Wilkie (fuzzy logics); Shengli Wu (methods for information retrieval).

Internet of Things

Girijesh Prasad (assistive technologies); Damien Coyle (brain-computer interfaces); Joan Condell (ambient intelligence, HCI); Chris Nugent (development and evaluation of technologies for ambient assisted living, activity recognition and behaviour modelling); Kevin Curran (activity recognition); Haiying Wang (activity recognition, smart devices, smart homes); Richard Davies (IoT); Daniel Kelly (IoT, smart sensors); Paul McCullagh (IoT, smart sensors); Philip Morrow (IoT); Maurice Mulvenna (IoT, smart sensors); Huiru Zheng (IoT, smart devices); Ian Cleland (smart sensors, biometrics); Roy Sterritt (IoT); Sally McClean (IoT, sensors); Raymond Bond (smart devices); Bryan Scotney (smart sensors); Mark Donnelly (smart sensors); Leo Galway (BCI); Gaye Lightbody (smart sensors, BCI); George Moore (smart sensors, health monitoring); Jonathan Synnott (smart sensors for health).

Medicine

Tony Bjourson (genomics based personalised medicine in cancer, autoimmune disease and pharmacogenomics); Shu Dong Zhang (development of bioinformatics methods and techniques and applications in biomedical sciences); Girijesh Prasad (brain modelling, brain-computer interfaces and neuro-rehabilitation); Liam McDaid (computational neuroscience); James McLaughlin (cardiology based medical diagnostics for cardiac arrest, heart failure and ubiquitous predictive monitoring); Sonya Coleman (neuroscience); Sally McClean (health applications in planning/optimisation); Kevin Curran (dementia studies); Joan Condell (biometrics); Dewar Finlay (cardiovascular medicine, computerised ECG analysis); KongFatt Wong-Lin (cognitive neuroscience); Raymond Bond (data science for health data analytics, modelling, processing and visualisation for clinical decision-making, decision support systems); Huiru Zheng (medical applications of machine learning); Fiona Browne (medical applications);); Jun Liu (neuroscience); Darryl Charles (health applications); Richard Davies (health applications of smart sensors); Jim Harkin (computational neuroscience); Daniel Kelly (health applications of smart sensors); Paul McCullagh (health monitoring); Martin McGinnity (computational neuroscience); Bryan Scotney (health applications of imaging); Prathheepan Yogarajah (biometrics); Michaela Black (health applications).

Robotics

Sonya Coleman (tactile sensing, swarm robotics, obstacle avoidance, sensing, planning, advanced manufacturing); Roy Sterritt (robotics, sensors,

optimisation); Damien Coyle (cognitive robotics, BCI); Sally McClean (monitoring, optimisation); Emmett Kerr (swarm robotics, autonomic systems); Jose Santos (robotics); George Wilkie (swarm robotics, obstacle avoidance, planning); Bryan Gardiner (tactile sensing, swarm robotics, obstacle avoidance, planning).

Multimedia Analytics

Sonya Coleman (image recognition); Bryan Scotney (image processing and computer vision, pattern recognition and classification); Hui Wang (image and vision applications of machine learning); Philip Morrow (computational vision); Zhiwei Lin (NLP, text mining); Pratheepan Yogarajah (image processing); Huiru Zheng (image processing); Bryan Gardiner (image processing); Dermot Kerr (neural computation for imaging)); Martin McGinnity (sentiment analysis).

Minor Clusters of AI Research Excellence

Economy

Sonya Coleman (fintech); Martin McGinnity (fintech); Xuemei Ding (fintech, forecasting, volatility modelling); Kevin Curran (economic modelling, sustainability).

Government

Sally McClean (modelling for policy); Glenn Hawe (government); Jonathan Wallace (data science for health policy); Michaela Black (data science for policy).

Hardware

Liam McDaid (bio-inspired architectures, fault tolerant architectures, neuromorphic hardware); Jim Harkin (hardware architectures for bio-inspired AI, fault tolerant architectures); Junxiu Liu (hardware architectures for bio-inspired AI, fault tolerant architectures); Liam Maguire (fault tolerant architectures).

Cyber Security

Kevin Curran (cyber security, encryption, steganography; location awareness); Joan Condell (cyber security); Chris Nugent (cyber security); Pratheepan Yogarajah (cyber security); Omar Nibouche (cyber security); Paul McKevitt (steganography).

Ethics

Raymond Bond (ethics); Yaxin Bi (ethics).

Humanities and Social Sciences

Michael Callaghan (digital humanities); Darryl Charles (digital humanities); Glenn Hawe (agent-based simulation, emergency response); Kevin Curran (technology impact; service innovation).

Building on Strengths

Brain-computer interface (BCI) and bio-inspired machine learning are distinctive areas of AI research in UU that are not currently represented within The Alan Turing Institute research portfolio.

BCI research aims to develop ways for the human brain to communicate directly with computational devices. Applications of BCI include assistive devices for people with physical disabilities and devices aimed at restoring neurological function – in vision, for example. A search of Google Scholar revealed over 34,000 publications globally in BCI since 2000 and 19,000 since 2010, so this is clearly an important, developing area. UU researchers have published over 100 papers in BCI since 2015, which is indicative of the institution's strength in this field. The exploitation of UU's BCI research through NeuroCONCISE will be the focus of a REF 2021 impact case study.

Bio-inspired machine learning aims to exploit the growing understanding of natural individual (i.e. neurological) and social (i.e. self-organising) computational systems to develop more powerful and resilient AI. UU is making notable contributions in bio-inspired machine learning in two specific areas.

The first is in the field of spiking neural networks (SNNs), which aim to imitate the behaviour of natural neural networks more faithfully. Among other advantages, SNNs have lower latency and are more energy efficient than conventional artificial neural networks (ANNs). A search of Google Scholar revealed that there have been 11,500 publications globally in spiking neural networks since 2000, of which 9,470 date from 2010 and 5,540 date from 2015, strongly suggesting that this is a core field of AI that is of growing interest and importance. Moreover, UU researchers have published over 30 papers in this field since 2015, including several appearing in journals categorised as A* in the CORE journal database[19];

The second area of bio-inspired machine learning in which UU is making a distinctive contribution is self-repairing neural network architectures, which have important applications in environments where high reliability is critical,

[19] http://www.core.edu.au/conference-portal

such as autonomous vehicles. A Google Scholar search revealed that there have been 1,680 publications in this area globally since 2000, of which 961 date from 2010 and 458 from 2015. In this field, UU researchers have published over 20 papers since 2015.

The papers emanating from UU in these two areas are indicative of its strengths in bio-inspired machine learning. Moreover, the fact that UU occupies a position of leadership in this realm places the UK in a favourable position as the field develops, since some observers now predict that it will become increasingly important for the development of more powerful and resilient AI techniques and applications[20].

The current investment in 12 new academic posts associated with CARL will help to deliver on UU's ambitions to be in the top 10 in the UK for computer science research in REF2021, but UU also aims to grow CARL over the next 5 years to become a 200 strong, world-leading centre of excellence in Cognitive Analytics, attracting leading experts in the global research community. In pursuit of this goal, as part of its submission for funding from the Derry-Londonderry City Deal, UU has proposed the construction of a landmark 2,500m^2 building on the Magee campus to house the existing staff of CARL and facilitate its further growth.

This would be located strategically in Derry/Londonderry to leverage synergies with other research expertise in Stratified Medicine, Intelligent Systems, Robotics and automation and Data Analytics. It would also complement proposed investment in the Northern Ireland Graduate Entry Medical School ("NIGEMS"), the Centre for Industry Digitalisation Robotics and Automation ("CIDRA"), and the Transformation for Healthcare Innovation and Value Based Ecosystem (T-HIVE"), with CARL providing the specialist AI skills and analysis across all three of these projects.

CARL aims to place UU on a footing that will significantly increase its standing as a centre of excellence in AI. These aspirations have been boosted by a recent philanthropic donation of £5m that will allow the university to establish the Dr George Moore Chair in Data Analytics, an associated research fellow and 3 PhD students, all of whom will contribute to AI and data analytics research.

Funding for T-HIVE is also being sought in UU's Derry-Londonderry City Deal submission. T-HIVE is a research-led, industry-facing research facility

[20] Aimone, J.B. (2019), 'Neural Algorithms and Computing beyond Moore's Law', Communications of the ACM, 62(4), pp110-110

developed in response to the strategic needs of the Northern Ireland health and life science industry. The focus of T-HIVE is personalised medicine, which aims to address postponing the age of disease onset, providing more accurate disease diagnostics and better targeting of smart personalised treatments at an individual participant level, particularly as it applies to an aging population. T-HIVE complements a developing partnership between UU and QUB that is scheduled to be launched at BIO 2019 in June 2019.

T-HIVE will conduct a longitudinal study over 10-20 years using a combination of participant data from (a) health & lifestyle devices and Apps capturing physical activity, mental state, diet and location information; (b) secure clinical data from GP and hospital records and (c) genome mapping and/or sequencing. This data will have commercial value and will be important for discovery of health status and for new biomarker discovery. It will also serve as a highly valuable registry of potential participants for inclusion in clinical trials in commercial partnerships with diagnostic and pharma companies.

The Digital Health Technology Hub at Jordanstown is a £55m investment that will focus on data analysis underpinned by machine learning for algorithm development. It will bring together expertise from CHIC, CACR, the BioDevices Lab (a strategic partnership between Invest Northern Ireland, Ulster University, Randox Laboratories and Heartsine Technologies that was established in 2017 to assist companies to develop prototypes for the biomedical, engineering, electronic device and aerospace sectors) and the Eastern Corridor Medical Engineering Centre (a cross border research project with partners in Northern Ireland, Republic of Ireland and Scotland) to facilitate the rapid development and application of technologies such as wearable sensors and implantable devices.

2.2.2 Queen's University Belfast

Institutional AI Publication Performance

Based on Elsevier's search of publications included in the Artificial Intelligence sub-category of the ASJC from 2014 to the present day, QUB researchers published 156 papers in AI, making it 35th in the UK rankings in terms of number of publications. Almost ten percent of QUB's AI publications were in the top 10% citation percentiles in AI, and QUB had a Field-Weighted Citation Index (FWCI) of 1.04.

In the additional analysis provided by Elsevier to the review team, which only covered publications dating from 2014 to 2017 but drew on a broader set of publications than those included in the AI sub-category of the ASJC, the results for QUB were similar to those described above in terms of number of publications, with QUB 31st in the UK rankings. The FWCI, however, was

significantly higher (2.61), largely because the new, exploratory approach of Elsevier picked up some very highly cited AI papers in conference proceedings and journals not included in the AI sub-category of ASJC[21].

Once again, in line with our assessment of the publication performance of UU, the main conclusion to be drawn from the perspective of this review is that the overall publication performance of QUB is impressive in terms of scale and calibre.

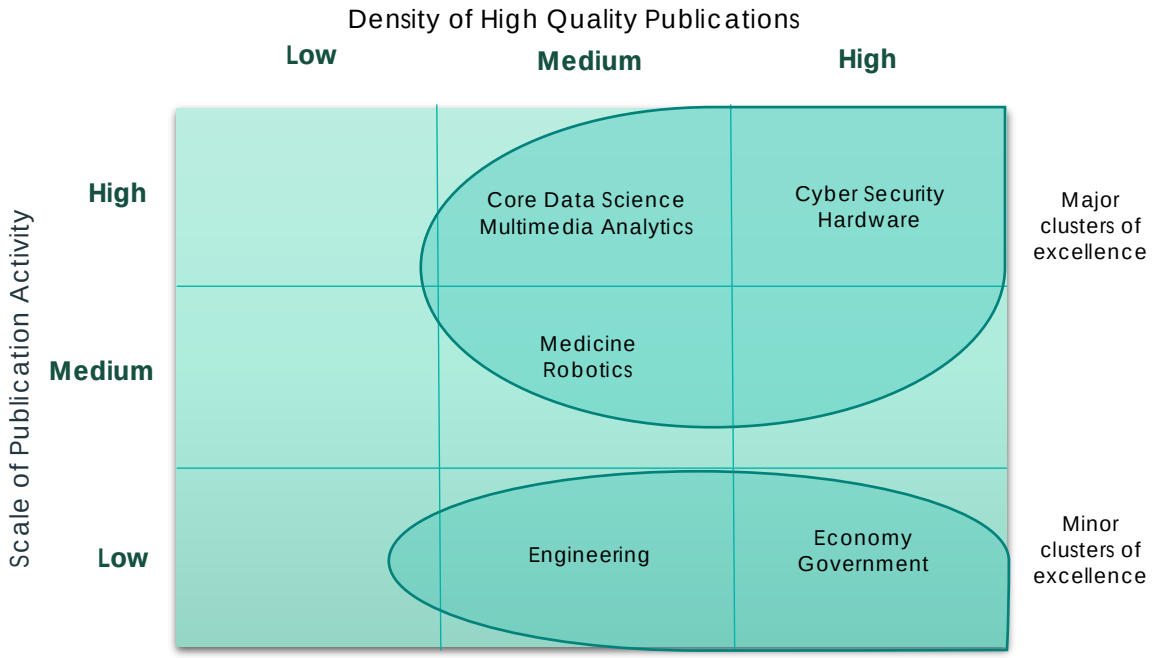
Clusters of AI Research Excellence

QUB was ranked 38th overall out of 89 universities in the 2014 UK REF results for the unit of assessment termed 'Computer Science and Informatics' (44th for quality and 37th for power).

