eResearch Framework: 2016 and Beyond

Working Paper Third Draft

Methods Are King
Digital Data is Disruptive
Research Communities Are Leading

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Introduction

Between 2007 and 2015, investments made through the National Collaborative Research Infrastructure Strategy (NCRIS) contributed to a significant growth in Australian eResearch infrastructure. The infrastructure created as a result supports advances in all fields of research and dependencies on it now exist.

It is timely to take a comprehensive look at what arrangements are needed from 2016 and onwards to align further investment in eResearch infrastructure with current and emerging needs.

The working paper is intended to stimulate discussion, to allow inputs to be made and to provide confidence that issues identified and nominated are included. Its Viewpoint structure will mean the Framework can be reviewed against each issue raised, each property thought necessary and each change thought desirable.

A separate eResearch Framework document will be generated building on its content.

Objective

'The objective of the project is to develop an eResearch Framework (the Framework) to assist the Department plan national eResearch infrastructure from 1 July 2016.

Where possible, the Framework will identify current and emerging eResearch requirements of the research sector into the next decade and what technologies, in a broad sense, might meet those needs.'[1]

This objective requires a definition of eResearch and the rationale for government investment in infrastructure (the NCRIS funded eResearch infrastructure) to support it.

Scope

'The Framework will be developed in consultation with key stakeholders from the research sector, industry and government to identify the capability required of eResearch infrastructure into the future and the arrangements that optimise the benefit of that infrastructure to research.

The eResearch Framework will describe:

a) International and domestic trends and likely changes in research needs;
b) The likely type, maturity and scale of eResearch infrastructure needed to support Australian research;
c) How existing eResearch infrastructure would meet these requirements;
d) Strategies to support and build the skills required for eResearch;
e) The role of national funding in meeting these needs given the various missions eResearch capabilities can have;
f) Strategies to maximise the efficient delivery of eResearch infrastructure; and
g) Other issues that emerge through the consultations.'[1]

The role of this document

The approach adopted is as follows:

1) Gather key issues into a working paper and revise in January and again in February;
2) During January select framework topics;
3) During February and March firm up content for those topics; and
4) Around March/April gather commentary on the result to submit with the Framework to the Department.

[1] From the Terms of Reference of the eResearch Framework Project.

Setting the Scene

The information age

The information age is a phenomenon that has been well document over the last half century. A relevant perspective can be taken from the recent Innovation statement.

> 'Advances in technology are transforming just about every part of our lives, from the way we work to the way we communicate and access services.
>
> Innovation and science are critical for Australia to deliver new sources of growth, maintain high-wage jobs and seize the next wave of economic prosperity.'
>
> 'The pace of change, supercharged by new and emerging technologies, has never been so great, nor so disruptive.
>
> It is being driven by rapid advances in computer processing power and data storage capacity, with an average smartphone more powerful than the combined computing power of NASA in 1969.
>
> The Internet is also disrupting traditional jobs, businesses and industries in a manner that would have been unimaginable just a few decades ago. Uber, the world's largest ridesharing company, has disrupted the taxi industry, Airbnb the holiday rental market, Facebook the advertising industry and iTunes CD sales. The pace of change is more remarkable than the scale — Uber and Airbnb were both founded less than a decade ago.'

The open agenda

The open agenda relates to many policy issues. For instance it helps with the ability to achieve and track impact, assert provenance and support innovation. 'Borders' applied to information, including borders between institutions tend to inhibit all the above. An innovation agenda in the research sector would seek to break down such borders and encourage open information, open data and the open availability of the methods applied to that data.

Why eResearch?

The importance of eResearch and eResearch infrastructure can be reasoned as follows.

1. Research advances ideas and drives the growth of the stock of knowledge. Its importance is underscored by the substantive public funds committed to it.
2. Research is deeply involved in the transformations generated by the information revolution and the continuing advancement of information and communication technologies. The fact that research and research relevant technology evolve together can be readily demonstrated.
3. As a result, new means and opportunities for improving research outcomes and processes are arising continuously, sourced from technology development occurring both inside and outside the research sector.

Competitive positioning leads to a desire to understand these opportunities and gain benefits for Australian research at least as quickly as others and where affordable in advance of them.

The purpose of eResearch is to connect the information and communication technologies advances occurring to research, to advance research, to better enable research outcomes and to support the best possible output from researchers.

Why cooperate?

Access to unique capabilities is one reason. Some desirable research inputs require instruments or observing platforms constructed at scales or in a manner that is beyond institutional means. These research inputs can only exist as a result of co-operative action. Some compute and some data infrastructure are in this category.

Digital data is another. As the dominant means of capture for observation, digital data is emerging as a fundamental input and output of research. Once data is digital, technology makes it more easily shared, repurposed and reused and in ways unknowable at its point of origination. Technology also allows aggregation of data that enables new data methods, new research tools and new technologies. The full value of research data depends on co-operative action around the availability of data, the aggregation of data and the technological infrastructure as well as the policy and practice that grows the value of the data.

Technology and Research

The expert application of advancing technology to research has several categories of benefits.

• Increased scale and sensitivity of instruments and sensing platforms; opening up new research and entirely new research fields. • Improved performance of numerical simulation and computational science; modelling phenomena otherwise un-researchable. • New forms of data analysis enabling new kinds of knowledge discovery; detecting relationships that might otherwise be undiscoverable.	• Data as a digitally accessible and digitally re-usable stock of knowledge; adding a new dimension to the performance and innovation potential of research. • Increased connectivity allowing entirely new research capabilities to be built; connecting instruments, data resources and analysis tools as never before. • Expanded collaborative possibilities; allowing larger research teams to attack more complex problems.

The kinds of goals that might give rise to co-operation are also well rehearsed:

a) Grow data holdings to new scales, with analytics to accelerate data science;
b) Grow computing capabilities to open new frontiers for in-silico research;
c) Develop and deploy virtual environments to digitally enable research communities;
d) Improve data management, description and access, to attack problems with rich data;
e) Improve the quality, functionality and accessibility of software based research tools;
f) Support national and global inter-operability to allow new research data workflows; and
g) Remove connectivity barriers between researchers and research resources.

Towards eResearch 2025

High Level Needs

The transformative use of computing and communication technologies in research is being addressed everywhere. Understanding and improving the way that these technologies interact with research instruments, research data, research methods and research skills is eResearch.

In terms of hard infrastructure, the demands on compute and connectivity infrastructure that have existed for decades continue unabated with an increasing number of researchers taking advantage of them. A clear global trend relates to a rapidly rising dependence of research on digital data at new scales and of a variety of data previously not addressed. This both expands demands on existing infrastructures and creates requirements for new infrastructures.

While hard infrastructure is crucial, eResearch activities worldwide also focus on other factors.

- It is universally acknowledged that new informatics skills and expertise, and their availability to research teams, is now a critical success factor in many fields of research.
- It is recognised that a new means of gaining knowledge (big data) can only be achieved if the growing pools of data and software are brought together and made available so they can be used for new research.
- Reproducibility of research is a core value and yet there are real concerns that without some specific attention, the preservation and reproducibility of research, including its data and methods, is at risk.

It is not that difficult then to set out eResearch goals where progress would advantage Australian research and a lack of progress would disadvantage it, as follows.

Goal	*Description*
Empowered Domains	Tailored virtual laboratories supporting research community data use and method development aimed at priority research challenges.
A National Digital Platform	A data sharing and data using infrastructure supporting researchers using data producing infrastructures.
Open Access	Policies, practices and systems that enable ready access to the highest quality research data and software assets.
Borderless Data	A national data system that participants can use to preserve, access, publish and share their data, in a way intended to underpin innovation.
Peak Power	Scaled up compute and data facilities enabling research to be performed in world competitive time frames.
Advanced Methods	A mid range platform providing new compute and data methodologies to an increasing number of Australian researchers.
Frictionless Infrastructure	The implementation of an eResearch policy framework, standardising access, participation and interoperation arrangements, operationalized as needed.
Extensive Connectivity	High performance digital connectivity reaching national and international research resources with headroom to meet future demand.

The scale of investment in any of these depends on the urgency that researchers place in them and the expected demand or usage. Experience suggests that an improved maturity in demand and in provision is required.

The framework therefore aims at a small number of eResearch components that address those needs and that provide:

- an improved leadership;
- an increasing institutional engagement across the board;

- more specialist skills in infrastructure and data, and in using both of them for research;
- more support for creating researcher value from infrastructure and from data; and
- more hard infrastructure capacity in all its dimensions, but especially scaled up.

Framework Response

The intention is that these goals will be pursued through a focus on two critical aspects of scaled up production quality computation and data infrastructures, associated with focussed leadership.

eResearch-Green[2]:

- is about the performance of high impact and nationally prioritised research;
- provides for the competitive use of scarce resources specifically building on high performance computation modelling and data reduction and analysis; and
- is a computational simulation and data generating and data using infrastructure.

eResearch-Gold:

- is about the achievement of a borderless accessibility of quality research data;
- supports the co-operative possession of digital data assets in a way that allows for the maximum possible use and re-use of them; and
- is a data organising infrastructure supporting discipline and research challenge needs.

The full framework recognises two further activities around these core infrastructures: foundational services that make universal connectivity possible; and the ability to create and sustain highly tailored environments relevant to disciplines, fields of research and specific research challenges.

Therefore the framework proposes a national eResearch landscape as follows:

GREEN	National Computation Facilities
GOLD	Australian Research Data System
COMMUNITIES	Virtual Community Platforms
FOUNDATIONS	Networks and Access Services

The eResearch-Green and eResearch-Gold components are sufficiently desirable that they cannot be considered alternatives. In addition they have widely different purposes.

eResearch-Green relates to well developed existing facilities and is research performance serving, and importantly is a crucial component in creating value from compute and from data.

An eResearch-Gold infrastructure is nascent but when instantiated would participate in a broader set of missions. It would support research access and use, provide for data publication, enable the connecting of data to other data to create new knowledge possibilities, and provide for data sharing across the sector and into other sectors.

The relationships, arrangements, metrics and governance for eResearch-Green and eResearch-Gold will be significantly different. Consequently the identification of these two missions as two different missions is warranted.

