Future Opportunities Report

National Imaging Facility

Enabled by

NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

Contents

Foreword

The National Imaging Facility undertook an extensive national consultation during the second half of 2020 to identify the gaps and opportunities available for future investments in imaging technology under Australia's National Collaborative Research Infrastructure Strategy. This year has been the perfect time to step back and reflect on the way in which future work will be undertaken and future problems will be solved. The ever-pressing impacts of Climate Change and COVID-19 have not only stressed the urgency of solutions but have also shown how much can be achieved when individuals work collectively across disciplines and with the community at large.

Participants contributed from all parts of Australia, across disciplines ranging from archaeology to zoology, and yet all saw and argued for what is just within our reach: the power of harmonising data across different platforms, of integrating data gathered from different modalities, of catalysing the skills and expertise embodied in the NIF fellows, and of focusing Australia's research effort to solve major societal challenges to provide tangible impact for the community at large.

This Future Opportunities Report outlines the thinking that drives the community of researchers and positions NIF to develop a strategic plan for future investments in capital and people to advance Australia's imaging facilities and increasingly rich data repositories.

Personally, it was a huge privilege to share in this national conversation. The quality of our researchers and the nature of the problems they are tackling positions Australia well to continue its role as a major research powerhouse and a force for international collaboration.

Emeritus Professor Robyn Owens

Summary

From all perspectives, the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS) program has been incredibly successful.

Since NCRIS was announced in 2004, it has seen support from both sides of Government and has ensured Australian science is counted as world-leading. Investment has leveraged massive co-investment and supports internationally significant activities that will have impacts and outcomes for decades to come.

The National Imaging Facility (NIF), as one of the 24 supported facilities of NCRIS, is no exception. Established in 2007, NIF provides state-of-the-art imaging infrastructure and highly specialised expertise to enable researchers to address nationally significant and global challenges. NIF's imaging facilities and expertise help Australian research communities to understand the form and function of humans, animals, plants and materials. As an unincorporated joint venture with 11 participants, NIF provides researchers with the tools to explore the inner space of human health, agricultural science, and the environmental and material sciences.

Summary

The consultations demonstrated strong support to take NIF to the next level: from Infrastructure at the Node to Infrastructure on the Grid.

Increasingly, the impact of the NIF investment will need to be evident through partnerships with industry, governments and other infrastructure facilities. The more embedded NIF is into the fabric of Australian research and innovation, the easier it will be to sustain.

Across all user groups consulted, there is a desire to extract more value from the data gathered by the NIF instrumentation through image data banks, AI tools, and analysis pipelines making image data itself the core of the infrastructure, rather than merely the equipment that captures that data.

A focus on interoperability and reusability of the NIF data would ensure that the NIF legacy endures beyond the lifetime of an instrument.

NIF Nodes can overcome the barriers of geographical location to ensure that, through a diverse portfolio of imaging technologies, they each provide services across the Nation. The NIF Fellows are clearly core to such a strategy, and those consulted supported a renewed focus on how NIF Fellows work effectively as a collective.

Participants supported a mechanism for NIF data from all instrumentation to be available in a National Imaging Databank, with data and protocol harmonisation, virtual desktop environments, common analysis pipelines and workflows, and simulation and modelling tools.

Integrating NIF data and processes with other NCRIS capabilities (e.g., genomics, microscopy, health administration, pharmacological data etc.) and using Australia's outstanding supercomputing and network infrastructure will place Australia in a leading international position across the many disciplines needed to address some of the major challenges of our times.

Process

During approximately three months from mid-July until mid-October 2020, a community consultation was undertaken to assist NIF with the identification of infrastructure gaps and the planning for future investment opportunities. The consultation comprised three major components:

Stage 1
Initial Survey

Identify the various community research challenges and opportunities for nationally significant investments that could put Australia at the forefront of international imaging developments. The survey elicited 40 completed responses. Respondents identified several themes to be explored further in the themed consultation meetings.