Our assessment of research strength in the current REF period in the narrower field of AI is depicted in Figure 5. This maps technical areas in a matrix depicting our assessments of the scale of research activity in each technical area along one dimension, and the density of high-quality publications in each technical area along the other.

[21] The ten most cited QUB entries that were not included in the ASJC dataset accounted for over a third of all citations in both datasets combined. This goes some way to explaining the higher FWCI when the new Elsevier approach is used.

Figure 5. Clusters of Research Excellence in QUB



We identify nine Clusters of AI Research Excellence: six Major Clusters of AI Research Excellence (Cyber Security; Hardware; Core Data Science; Multimedia Analytics; Medicine; Robotics) and three smaller Minor Clusters of AI Research Excellence (Economy; Government; Engineering).

Major Clusters of AI Research Excellence

Cyber Security

Sakir Sezer (traffic forensics and anomaly detection in networks); Maire O'Neill (cryptography); Paul Miller (intelligent surveillance systems, anomalous behaviour in networks); Kieran McLaughlin (cyber security); Philip O'Kane (cyber security); Sandra Scott-Hayward (security protocols and architectures); Neil Hanley (secure hardware); John McCanny (cyber security); David Laverty (cyber security); John Morrow (grid security); Anna Jurek-Loughrey (malware detection).

Hardware

Dimitrios Nikolopoulos (HPC, cloud); John McCanny (High performance chip architectures); Roger Woods (edge computing); Peter Kilpatrick (HPC for data science); Hans Vandierendonck (HPC and cloud computing for data science); Charles Gillan (scaling algorithms); Blesson Varghese (cloud, edge computing); Ivor Spence (HPC); Georgios Karakonstantis (cloud, edge computing); John McAllister (signal processing architectures).

Core Data Science

Adele Marshall (survival analysis, bayesian modelling, data mining, Markov modelling, stochastic models, longitudinal data analysis); Barry McCollum (scheduling methods); Karen Rafferty (machine learning algorithm theory); Cassio de Campos (Machine learning); Charles Gillan (methods); Salissou Moutari (methods); Karen Cairns (methods); Barry Devereaux (deep learning); Neil Robertson (deep learning); George Irwin (methods); Niall McLaughlin (methods); Jesus Martinez del Rincon (methods); Ming Ji (wide learning).

Multimedia Analytics

Neil Robertson (deep machine learning and vision); Karen Rafferty (imaging, augmented reality); Huiyu Zhou (image processing); Danny Crookes (image processing); Yang Hua (vision, tracking and human behaviour learning); Jesus Martinez del Rincon (deep machine learning and vision); Ji Ming (speech and image processing); Darryl Stewart (speech recognition); Garry McKeown (behavioural science); Niall McLaughlin (imaging); Barry Devereaux (NLP, deep learning); Paul Miller (imaging); Anna Jurek-Loughrey (sentiment analysis, social media information diffusion, information retrieval); Ming Ji (speech recognition, face recognition, image retrieval).

Medicine

Mark Lawler (precision medicine); Brian Murphy (machine learning and Health Informatics); Barry Devereaux (neuroscience, health informatics); Frank Kee (public health) Karen Cairns (biostatistics); Salissou Moutari (statistical modelling); Chris Elliot (food safety); Katrina Campbell (environmental monitoring); Cuong Cao (biohazards); Moira Dean (public health, food security); Jesus Martinez del Rincon (medical applications of computer vision); Charles Gillan (health applications); Karen Rafferty (medical applications of computer vision); Alberto Longo (public health); George Hutchinson (public health); Anna Jurek-Loughrey (public health communication).

Robotics

Sean McLoone (automated optimisation and control using machine learning and AI); Adrian Murphy (virtual factory simulation); Kang Li (Intelligent Systems); George Irwin (AI for control, autonomous systems); Yan Jin (robotics, planning/scheduling); Wasif Naeem (autonomous systems, robotics, control); Vien Ngo (Machine learning and robotics); Stuart Ferguson (robotics); Liu Xueqin (robotics); Salissou Moutari (simulation); Karen Rafferty (robotics).

Minor Clusters of AI Research Excellence

Economy

Alberto Longo (environmental economics, urban regeneration); Frank Kee (urban regeneration and health); George Hutchinson (environmental economics); Moira Dean (food supply chains, marketing, sustainability).

Government

Frank Kee (public health policy); Moira Dean (food security policy).

Engineering

Su Taylor (built environment); Jennifer McKinley (built environment).

Building on Strengths

QUB has recently announced the creation of the Global Innovation Institute (GII), to be funded as a consequence of the successful Belfast City Deal. GII will bring ECIT together with the Institutes of Health Sciences (IHS) and Global Food Security (IGFS) to stimulate innovation in regional priority growth sectors such as Health and Life Sciences and Agri-food. AI infrastructure provision will include a peta-scale supercomputer and a 'best-in class' real-time 'AI Cloud'. The aim is to harness AI Cloud capability and associated academic expertise through ECIT's established partnership model with a view to growing both the existing cyber cluster and the regional data analytics and wireless/networks sectors.

As a response to research in AI and allied areas being too siloed in QUB, ECIT set out to become a centralised focus for QUB's research in AI. It is encouraging, therefore, to see that ECIT is working to complement its reputation in traditional High-Performance Computing (HPC) with research into scalable architectures for computing (e.g. cloud), edge computing and data management for AI, as these will be essential if QUB is to continue to meet the needs of its own researchers and regional businesses as applications of AI and data analytics develop.

CSIT has spearheaded the growth of the cyber security sector in Northern Ireland and now has approximately 90 staff in a dedicated building in Belfast. It acts as a magnet for Foreign Direct Investment (FDI) and as a platform for spin-outs and the potential for continued leadership in its field is substantial. Its pioneering 'open innovation' model and rapid development of a cluster of 40 cyber companies is also being used as a model for the development of the new GII at QUB.

CDSSAS has strength in depth in machine learning algorithms and in a range of applications of AI, including health informatics and computational vision,

and the potential for consolidation and growth is significant in these fields. It actively pursues commercialisation of its research through knowledge transfer projects and has a number of important collaborations with regional and international businesses, including Allstate, which is using AI to analyse customer interactions and to detect insurance fraud.

i-AMS has breadth and depth in research into applications of AI in advanced manufacturing. Many projects are undertaken in collaboration with industry in areas such as process monitoring, control and optimisation, time series prediction and in-line sensor characterisation. Current applications are in advanced manufacturing informatics, energy and sustainability. I-AMS is expected to link with, and benefit from, the establishment of a new Advanced Manufacturing Innovation Centre (AMIC), plans for which constituted part of a submission by QUB and other partners (including UU) to establish a centre that would operate at the interface between academia and industry and become a springboard for manufacturing innovation within the region.

Beyond the EEECS cluster, SCMC is showing growing leadership in the application of data analytics to cancer research, including computational genomics and image analysis for digital pathology. Its partnership in the recently announced HDR Wales and Northern Ireland promises to accelerate its progress in these areas.

Foundational research in methods for AI does take place outside the EEECS cluster, but there is a stronger emphasis (as demonstrated by, for example, the work of CenSSOR) on exploring ways of adapting established methods, such as Markov models and Bayesian modelling, to solve emerging practical challenges in data analysis. Similarly, CDSSAS has developed expertise in matching deep learning architectures to data and problems. NLP is one area where there is less evidence of a clear focus, though QUB has active collaborations with companies providing NLP applications and there is scope for further development in this sphere.

2.2.3 Overview of Academic Strengths in UU and QUB

Institutional AI Publication Performance across the Region

In terms of publication performance, Elsevier provided the review team with key metrics concerning the combined performance of UU and QUB during the current ref period[22]. As a combined entity, UU/QUB ranks 6th in the UK in

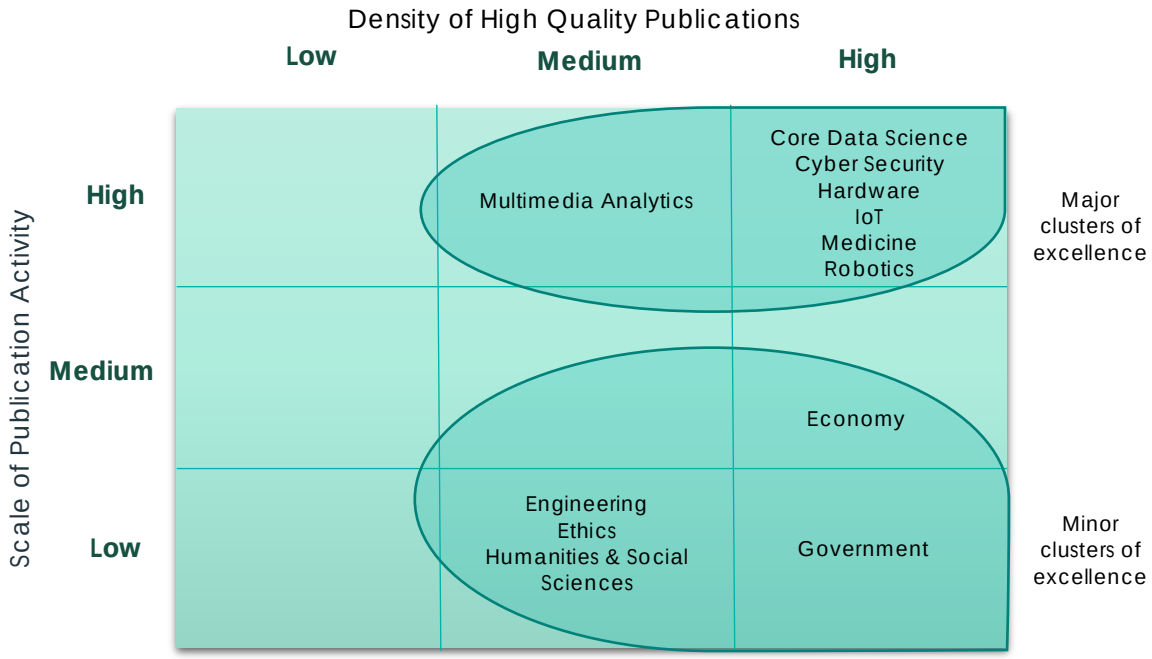
[22] This analysis used the AI ASJC journal set and covered publications from 2014-17, with citations up to the present date.

terms of AI outputs, 9th in terms of publications in Top Journal percentiles; 11th in terms of outputs in Top Citation percentiles; and 12th in terms of Citation Count. There is no doubt, therefore, that UU and QUB together constitute a major force in the AI research field in the UK.

Regional Clusters of AI Research Excellence

Figure 6 shows the results of combining the data underpinning Figures 4 and 5 to show Clusters of AI Research Excellence across both UU and QUB.

Figure 6. Regional Clusters of AI Research Excellence (across UU and QUB)



At a regional level, we identify twelve Clusters of AI Research Excellence: eight Major Clusters of AI Research Excellence (Core Data Science; Cyber Security; Hardware; Internet of Things; Medicine; Robotics; Economy; Multimedia Analytics; and four smaller Minor Clusters of AI Research Excellence (Government; Engineering; Ethics; Humanities and Social Sciences).

2.3 Academic-Industry AI Linkages

2.3.1 Ulster University

UU has a number of well-established collaborations with industrial partners, including large multi-nationals (e.g. Allstate, Seagate, Ernst & Young, Pramerica, BT, Amazon Web Services), large indigenous firms (e.g. Kainos), and regional SMEs (e.g. Nightingale Analytics, ActionSense).

The establishment of the BT Ireland Innovation Centre (BTIIC) is particularly noteworthy as evidence of UU's strengths in application-oriented AI, data analytics, cloud computing, optimisation, vision systems, resilient communications, smart environments and big data analytics. BTIIC was launched in November 2017 and is a partnership between BT and the Centre for Computer Science. With a total investment of £28.6m, it will create 25 new research posts and is the first of its kind in the UK established by BT outside Cambridge. The focus will be on advanced R&D in a number of core technology areas related to future telecommunication networks and services, including Future Big Data Analytics, Internet of Things (IoT), Cyber Security, Fixed and Mobile Network services and new products and service development.

UU is also one of just eight UK universities to form a major five-year Data Science Research Partnership with the BBC that aims to unlock the potential of data analysis in the media. The university's advanced research into machine learning, data-driven journalism and viewer engagement will be of particular relevance to the partnership.

UU has been active in launching spin-outs in AI. These include:

- **Intelesens**, a NIBEC spin-out, which uses AI and machine learning in wireless wearable ECG and respiration rate detection systems and associated algorithms;
- **Heartsine Technologies**, another NIBEC spin-out (now owned by Stryker Corporation), has developed Automated External Defibrillators using arrhythmia detection and defibrillation algorithms);
- **NeuroCONCISE** (Professor Damian Coyle), which has invented a wearable neuro-technology that interprets brainwaves and translates them into control signals for BCI. People will be able to use the technology NeuroCONCISE is developing to interact with computers without moving, with applications for people with disabilities;
- **ActionSense** (Joan Condell, CEO), which is developing wearable sensor devices and systems;
- **axial3d** (Nial Haslam, CTO), a Northern Ireland based medical technology firm focused on driving the global adoption of 3D Printing within healthcare;

- **Nightingale Analytics**, which is licensing IP created by ISRC to develop a predictive tool for dementia. They will be shortly be launching a service for GPs to diagnose dementia online;
- **Datactics** (Jens Rasch), which develops software platforms that profile, cleanse and reformat data for intelligent analytics for industry, banking and finance, government and healthcare sectors;
- **Performa Sports**, which has developed a real-time analysis application and integrated Cloud analysis platform that helps coaches and players to assess and improve individual and team performance in sports.

