APPLIED

Australian Academy of
Technology & Engineering

Digital technologies: Australian developments

Comments from the Academy Specialist Advisors in its Digital Futures Forum
Edited by Mike Miller FTSE, October 2018

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Introduction

In the process of preparing an Academy Digital Forum Action Statement on "*Positioning Australia as a leading digital nation*", selected Academy Fellows in the Digital Futures Forum were invited to provide advice on the present status in Australia of their specialist digital technology area. These Specialist Advisors represented Fellows with outstanding expertise in approximately 20 areas of digital technology.

The Specialist Advisors were asked to contribute brief answers to the following questions in regard to their specialist area.

Q1: Summarise the main technology in your area of interest and where you believe Australian research is world class and influential.

Q2: How do you see this technology area developing globally over the next 3-5 years and how Australia could play a role?

Q3: What businesses and government agencies are most likely to benefit from uptake of this technology?

Q4: Suggest methods by which the research community might act as technology ambassadors to help businesses become aware of and adopt the technology.

The Specialist Advisors' responses are summarized in this document. It presents a series of expert statements regarding the current status of digital technology research and application in this country.

1. Artificial Intelligence (AI) and Machine Learning

Professor Ian Reid FTSE, University of Adelaide, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Very broadly, AI encompasses any machine/computer agent that exhibits (or tries to exhibit) human-like intelligent responses or behaviour. Although it has been the subject of much study for more than 50 years, it has seen a massive upsurge in attention over the last few years. Machine Learning is the area in which most of the recent progress in AI has come. Again, very broadly, it describes any algorithm that is able to improve its own performance over time, usually by observing data.

AI/ML is an area in which more CompSci schools self-identify as being world class than almost any other area. However much of this may be related to the hype associated with this field, the constant references to the game-changing nature of the technology, and a "need to be on the band wagon". Without questioning the worth of much of the research done, it is debatable exactly how much of this could be considered "influential". Furthermore Machine Learning is a broad all-encompassing term and is often used to include work in Computer Vision, Robotics, Natural Language Processing and Big Data Analytics. As Machine Learning impacts these closely related fields -- and as these fields push the boundaries of what is possible through Machine Learning, (indeed many of the recent breakthroughs in Machine Learning derive from work specifically in visual recognition), hard distinctions become more difficult to make.

There are strong academic groups AI/ML based at many of the Go8 (and other Universities) including ANU/Data61, UMelb, UAdel (Australian Institute for Machine Learning), USyd and UNSW, all of which rank in the top-100 worldwide on csrankings.org (*) for Machine Learning. ANU and UAdel are in the top 5 in Computer Vision. There are also pockets of excellence that are in machine learning either directly (eg Deakin's PRaDa group) or indirectly (eg QUT and USyd robotics group).

(*) this particular ranking is based on volume of recent publications in the top-ranking conferences and journals.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: AI, and Machine Learning specifically, are technologies that are already having game-changing impact in a wide variety of application areas: fintech; in the home (eg Google Mini, Amazon Echo); in perception systems for robots, especially self-driving vehicles; in medicine (eg through automated medical image processing and other medical diagnoses); in law (recent results demonstrate that AI can find/fix errors in contracts with greater speed and accuracy than most human lawyers); in mining (eg through in situ core analysis, and more effective use of data).

It is hard to make predictions about exactly what will happen in this fast-changing field in the next 3-5 years, and to pick the winners from the hype. In some areas, the technology is getting ahead of the legal and ethical frameworks that currently exist -- eg medicine and self-driving cars. Indeed the nature of our society (in comparison to a more autocratic/authoritarian one) can be a brake on progress. For example, access to medical data that could be used to train machine learning systems is hard to come by because of (correct) measures to protect patient privacy.

A further area of uncertainty is whether the pace of progress that is currently being seen can be sustained. A major breakthrough in 2012 showed for the first time that a deep neural network could outperform all other methods for doing visual recognition. This work has directly led to the current revolution in machine learning. Although applications and problems that are amenable to s=deep learning continue to be discovered, it is not entirely clear where the next breakthrough will come from. Deep learning is almost certainly not the simple answer when it comes to trying to solve problems that involve human-like abilities at extreme generalisation (eg learning through seeing a single example), or being able to invent complex processes such as algorithms. There is an opportunity for Australian researchers to participate in the next wave of breakthroughs, and a number (including the groups mentioned above) are well-placed in this regard. The most likely application areas for Australian researchers to have impact in the short term are areas such as medicine, defence and robotic perception, and in adding value to places of existing strength in Australia such as mining and agriculture.

Because this technology, (like much in ICT/ICS), is driven by smart people working on software, there is great potential for Australia to participate and to generate significant wealth through creation of AI/ML technologies. However this potential has also been recognised elsewhere, earlier, with much greater impetus injected by governments in places such as Canada, UK, France, China and very recently India, not to mention the vast sums that cash rich tech companies like Google, Facebook, Amazon and Apple are all investing. While Australia has not yet missed out, there is a risk that the window of opportunity is closing.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Fintech; Defence; Medical; Police; plus areas of traditional strength that can benefit from added value created by better/smarter use of data such as mining and agriculture.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: Formation of Interdisciplinary research Centres and Institutes; Creation of micro-credentials in (say) “Applied machine learning”; CRC.