Stage 2
Themed Meetings

Four major community consultations organised around the primary user groups: Agriculture and Food; Materials, Artifacts & Ecosciences; Human Health; and Neurosciences. The research theme consultations and Participant Council consultations involved 66 leaders and researchers and spanned approximately 20 hours of discussion. Many common themes arose across the different discipline groups and from partner organisations.

Stage 3
Follow up Survey

A follow-up survey was sent across the broader research community to relevant organisations and through social media, eliciting 305 completed responses. The outcomes of that survey provided further clarity and detail on the barriers to using imaging technologies, the data needs of researchers, the specific platforms currently missing from Australia's imaging suite, and the potential for this infrastructure to provide economic, environmental and social impact.

Findings

Research impact has an extended timeline and requires many partners. Nevertheless, it is possible to build the pathway to impact into early-stage research.

1 Impact

The community consultations highlighted research questions that various disciplines were seeking to address at the national level, where advanced imaging and new acquisitions could make a significant difference to progress.

Lifting the Australian Agricultural Industry from $80B to $100B within 10 years is a crucial component of *Australia's Food Security and Economic Growth* challenges. There is already a coordinated effort to address this challenge across the major agricultural research organisations and government agencies.

There was keen interest in Australia developing underground imaging capability to understand how root and rhizome functions **impact on crop productivity**. Interestingly, underground imaging capability was also identified by the Materials group as a way of addressing *Climate Change*.

The Human Health and Neurosciences groups are broadly working towards *Improving the Health Life Course of Australians*.

Impact case studies and industry linkages are likely to be important components for future NCRIS investments, so planning for impact should start as soon as possible and should be embedded in all future investments.

There was strong agreement that both Expertise and Data Science could facilitate collaborations between scientists, clinicians, radiologists and other health professionals to realise the **benefits of advanced imaging of cohorts**. As many health impacts are measured through changes to health policy, Local Health District or Health Department representatives must be included in these collaborations.

Further investment in Data Science and Expertise was also seen as essential to lift the power of clinical trials and meta-analyses. Australia's strong national research collaborations in **epilepsy, neurodegeneration, cardiovascular disease** and **cancer** would all benefit from image biobanking and data integration.

Researchers working in Developmental Neuroscience and Paediatrics were not the only ones wanting higher resolution and lower radiation imaging for human subjects. But these researchers did point out the opportunities for such improvements to make a real **impact in early childhood health**, addressing the research challenge of *Ensuring a Healthy Start to Life*. Portable imaging was raised across all groups as it has the potential to open advanced imaging technologies to **regional researchers and regional research issues**. Such technologies could address the research challenges of *Improving Indigenous Health Outcomes, Assuring the Quality and Provenance of Australia's Food*, securing *Economic Growth* in our resources sector, and *Recording Australia's Cultural Heritage*.

Research impact has an extended timeline and requires many partners. Nevertheless, it is possible to build the pathway to impact into early-stage research. While each NIF Node will have targets for impact set by their home institution, there is an opportunity to explore impact at the network level by working collectively. Impact case studies and industry linkages are likely to be important components for future NCRIS investments, so planning for impact should start as soon as possible and should be embedded in all future investments.

2 Gaps & Opportunities

Several consistent themes arose from both the surveys and the consultations across all discipline groups with some specific needs and opportunities aligning with particular research challenges for the Nation. Through the surveys and consultation meetings, several research problem themes were identified that NIF could address spanning partnerships, expertise, data and distance.