UU also hosts a number of AI-related Knowledge Transfer Partnership (KTP) projects with local SMEs, including axial3d. Indeed, in 2015 UU was ranked sixth out of 140 KTP providers across the UK, having been involved in 193 KTPs between 1985-2014[23].

AI-related KTP projects include work with:

- **Axis Bioservices Ltd:** To develop a system for 3D modelling and measurement of tumours grown on mice/rats via sophisticated image processing algorithms, increasing the accuracy and robustness of measurements;
- **Axial Medical Printing Ltd:** Development of a 3D web-based visualisation system, for use by medical professionals, enabling realistic and accurate representation of anatomy at a pre-production stage;
- **Verbal Arts Centre:** The objective is to extend the current accredited, curated, shared reading experience intervention called Reading Rooms Affective Bibliotherapy Model by the development of a new digital, chatbot-based technology platform;
- **Kraydel Ltd:** This KTP will develop the core underpinning AI algorithms as well as an intuitive Chatbot voice interface. Kraydel's modular low-cost

[23] WECD (2015), The Impacts of KTP Associates and Knowledge Base on the UK Economy, p10 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/467141/KTP_Report_July_2015__1-SEP-15_.pdf

platform and service solutions for the elderly to live well and safely in their own homes;

- **Datactics Ltd:** This project will extend the current capabilities of Datactics data quality application "Flow Designer" to provide data discovery, profiling and predictive capabilities using machine learning;
- **Sandvik Ltd:** Sandvik mobile crushers and screeners vision is to be class leading in automation and digitalisation. Sandvik has recently deployed Telematics across the range. This project is to develop advanced data analytics and visualisation tools to provide competitive advantage for Sandvik and end customers;
- **MetroCCTV:** To develop a unique cloud-based video surveillance system for people and vehicle detection using sophisticated, advanced image processing algorithms, to increase the accuracy and robustness of detection with potential to have significant commercial and social impact with global reach;
- **B-Secure:** This project aims to deliver the next generation of health data driven algorithms. The algorithms will make use of emerging signal processing and machine learning techniques to allow analysis of human vital signs in order to reveal patterns that will indicate well-being;
- **Cirdan Imaging Ltd:** To develop a novel user-centric digital platform for stakeholder engagement to optimise in-house Laboratory Information Systems design and increase product fit in marketplace;
- **CDE Global Ltd:** The project will develop a Smart Data Mining System (SDMS) for inclusion within the current and future range of CDE machines. The SDMS will provide vital design and performance information for designers and users of the equipment;
- **James Leckey Design Ltd:** To develop and embed the skills and knowledge necessary to successfully integrate existing and emerging technologies into new Leckey products and understand how data gathered can be used to provide evidence for clinical practice within paediatrics.

2.3.2 Queen's University Belfast

QUB AI research benefits from strong collaborations with an impressive and diverse range of companies, including large multi-nationals (Seagate, Philips,

Allstate, Citi, Xlinx) and regional SMEs (e.g. Ampliphae, Camlin). Its academics have also been active in launching spin-outs. These include:

- **AnyVision** (Neil Robertson, CTO), which has emerged as a world leading technology provider of real-time face recognition for surveillance and has offices in Belfast, Tel-Aviv and Singapore;
- **BrainWaveBank** (Brian Murphy, CSO), which is developing a neuroscience platform to track cognitive fitness outside of the lab by creating a low-cost wearable EEG recording headset to detect non-concussive cognitive impairments in sport and the early detection of cognitive decline;
- **Analytic Engines** (Roger Woods, CSO), which has developed XDP, a flexible, modular re-targetable data platform that enables data curation, orchestration and analytics with applications in, e.g. information extraction from unstructured text and fraud detection;
- **Sonrai Analytics**, which has developed an integrative software solution for big data analytics;
- **PathXL** (now Philips-owned), which has developed novel image analysis algorithms for digital pathology;
- **Almac Diagnostics** (Tim Davidson), which has applied advanced computational genomics for treatment prediction;
- **Yedup** (Martin Spollen, CEO), which focuses on real time news and events analytics for time-critical applications in finance.

In 2015, QUB was the leading KTP provider in the UK, having participated in 322 KTPs between 1985-2014[24]. Recent AI-related KTP projects include:

- **Adoreboard**. Developing and commercialising advanced big data analytics for optimisation of emotional analysis;
- **Sensumco.** Using multimodal biometric data across a range of contextual circumstances, including signal to noise identification and

[24] WECD (2015), The Impacts of KTP Associates and Knowledge Base on the UK Economy, p10 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/467141/KTP_Report_July_2015__1-SEP-15_.pdf

multimodal data investigation to understand emotional biometric response;

- **Sensumco.** Building artificial intelligence models of felt emotion (Emotion AI) by combining evidence from human body, face and vocal sources. These models aim to reveal motivations and behaviours of people with uses in many industries, e.g., health and wellbeing, sports performance, entertainment, and market research;
- **Limitless Digital Solutions Limited.** Developing a prescriptive analytics platform for retailers to allow the delivery of location-based offers that are personalised and relevant to customers. This will happen live in store which is its USP. No app will be required as the system will be able to analyse data through instore Wi Fi networks and communicate through text or e mail;
- **Linden Foods Limited.** To investigate and embed world class manufacturing and robotics technology within the production process;
- **Thompson Aero Seating Ltd.** To develop high efficiency, flexible 'Smart Factory' capability based on Industry 4.0 connectivity, Analysis and Optimisation Techniques;
- **Ampliphae Ltd.** To develop techniques and algorithms which can detect enterprise security threats and exposures by analysis of network traffic patterns;
- **Cirdan Imaging Ltd.** Enhancing Pathology Medical device products with clinical expert intelligence derived from embedded Deep learning system;
- **Pearlai Ltd.** The aim of the project is to apply advanced analytics to enhance business value and understanding of consumer behaviour;
- **GLT Ltd.** Develop a novel business model/management tool that will utilise data analysis techniques in order to gain market insights that will enable GLT to predict the probability of success for their business portfolios;
- **Precision Livestock Management Ltd.** Apply advanced animal sensor technology and associated engineering methods to develop a next generation rumen bolus for cattle that will provide information on pH and temperature to be used to improve cattle performance, health and welfare.

2.3.3 Overview of Regional Academic-Industry AI Linkages

Both UU and QUB have significant linkages with industry in terms of spin-off activity and collaboration with multi-national and regional SMEs, indicative of the strong application focus of AI research within the two universities, its relevance to industry in the region and the potential for significant impacts on the local economy. For both to rank in the top 6 KTP providers over the period 1985-2014 says a great deal about the existence of strong academic-industry links in the region.

Linkages appear particularly strong in the areas that we have designated as Major Clusters of AI Research Excellence, especially cyber security, medicine and Internet of Things. There is also substantial and significant activity in areas such as fintech, robotics, multimedia analytics and data services. Fintech, in particular, is primed to grow significantly given the numerous academic linkages with companies in the Northern Ireland fintech sector (Citi, Allstate, Pramerica, First Derivatives, Ernst & Young), many established and nurtured in the Capital Markets Collaborative Network, a joint initiative between QUB and UU and the fintech sector.

Several multinationals collaborate with both QUB and UU. UU researchers for example, frequently work with firms in the cyber security area (e.g. Allstate, Deloittes, IBM, Liberty Mutual, Metacompliance and PwC) that also collaborate with CSIT at QUB. Amongst SMEs, however, this review detected a tendency for firms to work either with QUB or with UU, but not with both. Typically, collaborations came about as a consequence of informal contacts rather than planned searches for relevant sources of expertise, with subsequent familiarity favouring continued collaboration and the establishment of patterns of behaviour linking SMEs with just one or the other of the two universities.

2.4 Industrial AI Activities

2.4.1 Levels of Activity

Discussion partners during the course of this review estimated that approximately 80-90 companies are currently involved in AI development in Northern Ireland. These include:

- Companies with a group turnover in excess of £7m such as Allstate, Kainos, Citi, BT and PWC;
- Companies with a turnover between £1m and £7m such as Etain and RepKnight;
- Companies with a turnover of under £1m such as Analytics Engines, Serafim and Big Motive;
- Early stage companies such as Cyberlytic, Kraydel and axial3D.

This review, which included interviews and discussions with 29 representatives of 23 firms either developing or using AI in Northern Ireland, found extensive evidence that the Northern Ireland business sector is very active in the development AI and its application in products, processes and services. Established businesses are looking to use AI to improve their business processes (BT, Seagate, Citi, Ernst & Young, Allstate), while new SMEs (many starting life as academic spin-outs) are working vigorously to advance and compete in rapidly emerging new markets for AI-driven products and services. Noteworthy examples of successful endeavours include Kainos (digital platforms and services for AI), PathXL (digital pathology), Sonrai (computational vision for digital pathology), Yedup (real time news and events analytics for time-critical applications in finance and best Fintech start-up in Ireland in the 2017 Bank of Ireland Awards), and Analytics Engines (scalable business data platforms for data analytics and management).

2.4.2 Levels of Interest and Expectation

As elsewhere, many businesses in the region have yet to investigate and/or make decisions about the relevance and value of AI either to themselves or their customers. Interest is undoubtedly growing, however, and this review found impressive evidence of activities designed to raise awareness amongst regional businesses of the opportunities presented by AI. The activities of Artificial Intelligence Northern Ireland (AI NI), an organisation set up to network the Northern Ireland AI community, are particularly noteworthy. In a very short period of time, AI NI has succeeded in creating a large network of more than 1000 individuals drawn from many different sectors of the Northern

Ireland economy, supporting them via the organisation of awareness raising meetings, training events and hackathons.

In terms of the growth of interest amongst firms, Austin Tanney, one of the co-founders of AI NI, is also the facilitator of the Northern Ireland Artificial Intelligence Collaborative Network, which he estimates is likely to grow from just over 20 companies to more than 60 companies as it enters a second phase of its existence.

Amongst firms already active in AI development, this review also detected a welcome degree of confidence in their own ability to meet rising expectations concerning the potential of AI. In the past, the promise of AI has often been oversold in many quarters and developers have not been able to meet the expectations of users. Currently this does not appear to be the case in Northern Ireland.

Neither does it appear to be the case elsewhere in the UK. As noted in the recent report by Dame Wendy Hall and Jérôme Pesenti[25], expectations about the capability of AI to transform both businesses and the public sector are high across the UK and significant investment (both private and public) is riding on the current generation of AI technologies being successful.

Grounds for optimism exist because:

- The new generation of AI technologies has matured rapidly, and these technologies are now available to businesses as 'commodity' solutions;
- The computational infrastructure AI requires (compute and data storage) is now available through cloud computing in ways that are both sufficiently scalable and cheap enough for businesses companies to develop and apply AI in their products and services;
- New forms of data are now abundantly available;
- Statistical machine learning and natural language processing have eliminated some of the bottlenecks that hampered the previous generation of AI technologies.

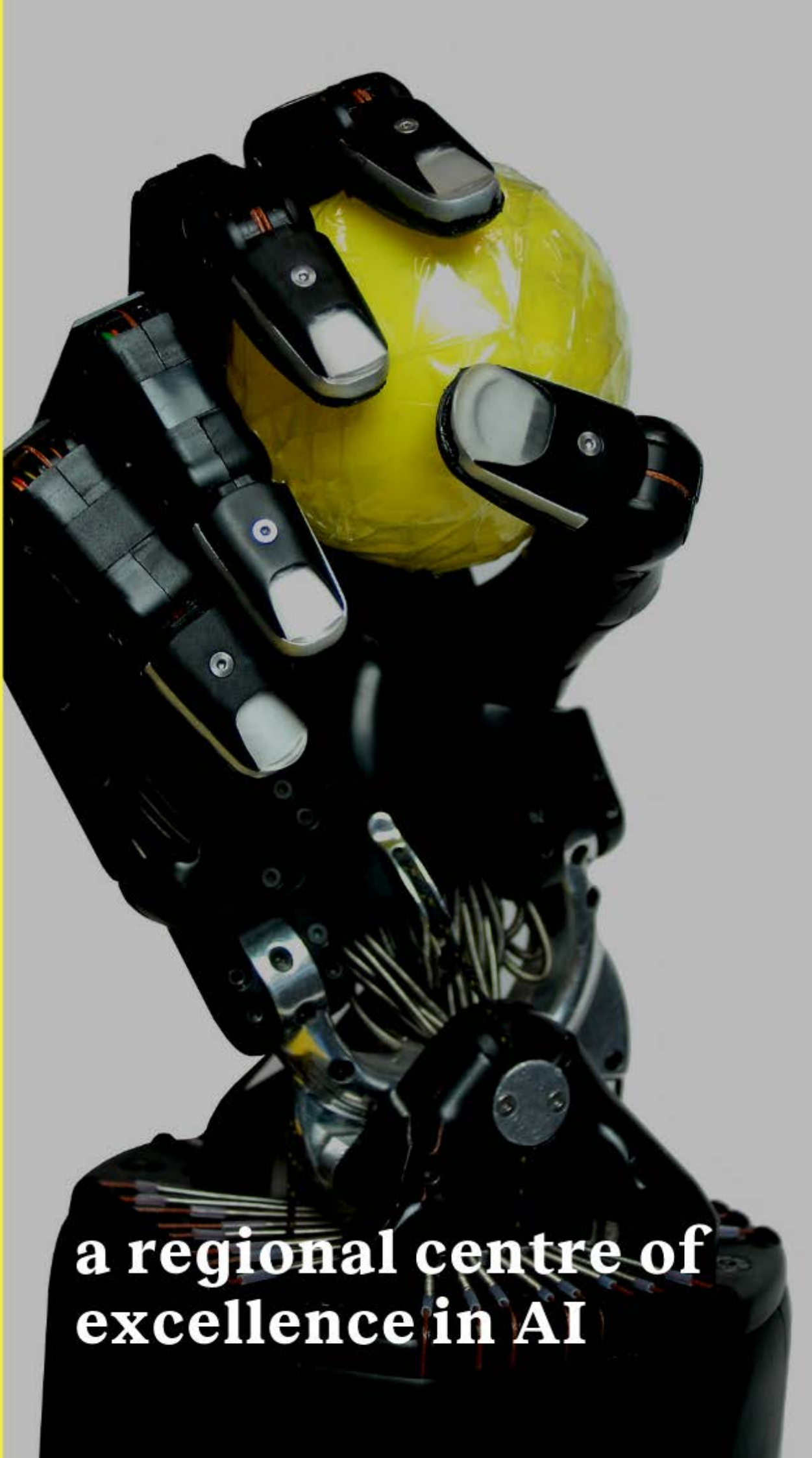
[25] Growing the Artificial Intelligence Industry in the UK (2018) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652097/Growng_the_artificial_intelligence_industry_in_the_UK.pdf