2. Big Data and Analytics

Professor Svetha Venkatesh FTSE, Deakin University comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Machine Learning research in Australia is world class. This area examines how data can be used to derive patterns for predicting future trends. Such trends include adverse events, anomalies and even predictions of novel drugs.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: Machine Learning is the first stage of building Artificial Intelligence systems. AI will play a significant role in shaping the world in the next decade. Australia needs to be in this game.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: The impact of AI will be all pervasive, affecting the entire social and economic fabric of society. It will transform the way people live.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: It is important that we not only disseminate information about the technology, but also start the debate on more important questions: How can humans trust machines? How can we be sure we can trust the machines to take important decisions for

us? How do we regulate such AI algorithms?

3. Broadband Communication Networks & Contents

Professor Rod Tucker FTSE FAA, University of Melbourne, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: The key technologies in my area of interest are:

» Optical fibre transport systems, including long-haul and access networks.

» Optoelectronic and photonic subsystems for broadband networks.

» Fibre/wireless devices and systems.

» Australian research in this area is world class in regard to the following:

» Advanced modulation schemes for high spectral density (Monash, U. Melbourne)

» Optical fibre devices (U. Sydney, Macquarie U, Adelaide U.)

» Optical multiplexing and signal management (Engana, a very successful startup)

» Microwave photonics (U. Melbourne)

» Nonlinear optics (ANU)

» Nanophotonics (ANU)

» Biophotonics (UWA).

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: Many (but not all) telecommunications systems technologies that will be introduced over the next 3-5 years are already being standardized. This makes it difficult for Australia to play a role in new broadband technologies or advanced high-capacity long haul systems. But there are exceptions at the device level, as has been shown in the past with companies like Indx and Engana. Australia may be able to develop new devices for bio-photonics (e.g. imaging), microwave phoronics, or provide breakthroughs in nano-photonics, at the device level.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Everyone benefits from telecommunications and broadband services.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: The Federal Government has been talking down the need for broadband by trying to show, (through reports that fit their purposes), that Australians do not need high-speed access. Many countries look towards 1 Gb/s to the home, but the Federal Government says that we only need 49 Mb/s to the home. The best way for the research community to counter this is to demonstrate examples of their technology that achieve high internet speeds.

Mr Michael Quigley FTSE comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: The delivery of broadband services will continue to be via both fixed line networks, with the trend being increasingly Fibre to the Premise (FTTP), and for mobile networks there will be a shift towards 5G starting within a few years.

There is currently no Australian industry involvement in either the components or products that are used to build these broadband networks and little opportunity to change that position. The hardware and software required for these systems are largely provided by the major Telco suppliers who operate on a global basis, including Ericsson, Nokia and increasingly the Chinese vendors such as Huawei. The component suppliers who supply the devices

such as lasers, ASICs, etc are also mostly large and established global players.

It is very difficult to see any potential role for Australian research or development in either the component or product industries that provide broadband communication systems.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: While Australia may not have a role in components and products for broadband communications there is an opportunity in two areas related to the deployment and use of broadband infrastructure.

The first is in the development of tools and applications to optimise the network planning, network construction and operations of broadband networks. These types of solutions are currently offered, in part, by the small Queensland commercial mathematics company Biarri. Refer https://biarri.com/industries/fibre-network-design-optimisation/. There is considerable scope for the expansion of such optimisation work beyond its applications to broadband networks.

The second opportunity is to use the large amounts of data that is produced by the network management systems of broadband networks to allow analysis of traffic patterns and traffic content - provided user privacy can be protected. Finding ways to access and utilise this data is a potential area of new business.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: The use of high speed and high capacity broadband services provided by a ubiquitous and seamless broadband network would have obvious application in remote education and remote heath solutions. However, this is a non-trivial exercise and many large consulting companies have attempted to provide such solutions with limited success.

There is also the potential for the research community to provide assistance and guidance in the application of broadband solutions to remote education and remote health. This type of initiative would likely be first targeted to Federal and State Education and Health agencies.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: It can be argued that the majority of Australian senior management are not aware of the potential benefits of mathematical and statistical tools in the optimisation of costs and performance in the businesses that they manage.

Of course, optimisation tools are not only applicable to broadband networks but also in any other type of network business from rail, road and air transport to electricity, water and gas networks. The gathering and analysis of the large amounts of data averrable form broadband networks mentioned above, would allow some very sophisticated optimisation to be carried out.

4. Cloud Computing & Environments

Dr Craig Mudge AO FTSE comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Cloud computing is a way in which a company or government can obtain its information technology (IT) infrastructure (computer servers, storage, networks, and applications) as a service, obtaining those resources as a utility, just as we acquire electricity and water at home. A matching business model, pay-per- use, means that entities can replace CAPEX with OPEX. Self-service and payment by credit card further simplify ease of use and cost.

The "cloud": The term "the cloud" is used to refer to the location of information stored with a cloud service provider and accessed via a web browser to be shared (business documents and photos), copied for backup (against losing a phone or deleting information on a laptop), or as part of an ecommerce distribution system (for example, eBooks and music).

Dominance of three players: Amazon (actually AWS Amazon Web Services), Google, and Microsoft Azure are by far the three dominant cloud service providers, as measured by market share and investment in innovation to improve customer experience.

We note that Academy formed a Cloud Computing Working Group in 2009 because Australian universities and Australian industry in Australia were not adopting cloud computing, or even aware of its benefits. [1]

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: The technology will evolve incrementally, without any major disruptions over the next 3-5 years. The three main providers, Amazon, Google, and Microsoft Azure will make a few major applications, most importantly machine learning, *easier to use and less expensive.* They will adopt important base technologies in their data centres, for example *software-defined networking,* which facilitates programmatically efficient network configuration in order to improve network management, performance, scalability, and monitoring.