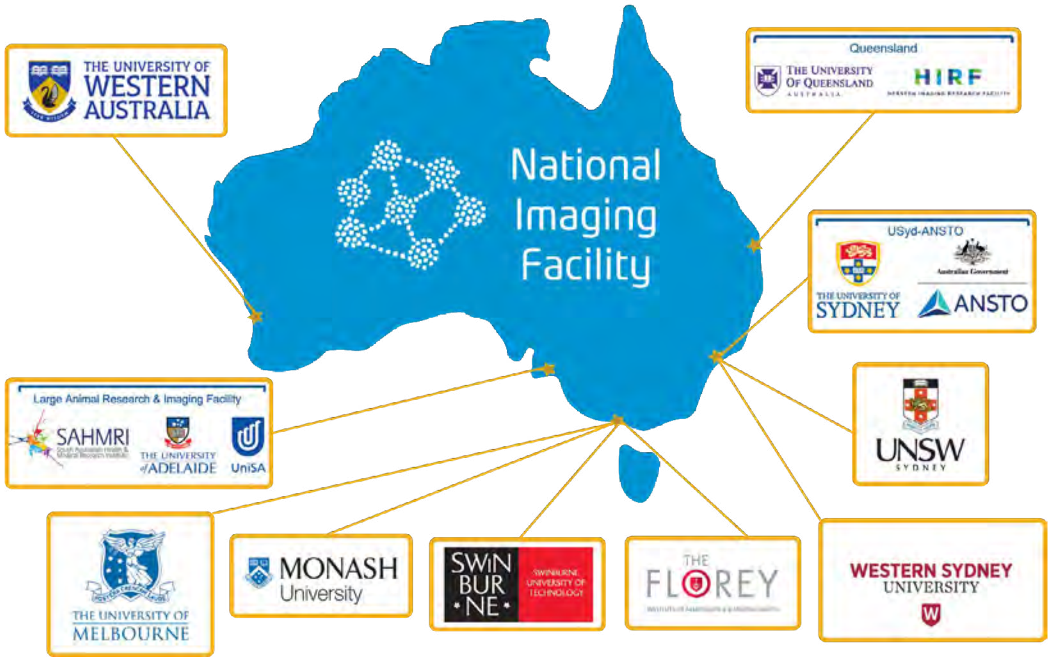
There was little consensus on the significant research challenges and opportunities for national collaborations using imaging technologies. However, the participants put forward a number of suggestions that would place Australia in an internationally leading research position with real potential for industry collaborations and social benefits.

One suggestion was that an International Scientific Advisory Committee could be used to review the quality, impact and collaborative nature of the research undertaken using NIF facilities and to set national research imaging challenges to enhance the international position of Australia in global imaging science.

Integrating expertise and data across platforms and disciplines will provide Australia with a leading position to contribute to global solutions in health, food security and biotechnology.

PARTNERSHIPS

Many responses highlighted a role for NIF in stimulating or enabling interdisciplinary collaborations, either through improved data services, highly networked equipment, or by direct facilitation.



Partnerships with industry need to be explored, and NIF may be able to benefit from existing member partnerships with industry to lift these to the whole of the network. Likewise, partnerships with other NCRIS capabilities were identified as an opportunity. For example, flower and seed development represents a research avenue that could be advanced by collaborations between Microscopy Australia, NIF and the Australian Plant Phenomics Facility (APPF). Similarly, marine agriculture opportunities might benefit from underwater imaging through collaboration with Integrate Marine Observing System (IMOS).

The primary mechanism raised by respondents, to assist with generating impact through NIF, centred on people networks. Many responses highlighted a role for NIF in stimulating or enabling interdisciplinary collaborations, either through improved data services, highly networked equipment, or by direct facilitation. This was explicitly identified as a need in the clinical domain. A smaller theme identified impact through increased awareness. Respondents noted a role in imaging networks in disseminating knowledge; not just of outcomes, but of possibilities. This ties back to the desire for stimulating collaboration, along with a desire to 'spread the word' beyond their own research field, including governments that may sponsor future opportunities.

EXPERTISE

Expertise is seen as intrinsic to imaging infrastructure, and the Fellows are not viewed merely as operators of the equipment.

NIF Fellows are highly regarded across the whole network. There was consistent support for the Fellows and for more of them. Expertise is seen as intrinsic to imaging infrastructure, and the Fellows are not viewed merely as operators of the equipment. Their role includes experimental design, data capture, cross-disciplinary engagement, and the analysis, integration, interpretation and communication of research results. Fellows are essential to the functioning of NIF.

