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SPECTRA



IMAGES AND DATA IN ART/SCIENCE

The currency of images in the studio and the laboratory

Edited by Mary Rosengren and Cris Kennedy

SPECTRA: images and data in art/science

Proceedings from the symposium SPECTRA 2012

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SPECTRA: images and data in art/science

Proceedings from the symposium SPECTRA 2012

The book and the conference that begat it, SPECTRA 2012, originated in the ANAT Synapse residency artist Mary Rosengren enjoyed amongst the National Collections CSIRO manages here on Black Mountain in Canberra.

Among our Collection items are the materials gathered by Joseph Banks and Daniel Solander on the Endeavour voyage. I am struck with a sense of pride and awe whenever I am able to access and show off these items to visitors to our organization. These objects are priceless national treasures. Yet daily in the corridors of our laboratories I walk past hundreds of images on posters and screens produced by our contemporary researchers. Specifically, what currency do they have, and who will curate them and proudly show them off in two centuries time? Generally, can we place a cultural value and how do we assess and interpret the artistic nature of scientific data and imagery?

We are all conscious of the increasing significance of technology in shaping all cultural practices. Change creates tension, of course, and we are seeing both alliances and tensions between specialist fields of art science practices and knowledge. These are both creative fields, and the barriers that have separated them are coming down.

While Mary Rosengren, through her ANAT Synapse residency, began her time among the CSIRO Collections thinking about how these ideas could influence her practice, she found it was the dialogue with researchers and academics that was more fascinating, and more than we felt should be constrained to the output of just one artist.

The focus of the resulting SPECTRA program was less about science-art as a spectacle, more how contemporary visualising technologies and techniques for analysis, data management and imaging have radically changed the nature of art and science practices and the status of images in both fields.

The artists and scientists whose thoughts in this area are chronicled within these pages demonstrate a defining cultural force and we are both grateful for and inspired by their ideas.

We're not sure we've answered any of our questions but we're enjoying the conversation.

Cris Kennedy and Mary Rosengren
March 2014

*Dedicated to the memory of Scottish engineer/designer
and mountaineer Hugh McNicholl 1945-2012*



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Introduction

If we knew what it was we were doing, it would not be called research, would it?

Albert Einstein

Imagine, if you will, a choreographic language derived from data received from the Magellanic Clouds – and then performed to real-time data output. Or a suite of musical compositions created and performed for cochlear implant wearers. Or biofeedback-driven artworks that help children undergoing painful medical procedures to learn self-calming techniques. Perhaps the written word is more your thing... what might happen when two writers leave behind the real world to spend a week in a sleep research centre to test the impact of diurnal disruption and constant surveillance on their creative output? These and many other scenarios have been realised over the past 15 years through the support of the Australian Network for Art and Technology (ANAT) in partnership with the Australia Council for the Arts and a host of academic, government and private sector partners.

So why do we do this? Because we believe that collaborations between the arts and sciences have the potential to create new knowledge, ideas and processes, because artists and scientists approach creativity, exploration and research in different ways and from different perspectives. Bringing them together can lead to new experiences and interpretations of the world, now and into the future.

We live in an era of increasingly complex problems, challenged daily by issues that can only benefit from multifaceted and multidisciplinary approaches. By encouraging breaches between the silos of the arts and sciences, we hope to encourage other disciplines to see the benefits of collaborating across and between knowledge systems in order to find new solutions and new ways of doing things.

Speculative research allows artists and scientists to follow their noses, to traverse uncharted paths in the pursuit of the unknown. Sometimes they find useful things, sometimes they find beauty, sometimes they find themselves in entirely new places, sometimes they find nothing at all. The journey back and forth between disciplines is paramount – it opens eyes and ears, hearts and minds to the possible and to new ways of approaching those things that, for now, remain impossible.

Vicki Sowry

Director

Australian Network for Art & Technology

Opposite: BrightHearts app (iOS), heart rate controlled interactive artwork, 2011-2014, George Khut and Sensorium Health Pty Ltd

Vision's Evolutionary History

Andrew Parker

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The first optical devices in animals evolved in the Cambrian period. The first coloured reflector known dates from around 508 million years ago (Ma); the first eyes with lenses evolved at around 521 Ma. Consideration of the introduction of vision leads to a hypothesis for the cause of evolution's Big Bang – the Cambrian explosion. Suddenly, and for no obvious reason, the range and variety of life-forms erupted somewhere around 520 million years ago. At no other time in Earth's history has there been such a profusion, such an exuberance, and such an overwhelming diversity in so short a time, within around one million years. Prior to this Cambrian explosion event, all animals were soft-bodied and mainly worm-like, as they had been for millions of years before that. But during the Cambrian explosion many of the major animal groups on Earth today independently evolved their hard body parts for the first time. Following the appearance of the first trilobites, some animals evolved shells and spines, some with bright colours, to visually warn of their new armour. Others evolved streamlined appearances and swimming oars to advise trilobites that they could not be caught. The Light Switch Theory provides an explanation for what triggered this event – that it was the evolution of vision (in trilobites); the introduction of light as a universal stimulus for animal behaviour. Once visual capability arose, it allowed predators to identify prey, triggering an arms race. From here on, vision became a dominant force of evolution and resulted in the eyes and colours we have in nature today. A consideration of where vision and colour first began could prove interesting to the artist.

Optical devices in living animals

The range of optical devices in the form of reflectors (causing "structural colour") and

antireflectors found in nature was revealed in 2006 [1], although the functions that covered these had been summarized in 2000 [2]. Since then, the biomimetic manufacture and applications for reflecting optics has been demonstrated through the study of living cells that make reflectors [3].

Multilayer reflectors, diffraction gratings, liquid crystals and structures that scatter light have been found in animals with a diversity of designs. For example, diffraction gratings in ostracods (seed shrimps) produce iridescence that functions as a courtship display [4] (*Fig. 1*). More recently, following the identification of photonic band gaps in physics, natural photonic crystals have been identified with a range of architectures, including the opal and inverse opal structures [5].

Eyes, on the other hand, have long attracted significant attention. Eyes possess a range of lenses, including the compound eyes of insects and the graded-refractive-index lenses of fishes [6]. The latter prevents spherical aberration by focusing beams entering different regions of the lens onto the same focal plane – the retina. Some eyes contain complex optical mechanisms, such as in the mirror-box lenses and parabolic reflectors of some crustacean eyes, and the telephoto lens component in a jumping spider eye [6]. A more recent discovery in eyes is the micro-lens array of the bristle star [7, 8] – closely packed, tiny convex lenses made of calcite. The bristle star lens is not part of a complete visual system; rather a light sensor that determines the precise light conditions in its environment. It is interesting that the only other animal group to possess calcitic lenses was also the first to possess a fully-focusing eye – that of the trilobites. This will be considered further in this article. First, however, it is important to understand the range of animals that possess optical devices,

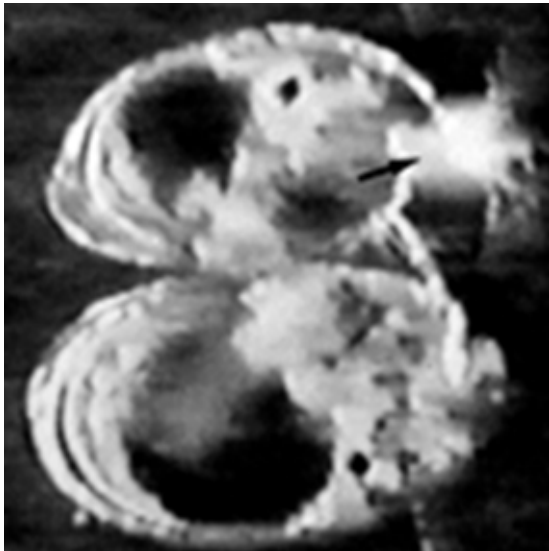
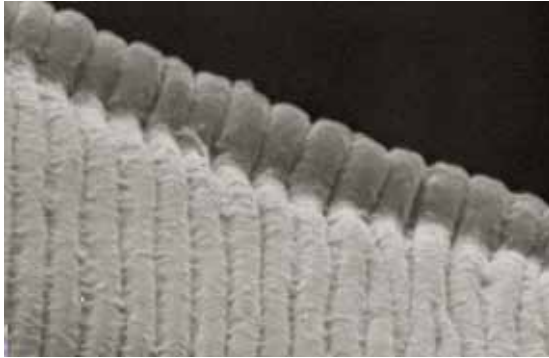


Fig. 1. (A) Scanning electron micrograph of the diffraction grating on a single halophore of the cyprinid ostracod *Azygocypridina lowryi* (above, ridge spacing = 600nm). (B) Frame from a video recording of a mating pair of the cyprinid ostracod *Skogsbergia* sp. The male is above and has released its iridescent hairs (arrowed) from within its shell, and consequently iridescence is displayed to the female (below).

Polyps, each only a few millimetres across, are the living parts of corals, which stretch out their tentacles to feed at night, appearing like small anemones or even upside-down jellyfish. Regardless of their external appearance and life-styles, corals, anemones and jellyfish actually belong to the same phylum – Cnidaria – because they share the same internal body plan. That is they have the same number and type of tissue layers, which are organised in the same way.

The coral skeleton of the reef is decked out with gardens of sponges, another animal phylum that matches the corals in their diversity of shapes and colours. The sponges provide shelter within their water-filled passageways for animals belonging to further phyla. These lodgers include the bristle worms (polychaetes) – a common group of animals that make up the annelid phylum with earthworms and leeches. Some display shimmering opalescent or iridescent colours, like the bizarre-looking sea mouse *Aphrodita*, whose setae and spines are photonic crystal fibres [10].

Sea gooseberries or comb jellies look like transparent variants of their fruit namesakes, flashing with eight iridescent bands (again due to photonic crystal fibres, [11]). These alien-like blobs of jelly have an internal body plan like no other group of animals and so belong to a phylum of their own – the ctenophores. Starfish are not only obvious during the day but some glow at night with their bioluminescence. Starfish are related to common sea urchins and bristle stars, belonging to the same phylum called Echinodermata. Giant clams display fluorescent blues, greens and purples. They belong to the mollusc phylum along with another animal rather more infamous for its colour – the blue-ringed octopus. “Worms” are ubiquitous

and indeed the diversity of animals per se.

The animal phyla

Animals are multicelled organisms that can be divided into about 37 “phyla” (groups at the first level of classification), based on their body plans or internal body organization [8a]. The external form of an animal has no relationship with its body plan, and this is important when considering the evolution of the phyla. This point is well-illustrated in the environment where one can encounter the broadest range of living phyla – the coral reef.

The vast diversity of multi-celled animal life forms today quickly becomes apparent in the shallow waters of Australia’s Great Barrier Reef. The antlers, domes, fans, brains and pipes of corals usually are first to manifest.

and include a plethora of phyla, such as the “ribbons”, “peanuts”, “arrows” and flatworms, some with colours that can shock. Many of these colours, however, rely on chemical pigments (including fluorescent pigments)[12].

Although very few insects are found in the sea, their crustacean relatives from the arthropod phylum are often at their most spectacular on the Great Barrier Reef, and include the crabs, lobsters, shrimps and ostracods. Another phylum that is best known for its terrestrial members is the Chordata. This name may sound familiar because it is the group containing amphibians, reptiles, birds and mammals, including humans. But the fishes of the reef, along with some lesser-known animals such as sea squirts, also belong to this phylum and were once its only members.

The Great Barrier Reef informs us that animal phyla today have both unique internal organisations *and* a diversity of external shapes. But did the internal organisations and first external shapes evolve *simultaneously* for each phylum? And *when* did they evolve? Now the spotlight falls on the Cambrian period in life’s history.

The Cambrian and exceptionally preserved bioatas

As the Earth’s plates moved around throughout geological time, and slowly crashed into each other, some things had to give. The rocks that now form the Canadian Rocky Mountains are one example. Originally, they

were formed underwater hundreds of millions of years ago by sediment in the sea settling out onto the bottom, forming a new sea floor. Following compaction they were forced up from below the water and into the air, turning an ancient environment upside-down. But in addition to preserving the sediments of an ancient time, the Rocky Mountains entomb another part of ancient history – the biological one. Any organisms that died on, or fell to the sea floor would have become covered by the next layer of sediment and potentially preserved as fossils. But sometimes a particularly heavy layering of the sediment itself can be the cause of death for an animal, in the form of a live burial.

The Burgess fauna and flora were organisms that lived around 508 Ma in a well-lit marine reef, at a depth of 70 metres or less. One day in the Cambrian, an abrupt inflow of very fine mud swept across the area, burying the local reef including the Burgess fauna and flora. They were preserved in all sorts of positions. Today the Burgess organisms are found fossilised, albeit flattened, in blocks of Canadian rock formed from the compression of that original, fateful mud. They serve as a snapshot of a community of life that existed in the Cambrian, in this case around 508 Ma.

The Cambrian is a relatively brief period in the history of the Earth, yet outstanding in the history of animal life. Lasting from 542 to 488 Ma, it was a period of monumental biotic change. The Burgess Shale fauna exhibits a

Fig. 2. An example of animals from the Burgess Shale – a scene of life on a reef environment 507-508 Ma.