A large number of institution or research based systems extracting and making use of data or software can be expected to arise around the national infrastructures. The fundamental nature of competitive research makes that likely. The number and focus of competitive investments is a matter for research investors to determine, investors such as institutions and centres of research excellence. The national eResearch capability should take the stance of supporting the effectiveness of dispersed investments, while ensuring that NCRIS funding is focussed on the

[2] The labels are intended to avoid the devolution to the use of ‘compute’ and ‘data’, which is erroneous. They were selected as a combination that associates with success by Australia.

development of aggregation options and the value that those aggregation options add. The national infrastructure should support competitive expansion in-situ as much as is practical.

The activities that can be associated with the Foundation component, AARNet and the AAF, and eResearch-Green component, the Peak Facilities, all have an established rationale for national supply, are operating at high levels of performance, fill a necessary role in research and deliver demonstrated value. In addition there is no impending end to the requirement they meet or a specific compelling reason to change; other than to unify the Peak Facilities.

For the eResearch-Gold component, a re-scoping of current activities and a targeting of them more closely on the needs of leading research and research institutions is now timely. In this component, policies and practices drive outcomes, engagement needs to be improved, and friction and uncertainty addressed. That said, at the infrastructure level, the scale of installations would be large, just as for a peak facilities, and overall the intention would be for national funding to work towards a small number of infrastructure sites and for commercial supply to play its part where it provides competitive cost/benefit.

The Communities component will provide the discipline specific and highly tailored resources required by future research needs. It will work with other infrastructures, centres of excellence and the eResearch-Green and eResearch-Gold components to create these environments.

The response therefore takes into account that:

A) The merit assignment of infrastructure to the performance of research and the co-operative use of infrastructure in value building around data, are two different things;
B) Data infrastructure goals include but are broader than the performance of research;
C) The project based and layered organisation of activity in eResearch should conclude;
D) Arrangements focussed into the Green and Gold impact areas should be put in place;
E) That each of Green and Gold involve methods, data and all needed technologies; and
F) That each of Green and Gold are full service providers accountable for the success of the solutions they provided to researchers, research centres, research institutions, research communities and other research infrastructures.

Arranging Supply

All participants in the research sector will spend on eResearch simply because their researchers use computers, use data, use computers to use data, write software, import software, import data, publish data, or move data from one place to another. It is unavoidable.

How do we understand who spends on what and why?

Therefore a specific role for NCRIS investment is needed. The suggestion is as follows.

In the service of Australian research, the NCRIS eResearch capability will prioritise the use of research practices and production quality infrastructures that:

- Enable excellence in scaled up computation and data driven research;
- Enable research communities using NCRIS capabilities to collaboratively develop, share and apply advanced technology and data enabled methods;
- Support a borderless, durable and coherent system of data holdings to stimulate leadership and innovation in data intensive research; and that
- Satisfy the NCRIS Principles.

Many consultations and discussions need to be undertaken regarding the arrangement of existing activities within the four components set out herein.

eResearch-Green – National Computation Facilities

The National Computation Facilities would make high performance compute and data driven research possible. National investment would add value by the physical realisation of peak facilities including buildings; under-writing capacity acquisitions for national purposes; and supporting the creation and durability of a corpus of expertise at international standard.

The intention would be that a future investment in National Computation Facilities would develop a unified approach to resourcing computational requirements inclusive of existing peak facilities and the national exploitation of mid-range HPC system invested in by institutions.

eResearch-Gold – Australian Research Data System

The Australian Research Data System would operate a borderless data solution for institutions to grow and use. In addition it would support the adoption of best practice and technologies in institutions and research facilities all along the data pathway in order to achieve the borderless outcome.

National investment would add value by making a coherent data organising infrastructure viable; supporting adoption of needed policies, practices and technologies; supporting Australian engagement with international data systems; under-writing capacity for directed national purposes; and supporting the creation and durability of a corpus of expertise at international standard.

The intention would be to assist the sector develop a coherent data system, to improve data quality, to improve data aggregation into highly scaled providers, while also assisting the domain and specialist data facilities that will continue to play an important role into the future.

eResearch-Communities – Virtual Community Platforms

Virtual Community Platforms would provide environments that provide digital solutions tailored to meet the needs of groups of researchers. The grouping might be based on a field of research, a discipline grouping or a research challenge basis. It is known that a significant number of such solutions will be needed.

The intention would be to improve the availability of focussed resources that directly fit the needs of different researchers. A second intention would be to allow researchers to migrate data off desktops and out of laboratories and similarly use data sourced from instruments and remote data sources, while achieving satisfactory levels of control, improved levels of usability and performance and a reduction in difficulty and cost.

National investment would add value by configuring resources and developing virtual laboratories; creating soft infrastructures in support of national research priorities; and supporting the creation and durability of a corpus of expertise at international standard.

eResearch-Foundations – Connectivity Operators

Connectivity Operators make a high performance communication and low friction national infrastructure possible. Connectivity Operators connect a diverse set of facilities and situate those facilities within global research infrastructure developments in terms of connectivity and access management. National investment adds value by enabling build outs of critical capability and service enhancements.

Supporting Expertise

In research domains where the very edge of technological performance is used, technology heroics are needed. Everywhere else the ability to relieve researchers of these demands, to free their time for research, should be the goal.

A key idea within the Australian Research Data System component will be to separate as much as is possible the people and infrastructure arrangements. The long-term intention would be to:

- Aggregate data so that innovative data use that depends on aggregation can be much more easily conceived of and achieved;
- Significantly alter the balance of human resources away from systems level skills, by reducing the number of separate systems being operated, and then reusing that resource base in data applications and data science areas; and
- Engage commercial suppliers in order to access the very large global investments in system operating expertise that they are making, and in the longer term potentially not duplicating this expertise base in the sector.

This development is a critical long-term objective that has a real impact on expertise. The willingness of institutions to forgo the possession of independent data holding infrastructure is a crucial step for these expertise outcomes to be realised.

In addition to that overall skills migration objective, it is also possible to require every infrastructure investment to have a skills and expertise component. The following three things should be explicit in the objectives of any eResearch infrastructure. It should:

- Nominate the skills the activity will give rise to in operating infrastructures;
- Nominate the application skills that will be developed to support users of the infrastructure; and
- Nominate the impact of training the activity provides in relation to user skills

An impact analysis relating to the benefits others obtain from each of those classes of skills should be a component of required reporting.

A final element in the skills picture concerns the Virtual Community Platforms component. If this component does not own infrastructure, then it can be an investment entirely in people and access to infrastructure capacity. That investment would directly build skills related to the discipline based application and integrations of methods, instruments, compute and data.

Delivery Strategy

The goal is that by 2020 NCRIS eResearch investment will have grown the value to the nation of eResearch investment through:

- The National Computational Facilities that support the merit based research use of digital data and digital methods at national scale;
- The Australian Research Data System delivering a borderless approach to digital data and digital methods to enable greater use and greater innovative use of research data;
- The tailoring of data, methods and technologies using those infrastructures and other suppliers in ways that add value to discipline use of data, methods and instruments;
- Supporting and developing a cohort of excellent staff that enable the above;
- Addressing policy and performance friction related to the above; and
- Inducing the maximum possible engagement of institutions with the above.

A strategy for making progress from the current state is needed.

A) Develop and implement a transition plan:

    a. allow a multi year transition from current projects, with conversion by 2018;
    b. support an evolutionary approach towards an evolving vision over time; and
    c. establish an Implementation Office to steer that process.

B) Take a more directive approach to unify the National Computational Facilities, establish the Australian Research Data System and create a Virtual Community Platforms project, as quickly as possible:
    a. Components would be composed of people located where needed and where primary hard infrastructure would be restricted to no more than two sites.
    b. If each component located its primary resources in independent sites, then a maximum of six primary sites arises.
    c. The concept would be that each component could make use of each other's assets, skills and arrangements in ways that become advantageous over time.
    d. An Implementation Office would be of short-term duration as the three components could be charged with coordination goals in the longer term.

C) Decide that the Virtual Community Platforms component will not itself provide hard infrastructure but deploy capacity within existing infrastructure providers.
    a. The infrastructure that would be used would be in the National Computational Facilities or the Australian Research Data System, other NCRIS Capabilities or be sector owned or commercial cloud systems.

D) The Department has asked what could happen in the event of a significant reduction in funding. A minimum component could be created against each arm of the eResearch mission (Green and Gold).

    a. The Connectivity Operators could continue as for all scenarios.
    b. The National Computation Facilities could reduce to one site.
    c. All other elements could merge into the Australian Research Data System.
    d. A small cloud service for some borderless data outcomes and mid range data usage targeting the needs of other NCRIS capabilities could be provided.

    The specific danger in eResearch is that the sliding scale once taken is hard to arrest as there are few natural stopping points; e-infrastructure scales fluidly, though at some point the question of materiality arises and closure is the only valid action. The other observation to make is that the aggregation of people and facilities improves quality and performance so that the downward sliding scale is not just a sliding scale in reducing technical capacity, quality and performance will also degrade. The evidence is that improved quality and performance is being requested.

Investment

A primary question concerns the relevance of each component set out here for NCRIS funding as part of an ongoing national eResearch capability. Each component should be:

a) needed by research over a sustained period of time, outcome driven and supportive of excellent and impactful research within national research priorities;
b) of a scale in capacity, inclusivity or remit beyond single institutions and arising in situations where piecemeal approaches are unreliable, inefficient or ineffective;
c) engaged with research organisations, communities and individual researchers to deliver reliable, world class capabilities that they depend on for their research;
d) as open and accessible to those Australian researchers needing access as is feasible, including their collaborators, noting cost is a factor on scarce resources; and
e) innovative in ways that enhance and even transforms the competitiveness of Australian research and Australian research supporting infrastructures.

The components meet these conditions as follows.