To enhance the role of the NIF Fellows and to extract their collective value in advancing Australian research, there is an opportunity to raise their role to the national level, rather than Fellows being seen as a Node resource. By and large, most Fellows are viewed as “infrastructure at the Node”, but consistently across the consultations, there was a view that they could move to “infrastructure on the grid”. There was a strong need identified for integration and management to allow for cross-disciplinary collaborations. Likewise, to build image data banks, to support national initiatives at the discipline level, to encourage and support cross-platform and cross-disciplinary collaborations, and to advance imaging science, Fellows need to be a connected national resource.

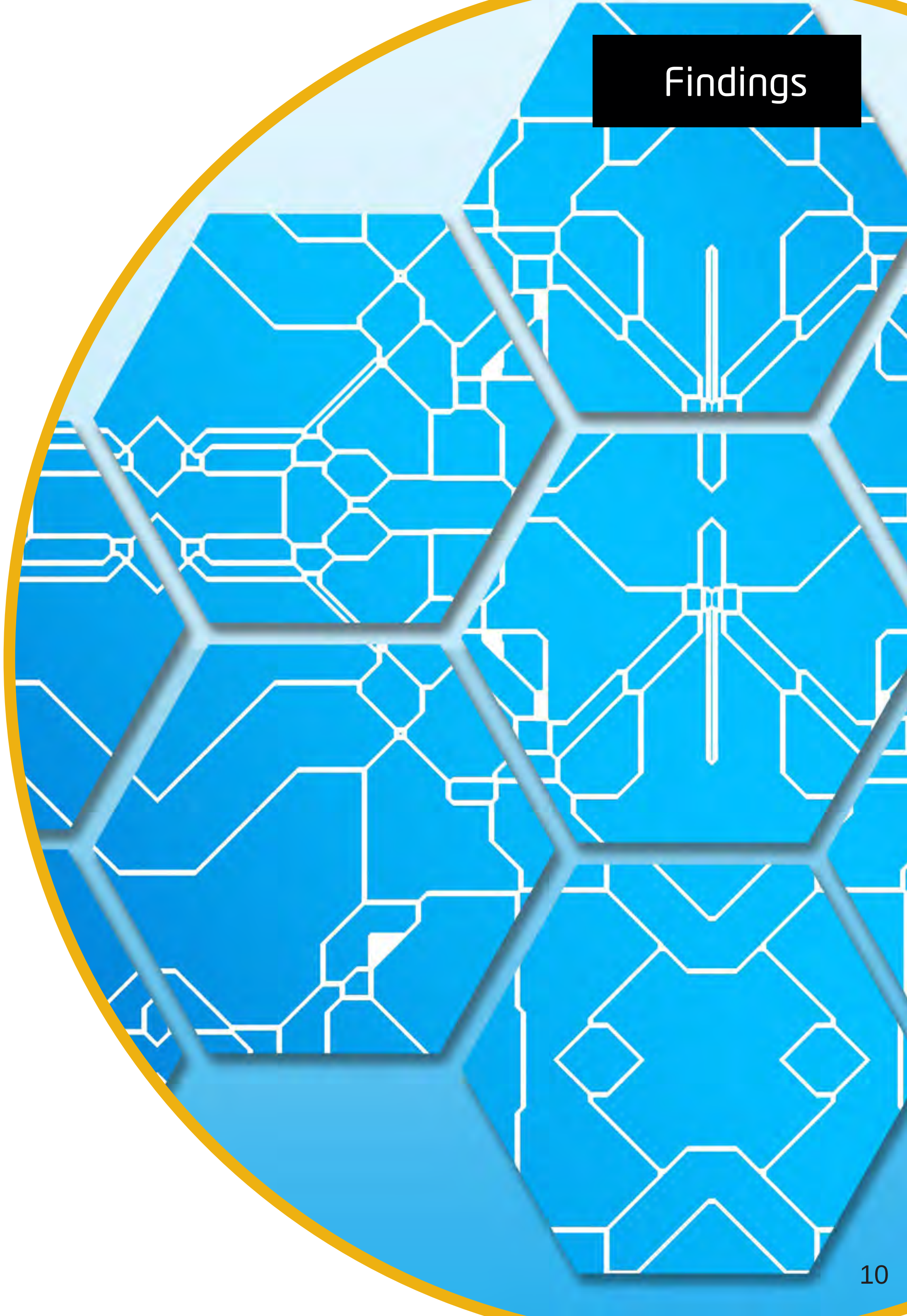
For example, a National Imaging Fellow in Agricultural Science was strongly supported as a way to enhance collaboration, build collaborations across the Nodes and across imaging modalities, and to act as the connecting point to other NIF Fellows, thereby facilitating cooperation with the Health Sciences to translate advances in that domain to the Agricultural Sciences.