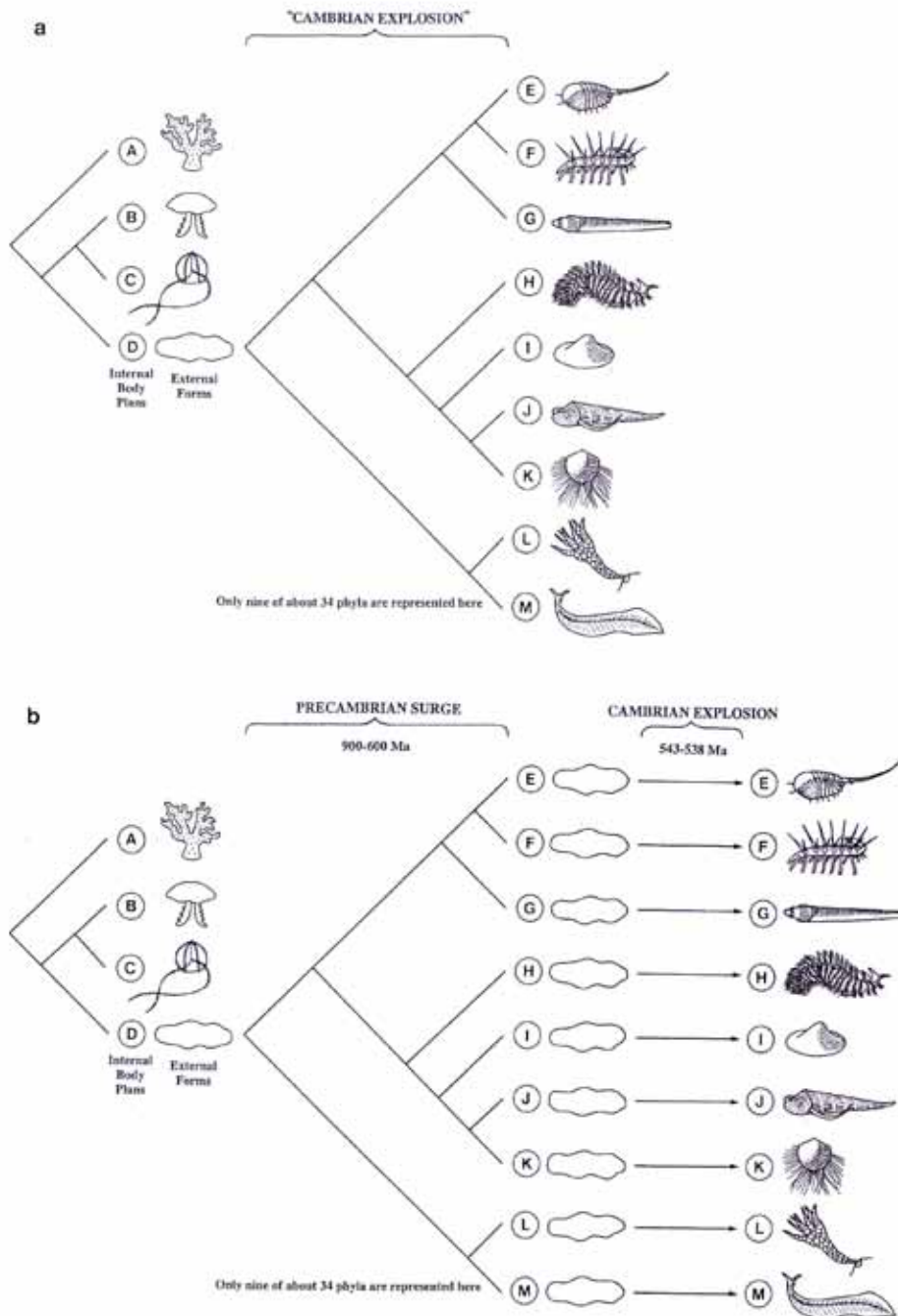


Fig. 3. Two versions of the history of animal phyla. From the first, soft-bodied form, evolutionary branching is equivalent in both models. (A) indicates that both internal body plans and external parts diversified throughout this branching, and most theories on the cause of the Cambrian explosion have been based on this model. (B) is the correct model and properly identifies the Cambrian explosion – that it was the *simultaneous evolution* of external forms in all phyla. These external hard parts became suitable substrates to evolve optical devices.

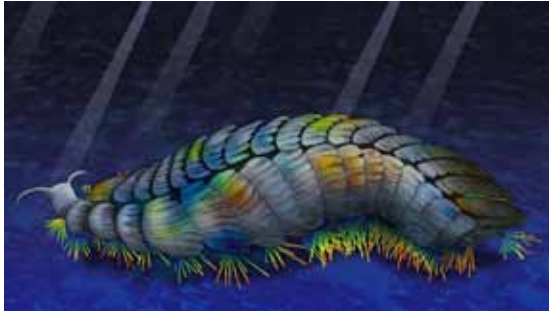
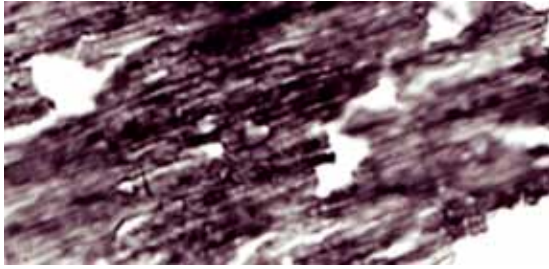


Fig. 4. Burgess Shale stem-group polychaete *Canadia spinosa*. Micrograph (x4,000) showing the surface of a palea (hair) as removed from the rock matrix, revealing the remnants of a diffraction grating with a ridge spacing of 900nm. Colour picture shows a reconstruction of the animals appearance 515 Ma.

range of external shapes comparable with the range found in animals today (e.g. Fig. 2), and generally we believe that the Burgess Shale animals belonged within today's 37 phyla [13]. Because animals with such a range of external shapes do not appear in the fossil record prior to the Cambrian, the idea of a 'Cambrian explosion' was conceived (see below). The Burgess Shale, however, is Middle Cambrian. Further resolution of the Cambrian period is required.

The Chengjiang fossils, from the hills and lakes of Yunnan Province, southwest China, have emerged to scientifically rival those of the Burgess Shale. Since the first specimen with soft parts preserved was uncovered in 1984, they have been found to be preserved equally well, and to reveal even the fine needle-like spines of some animals [14]. They also match the Burgess Shale fauna for diversity, and so provide another excellent snapshot of life in the Cambrian. This time, however, the fossils are dated at around 519 Ma [15, 16].

Further Cambrian fossil assemblages involving both soft and hard parts, all containing phyla already known from Chengjiang and the Burgess Shale, have also been found in other localities, such as Sirius Passat in Greenland, dated at around 519Ma [15, 16]. These, however, cannot match the fossils of Chengjiang and the Burgess Shale for their diversity and snapshots of Cambrian community life.

The Cambrian explosion

The Cambrian explosion, or Big Bang in animal evolution, was the most dramatic event in the history of life on Earth. During this blink of an eye in such history, most phyla found today evolved their first hard parts and distinct shapes at the same time. In other words, it is the event where animals suddenly took on very different appearances, in the form they exist today. The event itself, however, occupied only a small part of the Cambrian period, at around 520 Ma. Prior to this, there were only three animal phyla with the type of external shapes they still possess today. Yet in a geological instant later there were at least several more – and perhaps most – of the phyla known today [17].

So the Cambrian explosion is all about external body parts only. This point is illustrated in Fig. 3. Two evolutionary trees are figured, each representing a version of the history of animal phyla ("phyla"). There is a major difference between these two models, which greatly affects the interpretation of the Cambrian explosion. From the first worm-like form, the branching process is the same in both models. But the upper model indicates that both internal body plans and external parts diversified throughout this branching process. Nearly all theories on the cause of the Cambrian explosion are built on this upper model.

Based on *external* forms and not internal body plans, the tree of animal life, where evolutionary time increases with height of the tree, should take the form of a palm tree. Not a great deal happens as we travel up the trunk until suddenly, at one point the *entire* main branches, representing the phyla, fork

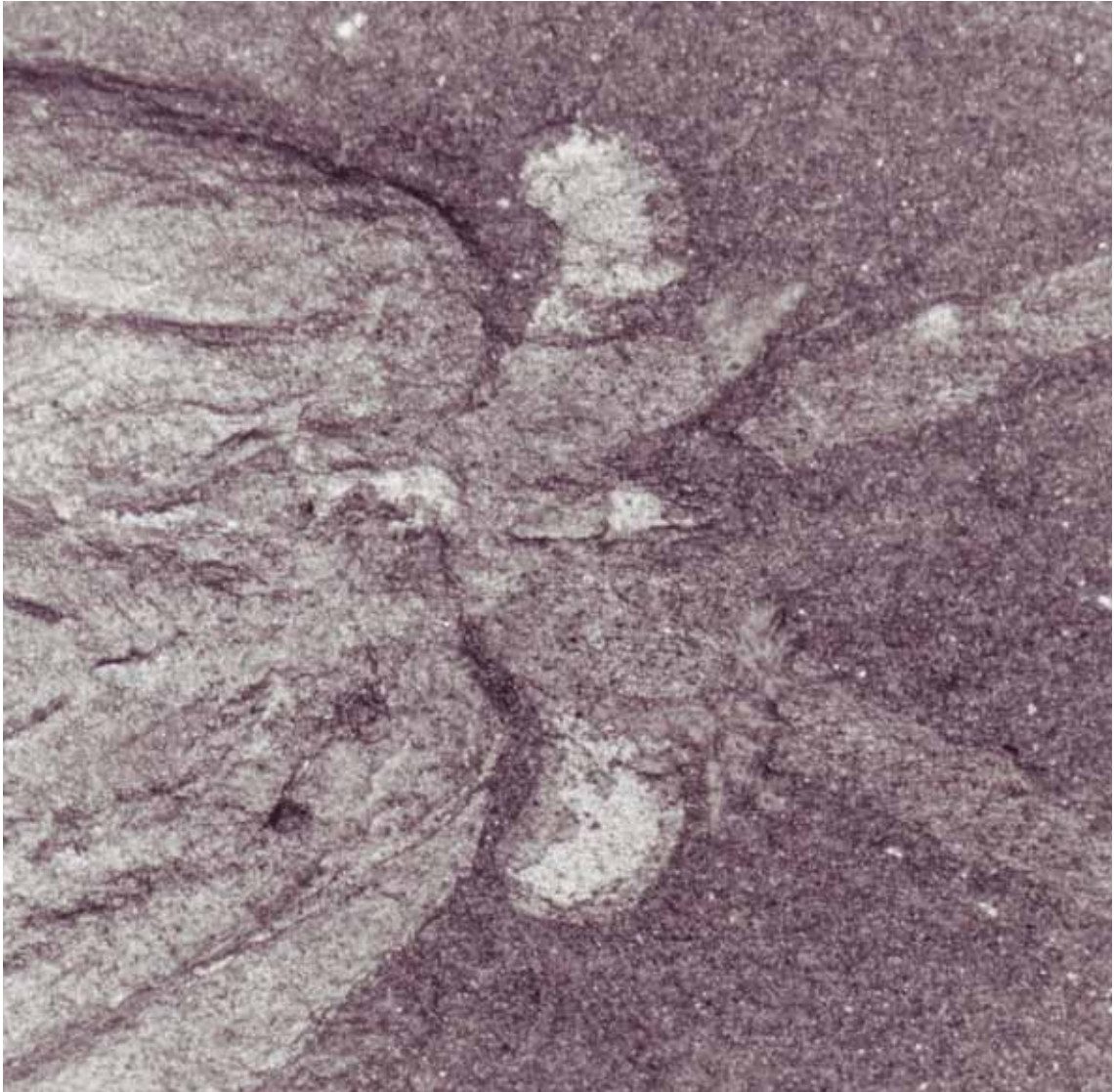


Fig. 5. Eyes in the Middle Cambrian period, around 508 Ma. The head of *Waptia fieldensis*, a shrimp-like arthropod a few centimetres long, showing well developed, stalked compound eyes

off. This point represents the Cambrian explosion. But what caused the evolutionary trunk to branch?

Previous explanations put forward [16, 17], such as an increase in oxygen and a decrease in carbon dioxide levels, or the evolution of Hox genes, have been fraught by a major red herring – the wrong definition of the Cambrian explosion itself. Originally, it was thought that the Cambrian explosion was the event

where all phyla (i.e. internal body plans) evolved – the top model in *Fig. 3*. Now, based on molecular evidence [18], we know that the phyla evolved earlier in traditional branching manner, and only their hard parts evolved in a single event – the lower model in *Fig. 3*. Other explanations, such as the Snowball Earth theory, suffer from timing problems; in this case the last Snowball Earth event had finished at least 32 million years before the Cambrian period.

The earliest optical devices

Optical devices are physical structures, and as such can potentially preserve as fossils, just the same as the bones of reptiles and mammals may fossilize. Optical reflectors, however, contain sub-micron components, and consequently preservation conditions for fossilization must be exceptional [19]. They need to be buried by sediment rapidly, before bacteria break down the animal bodies, and preferably preserved in a fine-grained sediment. A review has been made of optical devices found in the fossil record through time [20]. Usually the original material is replaced with a mineral and the animal is fossilized, but sometimes the original material is preserved. In this paper, however, we are concerned only with the earliest of these fossil reflectors – those of the Cambrian period.

On the broken surfaces of three Burgess Shale species exist remnants of diffraction gratings (*Fig. 4 a*) [21]. This means that these species would have appeared highly coloured when they lived around 508 Ma (*Fig. 4 b*). To make doubly sure, the original surfaces of these fossils were reconstructed, using holographic techniques on photoresist, in their entirety, based on the topography of the remnants that had preserved. The reconstructed surfaces were placed in seawater under sunlight, and the colours of three Burgess Shale species shone spectacularly as they once did some 508 Ma.

But why did these animals reflect colour? At this point, studies of animal colour and the Cambrian explosion begin to cross paths. The obvious answer to this question is that Cambrian animals possessed efficient, coloured reflectors to be visually adapted; that is, eyes existed in the Cambrian. Certainly, a whole diversity of Burgess Shale and Chengjiang and other Cambrian species existed with well-developed eyes (*e.g. Fig. 5*). Animals living at around 520 Ma interacted using light as they do today. But how far back can we take this scenario? The answer is to 521 Ma only.

Some of the best preserved optical devices in the fossil record are the calcitic (calcium carbonate) lenses of trilobites, distant relatives of spiders and shrimps (becoming extinct 280 Ma). Several species of trilobites, such as *Cambropallas sp.* (*Fig. 6*), suddenly appear in the fossil record at about 521 Ma, from Morocco, Siberia and Western North USA. These possessed hard, external parts. Also, they all possess compound eyes, although eyeless trilobites did evolve after these [22].