2.4.3 Industrial Needs

Many of the interviewees representing Northern Ireland businesses, both multi-nationals and local SMEs, spoke of the vital importance of creating a 'skills pipeline' that would ensure access in the future to talent and expertise in AI within the region. They also emphasised that courses capable of satisfying the needs of industry could be accredited by an appropriate professional body, e.g. the Chartered institute for IT (BCS). There is a sense in some industrial quarters that many current academic courses in AI focus on the production of 'AI researchers' rather than 'AI engineers'. Recent efforts, by UU in particular, to work with industry to develop courses of interest and relevance to industry were welcomed by many interviewees during the course of this review.

There is also an appetite in Northern Ireland for more extensive interaction between industry and academia on the research and technical assistance front. One manifestation of this has been the involvement of key members of industry in the creation and design of CARL at UU, which involved extensive consultations with regional industry and civic stakeholders on how to drive the economic and societal impact of AI and ensure that CARL's vision is in line with industry needs. Important stakeholders include: Seagate, Allstate, Kainos, Analytics Engines, Fujitsu, Zinc, NeuroCONCISE, First Derivatives, United Healthcare/Optum and Pramerica amongst others, as well as regional policy stakeholders such as DfE, InvestNI, NI Digital Catapult and Catalyst Inc.

However, many interviewees also mentioned some of the difficulties they faced in terms of identifying and accessing sources of expertise of direct relevance to their interests other than those with whom they had already established some form of working relationship. The plea was for a more transparent 'shop window' that would allow them to appraise the scale, scope and quality of the AI research and technical services on offer within academic institutions in Northern Ireland.



a regional centre of excellence in AI

3. The Prospects for a Regional Centre of Excellence in AI linked to The Alan Turing Institute

This section reviews the evidence concerning academic and industrial AI activities in Northern Ireland and examines the case for establishing a new AiCE@NI that would draw upon these and foster the development of a strong regional AI cluster in Northern Ireland.

3.1 Policy Alignment

The establishment of a strong AiCE@NI would be fully in line with both UK national policy and regional development policy:

Current industrial policy in the UK includes a specific strand geared towards support for the development of AI-related activities in academia, industry and society at large[26]. An important element of this AI policy strand has involved the establishment and strengthening of institutions focusing on research in data science and AI. Probably the most significant development in recent years has been the constitution of a national institute for data science and artificial intelligence, the internationally-recognised Alan Turing Institute. Established in 2015, this links the activities of major centres of university AI research via a hub and spoke structure to headquarters located in the British Library in London. Initially there were five founding universities (Cambridge, Edinburgh, Oxford, UCL and Warwick) – all members of the Russell Group of research-intensive universities. These were selected following an international peer review of research excellence. By November 2017, institute membership had increased to thirteen with the addition of eight more Russell Group partners (Leeds, Manchester, Newcastle, Queen Mary University of London, Birmingham, Exeter, Bristol and Southampton). In theory, this network of research centres could expand to encompass AI research establishments based in Northern Ireland, e.g. UU, QUB (which is a member of the Russell Group), or a new Regional Centre of Excellence drawing upon expertise resident in UU and QUB;

From a regional perspective, policy in the UK, as elsewhere across the EU, has included a strong focus on the development of innovation clusters that stimulate economic development in a region. Typically, these innovation

[26] See Appendix on AI-related policy developments – national, regional and international – prepared in conjunction with the Northern Ireland DfE.

growth poles include strong academic research and educational institutions that link effectively with locally-based industry.[27] In Northern Ireland, which lags behind most other UK regions in terms of value added per capita[28], the development of a strong AI-led innovation cluster would be an attractive option to stimulate regional development.

3.2 Prerequisites for Establishing AiCE@NI

So, what are the prospects for establishing a centre of excellence in Northern Ireland that could form the nucleus of a vibrant AI-led innovation cluster capable of stimulating economic growth in the region?

Prerequisites for the growth of a strong AI sector in Northern Ireland based on an AI centre of excellence are:

- The existence of an academic AI capability that has the potential to develop into an internationally recognised source of research excellence, perhaps linked to The Alan Turing Institute;
- The existence of an industrial base ready and able to develop and use AI in a range of products, processes and services;
- The existence of strong links between industry and academic institutions and the willingness of all parties to nurture and expand these links;
- The willingness of all relevant academic and industrial actors in the region to follow complementary paths that are in the collective interest of the region as a whole;
- The coherence of academic and industrial interests not only with each other but also with those of the public at large, especially in terms of satisfying societal needs and paying due care and attention to ethical concerns;
- Access to the capital and human resources capable of supporting a strong regional cluster.

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[27] Ibid.

[28] Gross Value Added (GVA) per capita in Northern Ireland in 2017 was 76.8% of the UK figure and only lower in the North East and Wales (UK Office for National Statistics). https://www.ons.gov.uk/economy/grossvalueaddedgva/bulletins/regionalgrossvalueaddedbalanceduk/1998to2017

3.3 Academic AI Capability

In terms of satisfying these prerequisites, the evidence provided so far in this report suggests that existing academic AI capability in Northern Ireland does provide a sound base for future development:

- With regard to academic AI research, for example, Northern Ireland possesses significant concentrations of excellence. AI publication performance is exemplary for both universities. Scopus figures for scholarly outputs are high, and Field-weighted Citation Indices for both institutions are higher than the UK average. International collaboration levels are also appreciable;
- The scale of academic AI research activity in Northern Ireland is impressive too, with an estimated 150 permanent staff involved in AI research spread over the two institutions. A selection of AI papers from a pool of 127 researchers (80 from UU and 47 from QUB) – all produced during the current REF period – were reviewed as part of our analysis of academic capabilities in the region;
- Across the two universities, eight Major Clusters of AI Research Excellence were identified: Core Data Science, Cyber Security; Hardware; Internet of Things; Medicine; Robotics; Economy; and Multimedia Analytics;
- Four smaller Minor Clusters of AI Research Excellence were also identified: Government; Engineering; Ethics; and Humanities and Social Sciences;
- In terms of establishing links with The Alan Turing Institute, a new AiCE@NI would be able to draw upon research expertise resident in UU and QUB in all these recognised areas of strength, which span a broad range of AI-related approaches;
- There is also a good match with the current research portfolio of The Alan Turing Institute. This is grouped currently into the following programmes: AI; Data Science at Scale; Data Science for Science; Data-centric Engineering; Defence and Security; Finance and Economics; Health and Medical Sciences; Public Policy; Research Engineering; and Urban Analytics[29];

[29] https://www.turing.ac.uk/research/research-programmes

- QUB's expertise in cyber security and in architectures for data science and AI would make significant and distinctive contributions to the portfolio of any new AiCE@NI and to the collective portfolio of the Turing network, as would UU's expertise in areas such as bio-inspired machine learning and Internet of Things;

- There is overlap between UU and QUB in areas such as medicine, advanced manufacturing and fintech. However, such is the breadth of current and future applications of AI in these areas that we did not find significant evidence of unnecessary duplication of effort. Moreover, where overlap does exist, combining forces would help to create a critical mass that would lead to higher quality and more impactful research;

- One area where synergies might be expected concerns medicine and, in particular, genomics. Northern Ireland, with its relatively homogenous population, integrated health and social care services, and an integrated health and care record system that is due to be launched in 2020, is well-placed to benefit from advances in genomics research. In terms of their current and planned research activities, UU and QUB are positioning themselves to capitalise on these developments and play a leading role in this priority area.

3.4 Industrial Activities and Linkages

The evidence presented earlier in this report suggests that an industrial base suitable for the future development of a strong AI cluster in Northern Ireland currently exists:

- AI-related industrial activity in Northern Ireland is burgeoning, both in terms of the growing number of firms – large and small – involved in the development and use of AI-related products, processes and services and in terms of levels of enthusiasm for establishing links with academic institutions that span research, development and the co-creation of educational programmes and courses that will help feed industry's expanding appetite for AI-qualified personnel. Hype-cycles have not been uncommon in the historical evolution of AI, with grandiose expectations in terms of the diffusion of AI-related technologies frequently unmatched by industrial interest or readiness to exploit academic achievements, but there are genuine signs – in Northern Ireland as elsewhere – that many current aspirations are potentially realisable;

- UU and QUB have significant AI-related links with industrial enterprises located in Northern Ireland. These include long-standing links with large international firms such as BT, Seagate and Allstate and numerous collaborations with SMEs;

- Notable examples of UU collaborations include work conducted with: BT UK Innovation Centre (big data and security); Ernst & Young (fintech); Seagate (advanced manufacturing); Allstate (fintech, CRM); Amazon Web Services (cloud-based services for AI); and the BBC (data science partnership programme). Notable examples of QUB collaborations include projects with: Ampliphae (cloud security, SaaS); Citi (fintech); BrainWaveBank (cognitive analytics); and Camlin (health, security and AI);

- There has also been significant spin-off activity in the AI sector from both universities. Notable spin-offs from QUB include PathXL (digital pathology, bought out by Philips); Yedup (real time news analysis, algorithmic trading); Analytic Engines (scalable analytics platforms); and Adoreboard (emotion sensing). Notable spin-outs from UU include NeuroCONCISE (brain-computer interfaces for disability enablement); Actionsense (wearable sensor devices and systems); Intelesens (wireless wearable ECG and respiration rate detection systems and algorithms); Heartsine (Automated External Defibrillators, using cardiac arrhythmia detection and defibrillation algorithms); and Axial3D (medical image analysis);

- One development of particular interest from the perspective of academic-industrial cooperation has been the involvement of industry and civic stakeholders in the design and launch of the Cognitive Analytics Research Lab (CARL) at UU, which will focus on research with a strong economic and societal impact and the development of an adequate skills pipeline. Initially this will involve over 60 UU staff, though the intention is to grow this to around 200;

- Although the collection of comprehensive data on the extent and nature of AI-related linkages between industry and UU and QUB was outside the scope of this exercise, the subjective impression gained during interviews with UU and QUB staff and representatives of firms with whom they collaborated suggested that there was only a modest overlap between the industrial communities served by UU and QUB respectively. Many firms, especially SMEs, had a track record of collaboration with only one of the institutions, despite occasional evidence of recruitment from both. This has implications for the

development of a vibrant AI cluster spanning Northern Ireland as a whole. Any attempt to base this cluster on the current academic-industry ecosystems of the individual universities would risk excluding a significant proportion of relevant industrial actors. Building an ecosystem around a new AiCE@NI drawing upon the resources of both academic institutions, however, would pave the way for synergies between these rival ecosystems;

- These synergies would also be enhanced via the establishment of formal links with a renowned centre of excellence such as The Alan Turing Institute, which would act as a magnet for industrial partners and cement collaborative bonds between all cluster stakeholders. For Turing, too, access to a truly regional ecosystem would provide an opportunity to explore new ways of interacting with industry and influencing economic development, over and above current interactions with individual universities in its current network.