NIF Fellows are core to building the Data Science Workflows and connectivity to AI infrastructure that will release the full potential of the imaging equipment. They are also essential to linking NIF data with other NCRIS data, to working with national groupings on major investment bids, such as through the ARDC and the MRFF, and to ensure that training is available for a sustainable pipeline of imaging expertise.

Training and career advancement were seen as critical issues that need to be addressed to achieve this vision of whole of network infrastructure. Early career researchers need the expertise to guide them through their studies, while experienced researchers want to use advanced infrastructure and methods to remain as attractive partners for international collaborations. The NIF Fellows themselves need opportunities to develop and advance their own careers if expertise is not to be lost.

The network of NIF Fellows is ideally placed to collectively ensure that the barriers to harmonised and integrated data, data analysis, simulation and modelling are minimised across Australia. In particular, this will facilitate multi-centre clinical trials and enhance national collaboration opportunities in agricultural science, materials engineering and environmental science. The NIF Fellows can advance data integration, ensure software licences are optimally procured, help with the issues relating to data ethics and ownership, and build a network of expertise and imaging leaders.

Apart from regular meetings between the Fellows, there was support for the Fellows to circulate between the Nodes and the potential for a group of Fellows and relevant researchers to create a proposal around training for image data analysis and pipelines, for example through an ARC Training Hub.



DATA

Participants acknowledged a desire to extract more value from their and other's research data. Image data banks, AI tools, analysis pipelines, integration, and harmonisation featured as identified needs in the data space.

NEEDS

In the follow up survey, participants were asked to rate their support needs in data from 1 (lacking support) to 5 (fully supported). The following charts show the results from the survey:

INTEGRATION

Data integration is the science of combining data from different sources to provide the user with a unified view that can yield knowledge not visible when looking at the sources in isolation. An image databank, comprising harmonised images from the NIF network, constructed on the FAIR (Findable, Accessible, Interoperable and Reusable) principles and enhanced with virtual laboratory tools and analysis pipelines, would result in a significant piece of research infrastructure for the Nation. This has the potential to improve the impact of the NIF network above and beyond the contributions of the individual Nodes.

Consistently across the whole consultation process researchers and research leaders stressed the importance of data integration across the NIF platforms and across other relevant NCRIS facilities.

The need for data integration grows as the volume of data grows, and the need for collaboration to solve problems becomes imperative. Data integration has exploded in the life sciences, where the need to integrate disparate datasets for a meta-analysis is the only way to solve large-scale problems. The Human Health and Neurosciences groups strongly acknowledged the value of expertise in imaging, not only in image acquisition but in data annotation, data analysis and deep learning. Integrated data across imaging platforms and with other data types (e.g., genomics) is critical for large-scale clinical trials and is imperative if Australia is to stay internationally competitive.
Examples of data integration and its benefits that were suggested included:

- Integration across NIF platforms, for example, PET, MRI and CT data particularly to enhance the power of multi-centre clinical trials;
- Integration across NIF and Microscopy Australia image data for materials and ecosystem science;
- Integration across NIF and BPA data to enhance clinical trials;
- Creation of data repositories so that researchers do not need to travel to other Nodes;
- Use of AI and deep learning algorithms to build multimodal simulations;
- Improvement of access to image databanks and translation of research results by making clinical access and navigation easier;
- Development of image data banks, analysis tools and data pipelines for multi-purpose use, freeing researchers to focus on the important tasks of posing the right questions and generating impactful answers.

While stressing the importance of extracting the best possible value from the images already created through NIF, the consultations also highlighted some of the challenges that would need to be addressed. These included issues around ethical restrictions and data ownership, not only between institutions but across State borders, software licensing and data storage, curation and meta-data annotation, training, visualisation and analysis tools, and sustainability.