National Computation Facilities	All factors are met. The national computation facilities meet the criteria by allocating scarce resource to prioritised research applications Also of note, national level funding supports peak computing in comparable jurisdictions and the up lift in mid range computing is present in many jurisdictions planning.
The Australian Research Data System	An Australian Research Data System naturally meets some of these requirements and could improve that alignment by supporting results data including for ARC and NH&MRC projects, output data from NCRIS infrastructures and reference data for Centres of Excellence. Alignment is improved by following prioritising processes that do meet the criteria and that in turn determine what data to support. Also of note, very substantial similar investments at a national level of funding are in progress in leadership jurisdictions worldwide.
Virtual Community Platforms	Similarly the Virtual Community Platforms can meet the criteria by selecting or prioritising research and research infrastructure investments in ways that satisfy the requirements. A focus on the requirements of national research and national research infrastructure investments meets all factors.
Connectivity Operators	All factors are met. The connectivity operators meet the criteria by virtue of being constructed to provide unique universal services to all of research. Also as the services they provide relate internationally to equivalent entities, their functionality and relationship set are generally outside of the remit if not the means of individual institutions.

Institutional Investment

A clear role and purpose for institutional engagement is critical to the scale and durability of the resulting infrastructure.

Engaging with the National Computation Facilities means either:

- Using capacity and scientific support made available through merit or priority systems;
- Funding a facility in return for capacity access and scientific support; or
- Funding cloud capacity and operating a virtual peak instance.

Engaging in the Australian Research Data System means:

- Co-innovating policies, practice and infrastructure to support the borderless goal; and to either:
- Make use of capacity and expertise available through merit or priority systems;
- Fund capacity in the system for data of own interest; or
- Construct a locally operated instance of the same functionality that complies with required standards and characteristics.

Engaging with Virtual Community Platforms means:

- Co-innovating, policies, practice and infrastructure to create a tailored platform; and to either:
- Make use of capacity and expertise available through merit or priority systems;
- Fund and use capacity in the platform, operationally managed by the platform;
- Operate an instance of a cloud node complying with standards and procedures; or
- Construct a dark site supported by remote platform management.

Engaging with a Connectivity Operator means:

- Obtaining services and service development as a member or on a fee paying basis.

The national investment would produce many virtual laboratories and other research environments of interest to researchers, all of which would be available as openly as possible. In addition the means would be provided to propose new platforms and environments for joint development and deployment.

Connectivity Operators

Because the costs of the Connectivity Operators are fully met by member subscriptions, the way they engage national funding needs specific consideration. That sector sourced operational funding sustains Connectivity Operators is a good thing that, in turn, should not prevent them from accessing development funding where there is a nationally-focussed business case. The Framework adopts the strategy that developments required by any of the other three components can lead to the expansion and enhancement of elements of the Connectivity Operators. That is, in a general way, the Green and Gold components are the two driving purposes and the Communities and Foundation components form around them.

Viewpoint Structure

The remainder of the working paper describes the current state from the following views.

Environment Viewpoint

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- Sector wide impact
- Enhancing innovation
- Transforming research

Opportunity Drivers
- Compute, compute, compute
- Data, data, data
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Practice and Policy
- An international orientation
- Research verticals set directions
- Reducing infrastructure friction

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- The leadership challenge
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- eResearch vision
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- A co-design is necessary
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Scale and Durability
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- Existing momentum
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- Make the right things simple

Challenges
- Funding levels
- Complexity
- The hero culture
- Consolidation

Environment Viewpoint

Scope of Benefits

Overall perspective

The eResearch investments in the period 2007 to the present did sustain, improve and expand pre-existing value delivery and did pioneer important new forms of value delivery.

The Status Report on the NCRIS eResearch Capability (2015) supports the proposition that eResearch infrastructure is needed, at issue is how best to pursue it. There is evidence that eResearch infrastructure is important in framing what research can be done and in the performance of that research and that the functions it makes possible are needed.

There is also a widely held view that recently pioneered components of the eResearch capability must be realised more robustly and durably to deliver more value. As eResearch moves from the province of a few to the province of many, it's infrastructure must be more robust and durable, support international standards and accessibility frameworks, be clearly research community centric and include research specific and consumer quality services and products.

There appears to be universal agreement that everything set out here is contingent on the means of access to skilled people able to support the adoption of new technology capabilities and to support the continuing innovation of research methods.

Sector wide impact

While this paper is focussed on the role of digital technology and digital data in making new and novel research more possible, eResearch infrastructure and investment in research data is also expected to enhance collaboration, provide research communities with new resources, underpin research translation, enhance the stock of knowledge and improve the quality of research.

The manner in which NCRIS eResearch investments contribute to these outcomes and support national research priorities and national research investments made by relevant authorities such as the Australian Research Council and National Health and Medical Research Council should be explained in any investment plan.

Enhancing innovation

Research creates data and methods of value beyond research. For instance the development of visualisation has proven to be an extremely powerful tool for knowledge discovery, in research and then in business. The liberation of the value in data and tools, created in research, can be part of improving knowledge exchange and can therefore contribute to securing higher levels of innovation. The desirability of the outcome is high.

The possibility of 'data bridges' and the interchange of data methods between research and industry, research and education, research and health and research and government, and an engagement with public clouds for implementation represent developments that should progress. The way eResearch infrastructure facilitates the outcome needs to be developed.

Transforming research

Historically, science and engineering domains have largely led the application of technology to the performance of research. Now, many research fields seek advantages from data aggregation, improved analytics, visualisation and the concerted development of new knowledge assets.

The institutions that are most strongly engaged (either with the NCRIS funded activities or through their own effort) report that eResearch and scaled up e-infrastructures for research are transformative in terms of what research is possible and how it is done.

Opportunity Drivers

Compute, compute, compute

One of the fundamental opportunity creators is compute. Compute means that information processing can occur in machines, whereas without compute all of our information processing occurs in our minds. Consequently labour costs no longer limit what information can be processed and the speed and processes that are used are no longer limited to what people can do.

As a result the embedding of information processing in all manner of things is ever more possible. Self driving cars are an example. Computing is achieving ubiquity and things around us are becoming smarter.

It is the also true that software is becoming more capable. A particular development is the concept of software configurable computing of which cloud is a leading example. These developments appear to be a game changer for research.

The specific opportunity for resourcing eResearch is that, for the first time ever, the means for information technology support in institutions and the needs of research can be matched to each other, if practices and beliefs can be overcome, a research acceptable service can be described and value and trust can be established.

Data, data, data

Data volumes and data richness is rising. Embedded computing is one of the developments causing that. Others include wireless connectivity and sensor improvements. The overriding factor however is price. The price of data acquisition is falling fast. The clear leader is in genomics. Over the last five years Australian facilities sequenced five hundred genomes. This year they will sequence fifty thousand. An explosion in data origination is happening.

Another important aspect of the data opportunity involves aggregation. ‘Data has gravity’ is a phrase coined to capture the observation that data attracts other data, attracts tools and compute, and attracts people, methods development and ultimately innovation. It really is important to understand where and under what agreements data aggregates. The location will set in stone much of the rest of the infrastructure build needed and the agreements will determine who can obtain the value of the result.

Connect, connect, connect

The Internet of things relates to the potential for the ubiquity of connectivity. It is estimated that every person has between one thousand and five thousand networkable objects around him or her. The Internet of things is expected to explode the data richness in environment such as health, urban landscapes, manufacturing and so on. The basic message is, that while the data tsunami may be arriving in some scaled up instrument domains, it will arrive in a much larger set of research domains in the near future.

Trust, security, access and ethics

While frequently posed as a barrier or challenge, the converse perspective is equally valid. Those institutions and jurisdictions that can deploy a technology platform to support trust, security, access and ethics will have an advantaged position in the global context.

Practice and Policy

An international orientation

Research is a global activity and the primary sources of impact or quality assessments in research occur in an international context. Therefore engagement with international approaches is crucial. A national eResearch infrastructure must be conceived within the context of international research and related eResearch developments.

Interest in eResearch infrastructures and e-infrastructures in general is rising. Significant investments are being made in leadership jurisdictions including the USA, UK and Europe. Ignoring or standing aside from these international developments cannot be recommended at the national level or at the institutional level.

Research verticals set directions

A key aspect of research activity is that it occurs within and between a set of verticals, by discipline or problem area, where verticals often exist across institutions and are international in extent. The proposition then is that effective support for researchers must be provided within the standards and processes and protocols in use and under development within these verticals.

> *An NCRIS eResearch facility must be able to provide and tailor generic digital resources, provisioned at scale, to support many differentiated research activities to international standards.*

It is important to note that innovation will be stimulated when linking across the verticals to solve complex real world problems. NCRIS investment must therefore also foster ways to unify underlying infrastructure over time.

Reducing infrastructure friction

The concept of a frictionless infrastructure where researchers can use assets and capabilities held in diverse ways, in facilities, national agencies, institutions and even specific research laboratories, with minimum overhead – is an oft stated ideal.

In addition to technical and facility design, policy arrangements need treatment too. Policy induced friction includes any variation in licencing terms for data or software; or the overriding of collaborative arrangements by institutional policies. Overriding occurs in employment arrangements, security policies, IP management regimes, public data policies and so on.

It is going to be helpful to define national infrastructure in terms of national facilities where a facility is a resource or capability with a managed policy framework. That framework will cover issues raised above, but also longevity, access and partnership, the funding approach, expansion rights and responsibilities, privacy, security and other matters.

> *The development of a policy framework for eResearch, that allows technical and content integration or inter-operation to proceed within a frictionless experience for researchers, is a matter of some considerable challenge and importance.*

Readiness

The Leadership challenge

A modernisation of research and science in the digital era is underway. The development and sharing of best practice is in the national interest. In addition, the fact that aggregation yields benefits in e-infrastructure and the fact that data is a resource that has pan-institutional value motivate a call for co-operative approaches.

A specific challenge arises where national e-infrastructures is established by funding activities in institutions, which legitimately stand separately. As a result, functionaries within institutions influence the outcome including pro vice chancellors of research or research infrastructure, chief information officers, librarians, lead researchers and research managers. In addition rewards systems operating within institutions incentivise local optimisations and the achievement of local benefits rather than incentivising broader optimisations and benefits. The result is that it is difficult to sustain leadership and progress can be reduced to fits and starts determined by changing personnel. This difficulty flows into the ability to sustain collaborative intent between institutions at a regional level.

Some counterbalance is needed to these inevitably disruptive effects, of the changing appointments to and the changing roles of functionaries within institutions and the inevitable localisation of benefits inherent in institution based decision-making processes. A strong and enduring commitment to an eResearch leadership function of some form should be made.