The calcitic lenses of trilobites, being minerals, have preserved well. There were two types of compound eyes in trilobites – holochroal (*Fig. 7*) and schizochroal [22]. Schizochroal eyes were large, yet contained relatively few facets. Indeed, each facet could be up to 1 millimetre in diameter, a dimension not even approached in today's compound eyes. A boundary region separated each facet from its neighbours, and the lenses were either elongated prisms or came in two parts that locked together, one above the other. This later lens type has an intralensar bowl design (*Fig. 8*) that enables light incident from objects at different distances to be focused at the same focal plane. This design is similar to that suggested for lenses by Huygens and Descartes in the seventeenth century.

The first trilobites, however, possessed holochroal type eyes (*Fig. 7*). Here the lenses were small and simple – thin and biconvex – and numerous. They were close-packed in square or hexagonal arrays. Unfortunately, the lenses alone do not provide a complete understanding of holochroal eyes. An additional focusing element is needed to form an image, but this may have been made of soft material that did not preserve. Similarly, the retinas of trilobite eyes have not preserved, although in schizochroal eyes we can reconstruct these at the position of the calculated focal plane of the many lenses that make up a single compound eye.

Nonetheless, the excellent preservation of holochroal eyes in many trilobites (*e.g. Fig. 7*), and their position on the head region where



Fig. 6. Eyes in the Lower Cambrian period, around 521 Ma. A Cambropallas trilobite fossil from Morocco, frontal view. Eyes are protruding from the head shield (left eye is casting a shadow) – this was one of the first animals on Earth with eyes.

we would expect to find eyes (*e.g.* Fig. 6), suggest that these animals possessed vision. Many had also evolved swimming capabilities and strong, grasping limbs and mouthparts: they were highly mobile, armoured predators – in fact, the first highly mobile predators, with visual search capabilities.

The “light switch theory”

The colour and Cambrian explosion path-crossing originated while contemplating the implications of ancient colours. Natural history museums display an array of colours, exhibited by birds and insects for example. Also demonstrated are the variety and incidence of eyes, and physical adaptations to a diversity of life-styles. The information gained here can be combined with that from the fossil collections. Then the workings of today’s ecosystems can be applied to ancient environments.



Fig. 7. Micrograph of a holochroal trilobite eye.

Eyes, and probably predators, evolved for the very first time around 521 Ma. These facts are recorded in the fossil record, but the important point is the significance given to them. Now the 'Light Switch Theory' can begin to unfold. Simply, the theory holds that the initial introduction of vision to the behavioural system of animals caused the Cambrian explosion. Vision was introduced with the evolution of the very first eye, capable of producing visual images, which took place around 521 Ma. The visual picture of animals that lived just before this time, as seen by the most sophisticated light receptors of the time, was that of a blurred "blue" field. However, the same picture imaged at around 521 Ma, again as it would have been viewed by an inhabitant with the most sophisticated light receptors of the time, would have revealed all the animals surrounding it. Unlike the receptors of other senses, the eye would have suddenly leapt in efficiency throughout its evolution as a lens evolved within the organ [23] (Fig. 9).

The difference between these two perceived images is comparable to our view when we close and open our eyes respectively. With our eyes closed we can determine the direction of sunlight but we cannot find a friend or food in a field, for example. So, using light, animals before about 521 Ma could have known which way was up in the water column, but they could not have found a friend or foe. However, in their favour, a potential predator could not have found them either. Hence there were no strong selection pressures for Early Cambrian or Precambrian animals to become adapted to light, which was to become the most powerful stimulus of all. In fact light became the most powerful stimulus of all almost overnight on the geological time scale, with the evolution of the first eye about 521 Ma.

With our eyes open, suddenly we see the world completely differently. We can see food from some distance, although we can only smell it if it produces a smell, hear it if it produces a sound and touch it if we are very close. So in the Precambrian and earliest Cambrian, not releasing certain chemicals

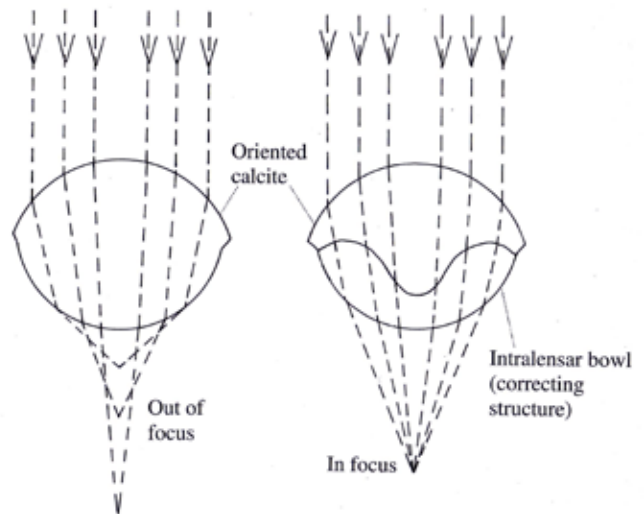


Fig. 8. The intralensar bowl design in the lenses of some trilobites; light rays striking all regions of the lens, from all distances, are focused in the same plane. An identically shaped lens of homogeneous calcite is shown for comparison.

or producing sounds was enough to avoid a potential predator, unless it was bumped in to. But later in the Lower Cambrian, life was lit up. The light switch was turned on, for the first and only time – it has been left on ever since. With our eyes open we see the size, shape and colour of animals, but we also see their behaviour – we can judge how fast they can move and whether we can catch them.

All of these qualities of animals suddenly mattered at about 521 Ma. At that very point all animals had to become adapted to light, or rather vision. Unlike sounds and smells, an animal will always be leaving a potential image in its environment because of the sun's rays, and the race to produce adapted images began at about 521 Ma. The worm-like forms had to display armoured parts or chemical defences, with complimentary warning colours, camouflage shapes and colours, or signs of swimming capabilities to out-maneuvre a pursuing enemy. On the other hand they could opt out of the visual environment and evolve bodies capable of burying into rock crevices or other substrates. All of these adaptations created a new type of evolutionary arms race. But after the initial chaos, further adaptations would become

gradual – evolution would have settled down to its habitual pace.

The picture painted above reflects what probably happened during the course of Cambrian evolution. The chaos *was* the Cambrian explosion. The evolution of a diversity of external shapes from soft-bodied worms explains why the first fossils with hard parts – those capable of leaving fossils – appear in Lower Cambrian rocks. Hence the evolution of the eye, and active predators, can explain why all groups of animals suddenly changed their appearance in the Lower Cambrian.

Vision remains

Since the Cambrian, vision has been paramount to life. Today, over 95 per cent of all multicelled animals possess eyes. Walk into a field full of animals and very few can be seen: life is adapted to sight, not just the simple light receptors that existed before the Cambrian, which could not form an image. Adaptations to vision include the array of

colour, body shapes and behaviours found in nature today. The Light Switch Theory describes how this all began. It could be useful background information for the artist. Artists may also consider the hardwiring of the first eyes, which may have become fixed in place and could hold the explanation for why certain colours combine well or not (possibly those commonly found juxtaposed in nature, such as the sun next to the sky, became selection pressures for eye evolution).

“As I see it ... a predator (a trilobite) evolved for the first time a working visual system, and was so successful that the other organisms had to evolve hard parts to survive, which produced the so-called Cambrian explosion,” wrote the late Francis Crick, the co-discoverer of the structure of DNA, after reading of the theory. “Your arguments seem very plausible to me,” he continued, in a letter from 2003. “I would have thought that detailed genetic (sequence) studies should settle the matter.” But then, he would say that.

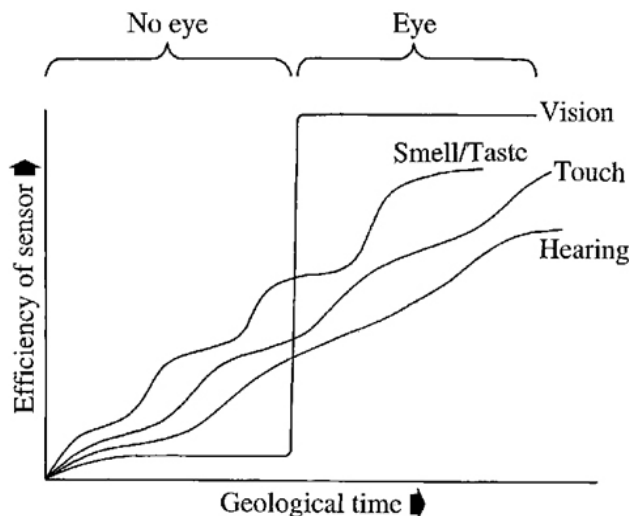


Fig. 9. The very approximate evolution of receptors of different sense systems throughout geological time. Vision is the only sense that was introduced rapidly in the history of life. Based on evidence discussed in [17].

The Intersection of Art and Neuroscience : The Case of Visual Awareness

Barbara Maria Stafford

My book *Echo Objects. The Cognitive Work of Images* [2007] and *The Field Guide to a New Metafield* [2011]-- both published by the University of Chicago Press, propose fundamental or enduring, if you like, issues that equally preoccupy the humanities and the neurosciences, and which require both disciplinary sides to resolve: moral “grammars” of expression; compressive spatial systems; the mimetic impulse; the role of the emotions in perception, imagination, memory; representation versus mental representation; and willed seeing.

Both volumes are an outgrowth of this effort to find precise ways of bringing neurobiology, cognitive science, and the new philosophy of mind together with cultural phenomena without falling into reductivism on either side. In this lecture, I tackle a comparatively understudied and relatively under-researched area in the contemporary neurosciences—an area where the imaging side of the humanities has much to contribute—is the importance of selective attention. What are the inducements for attending carefully to the world?

While researching *Echo Objects*, I became increasingly aware of the intense scientific focus (as well as media focus) on the brain as primarily a self-organizing, largely inward-directed autopoietic system recursively preoccupied with its own functions. To be sure, Gerald Edelman and other neural Darwinists and neural constructivists as well as cognitive scientists, such as Andy Clark, who fall on the side of distributed cognition, emphasize the importance of reentry, plasticity, and the dynamics of connection-making. Nevertheless, it is notable that from the early writings of Francisco Varela and Humberto Maturana to the current publications of Douglas Hofstadter, what

tends to get emphasized are the ways in which the brain’s activity is intrinsically in phase with things going on in the external world largely without our being conscious of it.

As I argue in the concluding chapter of *Echo Objects* (“Impossible Will?”), there are enormous social consequences (especially when coupled to the new reality of “tailored” medicine and the “chemical brain”) of this almost fatalistic “trapped in illusion” position. (Consider, for example, what I term the extreme phenomenology of Thomas Metzinger who is not alone in holding this thesis.) In this essay, I am thus interested, first, in analyzing the ways that different art formats variously engage and make viewers aware of the fact that our brain activity is both unpreventably isomorphic, or in phase with things going on inside of us and in the outside world and simultaneously capable of breaking that unreflective alignment. In short, I explore the intersection of art and neuroscience at one of its key nodes: attention, attentiveness, self-awareness.

Right above: Iridescent Peacock feathers
Right below: Molecular cuisine



Right: Damian Ortega Mano (Barbara Maria Stafford) Used by permission of the artist.



Left: Kai and Sunny by Barbara Maria Stafford. Used by permission of the artist.

True Stories-seeing and believing: the spectra of images and data in the digital aesthetic.

Mary Rosengren

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The Australian Network for Art and Technology (ANAT) *Synapse 6* residency in 2011 with Commonwealth Scientific and Industrial Research Organisation (CSIRO) gave me the opportunity to research CSIRO Biological Collections [1] and to work with Cris Kennedy, Director of CSIRO Discovery Centre to develop the art/science symposium SPECTRA 2012.

The current array of art/science conferences, publications and institutional /academic discussion on interdisciplinarity is the context for SPECTRA 2012. SPECTRA's scrutiny of the art/science relationship and its theme of images and data responds to concerns of both organisations (ANAT and CSIRO) and the spread of imaging technologies in their areas of specialist practices. The focus on images and data also extends my own area of visual art research [2] located in-between art and science, where historical and contemporary applications of optical, print and computational technologies for the production and use of images have implications for contemporary visual art practice(s).

Dialogues about interdisciplinarity [3] raise numerous philosophical and epistemological questions about aesthetics and visual culture, reflecting what WJT Mitchell [4] in *Picture Theory* (1995) refers to as "anxieties about the visual" and "a shift towards the pictorial turn". The interplay between respective practices that encompass methodologies of hypothesising/ imagining, collecting/displaying, describing/ representing, collaborative/ singular initiatives, observation/immersion, as well as correlations between sites (the studio/ laboratory) and spaces of display (gallery/ museum); notions of (visual) accuracy and veracity; experimentation, creation and invention; demonstration and spectacle;

education and entertainment —all indicate the scope of possibilities and thinking about overlays of technologies and interdisciplinarity.

Considering the re-orientation towards a contemporary digitized visual culture the art historian and theorist Barbara Maria Stafford stressed that:

"We need [therefore] to get beyond the artificial dichotomy presently entrenched in our society between higher cognitive function and supposedly merely physical manufacture of "pretty pictures". In the integrated (not just interdisciplinary) research of the future, the traditional fields studying the developments and techniques of representation will have to merge with the ongoing inquiry into visualization. In light of the present electronic upheaval, the historical understanding of images must form part of a continuum looking at the production, function, and meaning of every kind of design."

Barbara Maria Stafford (1997). *Artful Science: Enlightenment Entertainment and the Eclipse of Visual Education*. (xxv).

As the power and pervasive presence of digitized visual culture is apprehended Stafford's call for an "integrated (not just interdisciplinary) research of the future", auguries the rupture and challenge to specialist discipline boundaries is both complex and paradoxical. The significance of print and optics in the history of ideas, knowledge and across three centuries of western science is extensively documented. Although the study of Natural History and botany across the seventeenth and nineteenth centuries [5] was characterised by the endeavours of individual artist-scientists and collaborations, the lens and printing press facilitated the communication of visually

accurate imagery, where in some instances the image (in the herbarium) could even stand for the real thing. These technologies were critical for the development of a universal graphic language for representing botanical subjects by artist and scientists. In *Figure 01a-b*, J.D. Hooker's 1844 *Flora Antarctica*, Walter Hood Fitch includes the microscopic detail of Sphagnum within the table of other whole specimens.