The NIF Informatics Fellows have already initiated work in this area, including the ARDC-funded XNAT infrastructure to ensure the management and reusability of sensitive imaging data.

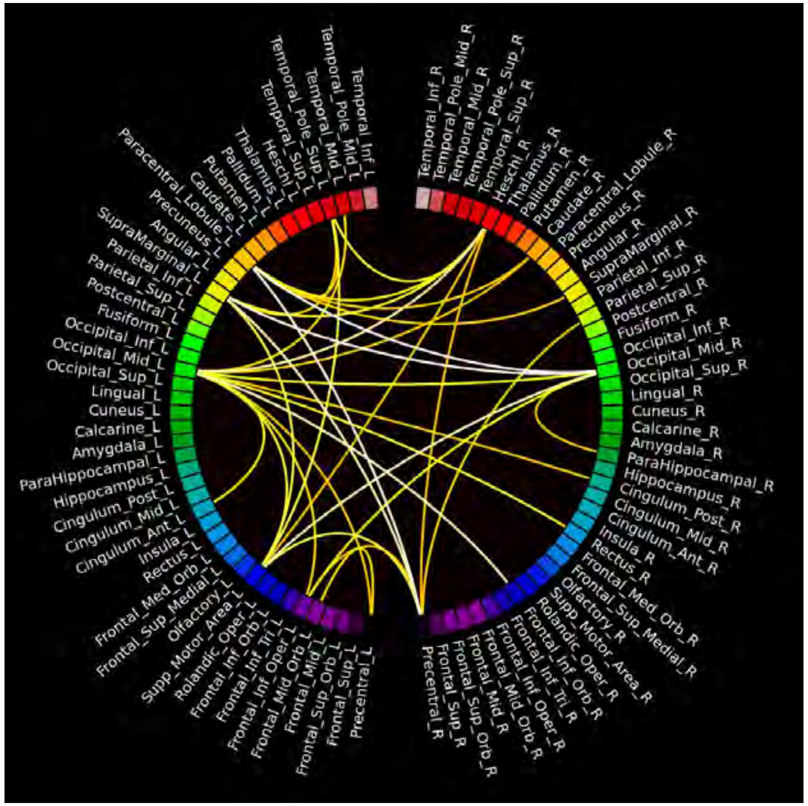


Image: Brain connectivity map using data derived from the MEG at Swinburne on a patient with OCD

Many of these issues are shared with other NCRIS capabilities and provide an opportunity for NIF to work across the NCRIS portfolio and with Government to ensure that archiving, curation, storage, access, interoperability and reusability are key principles of all data-gathering facilities.

The NIF Informatics Fellows have already initiated work in this area, including the ARDC-funded XNAT infrastructure to ensure the management and reusability of sensitive imaging data; the Australian Characterisation Commons at Scale (ACCS) project that will deliver an ecosystem of data repositories, workflows and services for imaging collections; and the Australian Imaging Service (AIS) building an end-to-end platform integrating data captured directly from instruments in clinical sites and containerised pipelines and workflows on both HPC and Cloud services. Such projects form the vision for NIF in the future: imaging infrastructure on the grid.

Developing opportunities for NIF Fellows to work across the Nodes will advance data integration and AI tools for imaging. One possible suggestion to facilitate this transition was to create a National Imaging Wiki so that the Informatics Fellows can share recipes and advice and build a repository of containerised pipelines and workflows, rather than each Node re-developing bespoke services.

The consultations and survey results highlighted the relatively low participation of researchers with the national supercomputing facilities, the NCI and Pawsey. Across all research fields, only 15% of respondents indicated use of NCRIS capabilities providing data infrastructures such as ARDC, NCI or Pawsey, while 18% were uncertain. More than two-thirds of respondents had never utilised these capabilities (or may be unaware that they had); these results suggest greater awareness or integration is needed to assist researchers in meeting their data needs using the available infrastructure. There is an opportunity for NIF to work more closely with these organisations to enhance imaging infrastructure.