Maturity is a key factor

It is not true that the entirety of the Australian research community is ready, willing, able to, or needs to, exploit national eResearch infrastructure. It is also not true that the entirety of eResearch capabilities is mature, stable and ready for broad based adoption.

Some model of maturity of supply and use is needed to shape investment and improve quality and performance. Noting, that high performance eResearch infrastructure will always require substantive investment by researchers when extracting the maximum research power possible.

State of development

A selection of slides is provided in the appendix summarising the overall capability. These are hard infrastructure centric. It is difficult to easily display diagrammatically the contributions relating to improved policy, practice and methods. Such contributions are being made.

What we know and have learned

- The eResearch capabilities supported by NCRIS are valuable and in increasing demand.
- Network and compute infrastructure requirements continue to scale up unabated and with increasing sources of demand.
- The impact of digital data on research is a third pillar of value adding to the traditional eResearch infrastructure values of connectivity and compute.
- Data must be connected with methods (tools and compute) and the publications relating to it if we are to be able to replicate and build upon that data.
- Mechanisms to develop and deploy skilled support staff are necessary to fully realise the benefits of investment in the infrastructure itself.
- Researchers will need to reskill themselves, or include new skills in their teams, to maximise the power that eResearch infrastructure can offer to their research.
- A build up of skills at the point of service delivery and in the service itself is required.
- Changes to culture and practice needed for the productive use of technology and the data it creates and holds are themselves important challenges.
- eResearch and digital data infrastructures underpin a globalising research world, so that strengthening them is part of improving national research competitiveness.

Feedback

A changed environment exists

Since the NCRIS and Super Science investments were made, the eResearch interest and capability of institutions, research activities and other NCRIS facilities has increased. In addition, some relevant eResearch infrastructure that was unavailable through commercial supply, or unavailable on-shore, is now available through commercial on-shore supply.

Achieving Reliance

Providers of feedback have highlighted the need for production-ready forms of the infrastructure pioneered by the more recent eResearch investments. This relates to cloud capabilities, virtual laboratories and data supporting services. While recognising the value of transformative exploration the argument is that the means for production delivery of the results needs to be achieved, or the impact of the overall investment on research is fraught.

Durability of the infrastructure is also frequently questioned and raised as a barrier to reliance on it, even though the alternatives might be no more durable.

Delivering Responsiveness

Where eResearch activities are established to meet emerging needs and in advance of well shaped demand they necessarily go through a period of development and value proving. A transformation to fit for purpose production infrastructure can be expected to include a significant reconfiguration of the infrastructure delivery and that the pattern of allocation and use would be expected to change as demand establishes itself.

Many who would depend on NCRIS funded eResearch infrastructure feel that the multiplicity of projects has not helped and that the conversion to production infrastructure is not occurring quickly enough. They say:

- There is an alphabet soup of separate activities and it should be more ‘joined up’;
- eResearch component processes need to align better with themselves and with the decisions of others, an uncoordinated implementation does impede adoption and use;
- The eResearch resources should be accessible in strategic allocations so that it can fulfil the function of a platform capability; and
- A means of overall accountability, other than through the Department, is missing.

Setting Directions

Commentary received across the feedback is summarised here as advice.

- Conceive of the desirable future and engineer a pathway to get there.
- Establish a high quality guidance process others can observe and engage with.
- Establish a mechanism for effective concerted accountability.
- Set out to make concerted strategic contributions to other parties.
- Use structures/processes appropriate for an operating infrastructure.
- Develop and apply more uniform research impact, value and quality measures.
- Address the expertise and skills issues in a more visible and direct way.
- Promote the ‘right things’ and also make those ‘right things’ simple.

Organisation Viewpoint

Vision and Role

Background

Researchers appreciate the ability to access and use infrastructure that is established, scaled and conditioned in ways that make their research more possible in the first instance, and easier over time where that is practical. On the other had, there are gaps between historical research practices and the practices needed to achieve the visions set out for eResearch

For elite infrastructures, world leading research goals and research efforts drive their establishment and use. This strong pull from elite infrastructure users on infrastructure planning, creates the often described 'long tail' of eResearch, where the question is asked, how is inspirational research at any scale of infrastructure use supported.

The eResearch community broadly believes it should make inspirational research more possible at any scale of infrastructure use. As a goal for the sector as a whole this makes sense, however NCRIS forms only one component of the sector's support of eResearch. Consequently while the Framework will set out a broad eResearch vision, it will also set out an NCRIS role within that vision.

eResearch vision

The eResearch vision adopted in the NCRIS 2007 eResearch investment plan was as follows.

> Australian researchers will enhance their contribution to world-class research endeavours and outcomes through the use of advanced information and communications technologies.

A modernisation might focus on the impact of technology through advanced methods and better data and refer to the value of the improving digital platform of infrastructure capabilities.

> Australian researchers will advance national research priorities and enhance their contribution to world-class research endeavours and outcomes through:
> - The use of the most advanced technology enabled research methods and the highest quality digital data; and
> - By exploiting a world leading digital platform giving a borderless integration of instrument, sensor, network, compute, data, software and human resources.

NCRIS role

Such a vision needs further shaping to be useful in planning NCRIS eResearch investment. A prioritising statement is needed to identify the role of NCRIS within the gamut of soft, hard, data and informatics resources the sector will create overall to underpin the eResearch vision.

> In the service of Australian research, the NCRIS eResearch capability will prioritise the use of research practices and production quality infrastructures that:
> - Enable excellence in scaled up computation and data driven research;
> - Enable research communities and NCRIS capabilities to collaboratively develop, share and apply advanced technology and data enabled methods;
> - Support a borderless, durable and coherent system of data holdings to stimulate leadership and innovation in data intensive research; and that
> - Satisfy the NCRIS Principles.

High Level Goals

Direction and leadership

eResearch infrastructure is complex and confronts many dilemmas. These include:

- Securing of established traditional value vs the capture of new value;
- The pursuit of immediate research impact vs whole of life asset and re-use values;
- Resourcing ground breaking activity vs sector wide capacity building;
- Supporting disciplines and users with established technology and data dependencies vs supporting disciplines and users new to technology and data dependency;
- Supporting elite vs average infrastructure demands, noting the quality of research is not determined by the extent of infrastructure used; and
- Adoption of in-house solutions vs adoption of commercial solutions.

The complexity means that a strong and valid vision needs to be in place backed up by high levels of competence in leadership and decision-making. Therefore, given the importance attributed to the eResearch technology and data infrastructures, a guidance system of international stature should be in place to oversee robust performance measures and reviews, in order to assure the sector of the quality of these infrastructures and their alignment with national research priorities..

A co-design is necessary

All participants in the research sector will spend on eResearch simply because their researchers use computers, use data, use computers to use data, write software, import software, import data, publish data, or move data from one place to another. It is unavoidable.

> *The question arising is:*
> *how do we understand who spends on what and why?*

The overall Australian eResearch capability will be a mosaic of many activities funded in many ways. NCRIS funded eResearch infrastructure therefore should develop as a co-design taking into account the requirements of other research infrastructure investments, major research centres, and program-scale and project-scale R&D needs and their own approaches to eResearch and eResearch infrastructure.

Aggregation

Aggregation has many effects. It is related to lowering costs and improving quality. It also gives rise to entirely new capabilities that without aggregation will not be achieved. In the world of data, the impact of aggregation is very strong. The value of aggregation is less clear in terms of human resources because advancing research through the application of leading edge technologies often applies a deep integration of relevant skills within research activities.

Often these conflate so that human and data resources are attached to system investment that is co-located with research investments. The result is an historical preponderance of investment in local facilities with necessarily small scale teams and the benefits possible from aggregation are unrealised. The development of commercial cloud demonstrates that such an outcome is no longer inevitable and the arrangement needs to be rethought.

> *At a national scale, the number of sites or organisations needed to deliver major elements of eResearch infrastructure will be unrelated to the number of institutions, less than the number of states and territories and sometimes singular.*

The geography of value delivered by eResearch infrastructure into research will nevertheless be related to the geography of research intensity in each field of research. The key point is that:

- The location of the human resource assisting researchers integrate e-infrastructures into their work should relate strongly to the location of the research intensity in the domain of effect; and
- The location of national and international e-infrastructure systems that support research domains and the human resource delivering those e-infrastructures will need to be more centralised than is the case for the research intensity in the domain.

Scale and Durability

From development to operating

Bills have to be paid for researchers to use infrastructure and in scaled up infrastructures large bills have to be paid. Therefore the mechanisms that cause the infrastructure costs to be met, and met equitably, must be explicitly considered.

The existing NCRIS eResearch projects (in contrast to the funded facilities) can create dependencies between unrelated parties by paying the bills in one for the use by another. The result can be implicit dependencies with non-binding and uncertain obligations. When changes to the disposition of national funding occur, a failure of one kind or another is likely. Damaging instances of this pattern have been experienced.

> *A development bias is a natural outcome of novel infrastructure creation and value proving. Different approaches will be needed in provisioning an ongoing and dependable e-infrastructure.*

The project style implementation made by NCRIS in certain eResearch components has resulted in highly innovative development. It is inevitable that significant change will be needed to make a transition into a higher preponderance of operational activity and expenditure. At the same time, such a transition may mean that it is more possible to engage operational funding lines in institutions not previously engaged by the innovation and developmental profile of the projects.

Because funding must move from innovation projects to operating infrastructures and the planning must explore the means to engage funding lines not currently engaged, the future arrangements may be best re-conceived from the ground up by a process established for that purpose. A transition to the new arrangements could then be developed with the goal of preserving the value created to date.

Co-funding

Nothing can secure durability more easily than a long term commitment from a party that is itself sustainable.

The need for durability is heightened in eResearch infrastructure as it entrains dependencies and can replace or erode alternative approaches. Respecting existing funding relationships and arranging new funding arrangements are essential elements of an e-infrastructure activity. Therefore it is vital that these infrastructures are created in ways that build value for institutions and government and in ways supported by institutions and government.

It follows that NCRIS investment in eResearch infrastructures will be more secure if participants can build within, expand or adapt those infrastructures to meet needs they value.

An 'expand by participants' approach would integrate national eResearch infrastructure more closely with research and bring related benefits to a broader research base.