Machine learning is a key application because it uses big-data, algorithms, and low-cost computing and at the same time could be easier to use.

Integration of cloud computing and Internet of Things (IoT) will occur, with the development of innovative systems architectures which result in true integration. Australia can play a role here via choosing bold IoT applications and build them with industry-university collaborations.

The big three continue to innovate and evolve their services, where recent examples are serverless computing, micro-services, programmable infrastructure (sometimes called infrastructure as code), voice recognition, and elementary software automation. Thus it is important for Australian industry, government, and research institutions to consciously position their ICT evolution as riding on the technology curves of the big three.

Finally, a research initiative that clearly defined multi-cloud environments and discerned their benefits, if any, would be of value.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Manufacturing plants where lots of new sensors are being introduced and their wireless networking by IoT are good targets.

Businesses where massive amounts of data are gathered and analysed and used for prediction are good targets; many datasets will provide contextual information, (weather, traffic, market prices, ...), for these new IT applications. For support for this idea, we need go no further than the earliest examples of commercial use of massive data sets -- from click streams on the web and financial transactions on the web.

Cloud-enabled collaboration via documents, designs, and images, for example, is used by high-performing organisations.

Massive Open Online Courses (MOOCs) will play an increasing role in life-long learning and in the University of the Future. The technologies of storage and networked communication of text, audio, and video, all delivered securely, are required for MOOCs and most economically sourced via cloud computing.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: By taking extra effort when publishing research results to cover the benefits of cloud computing in their papers as well as their scientific results. As a result, perhaps improved collaboration methodologies, workflows, data curation, and other tools of the area known as *eResearch or eScience* would spread easily. [2]

1. *Cloud computing: Opportunities and challenges for Australia* J Craig Mudge, Principal Author. Report of a Study by the Australian Academy of Technological Sciences and Engineering (Academy), Sept 2010. ISBN 978 1 921388 15 6.
2. Entities established to nurture these endeavours are https://conference.eresearch.edu.au/ and the *Australasian eResearch Organisations (AeRO)*

5. Computer Modelling, Simulation & Informatics

Professor David Abramson FTSE, University of Queensland, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: My areas of interest are supercomputing systems and high performance distributed computing platform (including clusters, grids and clouds), both from a hardware and software perspective. Australia is a fairly junior player in this field due to the lack of investment in large scale systems, although it has achieved some success in distributed computing systems software over the years. It also has a track record of applying supercomputing in particular domains such as weather and climate modelling, computational fluid dynamics, geology and geophysics, chemistry and some genomic and bioinformatics applications.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: Supercomputing in all its forms will continue to be an important technology underpinning advanced manufacturing and environmental management, to name a view. Australia could at the very least be at the leading edge of applying these platforms, which in turn would spin out into local software development activities.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Advanced manufacturing, environment, agriculture, medicine and biomedical research and health, to name a few.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: This is a chicken and egg problem. We need more businesses interested in exploiting computational thinking, which in turn drives students to specialise in these fields. On the other hand, most local companies lack the technical expertise to decide to invest in advanced computing approaches, thus limiting the demand for graduates. NCSA in the US has an excellent industry engagement strategy and has significant success in bringing businesses to advanced computing. However, this is built on a very significant, long term, investment in NCSA by state and federal governments. See http://www.ncsa.illinois.edu/industry.

6. Cyber Security

Dr Jackie Craig FTSE comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Cyber security has a broad range of technologies that are critical to its progress. I have categorized these into directly relevant and indirectly relevant (but not any less critical).

Directly relevant:

(1) Crypto technologies are critical to ensuring data privacy. Crypto mathematics is the main technology of importance. Quantum keys are a promising adjunct. Quantum computing may play a role in the future. Australia's capability in crypto mathematics in the classified arena is world class. We are also world class in quantum technologies.

(2) Data analytics is key to building cyber situational awareness which is a foundational requirement or good cyber security. Australia is not world class in this area. Companies like FB and Google are way ahead.

(3) Trustworthy Systems (including formal methods) provide solutions that guarantee data privacy and integrity. Australia is world leading in this.

(4) Human aspect of Cyber security (including behavioral science, psychology etc) is one of the most critical areas. I'm not sure Australia is world leading here but there are pockets of good work.

(5) Operations Research and Systems Analysis (including experimentation and red teaming) are very important. Australia is not world leading in this, but in the classified arena is well respected.

(6) IoT will dramatically impact cyber security - for the worse.

Indirectly relevant:

Autonomous systems, AI, machine/deep learning.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: The importance of cyber security will continue to rapidly increase as we become increasingly dependent upon digital systems, move to third party providers for e.g. Data storage and management, and the market is flooded with cheap IoT devices having very poor, if any, in-built security.

AI will come to the fore in cyber security data analytics, cyber security decision support. Human cognition, behavior and reasoning will also come to the fore. Australia can use its expertise to partner internationally to develop solutions. Importantly Australia should become active in cyber security standards forums to promote standards for IoT devices.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: All will benefit from the individual to big business and government.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: Industry partnerships, placements, joint workshops. Academy should have a targeted campaign (targeted at company board members) to get cyber security on the standing agenda of all boards. Academy should recommend that govt run a continuous public education campaign to encourage good cyber security hygiene by all - at work and in personal lives.

Dr Ian Oppermann FTSE, Data Analytics Centre, NSW Government, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Australia has developed several technologies of significance: The secure microkernel (Data61's L4 http://ts.data61.csiro.au/research/old/L4/), and quantum based cryptographic key management (Quintessence Labs https://www.quintessencelabs.com/) .