In post-natural history, where mid-nineteenth and twentieth century microscopy and biological science are embedded in the age of mechanical reproduction, representing phenomena that occur beyond the visible spectrum not only complicates the notion of visual accuracy, it changes the role, purpose and value of images it produces. In a digital environment such as remote sensing and spectroscopy, techniques for gathering, processing and presenting data (and producing the ubiquitous "pretty picture" [6]) is simultaneously seamless and authoritative. It is significant to identify this digital aesthetic and understand ways in which raw data is manipulated, image and context conflate, and meaning and value is constructed through the extension of interchangeable inter/disciplinary specialist practices.

While Michael Lynch (213) contemplates that the idea that "the artist's (slight of) hand embodies all the low disreputable features of the subjective idols a Baconian science aims to abolish", he also acknowledges that "the 'low' art of manual representation can also be transformed into the 'high' science of conceptual understanding".

For natural history artist-scientists and much of post natural history, calibrating colour between specimens and images in pigments with paint or ink was (and still remains) problematic. Colour being characteristically fickle, inconsistent and unstable resulted in black and white images being regarded as more reliable and authoritative for showing a visually accurate account of a subject's form and structure.

Well beyond the visible spectrum, the visualizations of data present the paradoxical

nature of the a digital aesthetic that not only challenges the graphic conventions of using colour in scientific imagery it highlights the complete revision of the way images are now regarded and function in science and other contexts.

Colour

"We often assume that mechanical reproduction provides a direct transfer from nature to image, untouched by human hands and uncontaminated by preconceived ideas"

Michael Lynch, *Science in the Age of Mechanical Reproduction*

Although the challenge of accurately representing and reproducing naturalistic colour for seventeenth and nineteenth century artists like Maria Sibylla Merian and Ferdinand Bauer was significant, colour was not the concern for showing the structure of the cell in illustrations by Robert Hooke in *Micrographia* 1665 or even in the 1920's cell diagram of Edmund Beecher Wilson (1856-1939). The latter's cell structures were delineated in black and white, and a range of tone and texture defined the cell's structures and forms with clarity. Colour in the recent twentieth and twenty-first century visualizations of microscopic phenomena is a significant departure from the naturalistic "true colour" [7] of the visible spectrum experienced by the human eye and replicated as accurately as possible by artists in the botanical treatise.

The use of colour in observing and imaging the microscopic dimension has a range of aesthetic and empirical aspects. Colour is introduced to specimens to reveal different characteristics and it is applied to images in order to represent these. Some light microscope images have natural colour and can appear green, others may present as pink-red where colour stain is introduced to the

Figure 01a. Walter Hood Fitch Plate LVII. Lithograph from J.D. Hooker, *The Botany of the Antarctic Voyage (Flora Antarctica)*. London, Reeve Brothers, 1844.

Figure 01b (inset). Walter Hood Fitch, Detail of Plate LVII. Fig. VI., Sphagnum, lithograph, from J.D. Hooker, *The Botany of the Antarctic Voyage (Flora Antarctica)*. London, Reeve Brothers, 1844.



A. subulata 7.



A. mutabilis.



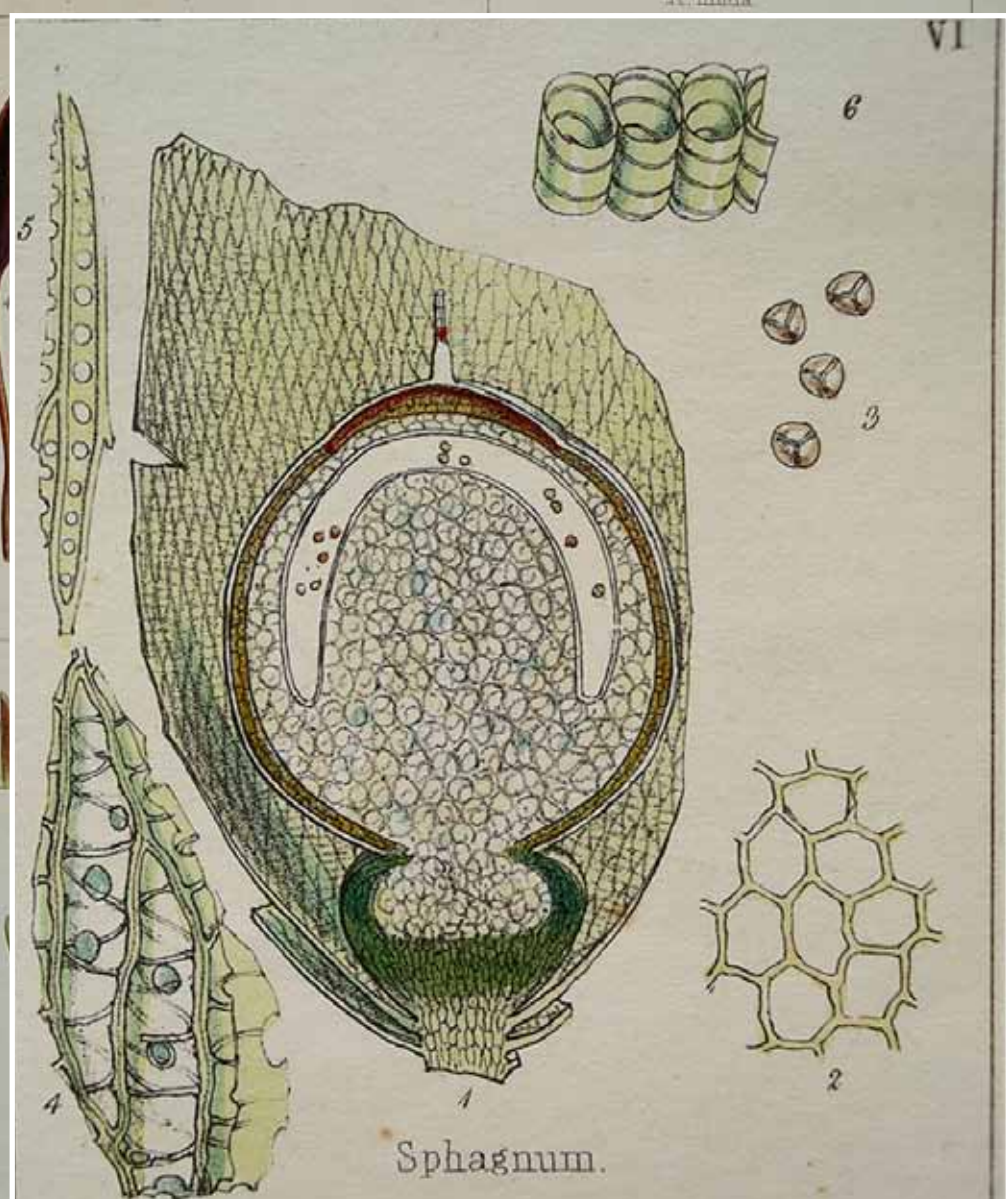
A. nuda.



A. umbellatum.



O. angustifolium.



Sphagnum.

specimen and it reacts with chemicals (such as lignin molecules). Transmission electron micrographs and scanning electron micrographs are characteristically black and white showing the electron density of the specimen, and stains are introduced to the specimen to highlight, emphasise and define particular chemicals and show the structure and form of the cells [8] as in the Scanning Electron Micrograph images that may even resemble highly coloured corals in an underwater vista.

In confocal and fluorescence microscopy shown in *Figure 1a-d* (the microscope) is reading, collecting and interpreting the (colour of) wavelength bands, and visualizations of these are artificially modified and coloured by the microscopists to define structures and functions of substances being represented. Colour is determined and applied by illustrators and animators in developing digital and analogue visualizations, as in David Goodsell's drawings and Drew Berry's recent animations of processes such as DNA unravelling (*Figure 2a-c*) and *Apoptosis 2007*.

The complex purposes of colour indicated here show it can be an empirical and aesthetic tool as well as an inherently subjective perception. As greater insight is achieved so too its "true false" ambiguity reinforces the paradoxical nature of cell images. Ironically, to produce the black and white images of cell structures the specimen may be stained to define and differentiate the density and properties of the specific parts (such as the nucleus cell wall). [9]

"The section was reacted with *acriflavine*, following oxidation in periodic acid, to stain carbohydrates yellow (e.g. in the cell walls and starch grains), and subsequent immersion in another yellowish reagent—iodine in potassium iodide—gave a generally stained preparation, best examined using blue light."

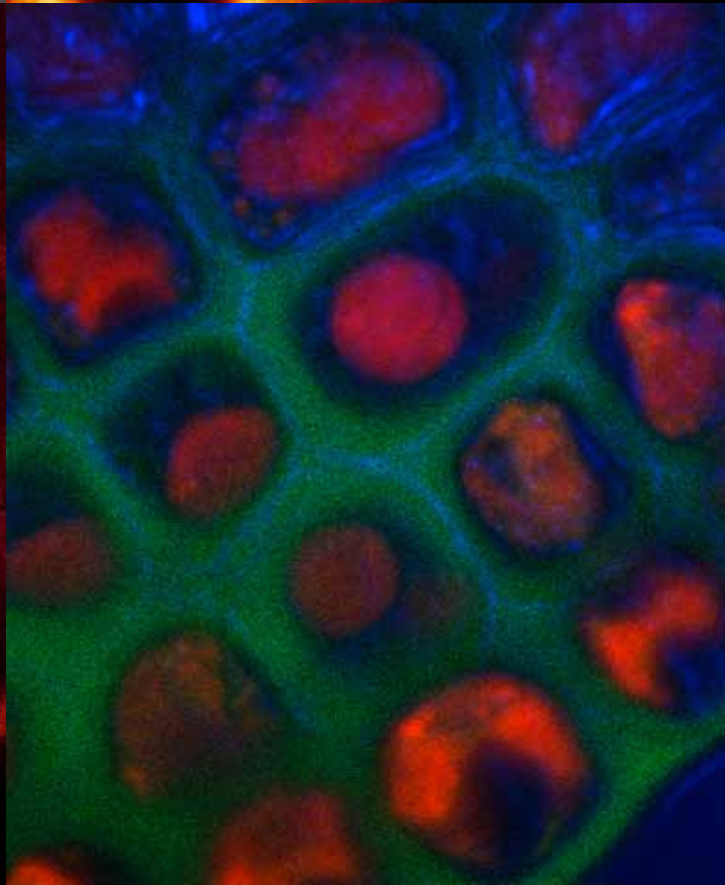
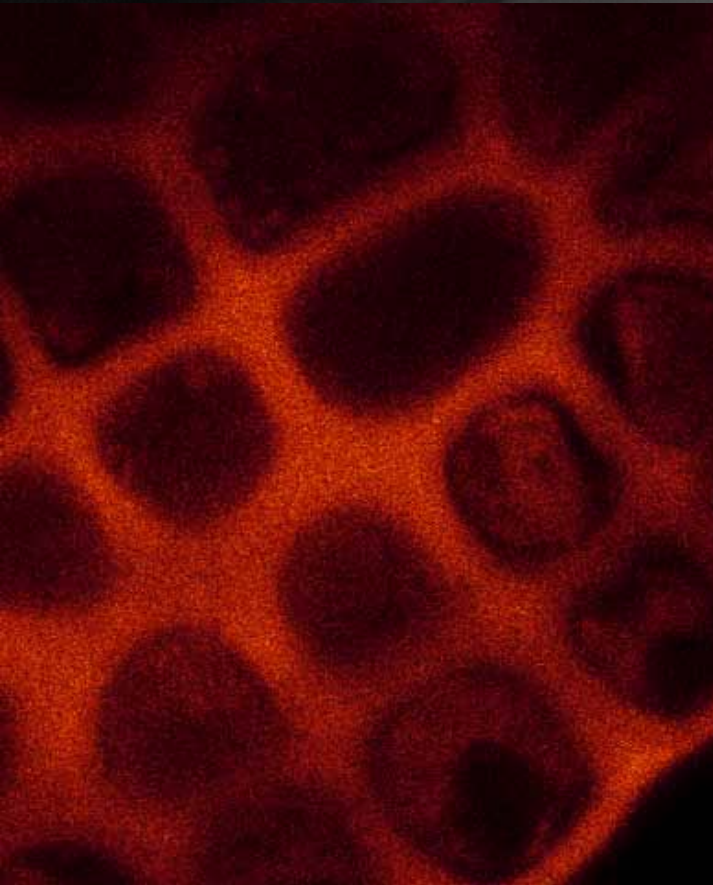
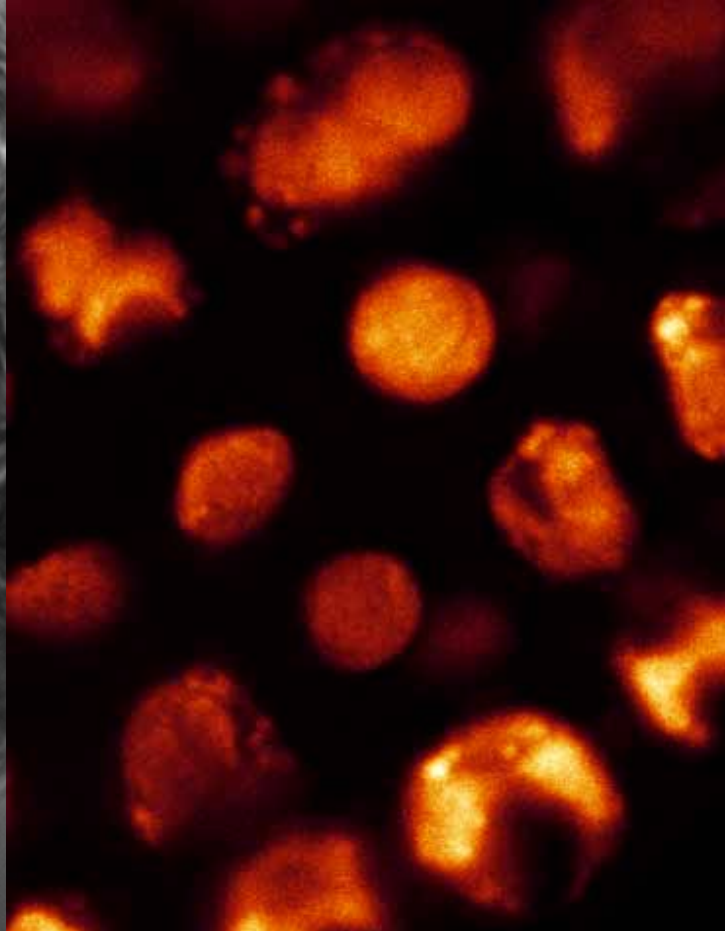
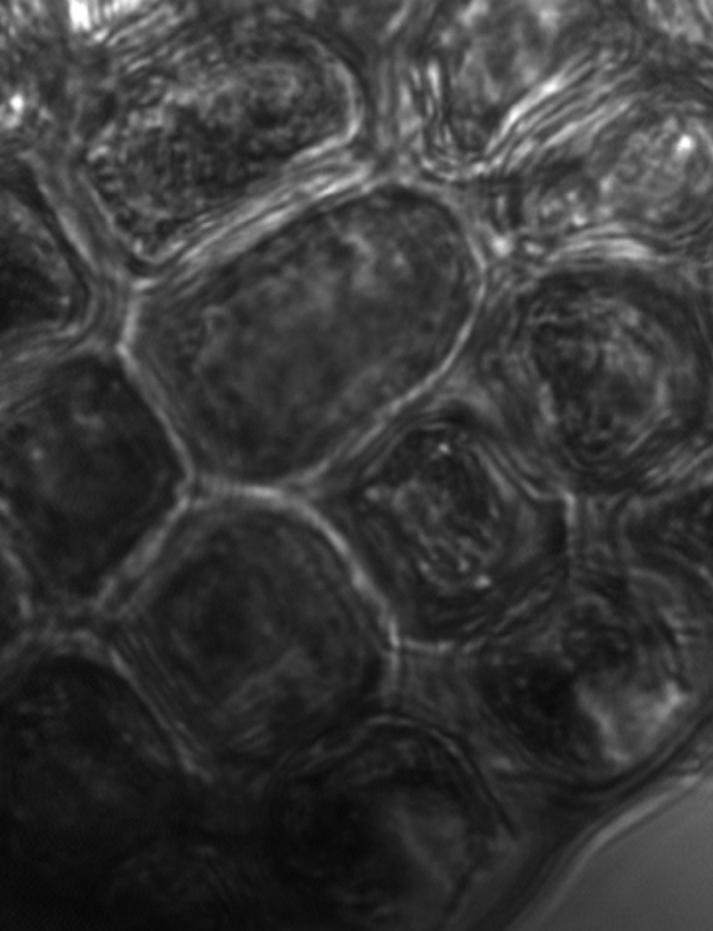
Gunning's precise description of the technique used to stain the section (of cells) to enhance visualization in the 1970s (of a colourless specimen) for using in phase contrast microscopy, indicates how colour