3.5 Willingness and Enthusiasm

Given the positive assessments of academic and industrial AI capabilities and the linkages between them, the willingness of the main AI actors in Northern Ireland to coalesce around the notion of a new Regional Centre of Excellence in AI is critical:

One of the most pressing issues is the willingness and readiness of UU and QUB to work together, both in terms of establishing such a centre and collaborating together successfully during its lifetime. Historically, competition rather than collaboration between the two institutions has been the norm. However, during the course of this review, levels of enthusiasm and support for the establishment of a new AI Regional Centre of Excellence were uniformly high amongst the staff – both senior and junior – of both institutions. Evidence of progress towards a more collaborative culture is also demonstrated by the recent series of joint UU/QUB proposals submitted to the UK Arts and Humanities Research Council (AHRC) and the Belfast and Derry/Londonderry City Deals;

Perhaps less surprisingly, levels of enthusiasm for UU and QUB to join forces vis-à-vis the establishment of a new AiCE@NI were also very high amongst the industrial representatives consulted during the course of this review. Despite a tendency for many to have had collaborative links with just one of the two academic institutions, all saw the potential for a new AiCE@NI to provide easier access to a broader base of academic expertise. Many also envisaged enhanced access to an expanded recruitment pool;

Both academic and industrial representatives were highly enthusiastic concerning a potential link to The Alan Turing Institute. All saw it as a positive step towards the creation of a strong regional cluster linked to an internationally renowned national network of leading-edge universities active in the AI domain.

3.6 Other Factors

Based on the ability, readiness and enthusiasm of academic and industrial interests in Northern Ireland, the prospects for the establishment of a regional centre of excellence in AI look good, and the potential to add value via the establishment of formal links with The Alan Turing Institute is appreciable. These possibilities are also affected, however, by factors outside the scope of this review, namely the fit with societal needs, the availability of the investment necessary to establish and operate a new AiCE@NI, and the willingness of The Alan Turing Institute to welcome a new regional hub into its fold:

The prima facie case for a new centre in terms of fit with societal needs is strong in that, as noted at the start of this section, its establishment would be in line with UK national and regional policy concerning the development of AI-related activities and innovation clusters. Fit with policy, however, is not necessarily synonymous with fit with local, societal needs. This is an area that would need to be explored in more detail if any decision in principle is taken to go ahead with a new regional centre of excellence. Of primary interest would be the ability of any new centre to interact with and satisfy local community needs;

In terms of the availability of investment, this too would need to be explored more fully. Potential sources exist in the private and public sector, but much depends on the scale of investment needed both up-front and on a continuing basis, which in turn depends on the scope of activities foreseen for the centre and the business models proposed for it. The costs involved in any link with The Alan Turing Institute would also have to be considered;

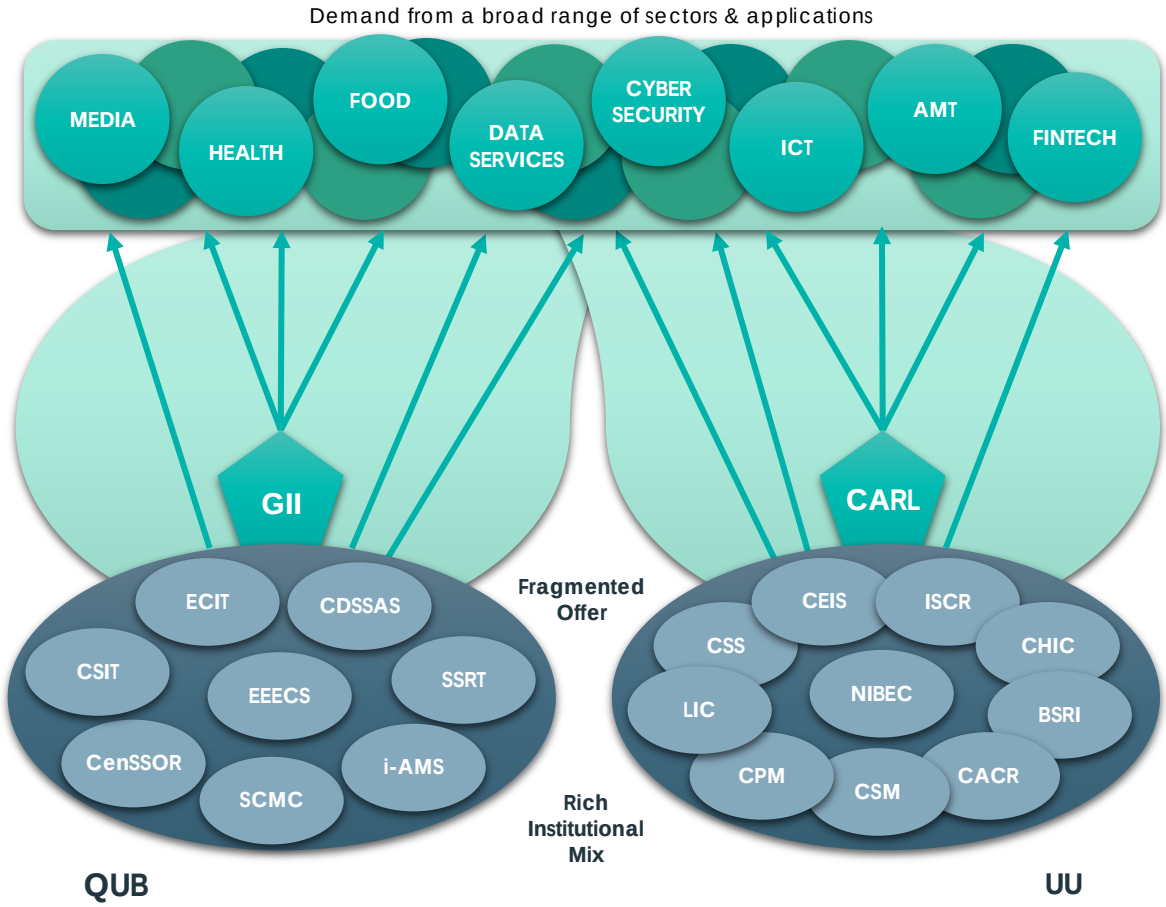
Whereas this review amassed ample evidence of the receptiveness of AI stakeholders in Northern Ireland to the notion of formal links with The Alan Turing Institute and discussed some of the advantages that might accrue to all involved parties, the position of the institute itself was not fully investigated. Factors such as those shaping the ability of the institute to expand in the near future, or those likely to influence negotiations concerning new models of membership, would all have to be explored thoroughly during the formulation of plans for future action.

Some of these issues are dealt with more fully in the next sections, which discuss possible configurations for a new Regional Centre of Excellence, including the gap it might be expected to fill in the Northern Ireland innovation ecosystem, its mission and the tasks it might be expected to undertake, its potential location, its funding and business model, and its relationship with The Alan Turing Institute.

3.7 Filling a Gap

The current landscape of academic centres conducting research of interest to a broad range of industrial sectors was outlined earlier in this report. Figure 7 summarises the 'AI Research Offer' that these centres present to industry. Within UU and QUB combined, there are at least 20 centres that have work programmes of interest to firms operating in technology areas such as advanced manufacturing technology (AMT), information and communication technologies (ICT) and fintech as well as – amongst others – the cyber security, data services, media, food and health sectors. New or expanded centres are also planned as a consequence of the Belfast and Derry/Londonderry City Deals. GII, for example, will help focus the AI research offer of QUB to the health and food sectors, while any expansion of CARL at UU would similarly help to focus UU's research offer to a range of sectors.

Figure 7. The AI Research Offer to Industry in Northern Ireland



The combined offer from both universities is impressive in its range and quality, but historically it has been fragmented and is likely to remain so despite the expanded remits seen for GII and CARL, which for the most part will act as focal points and conduits for research conducted by the separate institutional clusters that exist within QUB and UU. As such, they are unlikely to have any significant impact on the phenomenon described earlier in this report – namely the tendency for many firms, especially SMEs, to work collaboratively with either QUB or UU but not with both. The separation that exists between the industrial communities served by the two universities is depicted via the use of the two 'clouds' in Figure 7.

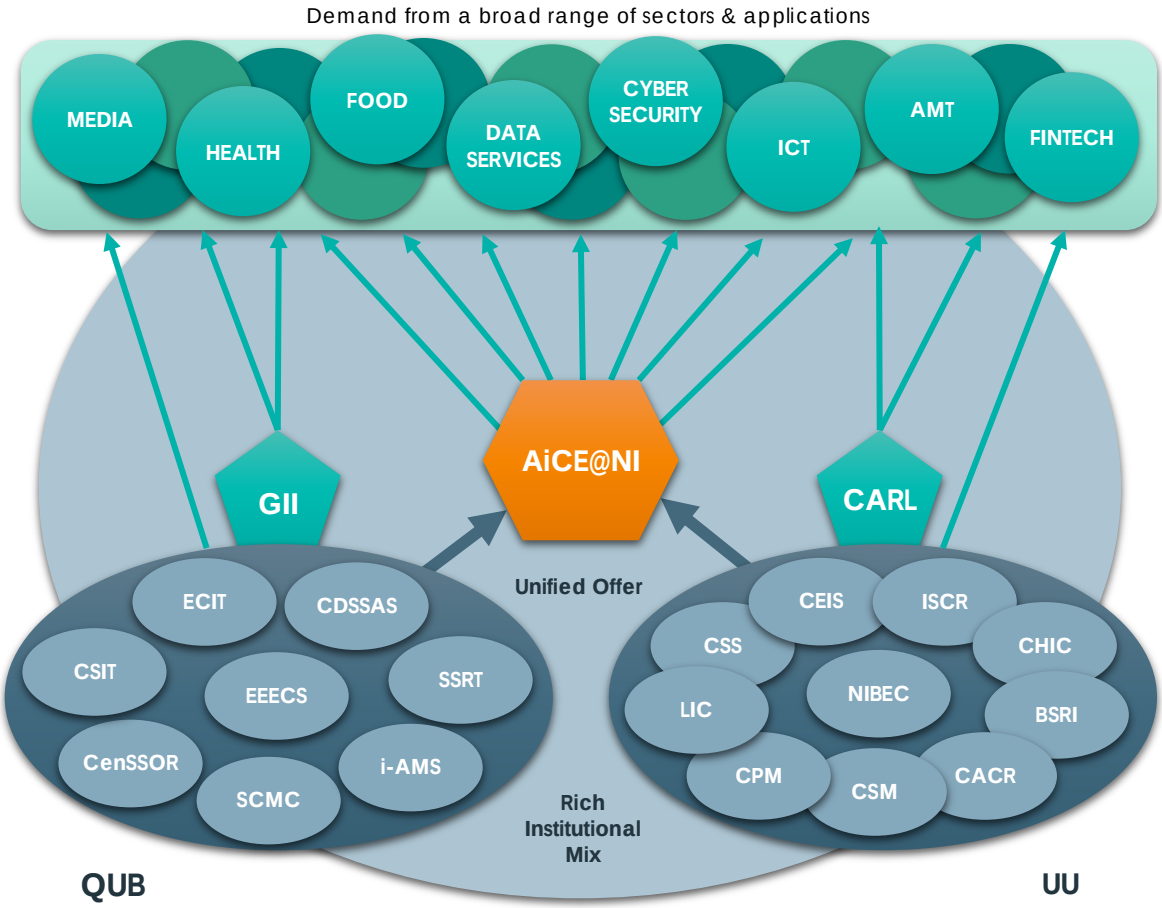
The offer that is currently available to firms is also fairly opaque. Locating pertinent sources of expertise within both universities via their respective web presences is difficult. Simple organograms indicating relevant research centres are absent, as are easy ways of determining the range of topics that are being worked on and the contact details of the people working on them. Like many other university websites, the UU and QUB web-sites tend to be 'student-friendly' rather than 'industry-friendly' and do not therefore

constitute an adequate 'shop window' for firms. This helps to explain why many of the research collaborations discussed during the course of this review came about as a result of personal contacts and past associations rather than as a consequence of searches for the best sources of available expertise.

The demand from many of the industrial personnel interviewed during the course of this review – and echoed and supported by most academic personnel – was for a mechanism that would allow UU and QUB to present industry with a clear, transparent and easily accessible research offer that was capable of drawing upon the resources available in both universities. In other words, on the demand side there is a professed desire for something akin to a 'one-stop shop' that would allow industry to locate and access relevant AI expertise within Northern Ireland with relative ease, complemented by an equally ardent desire for a mechanism that would allow research centres in academic institutions to put together a broader and more coherent research offer to industry.

Figure 8 depicts how a new AiCE@NI could be positioned to focus the offers from the two universities and present firms operating in a broad range of industrial sectors with a comprehensive overview of relevant expertise and simpler ways of accessing it. In such a configuration, planned developments such as those envisaged by the Belfast and Londonderry/Derry City Deals (e.g. a new GII and an expanded and strengthened CARL) are envisaged as vital pillars that could support the construction of a new AiCE@NI that serves the whole industrial community.