HARMONISATION

The NIF network provides a diverse array of imaging equipment and modalities, allowing for multiple ways to view the same object, but also leading to a diverse set of imaging protocols and datasets, even across the same platform. To extract the full value of this imaging data, researchers identified the need for harmonised protocols and harmonised imaging data. Inter scanner and inter protocol differences are known to cause significant measurement variability, which in turn jeopardises the ability to obtain reliable, accurate and repeatable quantitative measures and challenges the reliable integration of different datasets. If researchers were able to combine data that has been acquired from different scanners or at different times, they could dramatically increase the statistical power of clinical studies and facilitate national collaboration. Harmonisation of data and protocols is critical for moving NIF from Infrastructure at the Node to Infrastructure on the Grid.

Data harmonisation and the use of AI were a focus for the Materials, Artefacts and EcoSciences meeting. Tools are needed to work across modalities and across spatial and temporal scales and to help with the translation of research results for impact. They were very attracted to the idea of remote observing and re-use of the enormous datasets Australia already has, but which remain difficult to access, hard to visualise, and challenging to share. Likewise, the Human Health group saw the benefits of unified national infrastructure and argued for increased investment in a network of 3T MRI scanners coupled with the harmonisation of data and protocols across the network. Such connectivity has two huge benefits: patients would not need to travel across State borders, and researchers would be able to build genuinely national projects for national benefit.

DISTANCE

Distance and State borders create transfer barriers that at times can be challenging to overcome. For example, with the national Large Animal Research Imaging Facility in Adelaide, it is seen as difficult, if not impossible, for many researchers to access this facility. Animal models designed for various human diseases or conditions cannot generally be transferred across State borders. Nevertheless, there is the possibility to increase national usage of this facility by sourcing data, where possible, in South Australia for experiments designed in other States.

The imaging of humans, plants, animals and artefacts cannot be compared to ocean science or astronomy. Location matters for the data under consideration and remote observing is a long way off. Still, opportunities exist to enhance the value of the network by looking for mechanisms that decouple the geographical links between researcher, sample, instrument and analysis by developing national imaging pipelines.

Each of the theme consultation groups was asked about the appropriate balance between single, high-end imaging equipment at a unique national location (for example, total-body PET) and portable imaging equipment that could be used in multiple locations, including in regional and remote Australia. Geographical dispersion was acknowledged as a problem, and there is a need to join up the network, making access to all Nodes seamless to all researchers.

Many of those consulted saw the benefit of portable equipment: a network of portable MRI or CT scanners would be invaluable in addressing indigenous disease in remote and regional communities; portable imaging is essential for farm work and food grading applications; portable imaging could be used to catalogue museum samples; and portable imaging has the potential to advance capacity in the minerals industry by imaging core samples across multiple laboratories to determine how they store carbon dioxide or understand the impact of mechanical stressors on rock formations in applications such as fracking or nuclear waste storage.

While individual mobile imaging devices might not fit the NCRIS vision of physical infrastructure, an integrated network of portable devices and the resultant database of images, suitably annotated, linked, integrated with other data and interpreted, could be globally significant. Moreover, another strong argument advanced by health researchers for the value of imaging in remote and vulnerable populations is the need to mitigate bias introduced by only sampling patients within restricted domains.

Privacy and strong data protection principles are key in the collection, sharing and processing of data. NIF has a major role to play, along with other NCRIS facilities, in working with the Government to get Australia to adopt a gold standard in this regard, such as the EU's General Data Protection Regulation (GDPR) framework.

When travel becomes possible again, NIF user communities may benefit from funds that support researchers to travel to other Nodes to access technologies that are otherwise not available and where remote imaging is not possible.

Privacy and strong data protection principles are key in the collection, sharing and processing of data. NIF has a major role to play, along with other NCRIS facilities, in working with the Government to get Australia to adopt a gold standard in this regard, such as the EU's General Data Protection Regulation (GDPR) framework.