Other areas of note include the work of DSTG to link secure and non-secure compute environments in virtual ways, and the extension to the SFIA skills framework for Cybersecurity undertaken by the Australian Computer Society (ACS).

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: Cyber security will continue to grow as a challenge to a digitally enabled world. As we continue to become increasingly dependent on digital systems, the ways in which systems can be compromised will increase. It is an area Australia must take very seriously or risk significant impact to productivity, safety and national prosperity.

Critical focus areas for Australia will continue to be education and collaboration with trusted partners. Australia's lead in the development of provably secure system components provides us with areas of strength to build on.

Australia also has the opportunity to take a lead role in standardization of trusted data sharing models (such as extending the work of the ACS), blockchain (Standards Australia chair of ISO 307) and Information Governance.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Cyber security will impact all aspects of business, government and society. Smart infrastructure, smart grids, smart factories, smart health and smart government all are dependent on secure and trusted data sharing models in complex environments.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: There is a great deal of fragmented activity in the Cyber Security space in Australia reflecting the diverse nature of the challenge and the attempt by many groups to address areas of particular interest. The Cybersecurity CRC is an attempt to address the research challenges more holistically and the Cybersecurity Growth Centre is an attempt to develop the local industry.

The Academy connecting in a meaningful way to groups - including Cybersecurity CRC, Cyber Security Growth Centre, ACS, Standards Australia, Data61, selected research groups – can help to unite these areas of activity.

The Academy can also reinforce the message that Cybersecurity is a major challenge for all Australians. The Academy can take a lead role promoting the need for cyber security education at all levels – technical, managerial, government, and the general public.

7. Internet of Things & Large-scale Networks

Professor Gernot Heiser FTSE, University of NSW, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: My specific expertise is in operating systems (OSes), and formal (mathematical) proofs of safety and security properties.

The Trustworthy Systems group at Data61/UNSW I'm affiliated with is considered the world leader in this space. The specific technology is our seL4 microkernel, the world's first OS that was proved free of implementation bugs, and has furthermore proofs of its ability to enforce security. A related piece of technology is our Cogent framework, which is a high-level language that makes it easier to develop bug-free low-level OS code, and drastically reduces the cost of proving bug-freedom for such code.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: seL4 has been built into a number of critical systems. One is the AltoCrypt secure communication dongle produced by Canberra-based Penten, AltoCrypt is undergone security evaluation by UK's CGHQ for and approved for defence use, and Penten has won a AU Army contract https://www.defenceconnect.com.au/intel-cyber/1915-cyber-security-company-wins-1-3-million-innovation-contract. Together with DST we have developed the cross-domain desktop compositor (https://ts.data61.csiro.au/projects/TS/cddc.pml), which is presently being transitioned into a product and evaluated for national security use, and there is interest in the UK, US and Canada. There are companies that built seL4-based "trusted execution environments" for mobile phones, for all I know, some of these may already be in mass deployment.

This is just the beginning. There are projects around the world on building critical devices secured by seL4 (many of which we know nothing about, due to the open-source nature). There is an seL4 ecosystem developing, with at least two Australian companies (Penten and Cog Systems) developing seL4-based products, and the US DARPA funding an "seL4 US Centre of Excellence", something similar is happening in Germany, including seL4 being designed into products aimed at protecting industrial control systems. Similarly, Cog is adopting our Cogent technology, as is a US-based autonomous car company and a German company.

Over the next 3–5 years I see this ecosystem, and the resulting deployment of seL4 and Cogent, accelerating exponentially, and seL4 and Cogent deployments spreading to a large number of products across multiple verticals.

As the creators of the technology, we are is a good position to enable this uptake, and benefit from and participate in it. However, there is a risk that much of this activity will eventually shift overseas, as familiarity with the technology spreads. Fostering a local seL4 ecosystem will be critical to retaining the economic benefits, and governments buying products based on the technology would be an important enabler.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Short-term main beneficiaries are defence and other security-critical government users (eg DFAT). Medium-term, anyone who produces or deploys IoT systems is a potential beneficiary, especially safety-critical ones, such as medical devices, cars and critical infrastructure. Obviously, the degree of benefit depends on how much of such devices will be produced by Australian companies, but the technology could give them a competitive advantage (this is the main driver for

Cog and Penten).

Short-to-medium term, replacing/securing enterprise IT infrastructure is not feasible, the technology is mostly suitable for embedded and cyber-physical systems.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: That is an excellent question. I almost never decline an opportunity to speak about this ;-) but clearly more can be done. Obviously publicising the fact that we have something very powerful and world-wide unique at every opportunity is a must, and we're doing our share. Not sure what's the best way to get others into doing the same.

Professor Iven Mareels FTSE, Uni of Melbourne, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: In the IoT space Australia makes many contributions across the university sector, with most of the G08 and many other universities participating. Good examples include the Melbourne Networked Society Institute, at the UoM and the Center for IoT and Telecommunications at the USyd.

In industry we are well represented, and world leading in for example the IoT based solutions to large scale irrigation systems and water management, see e.g. Rubicon Water Pty Ltd. Rubicon manages 95% of the local irrigation market, and its solutions are adopted in China, India, Southern Europe, California and New Zealand. It has won many international accolades for its technology.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: IoT is an important technology in home automation, energy networks and utilities more generally. Much of its potential has been hyped beyond belief, and real large scale adoption examples with successful business models behind it are not easy to identify.