> *NCRIS funding could underwrite the fundamental nature of the eResearch infrastructure for such capabilities that are judged to require NCRIS support. The overall scale and overall research application could be the result of the build outs by government agencies, institutions and granting bodies.*[3]

An alternative formulation would be that the sector develops an approach to co-operative e-infrastructures for exploitation by participants and that NCRIS funding expands that infrastructure for identified national purposes. An advantage of such a formulation is that it naturally accommodates building on commercial infrastructures for national benefits. Given it is some way from current approaches; this alternative formulation might be best set out as the desirable long-term end point and a means for evolving towards it articulated.

NCRIS element

NCRIS funding must not undercut the willingness of institutions to invest in eResearch, and it must not by its action reduce or limit the size of the eResearch mosaic.

Within this kind of framing, the proposition would be that NCRIS funding would:

1) Underpin or underwrite eResearch capabilities that have appropriate scale or sector wide organisation or participation or for which no institution has a remit and that are judged to provide a nationally strategic value to research now and in the future
2) Provide capacity within eResearch infrastructure to meet national research challenges in a way needed by infrastructures and research investments that address them
3) Actively support expansion of those infrastructures by research institutions, relevant government agencies and funding bodies for their own purposes.

The development of the future national eResearch capability could be posed thus:

> *The most sustainable form of infrastructure would combine NCRIS investment with research leadership and corresponding infrastructure expansion by institutions, to support research excellence, and achieve national priorities, national research goals, and researcher and institutional competitive outcomes.*

Integrated support

A specific difficulty of an NCRIS funded eResearch infrastructure is that success can bring an increasing number of researchers to the door, creating a support challenge. The co-funding model of resourcing for national and local benefits could further motivate the availability of institutional support mechanisms for NCRIS eResearch infrastructure users.

[3] The NCI facility in Canberra exemplifies this characteristic and there is a build out occurring in some of the NeCTAR and RDS nodes.

Capability Viewpoint

People and Skills

Human capital

A focus on human capital was recently recommended by the review of national research infrastructure, which suggests that expertise related challenges are evident at a very high level and exist across research infrastructure taken as a whole.

In terms of eResearch, the challenges in skills development and deployment that are created by the increasing importance of digital data and the raft of new ICT enabled techniques and methodologies, has been documented for over a decade.

- The full complement of skills needed for complex research goals and many forms of elite research cannot be expected to reside in an individual and may not reside in even a small number of individuals.
- It is generally believed that the ability to apply the right skills at the right time is going to be a key feature of advanced research teams and institutions.
- It is also the case that the skills required by steps in research activities are often not required continuously.

The fixed term funding of research projects makes skills management difficult at the per project level, so that research teams and centres, facilities and eResearch providers must play a role in addressing the challenge. Consequently strategies for human resource management, team building and collaborative practice, for research, become key concerns in forward planning.

Workforce development

Like other infrastructures, eResearch infrastructure needs specialist skills to operate and needs to assist researchers develop methods around the infrastructure. However NCRIS funded facilities are likely to have limited means to provide promotions that support the careers of highly skilled staff. Therefore the approach to people and skills will need to engage with career opportunities in institutions and, if possible, between the research and commercial sectors.

The concept of apprenticeship schemes has been suggested and overall it seems opening the doors to student positions and other training strategies should become the norm. NCRIS facilities could also support experiential components of data science courses as another possibility.

Centres of expertise

Larger teams make deeper specialisation as well as greater impact more possible and mitigate the significant risks on skill loss inherent in small teams. It is likely that the scale of the AARNet, NCI and ANDS teams has significantly enhanced their effectiveness while the dispersion or small scale of the teams in other investments will have hampered their effectiveness.

An approach to improving quality, quantity and depth of expertise, could take the form of leadership centres in skill areas associated with scaled up delivery platforms. It would seem self evident that involving research partners in the skill area would be beneficial.

By definition, scaled up implies few and far between. Such investments would have to be based on an assessment of crucial expertise needed to empower Australian research priorities with significant longevity. To be considered in the NCRIS setting the expertise should relate to, and be able to be leveraged by, the users of a sophisticated and significant infrastructure platform.

Research Methods

A data using infrastructure

Researchers do not analyse large amounts of digital data using pencil and paper, or do image processing or perform numerical simulations in their head. Put simply, in eResearch, research outputs are created using some form of compute infrastructure, from handheld to peak systems.

Certainly, data has to be conditioned and assembled and software written and tested, but in some ultimate sense the compute platform available determines the power of possible digital research methods, within reason. It is not true that unbounded compute power provides ever more powerful methods because inherent properties of algorithms and the nature of available data provide diminishing returns.

Therefore the goal is to make infrastructure available that best serves the research methods being used and the size or complexity of the problems being tackled.

Scale out to more researchers

The use of digital data is mediated by software and the use of software is mediated by a compute platform of some form. As the investment in instruments and data sources grows, data volumes and data complexity will rise, and the requirement for assured methods and more compute power will also rise. The availability and suitability of digital methods and the computational infrastructure those methods need, could become one of the rate limiting factors on the advancement of research.

Today, the volume of new data generation is challenging. The challenge has been met to date but the load is growing and the discipline base in which it is occurring is growing. The value created by inter-connecting that data also adds demands in the areas of standards, software and compute. It is likely that both the availability of skills and the scale of budgets must be lifted to deal with the scale up of data, its improved interconnection, the roll out of new methods and the growing dependence on compute infrastructure that all of that implies.

Supporting research quality

Sustaining research quality and productivity in a compute and data rich future is a further challenge, especially when it is predictable that skills and resources will be stretched and could in parts be overwhelmed.

Many reports are indicating a rapid escalation in demand is occurring for access to people that can use e-infrastructure well, or use digital data well, or use either or both well at scale. The shortage can be traced back to the speed with which the need has grown but also to still under resourced courses and training options and to some extent a lack of student motivation.

It is expected that those who most effectively address the skill challenges will make the most headway.

Using commercial tools

The commercial cloud suppliers demonstrate clearly that the commercial sector is at the forefront of various forms of scaled up hard and soft infrastructures. Similarly, the increasing commercial interest in ‘big data’ analytics means that the publically funded research sector cannot expect to lead the way in all aspects of methodology and technique development.

The fact that the import and adoption of commercially originating methods (and infrastructure as well) comes with a price tag attached, is a strategic and philosophical hurdle the sector needs to come to some accommodation over. The role of commercially sourced data and methods in research is a key maturity enhancement for the Framework to address.

Research Data

Using data better

Research investment today is becoming strongly related to the creation and use of digital data for research and the growing opportunity and challenge of data is strongly present in people's minds. Data volumes are ramping up everywhere as a result. This can be expected to continue as one of the primary drivers of eResearch infrastructure for the foreseeable future.

Of note, compute infrastructure is itself a means of creating digital data at scale through simulation and modelling and is the only means of using digital data at scale. Also a growing load on networks is related to rising data volumes. Therefore 'using data better' depends on new data capabilities, the expansion of networking and compute capabilities in new ways and new types of eResearch expertise and development of researcher skills.

The concept often portrayed is of a growing data ecosystem – as data alone is not the issue – extracting value from data involves schemas, policies, tools, identifiers and links that make the data valuable combined with compute and connectivity capabilities and the skills to develop, support and use all of those.

Also, very large holdings of research relevant data will exist outside of research in general and, within research, will exist off-shore from Australia. Equally Australia will host data holdings of interest elsewhere. Therefore the ability to access data elsewhere and, where appropriate, to assemble data here in order to confront prioritised research challenges are necessary capabilities.

Data as an asset

The approach set out in the Research Data Infrastructure Committee's report that data creation, data organisation and data use are three different functions and possibly best conceived as three different infrastructures, even if implemented more coherently, is important and not contradicted by any feedback received to date.

- While it is tempting to say co-location or infrastructure as a service will bring these classes of infrastructure together, there appear to be many factors operating to keep data distributed in its location across the sector.
- The proposition is that data will for some considerable time be distributed across facilities and institutions in the sector, and this may always be the case, so that the Framework should not assume otherwise. The challenge is to understand and support a data ecosystem as it develops.
- The current infrastructure development has confirmed that compute and storage should be resourced together and that working data is a dominating concern for researchers. It also seems clear that new data is prioritised in research spending.
- Another aspect of the commentary around data is that the notion of data as a by-product of research is being replaced by a view of data and the tools around data as *the* critical resource and of instruments and computing systems as adjuncts to the creation and use of data. This is not to downplay the importance of instruments and compute, just that the growing role of data is adding a new dimension to the story.
- Data is also increasingly recognised as a critical and primary contributor to the advancement of the stock of knowledge.

Cutting across this characteristic is the notion that big data assembled across the verticals will also have value in future unpredictable ways so that the use of common underpinnings applied to the verticals can support the cross flow of data and hence add value.

Technology

The fundamental technology inputs to eResearch infrastructure include high performance networking, high performance computers, cloud systems, data systems, all the componentry elements of them, and a diverse array of software elements. Around that are technological and policy issues needing attention, such as data sharing, ethics and privacy, access and pricing, standardisation, reliability, durability, policy compliance, interoperation, and cyber security.

Computing and storage

The Australian research sector has significantly more expensive and scaled up compute and storage infrastructure installed and operating than at any previous time. This includes several peta flop capable systems (two which are NCRIS supported) and hundreds of petabytes of storage. Of course each element is significant only up to it's next refresh point. The point is not just that the capacity is higher, but the funding rate over the last five years is the highest ever.

Some factors are that data volumes are rising rapidly everywhere; the need for compute power in data conditioning and data using applications is a new rising factor; real time use of scaled up resources is sought; and the growth rate in absolute HPC peak performance has rising costs.

Cloud systems

The development of cloud systems is revolutionary for research as it allows a very large number of highly diverse applications to be supported on common rock solid systems infrastructure. It should be possible for research teams to deploy software of their choosing without managing compute and storage systems. Australia is a leading adopter with a large private research cloud, being one of the first of its kind.

Software

The variety and diversity of research leads to an equal diversity in research software tools. Because of that variety, research software is not as well funded from a quality and maintenance point of view as is software addressing large markets. Many projects here and overseas have attempted to improve the maturity of research software activities. However, given the market size for any specific research tool is inevitably small, the resulting multiplicity of independently developed software tools face significant quality and maintenance challenges.