3 Roadblocks

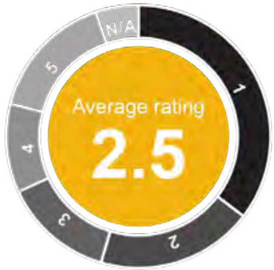
The consultations highlighted several issues that impede researcher capacity to access imaging technologies and inhibit the operation of NIF at the national level. These issues were also picked up in the two surveys and include:

- Access costs are seen as too high for many researchers
- There is a general lack of knowledge about imaging and informatics capabilities in many disciplines
- There is a perceived lack of development capacity to bring new technologies or new analysis tools to researchers seeking to expand their skillset
- The geographical location of some imaging facilities is too far from the source of data or the researcher
- There is a need for discipline-specific imaging skills to be efficiently promulgated across the network
- Many researchers are not aware of specific imaging capabilities, nor of the range of imaging technologies across the network
- There is inadequate national access to imaging expertise, domain-specific imaging expertise, and data integration expertise
- More support is needed for data storage, data analysis, data sharing, data interpretation and data integration
- There is a lack of research culture in some clinical settings
- Imaging technologies are difficult or impossible to access for regional researchers and those working on regional and remote research issues
- There is a lack of incentives for industry to collaborate on imaging research
- There is a need for PET analysis expertise
- There is a lack of national coordination and difficulty accessing radiochemistry tracers
- Regulatory hurdles across ethics, governance and data privacy impede the translation of medical imaging research to societal benefits
- Poor resolution, high radiation exposure and lack of harmonisation in protocols and data raise problems for multi-centre collaborations
- High throughput imaging is needed for agricultural applications

Below are the results from the survey when respondents were asked to rate the components in terms of the biggest barriers to using imaging in their research.

Location of imaging infrastructure: too far from my research samples

Location of imaging infrastructure: too far from my research lab



Inadequate access to transdisciplinary/bridging expertise

Knowledge about imaging capabilities

Disconnect with other researchers in my field who use imaging

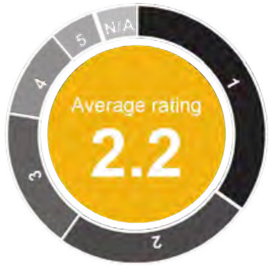
- 1 (Not a problem)
- 2
- 3
- 4
- 5 (Significant barrier)
- N/A

Lack of development capacity (i.e., new technologies or capabilities)

Inadequate access to imaging expertise

- 1 (Not a problem)
- 2
- 3
- 4
- 5 (Significant barrier)
- N/A

Inadequate access to domain expertise



Access costs are too high

Inadequate access to informatics/e-research expertise

Next Steps

The findings of the national consultations will inform the Board's decisions in development of the NIF strategic plan and future investments.

Appendices

1 Author

Emeritus Professor Robyn Owens

Robyn Owens is the former Deputy Vice-Chancellor (Research) of the University of Western Australia. Professor Owens studied Mathematics at UWA, Oxford and Paris XI. Her research has focussed on computer vision, including feature detection in images, 3D shape measurement, image understanding, and representation. She is an elected Fellow of the Australian Academy of Science, the Australian Academy of Technological Sciences & Engineering, and the Australian Computer Society, and she is a graduate of the Australian Institute of Company Directors.

2 Report Taskforce

Prof. Graham Galloway	NIF Chief Executive Officer
Saba Salehi	NIF Chief Operating Officer
Dr. Noni Creasey	NIF Engagement Manager
Bec Dickson	NIF Senior Administration Officer

3 Image Contributions

This report contains a number of images from the current NIF Nodes.
Images have been supplied with permission by:

1. The Florey Institute of Neuroscience and Mental Health, S Farquharson, p14
2. Monash University
3. University of Melbourne
4. Swinburne University of Technology
5. University of Western Australia
6. Large Animal Research and Imaging Facility, SAHMRI
7. Western Sydney University
8. The University of Queensland
9. The University of New South Wales
10. The University of Sydney

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4 Representation at Consultations

Themed Consultation Meetings

Follow up Survey (Stage 3)

State	**Response Count**
NSW	85
VIC	73
ACT	58
QLD	30
WA	28
SA	26
TAS	5
Total	**305**