Nevertheless propriety networks focusing on single function solutions or single industry solutions are becoming available: home security, home automation, irrigation systems, on-farm automation, and transport monitoring as well as energy HVAC/battery/PV systems and the like. The automotive industry will require an IoT supporting (driverless) cars as well.

Some difficulties that the industry faces
A) privacy and security in dealing with data
B) non-interoperability of sensors/actuators, lack of accepted standards, and the propriety nature of many solutions on offer (penalty for early adopters)
C) security of functionality as lightweight IoT devices can easily be hacked and repurposed (need much more attention)

True deployment will require advances in AI and cloud networking, as IoT devices living at the edge of the network will require services to be provided through AI agents (human intervention is not feasible) and will require serious resources to be made available through ad-hoc cloud solutions (services on demand, data exchanges on demand, as well as to ensure proper accountability).

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: The Telecommunication industry is backing this technology, as it will provide a new revenue stream for the networks. 5G and NBN networks are particularly well geared towards IoT uptake.

Utilities will need an IoT solution to manage higher density usage and better management of assets. Government agencies that can benefit, but the business case is weak, is remote monitoring of environments, but also (with a better business case) traffic management, and road and transport management.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: CRC and ARC centres of excellence should be mandated to have an educational arm that explains technology advances, and ensures that the public at large including industry is well informed.

8. Mobile Computing & Networks

Professor Branka Vucetic FTSE, University of Sydney, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: The main trend in mobile computing and communications is the new cellular standard 5G. It will provide connectivity for the emerging Internet of Things and enable new augmented and virtual reality services. Australian scientists and researchers have been responsible for major breakthroughs and technological advances in wireless communications, in particular in contributing to the Wi-Fi standard and satellite communications technologies.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: There will be an uptake of 5G in consumer IoT devices in smart homes, fitness tracking and wearables, as well as in smart metering, logistics, retail and agriculture. Large scale deployment of the Industrial Internet, including industrial robot control in advanced manufacturing, self-driving vehicles, automated energy grids and tele-robotic surgery, underpinned by 5G, will take up to ten years.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Healthcare will benefit from remote patient monitoring and patient records access, providing new business opportunities for telcos, app developers, pharmaceuticals, wearable device manufacturers, and insurance companies. 5G is expected to enable automation in manufacturing, increasing productivity and cutting costs. 5G connectivity will underpin self-driving vehicles and it will also benefit freight and logistics. The augmented and virtual reality applications that 5G is expected to support could transform retail, property, entertainment, and tourism.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: Researchers could assist in developing awareness of new technology benefits by organising workshops, conferences, demonstration projects, and collaborative programs with industry.

Professor Jay Guo, University of Technology Sydney, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Australia has the legacy of leading the world in antennas, millimeter-wave circuit designs, signal processing, and mobile communications networks. Our global influence is continuing and growing in certain areas such as reconfigurable antennas, array signal processing and super-fast wireless communications.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: With the renewed strong global interest in a variety of satellites and space-borne platforms, mobile computing and communications networks are evolving into integrated terrestrial and space networks. This will most likely become a key component of 6G. Owing to the required extreme data rate, millimeter wave technologies will play a key role in such networks. Growing our world-leading capabilities in millimeter technologies and mobile networking is vitally important for Australia's future.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Businesses and government agencies who will benefit most from the uptake of those technologies include industries such as telecommunications, logistics, mining, fishery, agriculture and defense.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: Academy would be well positioned to work with research organizations, industry and government agencies to run a series of focused workshops and seminars with business leaders. In conjunction with the above, Academy could also liaise the publication of some white papers.

9. Quantum Computing

Professor Michelle Simmons FTSE FAA, University of NSW, comments in THE AUSTRALIAN 12:00AM June 13, 2018:

Quantum computing could be at the forefront of the next wave of cost savings and productivity improvements across Australia's mining sector, according to Australian of the Year Michelle Simmons. Professor Simmons told The Australian the mining industry's record of innovation

and entrepreneurship meant it was ideally suited to embracing the potential on offer from the cutting edge of quantum computing technology.

Professor Simmons will be the keynote speaker at the Association of Mining and Exploration Companies' annual convention, which kicks off in Perth today, and said she was looking forward to engaging with the industry to discuss the opportunities. "Mining for me is a very hi-tech industry. It's very entrepreneurial with a culture of rapid adoption of new technologies," she said. "Quantum computing is part of a new wave of technology that promises real-time analysis of very complex problems, so I suspect there will be a lot of areas of overlap." Professor Simmons, a scientia professor of quantum physics at the University of NSW, a pioneer in atomic electronics and quantum computing was named Australian of the Year in recognition of her work in the field.

Quantum computing promises to solve complex problems far more quickly than conventional computing, and Ms Simmons said the mining industry represented the ideal candidate to take advantage of the technology. "Anyone who has got serious optimisation problems involving lots of data will benefit from having access to a quantum computer, and I certainly see that in the mining sector where they face some really difficult optimisation challenges relating to logistics, mine life planning, resource discovery and geological analysis," Professor Simmons said. "There are key areas there where they've got lots of data and would benefit from having a processor that can do massively parallel computing."

Iron ore majors Rio Tinto, BHP Billiton and Fortescue Metals Group are investing heavily in equipment such as self-driving trucks and automated drill rigs. The industry is also increasingly reliant on data technology to refine processing methods and maximise efficiency and considerable research is going into the analysis of exploration data in an effort to identify a new generation of discoveries.