High quality software used by research increasingly arises in community codes developed by international co-operative and open source efforts of researchers, and in commercial products supported by larger markets. It is important that eResearch investment works to increase the usage of these codes, as the functionality, certainty of implementation and repeatability of software performance is a critical factor in research quality outcomes.

Standardisation

Standards have long been a vital component of data intensive domains and hence eResearch and eResearch infrastructures. The adoption and implementation of standards is a critical element of any technology infrastructure, especially around the ability to assure implementations for compliance with inter-operability, access, ethics, security and trust requirements.

Of particular note are trends in the standardisation of interfaces by which distributed systems interact leading to the prospect of data applications reaching into and using data from many remote locations. The other trend concerns the increasing desire of institutions to comply with a number of key data and quality management standards, particularly relating to the access and use of sensitive data sets. It is also possible that 'quality of research' standards should be developed to address the challenge of reproducibility in digital research environments.

Connectivity

Networking

Modern research infrastructures assume the existence of research networks capable of providing very high bandwidth with very low contention to accommodate data-intensive research needs. Traffic on these globally interconnected NRENs (the National Research and Education Networks) continues to grow at 50% year on year. This growth is met in Australia as elsewhere by utilising direct access to fibre-optic infrastructure nationally, and by purchasing international bandwidth in bulk over long periods. The Australian research sector secured these objectives in 2003 through opportune national investment. A very important hurdle is approaching regarding the end of lease for some fibre assets and action will need to be taken over the next few years to develop a strategy for their continuation or replacement.

Removing friction

The concept of a frictionless infrastructure has been developing since the days of grid systems. The concept is that researchers should be able to use assets and capabilities held in diverse ways, in facilities, national agencies, institutions and even specific research laboratories as though they were co-located or managed as a single system.

The concept of the Science DMZ has arisen as a pathway to such a friction free infrastructure. It says that resources needed by research, especially where used by researchers from multiple institutions, should be brought together in their own policy and connectivity environment, separate to the policy and connectivity environment controlled at each institution.

Strengthening steps towards a science DMZ needs to be a goal of a national eResearch infrastructure. Providing fibre to the instrument for all high volume data producers, building out existing networks, is one possible step. However the Science DMZ should not be thought of as a technical exercise, it is a very significant policy exercise. It's achievement is the kind of improvement that could be sought through the establishment of an eResearch leadership function.

Authentication

A particular case of friction emerges where every element of infrastructure creates unrelated identities to control access. Some success has been achieved in Australia with approaches that allow identity sharing for authentication purposes, but more needs to be done. The approach to authentication must be coherent with commercial infrastructure solutions and also engaged with global identity providers for research, as they develop.

Cyber security

The confidence of good security practice needs to increase, implying that the total number of points of security management needs to be controlled and some assurance established that appropriate skills levels and policies are in place.

Collaboration systems

Collaborative systems, including web sites, video conference, distributed multi-authoring of documents and shared file systems, are now so effectively supplied by commercial providers that eResearch should prioritise its effort elsewhere.

It could be argued that global file system offerings, with version recovery, file sharing and multi-device access should be adopted as a matter of course.

Directions Viewpoint

Opportunity

Moment of change

The eResearch capability is in a position to reframe its further progress.

- Extensive investments have created a suite of capabilities on which research dependencies are increasing and from which increasing research impact is being delivered;
- A one year funding period is available to operate existing infrastructures through 2016/17; and
- The prospect of a longer timeline investment from July 2017 is available following a road mapping and planning activity.

While there is a capital refresh challenge that is not resolved by the above, the situation presents as a critical opportunity: a moment in time where a rethought future could be articulated; because the means to embrace it exists.

In addition, if the number of institutions investing in eResearch increases significantly, the balance of investment changes and new outcomes and approaches become possible.

Existing momentum

Australia has an experience base relating to the advanced use of eResearch infrastructure that is unparalleled in historical terms and at least equal to that available in any other jurisdiction. While planning has struggled with funding uncertainties and organisational arrangements and the appropriate process for focussing some resources, practice is proceeding apace building on the commitments made.

Stopping now is a bad idea. The level of commitment made over the preceding decade has created a technical and expertise platform on which a new approach can build. The level of skills and capability constructed should not be squandered.

Cooperative stance

The sector has many co-operative frameworks within which concerted action could be planned. In addition NCRIS itself provides a co-operative planning process at the national level through which priorities for eResearch investment can be resolved. An advantage Australia possesses is the relatively high level of concentration in decision making compared to the US or Europe.

One of the rationales for NCRIS is to use national funding to ensure our scaled up computing, research instrument, sensor and data capabilities are available to meritorious research regardless of the institution of the researcher. Creating a borderless infrastructure. Libraries, despite being resourced by institutions, provide an additional example where making knowledge available to the wider research community is part of the mission. As for manuscripts, an agreement not to balkanise our eResearch and data assets could be reached.

> *Could the universities and publically funded research agencies signal at the highest level possible that they agree to focus research competition around the creation and use of data and to cooperate around access to data including co-operating around the systems that borderless data access relies on?*

The agreement would be that the co-operative approach to access would apply to institutional investment in data holdings, as well as national investment in data holdings. Australia has an advantage, in that unlike many overseas jurisdictions, a meeting to agree that outcome is numerically realisable.

Imperatives

Focus on national

Because everyone will invest in technology infrastructure of some kind, a clear role for national eResearch investment must be stated if the best outcome from NCRIS funding is to be achieved.

A specific difficulty in sustaining a national focus arises from the complexity of the eResearch challenge, the number of institutional functionaries that influence the outcome, and the rates of staffing changes that occur across that cohort. In addition, as some decomposition will be needed for an effective implementation, to create activities that can be reasonably implemented and managed expeditiously, elements will exist that respond to less than the whole problem. These factors suggest that in order to sustain a focus on national outcomes, a process to sustain and adjust the direction will be required. This process would need to have co-ordination, advisory and value proving aspects as well as some ability to influence the use of funding.

Implement at scale

A criticism of current activities relates to the scale of the providers of eResearch infrastructure, which is an issue unique to eResearch. While a microscope of a given characteristic has a given scale, the scale of e-infrastructure can be varied in most of its dimensions at will. The section on Aggregation cannot be overlooked.

Make the right things simple

Put simply, issues such as one click data publishing, or the lifetime identification of data, or the capture of provenance and the support of reproducibility are problems the technology should address. The use of research labour to make up for the non automation of what can be automated is not appropriate. Correspondingly, the imposition of un-automatable requirements should be resisted, as the passage of time will significantly lift the bar on what can be automated.

A policy such as follows could be considered:

- Identification, Publication, Provenance and Reproducibility requirements, as set out at any point in time, shall relate strongly to what can be automated with available technology; and
- National funding should then seek to implement that automation in infrastructures it supports.

It would of course be wise to understand this is an aspirational goal.

Challenges

Funding levels

The rise of data and the commensurate growth in demand for compute power is rising sufficiently quickly that funding for eResearch and its infrastructure could be expected to be growing as a share of spending.

The feedback provided suggests that the overall investment in eResearch is below what is required. Whether true or not, significant discrepancies in spending between otherwise commensurate Universities are observable. As a result, some benchmarking is called for.

To encourage investment, research investors should be able to expand infrastructure supported by NCRIS funding, for their own reasons, within the limits of hosting entities. This would significantly reduce the hurdle to getting involved. The idea that only co-investments directly supporting the NCRIS identified purposes are allowed in the development of truly underpinning infrastructure cannot be a helpful idea.

Complexity

Because progress is needed in an area of evident complexity, a strategy for dealing with the level of complexity is needed.

- 'Fast fail' might have been reasonable a decade ago, but it is not possible now with infrastructure investments involving many and increasing dependencies and therefore it should be excluded from consideration now as a viable strategy.
- 'Picking winners' in the sense of identifying and solving solvable problems is a feasible strategy already in use. For instance, prioritising infrastructure able to support scaled up peak use or prioritising the publishing of results data, are examples of 'picking winners' that make immanent sense.
- 'Prioritisation' is another option, where areas in which eResearch excellence is to be prioritised would be resolved. This strategy concords with the concept that relating to other key investments, such as other national infrastructure capabilities or centres of research excellence, would provide leading innovation and research impact partners for the development, deployment and use of national scale eResearch infrastructure.

The issue is not just that some approach is needed but that it must be clear to all concerned.

The culture challenge

It is important to acknowledge that research has many aspects of a hero culture. Eminence and research success is acknowledged and rewarded, achievement yields respect, and researchers are conscious of standing and reputation issues. In times past this reasonably translated into technology heroics as well. In fact technical development would be traditionally viewed as an essential component of a laboratory.

In recognition of the commercial capabilities growing all around research, it is time for a change of mind. In peak areas and in some domains where the very edge of technological performance is applied, technology heroics are needed. Everywhere else the ability to relieve researchers of these demands, to free their time for research, should be the goal.

Consolidation

Up until recently, consolidated research infrastructure appeared to be infeasible given the variety of implementations wanted by researchers. The experience of the private research cloud, and the existence of the commercial cloud, suggests that consolidated infrastructure underpinning a variety of research uses of compute and data is now a real prospect.

From the perspective of national eResearch infrastructure there are four classes of participant:

I. Nationally funded and operated infrastructures:
II. Shared operator providers and commercial infrastructures;
III. Institutionally operated corporatized infrastructures; and
IV. Infrastructure arising in a decentralised and self managed environment.

In any future development of national infrastructure, a planned A and B outcome may need to be articulated, to represent the fact that some outcomes cannot be cost effectively delivered on some forms of infrastructure deployment. For instance, it is a widely held view that data must be migrated off desktops to ensure its management and retention.

In addition specific internal policy compliance may be needed to participate in the A outcome. If one considers security levels then a larger set of planned outcomes on policy assurance would be needed and much of the existing sector infrastructures might be unable to participate. The way in which institutional infrastructure enables or inhibits eResearch outcomes needs to be better understood.