Figure 8. The AiCE@NI Research Offer to Industry in Northern Ireland



3.8 Fulfilling a Mission

In modern innovation eco-systems, 'centres of excellence' that link university and industry activities in one way or another exist in many forms and configurations:

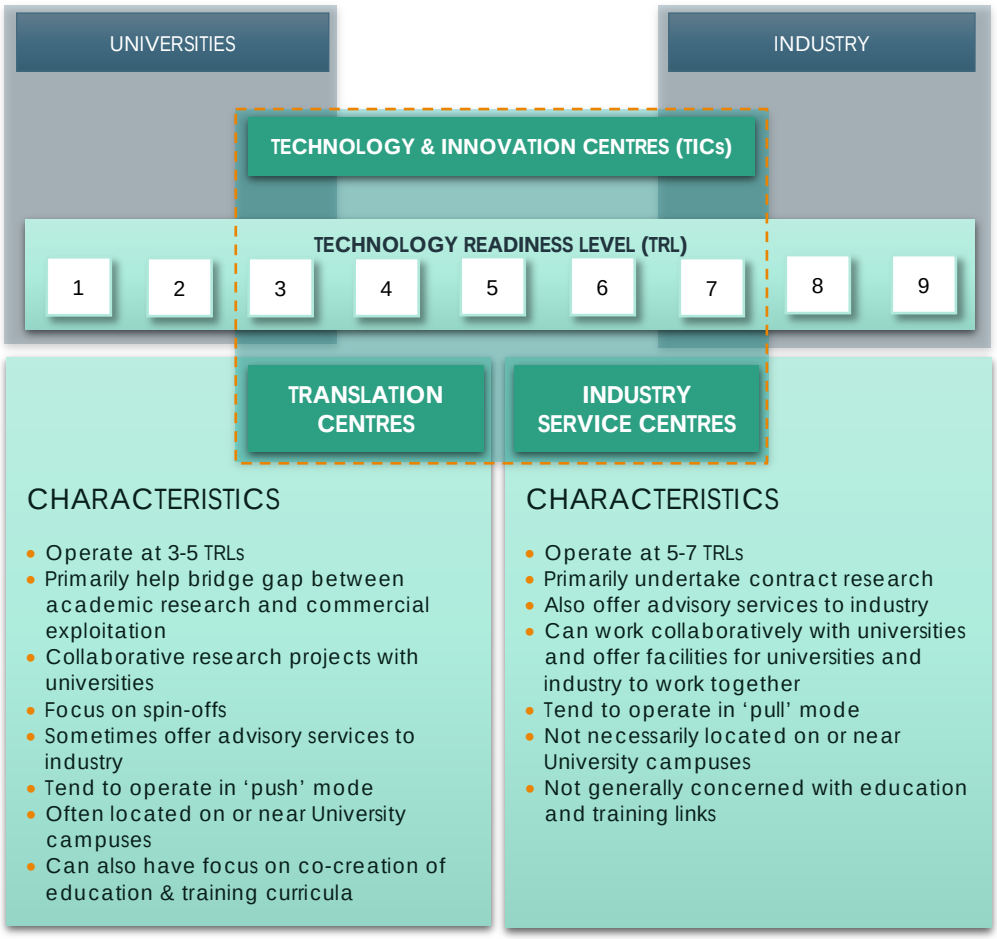
- Almost all are set up to conduct research at a physical location or locations;
- Most receive some degree of public funding, supplemented to varying degrees by private sector income;
- Some are primarily concerned with developing their own capabilities in order to better service the needs of industry;
- Others are primarily concerned with the translation of research into commercial outputs;

- Some are specifically set up by groups of companies to service their needs;
- Some are also concerned with the co-creation of educational curricula and courses that satisfy industrial needs;
- Almost all are focused either on specific technologies of interest to multiple industrial sectors or a range of technologies of interest to a single sector;
- Some have a specific focus on servicing the needs of industry within a given region, while others have broader national and even international target audiences;
- Governance structures and business models are invariably influenced by mission and are constituted to reflect the interests of a range of innovation system stakeholders

In a UK context, such centres are generically termed Technology and Innovation Centres (TICs). UK examples include the Catapult Centres, EPSRC Innovation Knowledge Centres and other independent Research and Technology Organisations (RTOs). Elsewhere, examples include the Fraunhofer Institutes in Germany, TNO in the Netherlands, and Competence Centres in many countries (Ireland, Austria, Sweden etc.).

Although TICs come in many flavours, it is useful to distinguish between the two broad types depicted in Figure 9:

Figure 9. Characteristics of Technology Innovation Centres



Translation Centres: These primarily aim to bridge the gap between the academic research base and commercial uptake by focusing on lower Technology Readiness Levels[30] (TRLs), e.g. TRLs 3-5. They undertake collaborative research with universities and industry and frequently have a focus on spin-offs. They can also have a focus on the co-creation of education and training curricula and courses. Typically, they are located within universities and operate nearer the 'push' end of the 'push/pull' innovation model spectrum.

Industry Service Centres: These institutions typically focus on TRLs 5-7 and are primarily concerned with conducting R&D and offering services to industry. An additional, but secondary aim, is to bridge the gap between the university

[30] Scales of Technology Readiness Levels typically vary from 1 – 9, where 1 denotes activities at the basic research end of the spectrum and 9 denotes activities at the commercialisation end. University activities generally span TRLs 1-3 while industry focuses on TRLs 7-9. In turn, TICs typically span TRLs 3-7.

research base and commercial exploitation, but they do not generally have a focus on education and training links. They offer equipment and skills that enable them to:

- Build up their own competence and expertise;
- Undertake contract research, especially for SMEs;
- Offer advice on technology transfer and commercialisation;
- Undertake collaborative projects involving university and industry partners, often offering facilities in which universities and industry can work together to move from TRLs 4 to 7.

Typically, they take the form of physical centres located on single or multiple sites linked horizontally (e.g. co-location models) or vertically (e.g. hub and spoke models). These sites may or may not be located on or close to university campuses. In terms of 'push-pull' innovation models, they function nearer to the 'pull' end of the spectrum.

During the course of this review, it became clear that demand exists for a new AiCE@NI that would have some of the characteristics of a Translation Centre and some of an Industry Service Centre. The mission of this hybrid structure would then encompass:

- Building up capacity to offer Translation Centre services at TRLs 3-5 and Industry Centre services at TRLs 5-7;
- Drawing upon and working with existing centres within UU and QUB to offer this broad spectrum of services;
- Operating at both 'push' and 'pull' ends of the innovation spectrum;
- Pursuing its own research agendas but also undertaking collaborative projects with universities and industry and performing contract research for firms, especially SMEs;
- Offering services ranging from advice and guidance on topics such as the formation of spin-offs, intellectual property rights and other to aspects of commercialisation to the provision of space and facilities for testing and piloting prototypes;
- Working with QUB, UU and industry to develop curricula, courses and training materials that would feed into a skills pipeline capable of satisfying industrial demand for a skilled AI workforce.

3.9 Location

The location of a new AiCE@NI was not a major focus of attention in our discussions with stakeholders. When the topic did arise, conversations tended to focus on the need for any new centre to have a real, physical presence, as opposed to being configured as a virtual centre linking research institutions located on multiple sites.

Some discussions partners did present cogent arguments for AiCE@NI to be located in Belfast on a neutral site. The central tenets of these arguments were as follows:

- For it to serve Northern Ireland as a whole and to have a profile likely to be recognised and acknowledged outside of the region, in both the UK and elsewhere, it needed to be located in or near Belfast;
- Locating it on UU campus sites in Derry/Londonderry, Jordanstown or Coleraine would affirm the association with UU but downplay the association with QUB;
- Similarly, locating it on either a QUB or a UU site in Belfast would downplay the perceived association with one or other of the universities;
- Locating it on a neutral site outside of Belfast, Jordanstown, Coleraine and Derry/Londonderry would weaken the links with both QUB and UU;
- A virtual structure linking institutions on existing campus sites in Belfast, Coleraine and Derry/Londonderry would do little in practice to integrate the existing capabilities and offers of QUB and UU;
- Locating it on a neutral site in Belfast would strengthen perceptions that the new AiCE@NI was the outcome of an equal partnership between UU and QUB capable of drawing upon the expertise resident in both institutions.

Other discussion partners noted that location was likely to be a contentious issue, and that many factors would have to be taken into account prior to any decisions about the eventual location of AiCE@NI. Moving forward will require deeper consideration and analysis of the advantages and disadvantages of different location options, including consideration of how any new centre could interact synergistically with research being undertaken in existing sites.

3.10 Funding and Business Models

As noted earlier, detailed exploration of how a new AiCE@NI could be funded and the business models it would need to adopt to operate successfully in the short, medium and long-term were outside the scope of this review. A few general comments are warranted, however.

- The vast majority of TICs depend for their initial financing and their operational costs on a mix of public sector and private sector funding;
- From the public sector, sources include institutional funding (funding provided to universities which they can then allocate as they see fit across different departments and centres); funding derived from a variety of national, regional and local bodies and programmes designed to support institutional developments and/or work in specific areas; and competitive project funding;
- In terms of public sector funds, UK sources include the AI Sector Deal, the Industrial Strategy Challenge Fund (ISCF) and the expected UK Shared Prosperity Fund. The ability of actors in Northern Ireland to access these will depend on the establishment of timely information flows and good relations with bodies such as the AI Council, UKRI/Innovate and UK/ESPRC;
- From the private sector, funding can take the form of philanthropic contributions or direct investment by individual firms; consortia agreements that guarantee members of the consortia access to services; or fees paid by individual firms for services rendered, e.g. contract research;
- The balance between different types of funding varies enormously and typically depends of the mission of the TIC. Translational Centres are usually more dependent on public sector contributions than Industry Service Centres, which depend more on fee income and often aim to be self-sufficient (i.e. not dependent on public sector income) in the medium to long-term.

Given that the demand in Northern Ireland is for a new AiCE@NI centre that would perform many of the functions associated with both Translational Centres and Industry Service Centres, it unrealistic to imagine either that it should be heavily dependent on public financing or that it should be expected to become largely self-sufficient in the long-term. A balance should be sought between core funding from public sources (and private if possible); income raised from competitive sources; and income raised from fees.

3.11 Links with The Alan Turing Institute

As noted earlier in this review, there exists widespread support in academia and industry for any new AiCE@NI to be linked in some way with The Alan Turing Institute, the national centre of excellence for AI.

For its part, The Alan Turing Institute's remit as a national institute lends itself to an expansion into Northern Ireland. It is also looking to consolidate and expand its potential socioeconomic impact and contribute in particular to economic development across the whole of the UK.

To date, there have been two waves of recruitment to the Turing network of UK universities: five in the first wave and eight in the second. Expansion via the recruitment of a new wave of members, however, is not a strong possibility. Incremental expansion via the adoption of single members of the same status as existing members is also not a priority.

Current interest is focused on the addition of a 'regional hub' in areas with devolved governance systems, e.g. Northern Ireland, Wales and Scotland. Such a hub would need to draw upon AI expertise resident in universities in the region and have strong links with industry, especially SMEs, across a wide area. This would be a way of extending both geographic reach and enhancing the prospects for socioeconomic impacts.

Northern Ireland is not the only region to date that has shown an interest in the creation of a new AiCE@NI that could link to The Alan Turing Institute, but discussions are at a more advanced stage than they are with other regions. The Institute has also suggested that further exploration of how a link could be established and configured would be welcomed if there is strong public and private sector support in Northern Ireland for the concept of a new AiCE@NI linked to The Alan Turing Institute.

Given the results of this review, which confirm the potential for a strong AiCE@NI to be established, the door is now open for further exploration of a link with The Alan Turing Institute if the institute is in a position to expand its geographic reach.

There is also scope for any new AiCE@NI to explore links with other AI research institutes of international standing elsewhere in the world. In terms of UK institutions, for example, links could be explored with the Hartree Centre for high performance computing and data analytics in Daresbury, which is funded by the Science and Technology Facilities Council (STFC).

Elsewhere, AiCE@NI could explore links with institutions such as the INSIGHT Centre for Data Analytics in the Republic of Ireland, which has just received €49.1m from Science Foundation Ireland (SFI) for INSIGHT Phase 2. Links such as these could play a critical role in cementing both north-south and east-west collaboration.

conclusions and recommendations

4. Conclusions and Recommendations

4.1 Conclusions

This review set out to provide an assessment of academic and industrial AI activities in Northern Ireland in order to establish whether or not there is a case for supporting the establishment of a new AiCE@NI, particularly one linked in some way with The Alan Turing Institute – the UK National Centre of Excellence in AI.

The main findings of this review are as follows:

- The quality of academic AI research currently being undertaken in Northern Ireland in UU and QUB and the relevance of this research to industry are both high enough to warrant policy efforts to strengthen capability even further via support for a new AiCE@NI that would build on these capabilities;
- The range of AI research being undertaken in UU and QUB is broad enough to be of interest to many user communities within the region as a whole;
- Key technology areas of great academic and commercial potential include: core data science; cyber security; computer architecture; Internet of Things; health-related technologies; robotics; and multimedia analytics;
- Levels of industrial activity and interest in AI in the region are high and expanding;
- Sectors where AI is expected to have significant impacts in Northern Ireland include: health; manufacturing; cyber security; financial services; and data services;
- Existing centres of AI excellence within UU and QUB are numerous, but collectively their 'offer' to industry is fragmented and not always highly visible;
- There is scope for improved collaboration between public sector research institutes and the private sector to rectify this situation;
- Current UK policy governing both the development of the AI sector and regional development as a whole recognises the key role that could be played in theory by the establishment of centres of

excellence that could nurture the development of strong regional AI clusters;

- The establishment of a new AiCE@NI that could draw upon the expertise resident in both UU and QUB to provide a stronger and more coherent, visible 'offer' to a broad range of industrial sectors in Northern Ireland would be fully in line with the current thrust of UK policy;

- Levels of enthusiasm for the constitution of a new AiCE@NI based on collaboration between UU and QUB was also high amongst both the academic and industrial communities;

- To satisfy industrial demand, the mission of a new AiCE@NI would need to span the complete range of activities covered by Technology and Innovation Centres (TICs), ranging from translation services at TRLs 3-5 (which help bridge the gap between academic and industrial activity) to various other industry services such as problem-oriented contract research at TRLs 5-7;

- Demand also exists for any new AiCE@NI to be involved in the co-creation of education and training curricula and courses that would help nurture the skills pipeline;

- A number of options exist concerning the potential location of a new AiCE@NI. Constituting it as hub located on a neutral site in Belfast that could draw upon existing expertise on the QUB and UU sites in Belfast, Jordanstown, Derry/Londonderry and Coleraine was an option that found favour with some discussants, but the majority expressed no opinion on this topic. There is little doubt, however, that many factors will have to be taken into account when determining the optimal location for a new AiCE@NI, e.g. the availability and cost of land, buildings and associated infrastructural requirements, the advantages and disadvantages associated with operating across existing sites, and core/periphery considerations concerning the location of a truly 'regional' centre of excellence inside or outside of Belfast;

- Exploration of funding and business models for a new AiCE@NI lay outside of this report. Given the range of tasks any new centre would be expected to perform, however, the expectation is that there would be a continual need for a mix of public and private sector funding;

- Interest in a formal link with The Alan Turing Institute was high in academic and industry circles;

- A link with AiCE@NI would offer The Alan Turing Institute a means of expanding its influence across the UK. By acting as a regional hub connecting AI expertise with industrial actors and economic development in the region, AiCE@NI would provide The Alan Turing Institute with an opportunity to be involved in an initiative that has a clear and measurable impact on the regional economy, a goal that is fully in keeping with its mission.