While the mining industry has suffered from a perception in parts of Australia that it is an old and dirty industry, Professor Simmons said her experience with the sector showed it was entrepreneurial and innovative. "The fact they've asked me to go and talk is a sign they're aware of the latest technology that is coming and getting on top of it," she said. "My sense is it's one of Australia's leading areas and I want to make sure they keep at the forefront."

Since being named Australian of the Year, Professor Simmons has been visiting communities around Australia to promote the potential of quantum computing and has been a strong supporter for the introduction of coding courses in Australian schools.

10. Robotics & Computer Vision

Professor Salah Sukkarieh FTSE, University of Sydney, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: The main technology is field robotics which focuses on research and developing intelligent mobile platforms (air, ground and sea) that can operation 24/7 in all-weather/terrain conditions.

Australia has been at the forefront in the research and its translation into industry for over 20 years. Mining, logistics, infrastructure and aerospace/aviation being examples.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: The technology that is required for field robotics (and robotics in general) is becoming easier to develop – both through the forms of start-ups and open-source hardware/software.

Australia can capitalise on this through greater innovation in business models and entrepreneurship. Academia needs a bit of a rethink as to what the future of robotics is, since Universities in the past have usually been the developers of robotic systems which can now be easily replicated outside.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Robotics/automation has a profound affect on operations through efficiency and productivity gains. It has improved the international competitiveness of many of Australia's business and government agencies and will continue to do so as well as improved on environmental performance (greater use of assets etc).

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: My feeling is that business is aware of the technology. Greater focus should be on the relationship between the startup, research, government and business community in the technology transfer. Also, aspects around the social and ethical impacts of robotics and automation should be addressed by the research community to help businesses in the long term.

Professor Robyn Owens FTSE, University of WA, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Australian research is world class in Robotics and Computer Vision, driven by a variety of application domains. For example, we are the sixth largest publication country in the International Journal of Computer Vision (and the largest per capita (data, Web of Science, 2015-2018)). We are the third largest publisher in Pattern Recognition over the same period, and the largest per capita. Australia has a number of critical mass research groups located at the University of Adelaide, Griffith University, the Australian National University, Data61, University of Sydney, University of Technology Sydney, UWA and Queensland University of Technology, for example.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: In the next 3-5 years, Artificial Intelligence will remain as the main technological disruptor and the largest share goes to computer vision sensing for robotics applications. From self-driving cars and artificial personal assistants to medical diagnosis, treatment planning and robotic surgery, Robotics and Computer Vision will play the dominant role. Australia is already a world leader in this area. It should take the initiative to make policies and invest in commercializing the research to capture the international market before it is taken by other competitors. It should also actively engage in the development of an ethical framework for AI research in general.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Basically, any businesses that use visual data or automation can benefit. Medicine is the obvious one but there are others such as customer care, the retail industry, mining and the financial sector. In the United States, there are dedicated companies working on delivery of such computer vision projects e.g. Amazon Go. Similarly, government agencies that perform city

planning, roads planning, city mapping, change detection, hazard perception, environmental monitoring and surveillance can also benefit. The Defence industry is an obvious application area.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: Researchers are already doing their part by publishing, presenting in conferences and inviting industry/businesses to conferences and workshops. There is increasing interest in having industry collaboration and co-supervision in research training, including periods of internship for research students. Further engagement will involve researchers making publicly available their data and code, along with their publications, to facilitate the uptake of their research. Collaborative work across research institutions and industry should strive to define and accept common data standards, reusable datasets and software containers for specific application domains.

11. Software & Computational Systems

Dr Phil Robertson FTSE, iiNet, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: My focus in the past 10-20 years has been more on the challenge of applying Australian technology expertise to create commercially sustainable outcomes, drawing on my experience of 10 years in a global technology company getting Australian technology into global products, and 10 years in NICTA whose main purpose was to address this very challenge or building industry skills and opportunities around deep technology from some of Australia's best researchers.

In my experience it is seldom the research strength or influence that is the limiting factor for this - rather it is the cultural background and lack of industry experience in the researchers, lack of strong and ongoing collaboration partnerships, and instability or lack of enabling public or industry policy initiatives.

As a result very few researchers have built the experience of a globally-focused industry CTO - understanding market drivers and opportunities, how to position products or services in such markets, and how to use deep technology IP to create a sustainable competitive advantage. This requires advanced skills at integrating research, R&D engineering, product development under market drivers, and quality systems.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: This is a rapidly evolving area, using such techniques as agile development, scrum-style contract and project management, collaborative techniques, meet-ups for advanced practitioners to share experiences, and shared tools including open source software.

There are a small number of Australian companies who are among the global leaders in this, and a few skilled groups in public sector organisations. On the other hand, efforts at transforming skills in the public sector have been less than convincing, probably largely due to the normal inertia factors that inhibit disruptive change, but also due to many players underestimating the difficulty in developing such skills from a low starting point. Many of our small and and energised companies find it almost impossible to find these skills in software engineering in Australia, and now typically will not employ experienced engineers because of the problem of "unlearning their bad habits" - they will instead employ immediate graduates to teach them modern skills.

Australia's best chance of building a broader base of such skills is through partnerships with global companies. This needs more encouragement for commercial partnerships, but also encouraging greater people mobility across research, industry, and government sectors. This requires removing the counterproductive drivers such as clonal promotion criteria and inequitable superannuation schemes. There may be scope for catalysing 2-3 year secondments into global companies such as Atlassian.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Industry and government both have a critical need for such technologies, but the challenge is how to introduce them, and the skilled people who can drive this, against the significant legacy obligation and cultural inertia barriers.