International Signposts

A large number of reports have been produced over the last decade in many jurisdictions around the world on the topics of eResearch, e-Science, e-infrastructure and cyber-infrastructure, elaborating different aspects of a single proposition:

> *The combination of information and communication technologies, data holdings of quality and software based methods are now integral to the advancement of knowledge and their continued evolution is adding to research power.*

The fact that there are many investments in eResearch related activities around the world supports the case for making such investments in Australia. It is the development steps and the rationale for the evolving trajectories that most informs the Framework.

National strategies

The Canadian approach provides a point of comparison as it is well regarded, encompasses compute, data and software, is a federation of facilities and regionally distributed capabilities, and engages with many Canadian universities.

The evolution of the UK eScience programme and the rationale for establishing the Leadership Council underscores the need for high level leadership.

Key Reports.

- "A Strategic Vision for UK e-Infrastructure, A roadmap for the development and use of advanced computing, data and networks" (2011)
- "Cyberinfrastructure for 21st Century Science and Engineering, Advanced Computing Infrastructure, Vision and Strategic Plan" NSF 2012, which set out six areas of focus: Grand challenge communities, scientific instruments, data, campus bridging and cybersecurity, software, advanced computation infrastructure and learning and workforce development. (2012)
- "Future science, computer science, meeting the scale challenge", Australian Academy of Science (2013) which elaborates the impact of computation and data mediated methods on Australian science and research and the advances that ensue, and sets out issues in skills and technique development and exploitation that then arise.

Compute

Both the USA and Europe have very large commitments to peak computing facilities, notably through PRACE in Europe and the US Department of Energy funds centres at a scale beyond Australian means.

In the UK, the Hartley Centre is an exemplar of a relevantly scaled, world-class peak facility.

Key Reports.

- "Future directions for NSF advanced computing infrastructure to support US Science and Engineering in 2017-2020" National Academies, interim report 2014, which confirms the continuing need for high end compute and data intensive capabilities.
- "PRACE Annual Report 2014", showcasing the impact of HPC, the integration of the role of HPC and data, the outcome of a leadership investment, and reporting on strategies for industry uplift and skills uplift across a range of science disciplines.

Data

The European experience in managing large volumes of aggregated multi-party genomics data is important – especially as that experience is leading to a changed strategy.

- EMBL/EBI/Elixer

The US National Science Foundation program is undertaking a third (?) generation strategy building regional high capacity data support centres.

- NSF – Accelerating the big data ecosystem

The evolution of the digital curation centre funded in the UK eScience programme is likely to be instructive.

- Digital Curation Centre (JISC)

Key Reports.

- "Riding the Wave, How Europe can gain from the rising tide of scientific data" EU 2010, and "A Surfboard for Riding the Wave - Towards a four country action programme on research data" EU 2011, which identifies three long term goals: data sharing will be part of the academic culture; data logistics will be an integral component of academic professional life and data infrastructure will be sound, both operationally and financially.
- "Seizing the data opportunity - A strategy for UK data capability", 2013, which identifies skills, infrastructure and the data itself as the three overarching aspects to a national data capability, that such capability is a critical overall economic enabler and that data access is a key part of knowledge transfer between research and industry.
- "The Australian Research Data Infrastructure Strategy", Research Data Infrastructure Committee 2013, which reviewed the role of data in research and recommended, along with the need for an improved commitment, sustainability and governance around data, that key views of data infrastructure are data collection and generation infrastructures, data organisation infrastructures and data use infrastructures.

The European Cloud Initiative – Building a competitive data and knowledge economy in Europe (2015). Its opening summary is below.

> 'There is an explosion in the amount and variety of available data: research data, digitised literature and archives, data from public services such as hospitals or land registries, data generated by connected objects and billions of people using digital devices and services. This is known as the "Big Data" phenomenon. Big Data creates new possibilities to learn, share knowledge, do research and science, develop and implement public policies.
>
> We also have the increasing capacity to make use of data thanks to "Cloud, i.e. the data infrastructures that store and manage data, the high bandwidth networks that transport it and eve more powerful computers that process it. Just as the advent of computers did, Big Data analytics is changing our economy and society and enabling major insdustrial and social innovations. It is also changing the way we do science, in a transition towards Open Science.'

The "signposts" present in that report are (in the order in which they appear in the report):

- Openness of data, and notably openness of data emerging from research, is important;
- Interoperability of content (and of systems) is a key area where much work is required;
- Fragmentation hampers data driven science and the data economy in general, where fragmentation arises from elements with separate governance, policies and standards;
- A lift in available world class HPC infrastructure is needed to process and use data; and
- The data producers and data users must be provided with scaled up infrastructure that is at least as reliable as their own.

Software

The USA's National Science Foundation's research software vision "identifies advancing new computational infrastructure as a priority for driving innovation ... Software is thus an integral enabler of computation, experiment and theory and a central component of the new

computational infrastructure … Software is also directly responsible for increased scientific productivity and significant enhancement of researchers' capabilities (Implementation of NSF CIF21 Software Vision).

Science Gateways are similar to the Virtual Laboratories of NeCTAR. The funding of a Science Gateway Software Institute is indicative of the growing importance of software.

Standardisation

There is a long history in value adding to software and data at the global standards and inter-operation enabling levels.

- CO-DATA, W3C, World Data system, Research Data Alliance

Appendices

Contextual definitions

National Research Infrastructure (2011)

'Research infrastructure comprises the assets, facilities and services which support research across the innovation system and which maintain the capacity of researchers to undertake excellent research and deliver innovation outcomes.'

'For the purpose of this Framework, investment in research infrastructure has been divided into three broad categories:

- Local – research infrastructure which could be expected to be owned and operated within a single institution.
- National – research infrastructure on a scale generally not appropriate to be owned or operated by a single institution and which often supports collaborative research and is generally regarded as part of the national research capability.
- Landmark – large-scale facilities (which may be single-site or distributed) that serve large and diverse user communities, are generally regarded as part of the global research capability, and engage national and international collaborators in investment and access protocols.'

Source: "Strategic Framework For Research Infrastructure Investment", report to government by the then National Research Infrastructure Council (2011).'

National Collaborative Research Infrastructure (2015)

'This term, and any variants, refers to Projects that incorporate all the following characteristics:

- is available to researchers outside the Project and Project Partners with minimal barriers to access
- has a primary focus on delivering the project outputs to the Australian research community
- operates research infrastructure (including data infrastructure) on a collaborative, national, non-exclusive basis.'

Source: Department of Education and Training NCRIS 2015 programme guidelines.

NCRIS Features (2011)

'Key features of NCRIS — namely the emphasis on collaboration from the outset, the strategic identification of capabilities through the consultative roadmapping process, the facilitation process to develop capability plans and the provision of funding for skilled staff and operating costs — contribute to the NCRIS model being an appropriate, effective and efficient mechanism for establishing critical research infrastructure for Australia. Incorporation of these key features should be considered in the development of policy for future research infrastructure programs.'

Source: NCRIS Evaluation Report (2010).

NCRIS Principles (2016)

The key principles underpinning NCRIS are that:

- Australia's investment in research infrastructure should be planned and developed with the aim of maximising the contributions of the R&D system to economic development, national security, social wellbeing and environmental sustainability;

- Infrastructure resources should be focussed in areas where Australia is, or has the potential to be, world-class (in both discovery and application driven research) and provide international leadership;
- Major infrastructure should be developed on a collaborative, national, nonexclusive basis. Infrastructure funded through NCRIS should serve the research and innovation system broadly, not just the host/funded institutions. Funding and eligibility rules should encourage collaboration and coinvestment. It should not be the function of NCRIS to support institutional level (or even small-scale collaborative) infrastructure;
- Access is a critical issue in the drive to optimise Australia's research infrastructure. In terms of NCRIS funding there should be as few barriers as possible to accessing major infrastructure for those undertaking meritorious research;
- Due regard be given to the whole-of-life costs of major infrastructure, with funding available for operational costs where appropriate;
- The Strategy should seek to enable the fuller participation of Australian researchers in the international research system; and
- Enable Government initiatives which seek to maximise opportunities for industry engagement and commercialisation of research.

Source: Included in all NCRIS roadmaps and all funding guidelines (current).

eResearch Vision (2006)

'Australian researchers will enhance their contribution to world-class research endeavours and outcomes, through the use of advanced and innovative information and communications technologies.

The vision encourages researchers to participate in the transformation process being enabled by ICT, as it offers the power to undertake research on a scope previously unattainable, to work collaboratively and globally in a way not previously possible, and to improve existing research.

The transformation brought about by ICT also extends and broadens the impact of research, by making its outputs more discoverable and useable by other researchers, and by making its benefits more available to industry, governments and the wider community.'

Source: The then e-Research Coordinating Committee (2006), adopted by the NCRIS Platforms for Collaboration investment plan (2007).

eResearch Infrastructure (2012)

'eResearch infrastructure comprises the information and communication technology related assets, facilities and services which support research across the innovation system and which maintain the capacity of researchers to undertake excellent research and deliver innovation outcomes.'

'eResearch infrastructure is increasingly a cornerstone of modern research; advancing the frontiers of research in ways that otherwise would be impossible:

- by providing the means to manipulate, manage, share, integrate and reuse research data;
- by enabling new insights through ever more powerful simulations, modelling and data analysis; and
- by enabling more extensive research teams to share resources and work together more effectively.'

Source: Annual Report, Australian eResearch Infrastructure Council (2012).

Explanatory Summary

The following explanatory summary was developed by the branch in government responsible for NCRIS activity and made available to the sector in 2012.

ICT intensity and eResearch

The performance of information and communication technologies (ICT) has grown exponentially in the last few decades, and continues to do so, creating an unabating engine for change across the economy.

We can now collect and use information at previously unimaginable speeds, and we can manipulate previously unfathomable quantities of data. This is revolutionising the way we do science and research, allowing us to answer questions that could never have been answered before and in ways never previously possible. Applied to research, these ICT effects are called eResearch.