has a central role in creating an image that differentiates tone, defines, and highlights features of the cells selected by the microscopist. The specimen (and the resulting image) has been manipulated similarly to the way in which Wilson in 1925 [10] and Tagawa 1960 [11] emphasised and selected features in their diagrammatic black and white images of cells.

In common with the EM SEM and TEM images discussed so far - colour is integral to the (monitor) image produced with the confocal microscope. Unlike the processes of specimen preparation: staining, fixing, and embedding that (usually) kill cells, the confocal microscope allows for a live specimen to be observed. Readings and measurements of the live specimen show functions and process occurring within the living cell. In this example, pigment [12] in particular areas of the specimen respond to the concentrated beam of the laser. [12] The artist-scientist, technician—microscopist is able to select specific areas within the specimen and see the (cellular) processes, in this example chlorophyll fluorescence of chloroplasts indicates levels of photosynthesis in moss. [14]

In this instance (*Figure 1*) the images made by Andrew Netherwood at University of Wollongong NSW are evidence of plant health and cell damage. Their value is their relationship and context to wider research where these indicators can be examined further, using other types of laboratory techniques or matched with data collected in fieldwork. They are a working document and tool similar to Robert K. Greville's 1824 herbarium specimen sheets with their coloured sketches (*Figure 3*). However these techniques and their images are a radical departure from the graphic conventions that

Figure 1(a-d) Confocal microscope monitor images of image specimen *Ceratodon purpureus*, Confocal microscope Andrew Netherwood Faculty of Biological Science UOW, 2003
Confocal microscopy allows for spatial optical sectioning a viewing through layers (rather than physical sectioning which destroys the specimen), allows for processes and functions such occurring within the living cell to be observed. In this example chlorophyll fluorescence of chloroplasts indicates levels of photosynthesis.



Greville employed. Multiple images representing temporal processes at these levels of resolution and magnification recalls Lynch's statement of the impossibility and irony of some images, *"In many cases there is no way to compare a representation of a biological phenomenon to the 'real' thing, since the thing becomes coherently visible only as a function of the representational work."*

Anne Cleary's recent "research work and visualizations" [15], as well as elucidating Lynch's statement, reiterates the relationship of images within the wider research context. Her technique of confocal laser scanning microscopy "is significant for understanding cell division". The value of the sequence of video frames for (cell) research exemplifies the capacity of images as multiples to represent temporal phenomenon—a technical practice beyond the scope of preceding imaging technology.

Veracity and value of images

"any phenomena which are difficult to conceive in term of any visual image" Crump

The proliferation of empirical information and observational data produced by current scientific research increasingly encodes in the visual what cannot be presented by other means. Similarly, our experience of it is encoded too, presenting as a naturally digitized environment, of simulations, virtual reality, and virtual truth. In interviewing the biologist and animator Drew Berry, Place quotes his (Berry's) description of the parameters that characterize invisible domains "A lot of molecular actions happen at a speed scale that is meaningless to us". The challenge of creating, deciphering and interpreting the images of nature mediated to this level is complex: and when artists and scientists begin to contend with the phenomena of Crump's post-modern science and combine it with digital imaging tools they are reinterpreting nature as well as the nature of representation. Digital techniques offer a visual empiricism to science through microscopy and spectroscopy, but in contemporary visual art practice this

veracity can be exchanged for verisimilitude. The former is undermined by the tools of image manipulation with its relative [16] ease, speed, and access to the computational tools of transforming, combining and seamlessly altering material.

In his systematic study of the way images are understood and used William J. Mitchell reconsiders photographic truth in the context of new technologies. Photographic manipulation has always been possible but as Mitchell states "extensive reworking of a photographic image to produce seamless transformations and combinations is technically difficult, time consuming, and outside the mainstream of photographic practice".

The plethora of images and the ease and speed of their production is enhanced by digital computation. When this is coupled with their veracity as visualizations of data, they are at odds with the readings of nature and the significance of images in earlier contexts. Such as the singular definitive icontype-specimen sheet in the herbarium that stands for the real thing [17]. As the "empiricism" of visualizations of data on the scale of nanotechnology increases and takes form in virtual worlds, the spectral, spatial and dynamic characteristics are reinterpreted. Simultaneously, the credibility of their aesthetic and graphical properties is altered and diminished in terms of the conventions established by earlier artist-scientists. While their images may have been less uniform, reliable, or accurate than data based visualizations they were generally comprehensible and identifiable to a non-specialist.

Artist-scientists such as the animator-cell biologist Drew Berry (b.1970-) and painter-crystallographer David Goodsell construct visualizations and fabricate visual accounts of phenomenon. Goodsell interprets the gap between (data of) molecular forms of X-ray crystallography and cellular organelle forms of electron microscopy (Flannery), to produce works "of imagination grounded in quantitative analysis of specific molecules and cell types".

Conflating the empirical and aesthetic, these artists employ a range of means and media, what Elkins refers to as *“the variety of pictorial means: from photographs to computer graphics to hand-drawn pictures, from geometric abstraction to organic approximations, from scales to perspectival views to projections, [from shaded pictures to wire-frame schemata].”*

Goodsell combines traditional and contemporary methods—“Some are created with computers, using 3-D graphic programs. But many others come about ... with watercolor and brush. The idea is to synthesize a view of something not accessible by any other means. Computer graphics, illustration and artistic interpretation provide a window into this tiny world.”; Berry cites “computers, Hollywood and 3D glasses” as his tools.

When Fenly notes that, “No microscope on earth can see what Goodsell creates” it is a reminder of Elkin’s suggestion that these types of images reconnect “with the ways that pictures (of western art history?) are used to try and see what can never be seen”. Berry’s comments (about his animations) align with this too when he makes the following statement: “The molecular world is so small, it can’t be seen. I’m painting pictures of what the world is like down there.”

Explaining the central role of visualization in his scientific work Goodsell describes that it is critical for him to “see” the shape, structure and components of the virus. “It’s completely visual. It’s modelling the 3-D structure of the drug to the 3-D structure of the virus, then grappling with the essential components”. Of his animations for *body code 2003* at the Australian Centre for the Moving Image Berry states that “the biggest bio-molecules are resolved as static blurry shapes, with scientists relying on other techniques to determine how they interact... Drawing upon this fragmentary evidence from all fields of biomedical research, my quest is to holistically construct the most accurate and insightful visualizations of cellular and molecular worlds that have ever been produced, with clarity and detail never before seen.” [18]

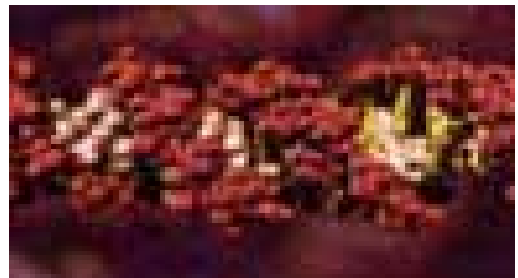
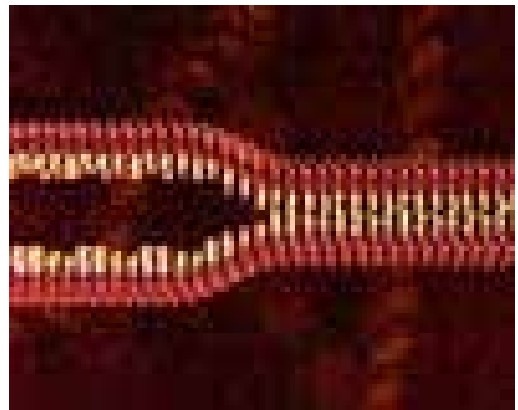
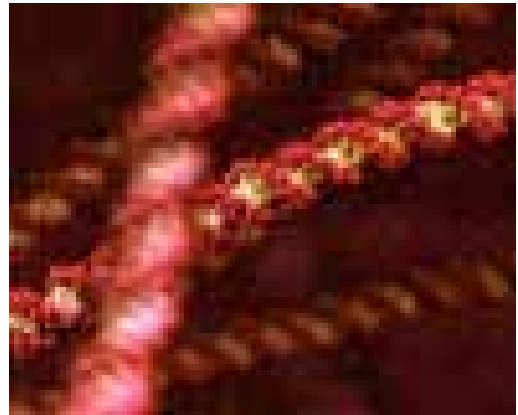


Figure 2(a-c). Drew Berry Digital Animation Stills DNA sequence unravelling. Drew Berry CD WEHI, CD-ROM 2006. Digital animation Stills from Quick Time Movies Chromosome_Coil.mov; DNA_CU.mov; DNA_mov; from Drew Berry WEHI 2006

The clarity and detail Berry seeks are what natural history artist scientists such as Merian and Bauer of the seventeenth and nineteenth centuries wanted: and notwithstanding the centuries between them and Berry, some aesthetic notions persist.

The static diagrammatic quality of the early-mid twentieth century drawings by Wilson, Tagawa and Gunning have a mechanistic authority that is accentuated by the simplification, clarity and ordering of the forms. While the value of these aesthetic considerations enables the images to function for a specific purpose, the cells were presented as uniform static entities and were likened to small machines (Flannery 196). In comparison to these is Goodsell's three-dimensional black and white drawing of *Escherichia coli* bacterium [19] magnified to one million times. Rather than the subject being positioned within a white decontextualized space the drawing resembles the micrograph where shapes and forms meet the frame. The interplay of a variety of organic forms and shapes create an interconnected structure, offering a dynamic interpretation of the cell, so that the image implies the processes of a living organism. Flannery describes the space within the cell walls as "A cellular environment: molecules and organelles are packed together", and Fenly quotes Goodsell himself who says, "I'm always struck by the incredible complexity of cells and yet the inter-connectedness of it all. There's such detailed structure on the gross scale and such randomness on the small scale".

As if picking arbitrarily from the array of visualizing tools and techniques, both Goodsell and Berry have been opportunistic in their choices of graphical means for representation and interpretation of spectral characteristics. Goodsell's colour clarifies, defines, and simplifies the complex colourless molecular world. Flannery explains "proteins in shades of blues, nucleic acids in shades of purple etc. The addition of colour makes the image more informative and even more visually attractive". For Drew Berry the choice is unequivocal, "There are no colours so I



Figure 3a. Herbarium specimen sheet. With coloured sketch 1824 Robert K. Greville (1794-1866) Greville Herbarium Specimen sheet, *With coloured sketch 1824.* moss specimen, drawing of magnified detail partly finished pencil and watercolour sketch. Herbarium RBG Edinburgh Photograph M.Rosengren, 2003.

make them up. Blue is for dead things, green is for sick. Pink always works for healthy stuff...I massage the whole thing to make it understandable to an audience." [20]

Spatial and spectral characteristics highlight the disparity between these artists and those who sought to reproduce a visually accurate account of nature such as Maria Sybilla Merian, Ferdinand Bauer, or Walter Hood Fitch. Art historian James Elkins proposes that, "as in the history of art, images of unrepresentable objects put a strain on the pictorial conventions they inherit, finally breaking them and becoming different kinds of pictures." The graphic language of these (New World) artists at the time of burgeoning science was a distinct departure from graphical conventions and media techniques of artists who had preceded them, such as Matthaius Merian in the sixteenth century.