Industry seems to be moving faster than government, for example with key financial sector companies buying innovative start-ups who have the skills needed (albeit in small numbers), to drive innovation and introduce disruptive skill sets. Government agencies are having a tougher time overcoming the inherent conservatism in their CIOs, partly due to the deep legacy system obligations they carry and the media and political reactions when something goes wrong.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: The challenge is that few in the research community have the experience or skills to help business become aware of these emerging software engineering technologies and the real role of a global CTO.

There are, however, notable exceptions such as the Engineering and Design group at Data61, and probably other smaller groups elsewhere. This suggests the need to strengthen those groups, and encourage staff mobility to companies and government alike through incentive schemes that are effective for such people. Typically those people can work anywhere they want in the world, but can be drawn to R&D organisations because of the interest in working with researchers - the challenge is to give them the freedom and flexibility they need to work effectively, which can be difficult in large organisations such as public sector agencies.

The education sector can provide smart graduates with open minds to learn new skills, but few universities have the industry experience to teach modern skills from a practical standpoint. This emphasises the need for more work-integrated-learning programs. It seems reasonable for students, for example, to learn skills in fusing functional programming for product development with experienced mentors through a 6 month work stint in a company, and then go back and do the theoretical underpinnings of functional programming at university - that order might make for better skills development. Perhaps more salient would be learning-integrated-work programs, where existing staff could be jumped out of their current roles and immersed in a modern software engineering course which included deployment into an agile company for on-the-job mentoring, to address the problem of re-skilling the workforce.

One potential may be to create an elite (in the constructive sense) Masters program around modern software/ systems engineering for public sector staff. My experience is that there are many good analytical minds, often with a background in physics, maths or engineering but also in law and other nontechnical fields, in the public sector who are often left feeling marginalised by the politics and policy changes in public agencies, who would be open to a 3-year supported training scheme designed to re-skill a modern public sector. Combining this with analytics and simulation skills would create a valuable work-force. Universities such as ANU have elements of such a program up and running (i.e. Masters of Applied Data Analytics, Masters of CyberComputing), but these are not coordinated as part of a larger-scale national skills re-builfding program that would generate the numbers of people needed, which would probably require dedicated funding and numbers commitments from Dept Secretaries.

I've been trying to work out how to respond to this, as fundamentally I don't think the technology depth and expertise in Australia is the primary limiting factor for digital transformation of the Australian economy.

In my experience, which covers a mix of public sector and private sector R&D, sustainable competitive advantage requires typically all four of:

1. Some form of protectable technology-based IP, that gives a core around which products or services (or

processes and systems) can be built.

2. Deep systems-level know-how, across all facets of research, development, product deployment and market responsiveness, that is difficult for others to build over 5-10 years.

3. Well-established (> 3-5 years, > 3-5 product collaborations, etc) partnerships and relationships in the supply chain, typically at least 3-5 years old, that catalyse and consolidate market opportunities and resilience.

4. Some form of "unfair" advantage, such as schemes like DARPA, NIH, SBIR/SBRI, preferential local prototyping and procurement policies, etc.

Our scorecard against these is very patchy - there are some good exceptions, but broadly:

1. Australia has good researchers, but very little technology is protected in global markets with a plan to capture opportunities around that protection.

2. We do quite well on systems-level know-how in areas where research strength has been maintained.

3. We have very poor sustained partnership record between large cos, SMEs, and research communities, compared with global markets.

4. We struggle to get schemes such as SBIR up and running, due to various factors, but this may be improving recently.

As a consequence, we have very few research/technology people who can operate in a role equivalent to that of a globally experienced CTO, which is indicative of our ability to compete globally. It's not that we don't have people who would have the capacity to build these skills and experiences - rather our cultural, educational and employment incentives largely act as deterrents to this.

So although my research background is imaging systems, I will focus my replies to the questions around the technology challenge of creating globally experienced and competitive CTOs, and the cadre of skilled modern software/systems engineers who could become such CTOs in the future. And I recognise that the closest of your categories to this is the Software and computational systems category!

I think the challenge in these fast moving areas is that the world is different from the experiences we had, and we need to draw in the people who are closer to hands-on experience.

Professor Robin Stanton FTSE, ANU, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: Transformational initiatives are often blocked by the cost of designing, building and deploying systems. Software engineering platforms, that is the infrastructure for developing software, target all three aspects and their trade-offs. Platforms are very powerful enablers. They allow skills in the underlying software technologies to be systematically applied. They also facilitate composition, testing and maintenance of complex systems.

Australia has world leading research into many of the software technologies which underpin development platforms. Technologies for "proven" behaviours is an example. Technologies for performance improvement in HPC environments is another.

Australia has world-class software engineering courses but little by way of assisting them to come to grips with uptake of transformational systems. Research into effective uptake techniques is relatively immature.

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: System development technology is a growth area. Lowering the costs will accelerate transition to digital economies. Impact on Australia will depend on backing up technical proficiency with leadership and entrepreneurial skills. With this in mind the growth of incubator environments, mentoring and secondment arrangements is encouraging; as is improvements in the climate for investments.