4.2 Recommendations

1. Recognise the central result of this review – namely that, based on capability, interest and need, there is a strong case for the establishment of a new AiCE@NI;

2. Recognise, too, that the pace of developments in the AI sector is so rapid that the demand for a new AiCE@NI needs to be satisfied as soon as possible if the window of opportunity is not to be missed. Without a development of this nature, the prospects for the evolution of a strong regional AI capability would be severely diminished;

3. Resist the temptation to consider the developments supported by City Deals in Belfast and Derry/Londonderry as alternatives to the establishment of a new AiCE@NI. They should be seen as essential foundations for the development of a new centre, not as substitutes for one;

4. Develop an Action Plan specifying the steps that need to be taken to establish a centre;

5. Recognise that ownership of any new AiCE@NI is likely to be shared across multiple stakeholders (government departments and agencies, universities and private sector actors) and that the development of an Action Plan should involve all interested parties;

6. Within this Action Plan, establish a procedure that will allow major stakeholders to acknowledge the results of this review and commit to working together on the further development of a proposal to establish a new AiCE@NI with links to The Alan Turing Institute;

7. This stakeholder group should include public sector representatives from national, regional and local levels; industry and industry association representatives; senior personnel from both QUB and UU; and representatives from The Alan Turing Institute;

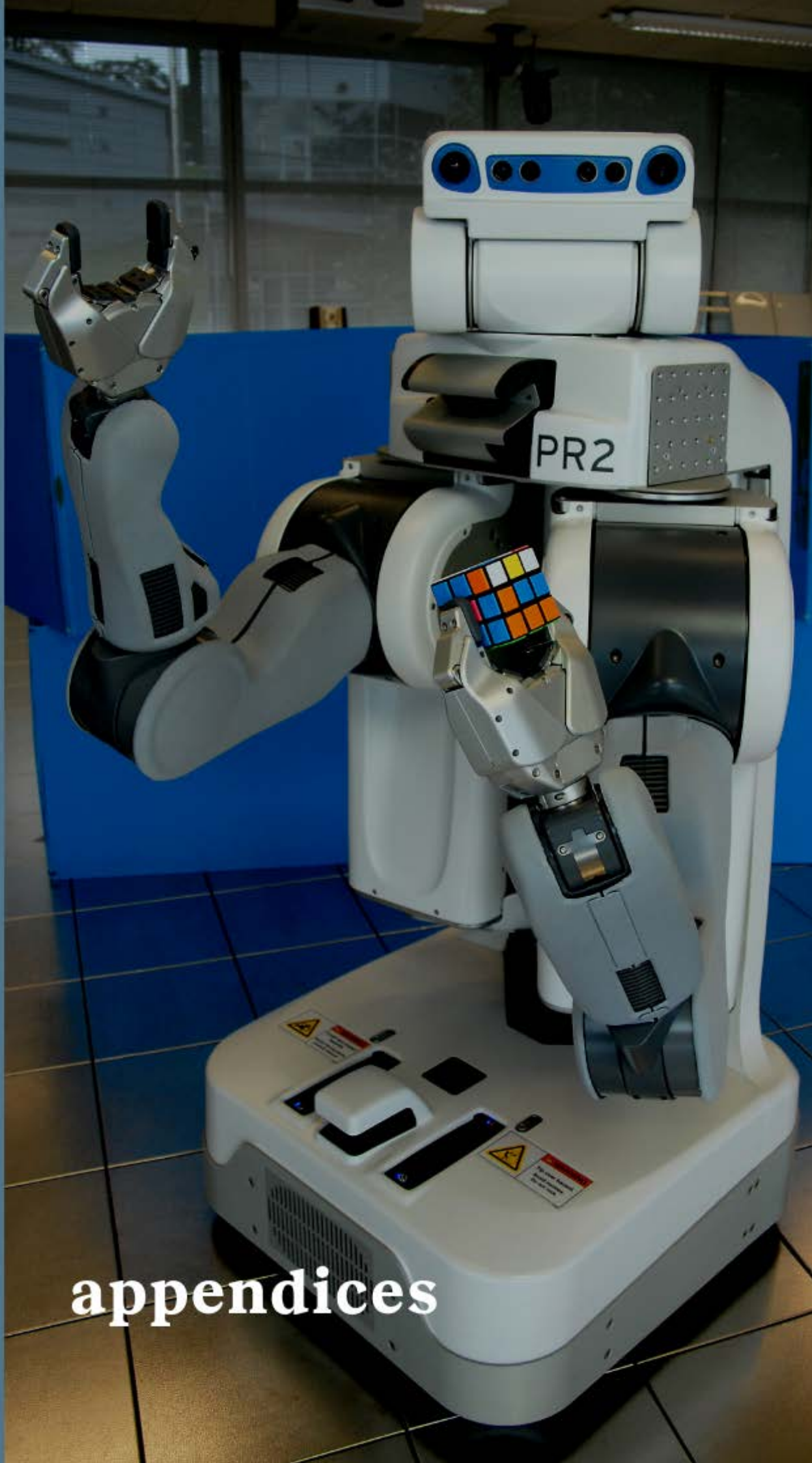
8. Particular attention should be paid to ways of raising start-up capital from the public and private (and philanthropic) sectors, and to the development of business models capable of covering operational costs in the short, medium and long-term;

9. Recognise that TICs conducting activities that span a wide range of TRL levels cannot usually expect to become self-sufficient and will need some degree of core funding from the public sector;

10. Concerning industrial contributions, potential sources of Foreign Direct Investment (FDI) should be explored, as well regional consortia structures such as those established for Competence Centres in many countries;

11. Concerning links with The Alan Turing Institute, fee structures will need to be explored. The normal fee paid by University Partners in the Turing network is £5m for a period of five years. A joint membership fee for a new AiCE@NI involving UU and QUB would need to be negotiated;

12. Potential contributions from the public and private sectors to these fees could also be appropriate given that effective interaction with The Alan Turing Institute could have a positive impact on regional development.



appendices

matrix.

Appendix 1: The UK Policy Context for AI

Prepared in conjunction with the Department for the Economy, Belfast

1. Growing the Artificial Intelligence Industry in the UK

In 2017, in recognition of the significant growth of AI technologies world-wide and of the impact that AI is likely to have on the global economy, the UK government commissioned a review of AI entitled 'Growing the Artificial Intelligence Industry in the UK'[31]. Led by Dame Wendy Hall, Professor of Computer Science at the University of Southampton, and Jérôme Pesenti, Vice President of AI, the Review examined how industry and government could create the conditions for the AI industry to continue to thrive and grow in the UK, as part of a broader Digital Strategy for the UK economy.

The Review offered a high-level overview of AI activity in the UK, the challenges to increasing AI activity and recommendations to address those challenges. It noted that many sectors across the UK economy were already embracing innovation through AI and benefitting from its day-to-day use.

The Review recognised that increased use of Artificial Intelligence (AI) can bring major social and economic benefits to the UK and outlined a vision for the UK to become the best place in the world for businesses developing and deploying AI to start, grow, thrive and realise all the benefits the technology offers. It contained 18 recommendations covering four key areas:

Data. To continue developing and applying AI, the UK will need to increase ease of access to data in a wider range of sectors. The Review recommended:

- Development of data trusts, to improve trust and ease around sharing data;
- Making more research data machine readable;
- Supporting text and data mining as a standard and essential tool for research.

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[31] *UK Review: Growing The Artificia*
l Intelligence Industry in the UK https://www.gov.uk/government/publications/growing-the-artificial-intelligence-industry-in-the-uk

Skills. Skilled experts are needed to develop AI, and they are in short supply. To develop more AI, the UK will need a larger workforce with deep AI expertise, and more development of lower level skills to work with AI. The review recommended:

- An industry-funded Master's programme in AI;
- Market research to develop conversion courses in AI that meet employers' needs;
- 200 more PhD places in AI at leading UK universities, attracting candidates from diverse backgrounds and from around the world;
- Credit-bearing online AI courses and continuing professional development leading to MScs;
- Greater diversity in the AI workforce;
- An international AI Fellowship Programme for the UK.

Research. The UK has an exceptional record in key AI research. Growing the UK's AI capability into the future will involve building on this with more research on AI in different application areas and coordinating research capabilities. The Review recommended that:

- The Alan Turing Institute should become the national institute for artificial intelligence and data science;
- Universities should promote standardisation in transfer of IP;
- Computing capacity for AI research should be coordinated and negotiated.

Increasing uptake. Increasing uptake of AI means increasing demand as well as supply through a better understanding of what AI can do and where it could be applied. The review recommended:

- An AI Council to promote growth and coordination in the sector;
- Guidance on how to explain decisions and processes enabled by AI;
- Support for export and inward investment;
- Guidance on successfully applying AI to drive improvements in industry;

- A programme to support public sector use of AI;
- Funded challenges around data held by public organisations.

These recommendations were considered in the development of the UK Industrial Strategy[32], launched in November 2017, and the subsequent Industrial Strategy Sector Deal[33] between government and the AI industry, which was launched on 26th April 2018.

2. UK Industrial Strategy

2.1. Overview

The UK Government's Industrial Strategy (UKIS) set out a long-term vision for how Britain could build on its economic strengths, address its poor productivity performance, embrace technological change and boost the earning power of people across the UK. The objective was to improve living standards and economic growth by increasing productivity and driving growth across the whole of the UK.

As well as attempting to address the drivers of productivity, the strategy set out to build on existing competitive strengths and shape new markets and industries. The strategy was framed around the UK's determination to address Grand Challenges:

- Clean Growth: Maximising the advantages for UK industry from the global shift to clean growth;
- Ageing Society: Harnessing the power of innovation to help meet the needs of an ageing society;
- Future of Mobility: Becoming a world leader in the way people, goods and services move;
- Artificial Intelligence and Data Economy: Putting the UK at the forefront of the artificial intelligence and data revolution.

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32 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/672468/uk-industrial-strategy-international-brochure-single-pages.pdf

33 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/702810/180425_BEIS_AI_Sector_Deal__4_.pdf

While it is significant that Artificial Intelligence was highlighted as a Grand Challenge in its own right, it was also recognised that AI could be applied in the development of solutions to the other Challenges.

Recognising the role AI can in improving the country's productivity, the UK Government's Industrial Strategy acknowledged AI as a Grand Challenge in its own right, while also recognised that AI could be applied in the development of solutions to the other Challenges. It therefore stressed the need for a focus on investment in artificial intelligence (AI), innovation, digital skills and infrastructure.

Each Grand Challenge was seen as an open invitation to business, academia and civil society to work and engage with the government to innovate, develop new technologies and ensure that the UK seized these global opportunities. The UK Government anticipated that it would establish competitive funding streams and invite proposals and ideas to identify and subsequently support a range of high potential projects. Furthermore, it was anticipated that each Grand Challenge would be advised by representatives drawn from industry and/or academia and led by a 'Business Champion'. These individuals were expected to engage with a diverse range of industry voices and raise the profile of the challenge.

2.2. AI-related Interventions

The UK Government wanted to ensure that the UK was at the forefront of the AI and data revolution and believed that embedding AI across the UK would create thousands of good quality jobs and drive economic growth. A study in 2017 estimated that digital technologies, including AI, had created a net total of 80,000 new jobs annually across a population similar to the UK[34]. One estimate foresaw AI adding £232bn to the UK economy by 2030[35].

The Strategy noted that the UK was starting from a position of strength and was already a world leader in AI. It acknowledged that the UK possessed some of the best research institutions in the world and was endowed with globally-recognised capability in AI-related disciplines, including maths, computer science, ethics and linguistics. The UK also had great strengths in

[34] Mckinsey (2017), 'Shaping the future of work in Europe's 9 digital front-runner countries' https://www.mckinsey.com/global-themes/europe/shaping-the-future-of-work-in-europes-nine-digital-front-runner-countries

[35] PwC (2017), 'Sizing the prize, PwC's Global Artificial Intelligence Study: Exploiting the AI Revolution' https://www.pwc.com/gx/en/issues/data-and-analytics/publications/artificial-intelligence-study.html

underpinning technologies such as microchips and microcomputers; UK innovators were pushing boundaries in robotics and the internet of things; and substantial datasets existed in public institutions where the use of AI could be explored safely and securely. Overall, the strategy recognised that the building blocks to make significant advances were in place.