Anton Von Leeuwenhoek had expressed incredulity [21] when he glimpsed the microscopic world in the seventeenth century. His amazement and wonder may have been similarly articulated by Drew Berry's response to what he sees and knows of phenomenon occurring at very high resolutions. "... a very alien world down there – a random, vibrating, messy place that's just so interesting to portray and engaging..."

Stafford's deliberation regarding the new optical instrument of the seventeenth century resonates here.

"The microscope's mysterious and beguiling images ...explode attractive forms into repugnant or non resembling patterns. The equivocal nature of information gleaned from optical apparatus, rendering the insignificant significant and the worthwhile worthless, also reveals how easily the observer's perception might become confused. What appeared clear and distinct to the naked eye was exposed as chaotic or flawed under the lens."

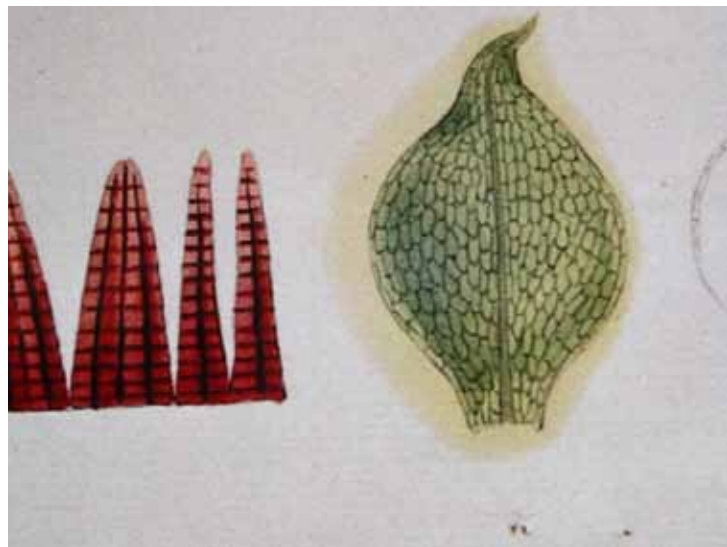
When Stafford refers to the incomprehension and confusion with which the micro-scopic dimensions were received by observers in the seventeenth century, it is easy to position contemporary observers at this same juncture.

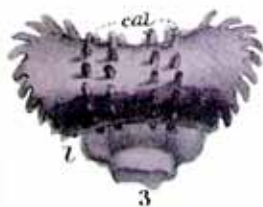
Images in natural history and post-natural history (botany and biological science) are characterized by the the empirical and aesthetic. The facts of structure, process and function and the presence of artifacts [22] that are synthesised in contemporary visualizations obscure the boundary between truth and invention, and contribute to maintaining the paradox of microscopy. Embedded in all these images made through the microscope is the measure of veracity (of the data) that places the invisible into the visible domain. The increasing scope of technology subverts inherited convention and dictates the re-imaging of nature.

With developments of photo-microscopy, spectroscopy, electron microscopy and other techniques of the mid-nineteenth and twentieth century, it became possible to measure, know and visualize processes and functions of molecules and atoms further within cells to a much greater extent than the artists/scientists of natural history could actually witness. The graphic language and the vocabulary of images is radically revised in the twenty-first century's inter/disciplinary visualizations of the data produced, using these and other techniques. [23] Spatial resolutions, spectral characteristics, and the veracity of images acquired, transmitted and archived by these instruments have become radical departures in visualizing the natural world, while building on the achievements of the early naturalists who used simple magnification devices to observe.

Overleaf: Vera narrent— True stories. Wallpaper print 3x 1.5 m (repeat).. M.Rosengren 2013

Figure 3b. Herbarium specimen sheet. Detail of *With coloured sketch 1824*. Robert K. Greville (1794-1866). Greville Herbarium Specimen sheet, *With coloured sketch 1824*. moss specimen, drawing of magnified detail partly finished pencil and water-colour sketch. Herbarium RBG Edinburgh Photograph M.Rosengren, 2003.



[illegible]

Open forest/woodland occurs on the north of Albury City. These ridges posed, some 450 million years ago, of mudstones and sandstones, but during the period of subsequent folding, the dikes and sills were intruded.

These metasediments support open White Box Yellow Box Red Stringybark (Eucalyptus) Red Box (E. popuillanensis) (E. goniorhiza). The understorey is condition and contains a high density of shrubs. It includes large populus and understorey plants that are now south-west slopes, including over Millonids (Burchardia umbellata) (Tinjana robusta) and Blue Pincushion. The ridges are the only New South Wales of the endemic Spider Orchid (Maladenia) only area in which the Ragwort daisy, So Pink-tailed Worm Lizard (Apr) and Growling Grass Frog (L) now occur.

Most of the hills and ridges about 100 years ago and paucity of large hollows. The rocky outcrops and understorey that occur on the the key fertile habitat with



<i>Madia bulbosa</i>	<i>Thymus</i>	<i>Trachymedusa</i>	<i>Eucalyptus</i>
<i>clathor</i>	<i>Bracteantha</i>	<i>triscus</i>	<i>conchilides</i>
<i>Chrysocaulum</i>	<i>apiculatum</i>	<i>Chrysocaulum</i>	<i>macranthum</i>
<i>compapposum</i>	<i>Leucodermis</i>	<i>Blitum</i>	<i>Microseris</i>
<i>lanceolata</i>	<i>Burmannia</i>	<i>austalis</i>	<i>lobatidentata</i>
<i>stricta</i>	<i>Burchardia</i>	<i>umbellata</i>	<i>Chrysanthemum</i>
<i>Callitriche</i>	<i>gouanifolia</i>	<i>Lepidocarpus</i>	<i>luteus</i>
<i>Schoenus</i>	<i>apocyn</i>	<i>Hibbertia</i>	<i>rigida</i>
<i>obtusifolia</i>	<i>Drosera</i>	<i>pellata</i>	<i>Stomatochloa</i>
<i>dumosoides</i>	<i>Leucopogon</i>	<i>Melilotus</i>	<i>cruciatellus</i>
<i>Dieris</i>	<i>latifolia</i>	<i>Ptilotium</i>	<i>serotum</i>
<i>Candollea</i>	<i>Hardenbergia</i>	<i>violacea</i>	<i>Harporhiza</i>
<i>linearis</i>	<i>Indigofera</i>	<i>australis</i>	<i>legumina</i>
<i>adelungifolia</i>	<i>Pultenaea</i>	<i>hololepis</i>	<i>graminifera</i>
<i>solanider</i>	<i>Gonocarpus</i>	<i>tetragynus</i>	<i>procumbens</i>
<i>erectus</i>	<i>milliflora</i>	<i>Dichapetalum</i>	<i>strictum</i>
<i>lilipense</i>	<i>Lemnandra</i>	<i>multiflora</i>	<i>Acacia</i>
<i>dealtalis</i>	<i>Acacia</i>	<i>implexa</i>	<i>Acacia</i>
<i>parviflora</i>	<i>Acacia</i>	<i>parviflora</i>	<i>Acacia</i>
<i>rubra</i>			

Concolor

ridges to the west and
were originally com-
sedimentary rocks of
as a result of heating
volcanic activity and
ged into slates, schists
(metamorphic rocks).
forests dominated by
Blush/s Red Gum,
ptus macrocarpa),
and Long-leaved Box
generally in excellent
ersity of herbs, grasses
ations of many wood-
o rarely, rare on the
r 46 species of orchids,
Frige Lily
Microseis
(*Microseis* *austalis*).
show habitat in
ngered Crimson
(*Concolor*) and the
reated Woolly
(*garlandii*),
(*parapulchella*)
(*rariiformis*)
r with in Albury.
edges were cleared
and thus there is a
oak bearing trees.
na good condition
ridges make them
thin Albury LGA.



HOLOTYPE

Brachymeria concolor D.L. Jones

Det. D.L. Jones 26 February 2007

Location: Natural Herbarium (CANB)

Brachymeria aff. *concolor* (Fitzg.)
D.L. Jones et M.A. Clun

Title: Orchid 13(9): 393 (Oct. 2001)

Flora of AUSTRALIA
AUSTRALIAN NATIONAL HERBARIUM (CANB)

ORCHIDACEAE

Caladenia aff. *concolor* Fitzg.

Det. D.L. Jones 17 Sep 1999

AUSTRALIA: Victoria: Western Highlands region,
Catharine Haines Ave, Chantrel, The Block Track.

37° 05' 42" S 144° 14' 20" E

South facing slope. Brown skeletal bark. Sordid, fine, blackish

grass. *Acacia* *acutifolia*

Orchidaceae, terrestrial, solitary.

D.L. Jones 17009

17 Sep 1999

S.M. Green

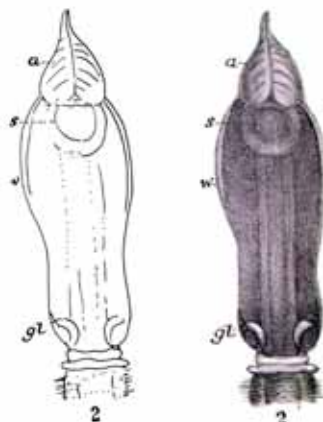
Plant, Field Card

Barcode number: 1

In this study, mycorrhizal diversity was examined in the terrestrial, photosynthetic orchid genus *Chiloglottis* to test the hypothesis of mycorrhizal-mediated diversification in the genus *Chiloglottis*. This orchid genus secures pollination by sexual deception, an obligate and highly specific pollination strategy. Here we asked whether the obligate orchid-fungal interactions are also specific.

Methods: Two sequenced loci, the internal transcribed spacer region (ITS) and mitochondrial large subunit (mtLSU), were used to identify fungal isolates and assess fungal species diversity.

Symbiotic germination of two species *Chiloglottis* aff. *jeaneshii* and *C. valida* were used to assess germination potential of isolates and confirm mycorrhizal association.



Caladenia concolor (Fitzgerald)

Caladenia concolor Jones only obtained from the granite hills near Albury, and it is very remarkable for the darkness (and uniformity) of colour of the flowers and stem. The edges of the labellum are much more narrowly divided than in *concolor*, and the column much narrower and straighter in form. It flowers in October.

DESCRIPTION

A rather robust species, hardly over 100 cm high. The flower and stem of a rather dark purple colour. At base generally unbranched, sepals and petals about five inches, dilated at the base and tapering to a fine point. Labellum without lobes, about seven lines long and four broad, imbricate, revolute, the edges for about half an inch from the point actually serrate. Call of the labellum longer, bent forward in four rows, or more the last six rows. Column slightly narrowed, winged from below the centre to the base, narrower and of more uniform breadth than in *concolor*. Two large glands at the base of the column.

EXPLANATION OF PLATE

Caladenia concolor. Fig 1 Column from the back; 2, Column from the front; 3, Labellum from the back; 4, Labellum from the side; 5, Labellum from the front; 6, Call of the labellum; 7, Column from the side.

CG



Colliding Light

Chris Henschke

School of Media & Communication, RMIT University, Melbourne

In 2007, I began a residency at the Australian Synchrotron through the Arts Victoria and the Australian Network for Art and Technology. The Australian Synchrotron is a source of energy ranging from infrared to hard x-rays. In the synchrotron, electrons are accelerated to more than 99% of the speed of light around a two hundred metre ring (see *fig. 1*). Beamlines are positioned around the ring to use the energy for various experiments. Based upon my observations of how the scientists worked with the light, and tea-room discussions, I developed my own experiments using the synchrotron light in unorthodox ways, partially to collect visual data to make artworks with, and partially to test my understanding about how and why the synchrotron does what it does, and partially to see the scientists' responses to my images. I conducted such experiments using the infra-red, optical diagnostics and protein crystallography beamlines, and the accelerator itself.

On the infrared beamline I experimentally gathered visual data of the beam using digital and film SLR cameras with infra-red lenses and film (see *fig. 2*). By 'interfering' with the beam via the insertion of a glass object in its path, I "visiblized" the infra-red light. This was composited with the lights in particle beam's accelerator and storage ring, and spectral lines of the light frequencies, which I recorded as sound with a photodiode. The process I used was a kind of audiovisual analogy of the "Fourier Transform", a mathematical processes scientists use to turn spatial visual data into frequency data. A similar experiment was made with the optical diagnostics beamline. Optical and ultra-violet light was diffracted through a glass light bulb and captured as a digital image sequence (see *fig. 3*). As the beam was so bright, direct capture may have caused some of the

charge-coupled devices on the camera to burn out, so the experiment had to be carefully set up to capture only the diffracted light.

I created a protein crystallography animation from an experiment I made with an insulin crystal sample placed in the X-ray beam (see *fig. 4*). Micron-scale protein samples placed on a rotating goniometer are hit by the X-ray beam, and the emitted energy is captured in the detector and reverse engineered in what's called reciprocal space using Bragg's equations, which lets the protein crystal be digitally reconstructed. All insulin proteins are the same - they all have an identical structure, except this particular insulin protein was different, it had a slight kink in it's carbon ring structure - the scientist adjusted this saying 'this is a subjective decision' - the uniqueness of my sample didn't fit within his generalised theoretical model. I was inspired to subjectively process my data thanks to a suddenly eloquent outburst from another usually reserved scientist, who told me that seeing the sample on its scale would be like gazing up at an infinite sky of endlessly repeated electron constellations. My version, in an empirical yet scientifically meaningless way, sought to capture that beautiful poetic insight, using the raw image data to visually recreate what I felt it would be like to be in such a molecular space.