Participations in international collaborations, important in their own right, also showcase Australian capabilities on the global stage. Collaborative development of the ACCESS weather modelling system is a good example. Through Australian software engineering expertise, the ACCESS were modified to greatly improve performance on advanced architectures. International collaborations of this kind do not fit readily into national funding programs, a barrier Academy could consider through the Digital Forum.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Organisations with strategic plans for increasing their involvement in the digital economy will be the main beneficiaries of leadership in technologies and their uptake. These would include most government agencies and a wide range of businesses. The recent Digital Transformation Impact and Readiness Study carried out by CA Technologies across 900 mid-to-large organisations in AJP regions found that most business and IT leaders acknowledged the impact of the digital economy with 80% agreeing that change is increasing. However, the Study reports that only 17% have "fully formed" digital transformation initiatives and only 9% are considering fully digitizing their organisations. Figures for Australia alone seem not to be available in national statistics.

It is reasonable to assume the AJP figures are representative of the national scene. It follows that a national scheme for high level digital transformation assistance makes a great deal of sense. Such a scheme fits into consideration of Q4.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: Assisting businesses in understanding how they can condition their business models to benefit from the digital economy should be a priority area for Academy. However, although many researchers could become effective technology ambassadors only a few would have an understanding of business models needed for the role. Expanding the idea to include software engineers and other technology professionals would expand possibilities. Graduate coursework with shadowing placements in cooperative organisations is an attractive possibility. Universities typically have graduate professional development programs capable of mounting that kind of course.

Other comments: First though I would like to raise a scoping issue. The draft Action Statement traverses the importance of technology and its uptake across business, government, communities and individuals more generally. The statement captures the digital revolution Weltanschauung quite nicely, however in its current form it does not make contact with Australia's maturity in engaging the opportunities for, or meeting the challenges of, participation in the burgeoning global digital economy. There is quite a lot happening to build momentum in Australia increasing national maturity in the process. Investments across the spectrum from angels to ASX would be an interesting indicator; informed opinion has it increasing.

From personal experiences over many years, I believe we are unlikely to make distinctive "Academy" contributions to digital futures challenges without proceeding from knowledge of the current state of play in Australia. It follows that Academy will need to develop ways to maintain knowledge of the issues holding Australia back in the digital transformation race; and of course many of those are not technological in character. Although identifying such issues is a challenge in itself, there are fortunately a number of surveys and "environmental scans" we could work from.

For example, the Digital Economy Strategy consultation paper released by Industry in September last year covers the ground the framework aims to build on. So maybe working with Industry on the outcome of their "Opening

up the conversation" consultative process would be a productive Action? I note that release of a Digital Economy Strategy is planned for the near future so the outcome might offer an early opportunity for Academy to relate its expertise to creditable data preparedness for transition to the digital economy.

I should also comment on my experience with respect to being listed in the Software and Computational Systems category. From a background in AI, programming languages and high-performance computing, my career has revolved around transforming practices and processes through the design on information infrastructures and associated services. Innovation through software development, licencing and associated commercialisation pathways are also part of my background.

While the technologies mentioned under the Software and Computational Systems category play critical roles in the migration to the digital economy, and especially the rate of change in those technologies, most of the challenges have been non-technical in nature. Rather they are found in community cultures where resistance to change and casting IT as a cost centre are masking the strategic roles IT can play. We need to do more to develop software engineers who can both design and implement systems for digital transformations and provide leadership for associated investments.

I hope you find these comments useful. Having had the opportunity to read Phil Robertson's informative response, I note that although Phil's and my pathways have been quite different, there is considerable overlap in our views on the draft Action Statement. Consequently, I have sought to broaden and extend Phil's comments with a view to "value-adding" from my experiences. I am copying this to Phil; I'm sure the Action Statement will indeed be front and centre when we get together next week. I'm happy of course to expand on any aspect this email.

12. Sensors and Transducers

Professor Lorenzo Faraone FTSE, Uni of WA, comments:

(Q1) – AUSTRALIAN RESEARCH STANDING IN YOUR TECHNOLOGY AREA: All variety of smart/intelligent sensors that provide input for AI/robotics/smart systems/intelligence gathering/decision making/diagnostics/threat mitigation, etc.

In our area, Australia has world class capabilities in infrared sensors for spectroscopy and imaging, and in robust microelectromechanical systems (MEMS) for adaptive spectral/temporal/spatial signal manipulation/control/selectivity for a variety of platforms and with dramatically reduced SWaP-C (size, weight and power, and cost).

(Q2) – LIKELY DEVELOPMENT IN NEXT 3-5 YEARS: Infrared avalanche photodiode (APD) technologies for eye-safe and covert LIDAR with applications in 3D imaging/mapping for autonomous vehicles and drones in adverse atmospheric conditions, for threat detection/identification in defence and security, and for remote sensing and surveillance in space-based platforms.

Next generation on-chip functionalities for real-time enhanced decision-making on field-deployable platforms for smart agriculture/food, more robust target detection/recognition/identification and threat mitigation, medical diagnostics, and industrial process control.

Further miniaturization and cost-reduction (SWAP-C) of smart sensing modules for integration into commercial mobile phone/computing platforms, space-based platforms, and autonomous vehicles/drones.

(Q3) – WHICH ORGANISATIONS WOULD BENEFIT FROM THIS TECHNOLOGY: Defence and security, smart

agriculture, consumer electronics, medical diagnostics/instrumentation, food security/provenance, Australian Space Agency, resources industries, environmental & pollution monitoring.

(Q4) – HOW SHOULD RESEARCHERS ACT AS TECHNOLOGY AMBASSADORS TO INDUSTRY: Facilitate the formation of spin-off companies that can provide new capabilities to solve high-priority, business-relevant problems.

Facilitate graduating students and early career researchers “to risk it all” and pursue commercialisation pathways/ entrepreneurship.

Provide mechanisms whereby researchers can showcase their capabilities to selected industry sectors.