The new research and research methods enabled by eResearch can be related to:

Techniques	finding patterns not otherwise discoverable
Scale	increasing the speed, extent or fidelity of research
Simulation	modelling phenomena unobservable by traditional techniques
Distribution	connecting, accessing and contributing to global resources

Necessary eResearch infrastructure

The Australian Government has invested $578 million in eResearch infrastructure since 2002 through three consecutive programs, as indicated overleaf and a small ($2 million) injection from departmental funds. Throughout this period, ongoing roadmapping processes have confirmed four strategic areas of investment:

Tools:	Advanced software-based research tools and integration capabilities connect researchers with data, computation, instruments and sensors to advance research endeavour in entirely new ways.
Data:	The scale at which data can be collected makes research on real world effects possible for the first time ever, unbounded by limited models or theories, opening entirely new research horizons.
Computation:	Improvements in the speed and fidelity of simulation and modelling translate directly into new research understanding that otherwise would not be possible. This can shrink the time to achieve significant research from years to months or even minutes.
Networks:	Researchers continue to require bandwidth at levels beyond typical commercial uses. Dedicated research networks offer solutions that are simply unavailable or unaffordable commercially.

eResearch Investment (cont.)

Government role

The Australian Government has a central role in eResearch infrastructure because:

- Public investment in science and research is essential to building innovation and productivity outcomes across the nation.
- Making leading contributions to global science and research endeavours requires strategic investment in nationally scaled infrastructure consistent with public funding approaches in other advanced economies.
- Australian research will need to extract the maximum possible contribution from ICT advances in order to remain internationally competitive.
- The scale of eResearch infrastructure needed is beyond the financial means of individual sector participants, creating a scope of activity for direct government investment.

An ongoing strategic investment needs to be sustained because:

- The ubiquitous deployment of eResearch is necessary if science and research productivity gains are to be fully captured.
- ICT development will continue to revolutionise science and research for the foreseeable future.
- A long term development of skills and expertise is needed.

Collaborative delivery and priority use

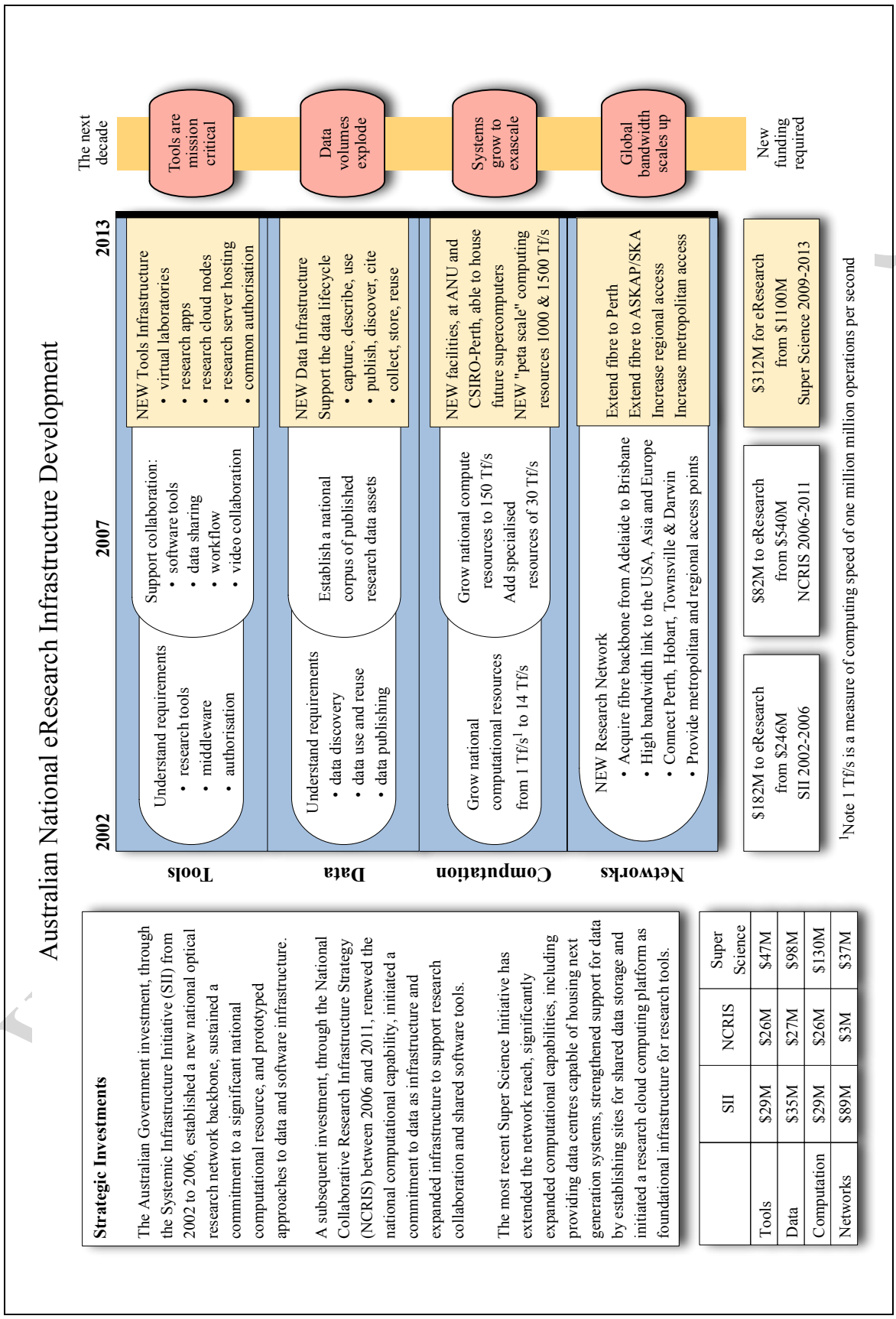
The Australian Government has developed an effective approach to planning and implementing nationally collaborative research infrastructure. It has delivered an array of complex, inter-related and underpinning facilities that are made openly available on the basis of research need, merit and priority.

The Australian Government is uniquely placed to coordinate national infrastructure, leverage sector and state resources and achieve implementation that maximises return on investment.

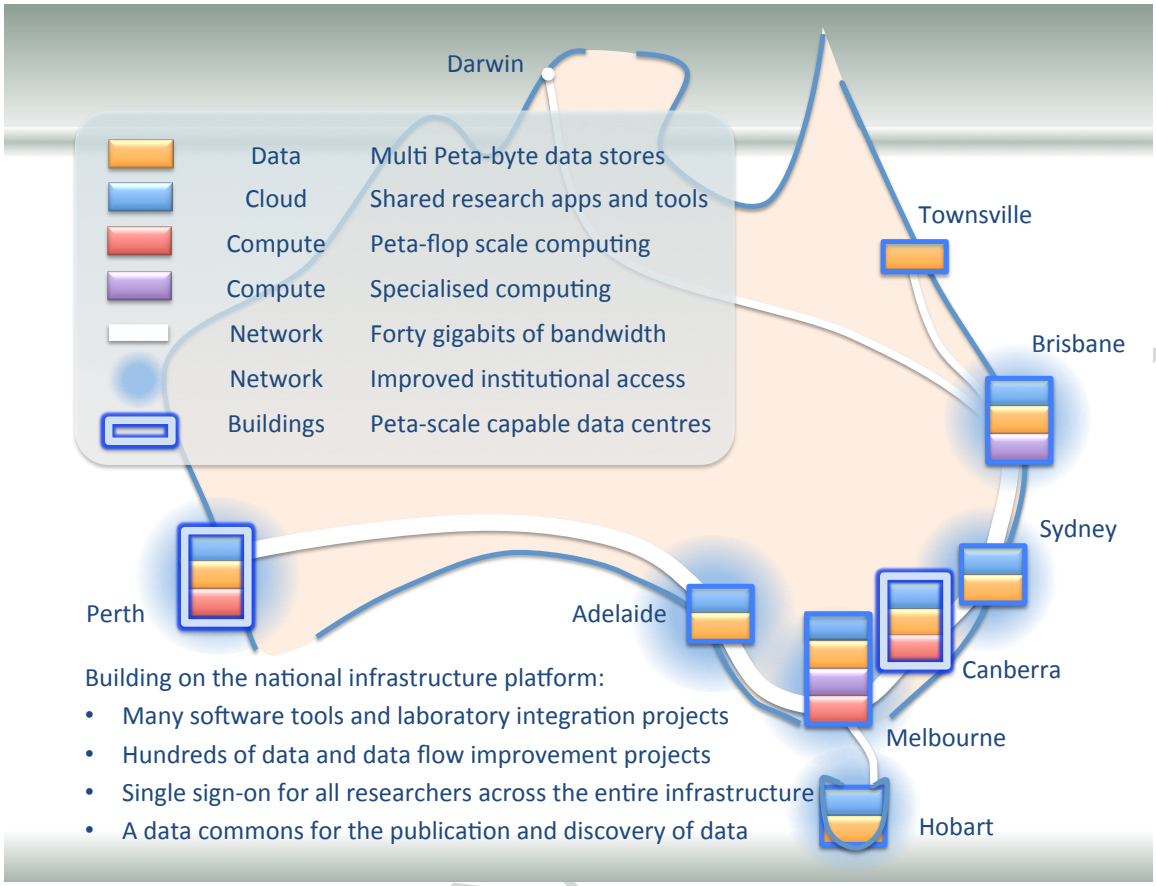
Sustaining this cooperative approach will accelerate the dramatic transformation of discovery made possible by deploying and adopting eResearch infrastructure.

Background Slides

Summary produced by Department in 2012.



The following image has been used over the last few years to display the physical realisation of the infrastructure. This slide is reproduced from a meeting held in December 2015.



The following summary was provided to that meeting in relation to the slide.

- Three Pflop rated general research systems and others
- About 43 PB of data targeted for ingest into national storage nodes, 61% complete – very large holdings arising in institutions.
- Eight cloud nodes are installed and operating a private research cloud now growing beyond its initial scale out of ~30,000 cores
- All network buildouts completed, general network use, about 170 point to point 100Gb/s links are lit across the backbone and a national 40Gb/sec data highway is installed
- 15 virtual Labs (eg. climate, marine, humanities, astronomy, imaging etc) continuing
- ~100,000 collections published in research data commons

This understates the improvements made in policy and practice around data and software as a result of supplying expert skills into very many data management and software development activities.

The following slide is from a presentation to the Department in 2011 summarizing the point in time investments and their vey high-level contribution. The dates on the slide reinforce that reconsideration is now timely.