My final experiment was with the accelerator itself. I was intrigued by the delicate balance of complex magnetic and electrical fields and forces needed to make the synchrotron beam actually work, which is called the "synchrotron tune", a frequency of about 13.3 MHz. The idea for this experiment was developed over the course of the residency, in collaboration with accelerator physicists Martin Spencer and

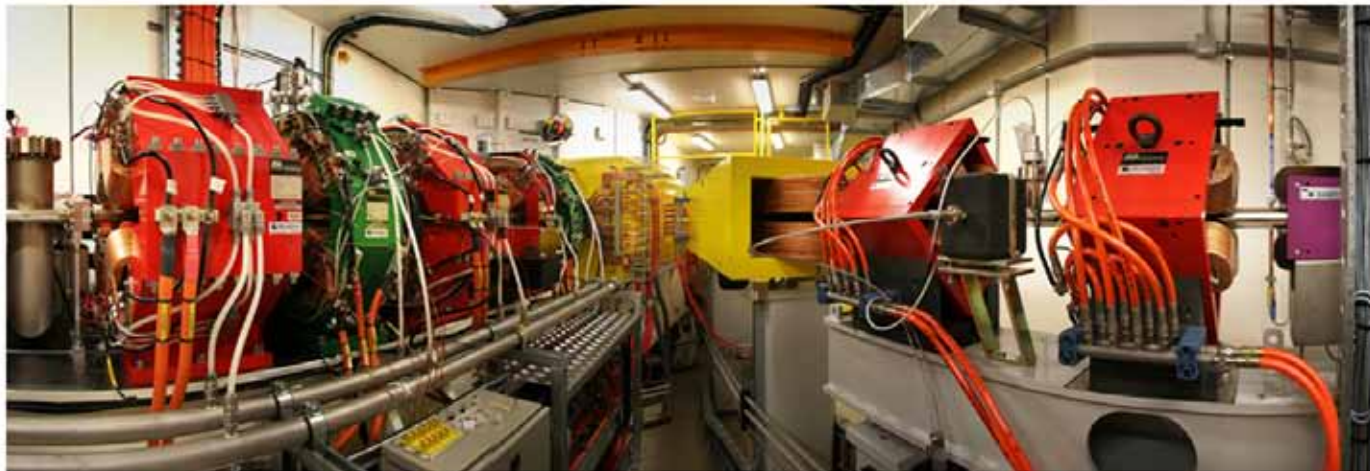


Figure 1: Photograph of particle beam apparatus at the Australian Synchrotron

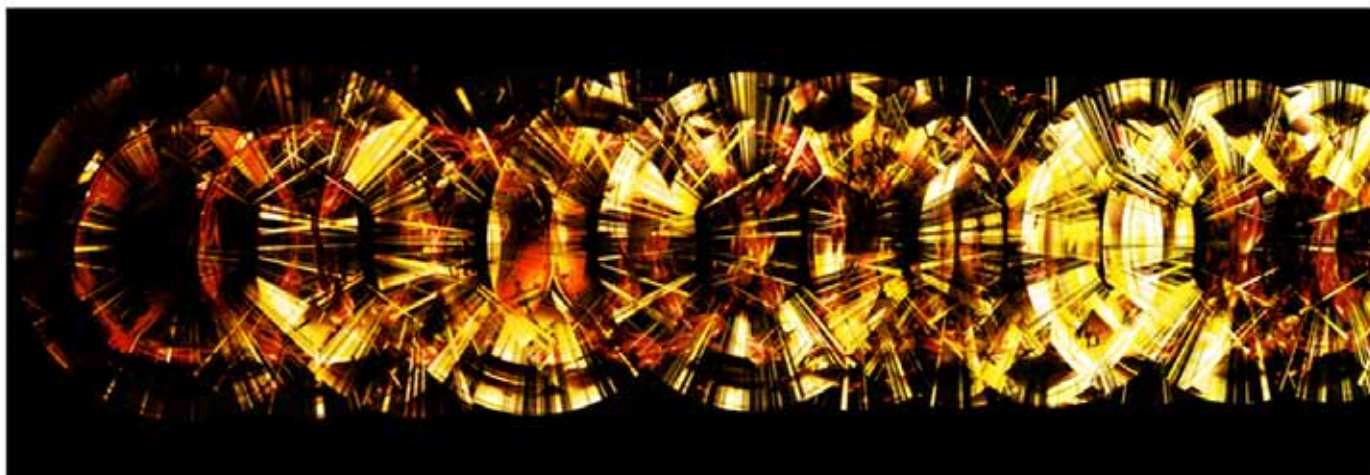


Figure 2: Infra-red energy visualisation

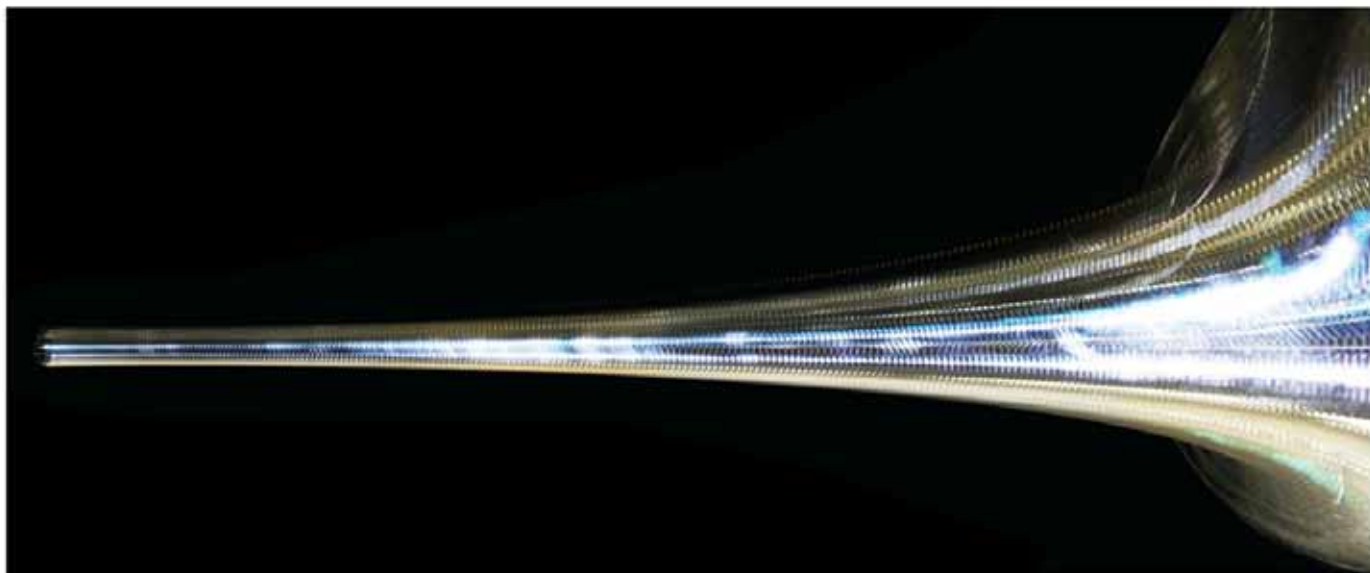


Figure 3: Optical diagnostics attraction experiment

Mark Boland. Wondering what this might sound like led me (online) to Dr. Andreas Wilde, at the Fraunhofer-Institut fuer Integrierte Schaltungen Aussenstelle Entwurf-sautomatisierung, in Dresden. With his expertise in acoustic mathematics, we were able to 'pitch shift' the synchrotron tune down to a frequency range that is audible to the human ear (which was basically just a sinusoidal tone). Reverse-engineering this process allowed me to put a sound into the synchrotron.

The day before the experiment was to be undertaken, I was out the front of the synchrotron complex, under the hot summer sun, and the shrill cry of a cicada stopped me in my tracks. The cicada's deafening high-pitched tune was not only geoacoustically relevant, it also gave me a perfect "synaesthetic" picture of the energy beam whirling around the synchrotron ring. Thus I recorded it, emailed it to Germany to be encoded, and gave it to the accelerator physicists. On the day of the experiment, the sound file was pitch shifted up from a base frequency of 5 kHz to 1 MHz to make the vibration fast enough to modulate the amplitude of the beam, in a way similar to how AM radio works. Martin Spencer put the data into the control system and tried to oscillate the beam around this frequency.

But something went wrong and the beam literally crashed and stopped: I dumped the beam! But then the physicists re-launched particles into the accelerator, pitch-adjusted the data and put the maximum energy into the beam. The data was 're-injected', and this time it worked. The cicada frequency this time was in harmony with the 'natural' frequency of the synchrotron beam, and thus the beam vibrated with the sound of the cicada tune. It was an exciting and poetic moment. Even though nothing was directly perceivable, just to know that the heart of the huge and incredibly complex facility around me was pulsating with the sound of the cicada that lived next to it somehow connected the synchrotron back to the world around it. The experiment revealed a relationship between sound and light and energy and matter, the cicada singing in the sunlight and the light in the synchrotron singing with the cicada's tune.

At the end of the residency, I developed Synchrotron Eye, an animated montage that combined all the audio and visual recordings made over the course of the residency program (*see fig. 5*). This work used the media to express the nature of the beams, through an intuitive and chance-based methodology, by combining all the audio and visual material in a kind of spinning spectral

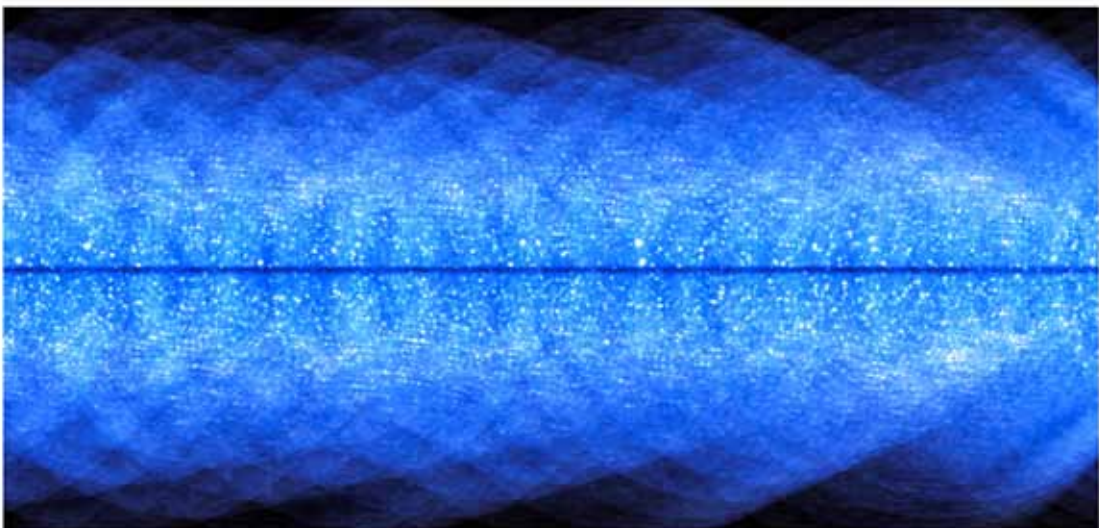


Figure 4: Protein crystallography data visualisation (still from animation)

mashup. When viewed from above it appeared like an eye, capturing and revealing the essence of the device: the synchrotron is an eye, an enhanced human eye, it is us looking back at ourselves using an extremely complex lens, that through fundamental aspects of nature, lets us ask what we are made of.

In conclusion, my experiences and experiments at the synchrotron have shed light on both my personal methodology, and provided me with insights into the nature of scientific research. Analogous to the way physicists experiment with and study the fundamentals of matter and energy in a lab or particle accelerator, my works experiment with and study the nature of perceived light, and its effects on the viewer. Physics can be very abstract, and so abstractive artworks can relate to it. In both disciplines research is done using reductive factors and fundamental properties, and theories about such properties are tested with experiments - this creates a tenuous yet poetic connection between my experiments and those undertaken in synchrotrons! In a way perhaps similar to the abstract yet universal properties in physics, such as the way light behaves, art also works with similar universal elements of light and space and time in terms of our perception of it.

There is also the cross-disciplinary correlation in the use of collage and montage, and the role of chance. The physicist David Bohm championed the importance of mental "play" in connecting seemingly disparate phenomena or ideas in scientific research, he described the state of mind in developing new ideas in science as being a 'poetic equating of very different things [in which there is] a kind of tension or vibration in the mind, a high state of energy' [1], which is equally applicable to many artworks. Physicist-cum-anarchist philosopher Paul Feyerabend takes such notions of creative play even further - Feyerabend was an advocate of opening up scientific practice to non-scientific methods, summed up by his radical empirical principle of 'anything goes' [2]. This seems to be an ideal epistemology for framing my own research methods. The influential physicist and philosopher of science Karl Popper questioned the epistemology of science, stating that scientific discoveries are born from processes of stimulation and release of inspiration, which itself is not a scientific or logical process. Popper said that every discovery contains 'an irrational element or a creative intuition' [3]. This is also what some of the scientists at the synchrotron have described, in their quests to solve complex and unique research problems. Again, this is applicable to art in general and my work in particular.