New measures to support Britain's world-leading AI sector were therefore announced as part of the UK Industrial Strategy to boost growth and deliver a thriving, outward-looking digital economy.

To date, UK Industrial Strategy interventions relevant to AI have included:

- The AI Sector Deal;
- The Industrial Strategy Challenge Fund;
- Investment in Skills;
- The UK AI Council;
- The Machine Learning Garage;
- The Centre for Data Ethics and Innovation;
- The Strength in Places Fund;
- The National Research Centre for Artificial Intelligence.

2.2.1. The AI Sector Deal

Building on the UK Review of AI by Dame Wendy Hall and Jérôme Pesenti, Government and the AI sector agreed a Sector Deal to boost the UK's global position as a leader in developing AI technologies and anchor the UK as the 'go-to place' for AI innovation and investment. The Sector Deal was launched on 26 April 2018.

The government announced that there would be £300m of 'new' public sector investment. While not insignificant, this is still relatively small in global terms compared to spend in China, Japan, the US or the EU as a whole. The expectation was that the private sector would step forward to fill the gap[36], providing a further £700 million to create a £1bn national programme.

[36] https://internetofbusiness.com/uk-launches-1-billion-new-sector-deal-for-ai-our-analysis/

In summary, the Sector Deal aimed to:

- People: Attract and retain both domestic and global AI talent;
- Infrastructure: Deliver major upgrades to the UK digital and data infrastructure;
- Ideas: Boosting R&D spending in AI through the Industrial Strategy Challenge Fund;
- Business Environment: Ensure that the UK is the best place to start and grow and AI business;
- Places: Contribute to communities' prosperity by spreading the benefits of AI across the country.

2.2.2. The Industrial Strategy Challenge Fund

The Industrial Strategy Challenge Fund was created to provide funding and support to UK businesses and researchers. When it was announced in 2017, the first wave of £1bn focused on:

- Robotics and artificial intelligence;
- Healthcare and medicine;
- Batteries for clean and flexible energy storage;
- Self-driving vehicles;
- Manufacturing and materials of the future;
- Satellites and space technology.
- Funding opportunities in the second wave spanned:
- Data to early diagnosis and precision medicine;
- Healthy Ageing;
- Energy Revolution;
- Transforming Construction;
- Transforming food production: from farm to fork;
- Next Generation Services;

- Audience of the Future;
- Quantum technologies;
- Creative industries clusters.

Challenges in a third wave, to be announced in 2019, will be chosen from a shortlist that includes:

- Accelerating detection of disease;
- Commercialising quantum technologies;
- Digital security by design;
- Driving the electric revolution;
- Industrial decarbonisation;
- Manufacturing made smarter;
- Smart sustainable plastic packaging;
- Transforming foundation industries.

Challenges of particular interest to AI researchers and firms have included the use of AI to create next generation services; the role of data in early diagnosis and precision medicine; the development of immersive technologies; digital security; AI in robotics; and smart manufacturing.

2.2.3. Investment in Skills

Investment of £45m was made available to:

- Support additional PhD's in AI and related disciplines;
- Create a prestigious AI Fellowship Programme;
- Create an industry funded Master's programme;
- Provide support to industry to train cross-discipline professionals to apply AI in their specialist areas.

2.2.4. The AI Council

A new UK AI Council, supported by a Government Office for AI, was announced to promote the coordination of AI-related policy initiatives and the uptake of AI. The Council will focus initially on six priority sectors:

- Cyber Security;
- Life Sciences;
- Construction;
- Manufacturing;
- Energy;
- Agri-Tech.

2.2.5. The Machine Learning Garage

Digital Catapult launched a new programme in January 2018 to provide low-cost access to high-quality machine learning computation power for start-ups. It also aimed to support businesses of all sizes with expertise on cost-effective machine learning computation.

2.2.6. The Centre for Data Ethics and Innovation

The Centre for Data Ethics and Innovation (CDEI), a quasi-independent body led by an independent board of expert members, was set up to investigate and advise the UK Government on ways of maximising the benefits to society of data-enabled technologies, including AI. The Centre's activity includes promoting best practice and advising on how Government should address potential gaps in the regulatory landscape.

2.2.7. The Strength in Places Fund

The Strength in Places Fund (SIPF), led by UK Research and Innovation, was established in 2018. It set out to support significant regional growth via a new competitive funding scheme with a place-based approach to research and innovation funding. The aim was to build on existing areas of excellence by funding collaborative programmes proposed by universities, local employers, Local Enterprise Partnerships (LEPs) and their counterparts in the Devolved Administrations, e.g. Invest NI.

2.2.8. The Global Entrepreneur Programme

The Department for International Trade's (DIT) Global Entrepreneur Programme (GEP) was set up to help overseas entrepreneurs and early stage

technology businesses or start-ups to relocate or establish headquarters to the UK, including AI and data-led businesses.

2.2.9. The National Research Centre for Artificial Intelligence

The UK Industrial Strategy announced The Alan Turing Institute's designation as the national research centre for Artificial Intelligence, with the aim of making the UK the leading place in the world for data science and AI research, collaboration, and business. In May 2018, the institute announced that its long-term vision was to be:

> *"The centre of a connected network that brings together academic expertise from the UK's world-class university sector with industry, government, and third sector partners to research, catalyse, apply, and drive global impact in data science and AI".*

2.2.10. Catapult Centres

Catapult centres that promote research and development through business-led collaboration between scientists and engineers were first announced in 2011, with a Digital Catapult established in London in 2013. In 2017, Digital Catapult launched a new Immersive Lab in Belfast, which moved to the Ormeau Baths in 2019. The Immersive Lab provides local organisations with an opportunity to get hands-on experience with the latest immersive technology, including augmented reality, virtual reality and mixed reality, and enables them to test their own business ideas.

3. AI-related Policy in Northern Ireland

3.1. Northern Ireland Innovation Strategy

In 2012, the Northern Ireland Economic Strategy37 recognised that innovation underpins the growth of the best performing regional and national economies across the world and called for an economy "characterised by a sustainable and growing private sector, where a greater number of firms compete in global markets and there is growing employment and prosperity for all". Subsequently, in 2014, the Northern Ireland Executive agreed a ten-year Innovation Strategy for Northern Ireland that expanded and refined the innovation-related component of the Economic Strategy. It set out to:

- Examine the feasibility of establishing an Innovation Council;

[37] https://www.economy-ni.gov.uk/sites/default/files/publications/deti/Innovation-Strategy-2014-2025_2_0.pdf

- Develop a workstream for the new Public Sector Innovation Lab;
- Implement a new Communication Strategy on Innovation;
- Develop new Social Innovation accelerator programmes;
- Prioritise R&D funding towards opportunities identified in the Programme for Government and the Economic Strategy;
- Undertake a new research and technology capabilities study across the public and private sectors;
- Develop a foresight programme that will identify new and emerging technologies and key future markets for local companies;
- Develop a Creative NI Framework to foster and nurture a culture of 'creativity and design thinking';
- Enhance support to companies to engage in open innovation activities, either through the development of an Open Innovation Centre or the provision of a new support service;
- Increase investment in establishing industry-led collaborative networks, particularly those focused on market opportunities identified in the Economic Strategy;
- Increase investment in programmes and initiatives that support collaboration between businesses and academia;
- Increase support to local companies and research organisations to secure at least e145m from Horizon 2020;
- Fund a new world-class Business Accelerator;
- Develop an Open Data Strategy and Action Plan for Northern Ireland;
- Increase investment in the use of SBRI;
- Support the expansion of the NI Science Park (NISP).

The innovation strategy recognised the need to focus funding for research and innovation in priority areas identified during the formulation of a Smart Specialisation Strategy (S3) for Northern Ireland, promoted and funded in part by the European Commission. The Northern Ireland S3 recognised five key priority areas:

- ICT;
- Advanced Manufacturing and Materials;
- Life and health Sciences;
- Agri-Food Technology;
- Sustainable Energy.

Within the ICT priority area, specific mention was made of the need to support activities relating to software engineering; big data/data analytics; cyber security; capital markets; and digital content.

3.2. Northern Ireland Industrial Strategy

The Draft Northern Ireland Industrial Strategy[38], which was published for consultation in January 2017, recognised that Artificial Intelligence is one of the key areas which requires support in order to grow the local economy through the acceleration of innovation and research. It stated:

"We will review how we support our companies to be more productive and to enhance their capabilities in crucial enabling technologies such as data analytics, robotics, automation, Industry 4.0, machine learning, artificial intelligence, augmented reality, advanced materials and production techniques, and exploit the growth opportunities these hold for the local economy".

The Draft Strategy undertook to:

"Develop a strategy focused on making Northern Ireland a pioneering region in capitalising on emerging artificial intelligence, robotics, automation technologies and internet of things".

However, it is over two years since devolved government in Northern Ireland collapsed and the lack of a Northern Ireland Executive has meant that, to date, the Industrial Strategy for Northern Ireland has not been agreed. This has

[38] Economy 2030: A consultation on an Industrial Strategy for Northern Ireland https://www.economy-ni.gov.uk/sites/default/files/consultations/economy/industrial-strategy-ni-consultation-document.pdf

had a detrimental effect on the development of a 'Digital Strategy' that would include emerging disruptive technologies such as AI.

3.3. City Deals in Northern Ireland

A City Deal is an agreement between government and a city. It gives the city and its surrounding area certain powers and freedom to:

- Take charge and responsibility of decisions that affect their area;
- Do what they think is best to help businesses grow;
- Create economic growth;
- Decide how public money should be spent.

A first wave of City Deals was announced in 2012; a second in 2013-14. It was not until 2018, however, that the Government committed £350m toward a deal for the Belfast City Region and began negotiations for a deal covering a Derry City and Strabane District Council area.

The Belfast City Deal had four pillars:

- Innovation and digital;
- Tourism-led regeneration;
- Infrastructure;
- Employability and skills.

In terms of investment in Innovation and Digital Capabilities, support was earmarked for:

- The Global Innovation Institute (GII);
- The Advanced Manufacturing Innovation Centre (AMIC);
- The Screen and Media Innovation Lab;
- Smart District and Testbeds Programme;
- The Centre for Digital Healthcare Technology (CDHT);
- The Institute for Research Excellence in Advanced Clinical Healthcare (i-REACH);
- The Digital and Innovation Platform and Partnership (DIPP);

- The Regional Innovators Network (RIN);
- The Infrastructure Enabling Fund (IEF).

The Derry/Londonderry City Deal bid included proposals to fund:

- The Cognitive Analytics Research Lab (CARL);
- The Centre for Industrial Digitalisation, Robotics and Automation (CIDRA);
- The Transformation for Healthcare Innovation and Value Based Ecosystem (T- HIVE);
- Investment in Skills and Pathways to Employment.

Appendix 2: Discussion Partners in Northern Ireland

N.B. Discussion partners representing more than one institution are indicated by the use of bold italics.

Universities

Ulster University	Yaxin Bi
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	Kongfatt Wong Lin
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	Sally McClean
	Liam McDaid
	Jim McLaughlin

	Paddy Nixon
	Chris Nugent
	Girijesh Prasad
	Bryan Scotney
	Johnny Wallace
	Haiying Wang
	Hui Wang
	Shu Dong Zhang
Queens University Belfast	Stuart Campbell
	Barry Devereux
	Godfrey Gaston
	Mark Lawler
	Adele Marshall
	Jesus Martinez del Rincon
	Darragh McArt
	Seán McLoone
	Paul Miller
	Conor Quinn
	Scott Rutherford
	Roger Woods

Industry

Adoreboard	Chris Johnston
Allstate	Kathryn Harkin
	John Healy
Amazon Web Services	Anthony Kelly
Ampliphae	Tim Croy
Analytic Engines	Alistair McKinley
	Roger Woods
Axial3d	Niall Haslam
B-Secure	Alan Kennedy
BrainwaveBank	Tim Davison
British Telecom	Nader Azarmi
Camlin	Colin McIlroy
Citi	Mark McCormack
Ernst & Young	***Sean Duffy***
	Gareth Kelly
	Eoin O'Reilly
Heartsine/Stryker	Rebecca Funston
Intelesens/Ultralinq	Jonny Francey
Kainos	Tom Gray
	Austin Tanney

Kraydel	Paul Moorhead
Nightingale Analytics	Brendan Crossey
Nuprint	Gavin Killeen
Pramerica	David Roche
	Deepanand Saha Roy
Seagate	Gerry Kindlon
Smashfly	Thom Kenney
Sonrai Analytics	***Darragh McArt***
Yedup	***Martin Spollen***

Other

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Catalyst Inc.	Steve Orr
Department for the Economy	Ciaran McGarrity
	Conor Dunbar
Derry City and Strabane District Council	John Kelpie
Digital Catapult NI	Adrian Johnston
Invest NI	Gary Campbell
	Padraig Canavan
	Tracey Walsh
	Laura Weir
Strategic Investment Board	***Martin Spollen***

Figures

Tables

matrix.

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