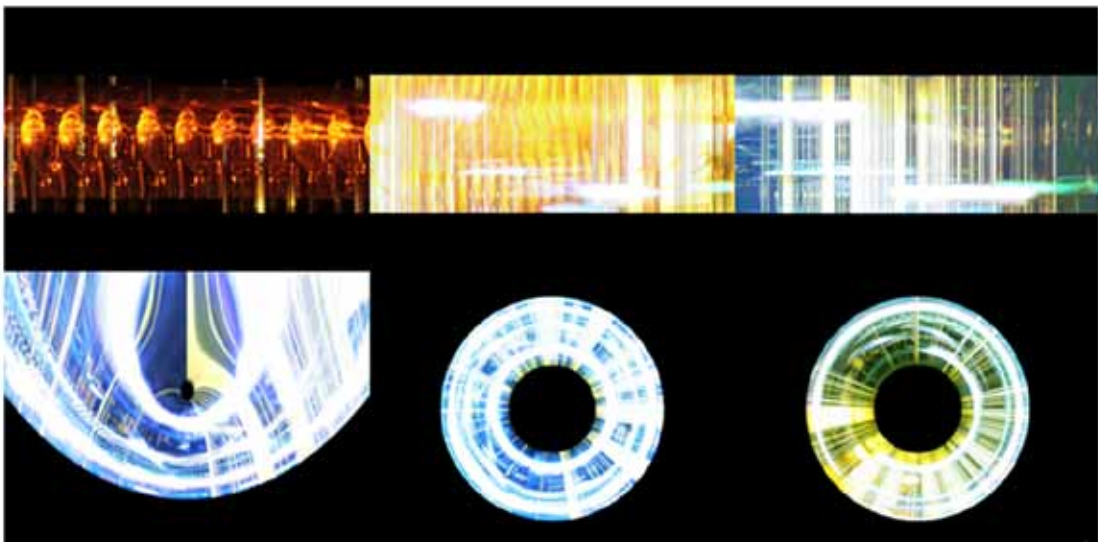
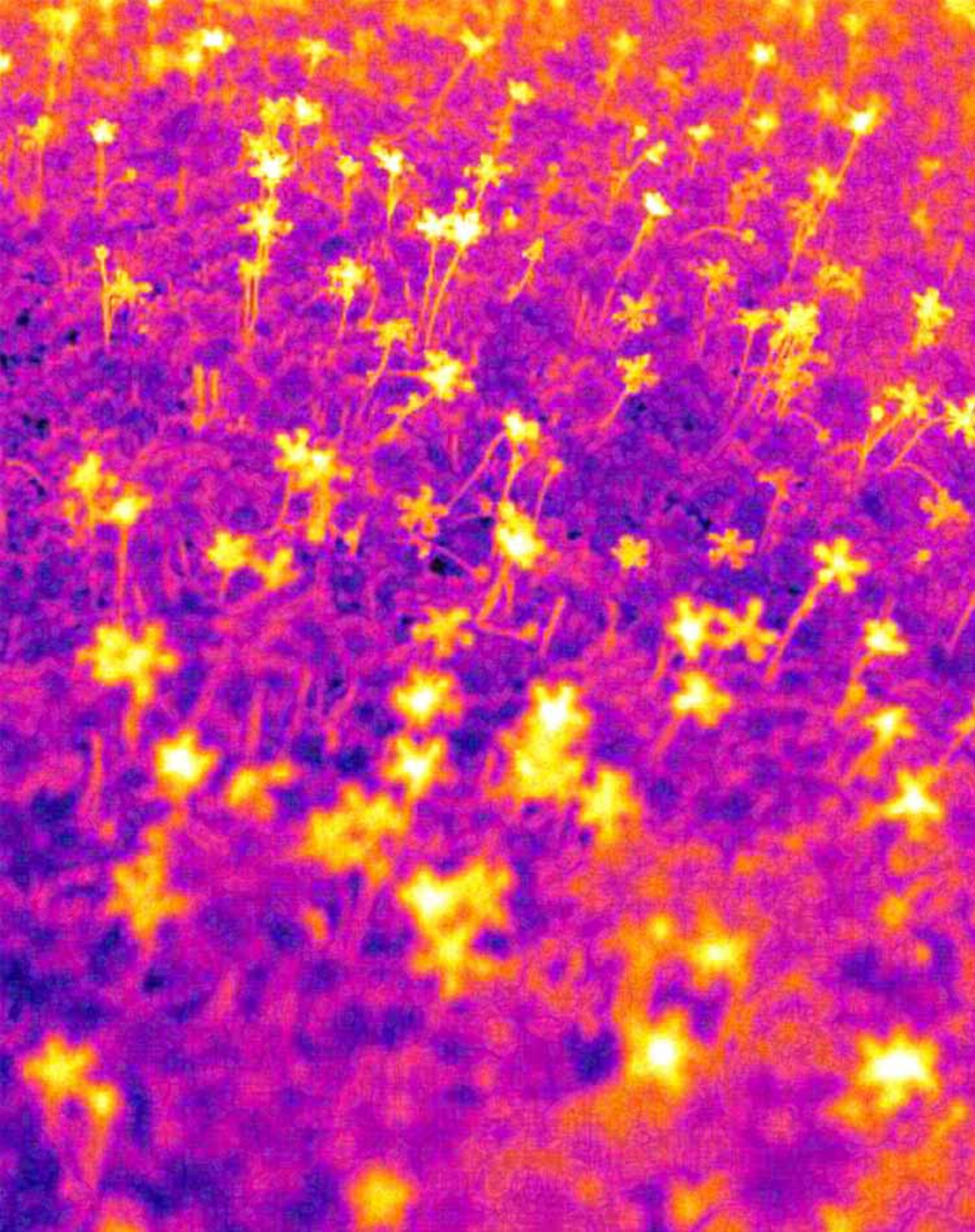


Figure 5: Still sequence from 'Synchrotron Eye' animation

A distinction between, but also an analogical connection across the scientists and artists worldviews, is that science is highly technical and specialized and deals with objective universal properties. Art is personal but can be universally applicable to all people. And yet both paradigms share formal and abstract properties, and even irrational and indefinable aspects. Experimenting with these properties in cross-disciplinary contexts reveal deep connections exists between the creative and scientific disciplines, which can propel both into new areas of research and discovery, as both are complementary aspects of how we understand our universe and ourselves.

Opposite: Unnamed artwork by Erica Seccombe. Used by permission of the artist.



GROW: an investigation of 4D Micro-CT

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Abstract

Erica Seccombe is a visual artist and currently a PhD candidate at the ANU School of Art. Her research is being facilitated and supervised by Professor Tim Senden, Head of the Department of Applied Mathematics, ANU. Erica's interdisciplinary project *Grow, visualising nature at nanoscale*, is an investigation of the aesthetic possibilities of computational extension of vision with dynamic 3D Microcomputed X-ray Tomography, or 4D Micro-CT, a process which has an additional dimension of time (3D + time = 4D). With this science she has captured in 4D Micro-CT the transformation of plant seeds as they germinate, from embryo to first leaf stage. She is visualising this data in a scientific volume exploration and presentation tool *Drishti*, a custom designed software developed by Dr Ajay Limaye at VizLab in the ANU Supercomputer Facility, NCI. Erica is visualising these virtual time-lapse datasets of germinating seeds and projecting the resulting animations in immersive stereoscopic installations.

GROW: an investigation of 4D Micro-CT

For the SPECTRA 2012 conference, Professor Tim Senden and I gave a shared presentation to highlight the cross-disciplinary nature of my project to visualise volumetric data of germinating agricultural seeds with 4D Microcomputed X-ray Tomography. For this paper I will be writing solely about my project from the perspective of a visual artist and look at some of the ideas that I am investigating through my studio research. As an artist I am interested in the ways the augmented lenses of contemporary scientific imaging can also engage us with the natural world through both a process of rational observation and subjective

experience. I am also curious about a possible disjuncture between the physical experiences of living in a natural world and our becoming more dependent on technology and science to mediate our experience and knowledge of nature to us. Therefore I am exploring phenomenological methodologies in my practice as a way of reflecting on possible experiences of nature in a techno-scientific society.

My practice-led research project *Grow: visualising nature at nanoscale* investigates the aesthetic possibilities of computational extension of vision with 4D X-ray Microcomputed Tomography (4D Micro-CT). 3D Micro-CT is a non-invasive process that uses X-rays to capture cross-sections of a static object that can then computationally simulated as a high-resolution virtual model. 4D Micro CT is the same process that includes an additional dimension of time, capturing dynamic phenomena of and around an object while it is subject to change. With this science I have attempted to capture the transformation of edible plant seeds as they germinate, from embryo to first leaf stage. I am visualising this data in a custom-designed scientific volume exploration and presentation tool known as *Drishti* (meaning insight in *Sanskrit*), producing virtual time-lapse datasets that are exhibited as immersive stereoscopic projection installations.

I proposed the idea of germinating seeds with Micro-CT to Tim Senden after the success of my first completed project *Nanoplastica* in 2008 (See fig. 1.) *Nanoplastica* was result of my initial three-month artist-in-residence in the Department in 2006 where I had the opportunity to 3D Micro-CT and visualise a collection of miniature plastic toys. It was through this process that I had become a

skilled and independent user of *Drishti*, which was at that time in a formative stage of development. I had become interested in the Department's research into 4D Micro-CT and how this data could be visualized in *Drishti*. Growing seeds for Micro-CT was not included in the Department's major research areas but I felt this proposal was more aligned to the ongoing preoccupations of my own practice to address ideas of authenticity, replication and simulation.

As I am exploring frontier research into 4D Micro-CT visualisation the results of my project are shaped by the possibilities and limitations of the science and technology I am utilising. However, the rationale for propagating seeds with 4D Micro-CT is not just to test the capabilities of this modern science and technology. I also want to consider questions surrounding a cultural relationship with the natural environment through a contemporary visual art practice. I am investigating the potential for my own work to meaningfully engage an audience with the concept of nature, even though the materiality of the 'real-life' phenomenon of a germinating seed has been relocated to exist in a digital platform.

However, it is important to clarify the idea of 'virtual data' in my work. The datasets I am visualising of germinating seeds are not derived from fragmentary evidence or rendered through mesh framing techniques used in conventional computer generated imagery, CGI. These volumetric datasets are instead the algorithmic recreation of the actual real-life seed, each volumetric (3D) pixel representing its real-life counterpart at five microns [see fig. 2.]. With this science I am capturing the most precise virtual model possible of the seeds in the process of germination, simulating the texture and material density of both the internal and exterior structure as the seed begins to sprout. It would be impossible to recreate the ambiguous textures and translucent effects of these germinating seeds using mesh frames.

My premise for germinating seeds is to capture a moment that life comes into being

and it is motivated by my concern for the future of our planet's natural resources and biodiversity. Rather than using native or endangered species I chose seeds that have short germination periods and are familiar edible varieties that are grown in crops, in domestic gardens or on windowsills. Historically seeds are a symbol of life, of fertility, abundance, good luck and were also a very early form of currency. Harvesting seeds continues to be essential to the survival of nomadic and settled communities, and our modern civilization is founded on the ability to cultivate crops. We are now living in an era that is experiencing the rise of mega-farms with maximum crop and stock production quotas relying on innovative agricultural production technologies and genetic engineering.

Our carbon footprint is extensive. Without even calculating other potential threats such as global warming, this significant surge in human industry, consumption and waste is already having a major impact on the world's natural resources and it is modifying the landscape at a considerable rate. It is estimated that at least one quarter of the world's species of plants today is already threatened with imminent extinction, this being primarily due to human activity. The growing evidence suggests that the sixth major mass extinction of life on Earth is underway and unlike the previous five, this one is predominantly due to the impact of human population and it is happening faster than any other mass extinction in our planet's history.

To understand more about seed conservation and scientific imaging of seeds, in context of my research project, I stayed at the Millennium Seed Bank in the UK as a resident on a research field trip for two weeks in 2012. Established by Kew Royal Botanic Gardens, the Millennium Seed Bank facility is based at Wakehurst Place on 565 acres of natural reserve in a relatively remote corner of West Sussex. In a secure vault embedded deep beneath the building there is more diversity of plant species in this one location than anywhere else in the world [see fig. 3.]. Dr Wolfgang Stuppy is an internationally

renowned and leading seed morphologist at the Millennium Seed Bank and I was privileged to spend some time with him during my residency. Stuppy is a specialist in the field of botanical evolution and conservation, which includes the understanding of the dispersal, anatomy and structure of seeds and fruits. His full colour publications, such as *Seeds – Time Capsules of Life* (Firefly Books, 2009), are based on his research and aimed at bringing to the attention of the general public the unique and unseen beauty of seeds and pollen as seen under the powerful electron microscope. Stuppy's electron microscopic images of seeds and pollen are exquisite. Blown up in a scale that is well beyond the proportion of the original microscopic object, these delicately coloured forms are revealed to have intricate mathematical surfaces and hyperbolic structures. Unless we are involved in the sciences, very few of us will ever have first hand experience of imaging material in this way.

However, these images are visual constructions. The electron microscope captures only fraction of the surface of the seed or pollen at any one time. To create the whole, Stuppy stitches the images together in a graphics program, cleaning, fixing and contrasting the object to give the layperson a better visual understanding of the complete object. The raw images are in greyscale so the final colouring effect is a later addition by the artist Rob Kessler. While the image exaggerates the truth of the original data, the super-realism of these final images adds to the dramatic visual experience. By bringing seeds to our attention in this highly aestheticised form, Stuppy's intention is to draw the viewer in and ignite their imagination, engaging them in an awareness of plant life and the importance of conservation.

Stuppy's images remind me of Susan Sontag's idea in her book, *On photography*, that, 'photographs really are experience captured, and the camera is the ideal arm of consciousness in its acquisitive mood.'^[1] This notion of the 'arm of consciousness,' can also

be applied to the electronic microscopic lens that Dr Wolfgang Stuppy gazes down. Even if these images are a reconstruction of the truth, they work to reflect the experience of the image-maker in the process of consciously acquiring scientific knowledge. It also highlights our continuing fascination with the invisible and our confidence in the visual data produced by scientific imaging technologies.

In the laboratory I am not looking down a conventional lens with 4D Micro-CT [see fig. 4.]. The initial CT scans can only be monitored through two-dimensional black and white radiographs. It is only when I can finally visualize these volumetric datasets in *Drishti* that I can start to see the potential for the virtual objects to create a transformative experience for an observer. *Drishti* enables me to visualize the volumetric data of the germinating seeds by controlling the colour and level of opacity of the object's material density through transfer functions. Movement and animation can be executed in real time, but for finished animations, the trajectories and effects are manually set along a key frame editor. 4D Micro-CT data also provides an additional capacity so that the subject can be observed from a multitude of angles, depths of field and positions in time. It is unlike the powerful lens of an electron microscope that focuses so close to the subject that it provides a single fixed view-point abstracted from the rest of the object. In my project the seed is the object in focus but the catalytic forces of germination, the changing interfaces between the shooting seed and its immediate environment, and the inclusion of time are the constituent parts of the whole subject.

Acquiring this data through 4D Micro-CT experiments is not a straightforward procedure as capturing the full process of seed germination over an extended period of time has presented many unforeseen challenges. Eventually I hope to use a wider range of seeds but for the moment mung-beans and alfalfa are the fastest and the hardest to use for this purpose. The majority of my seeds have failed just before the first

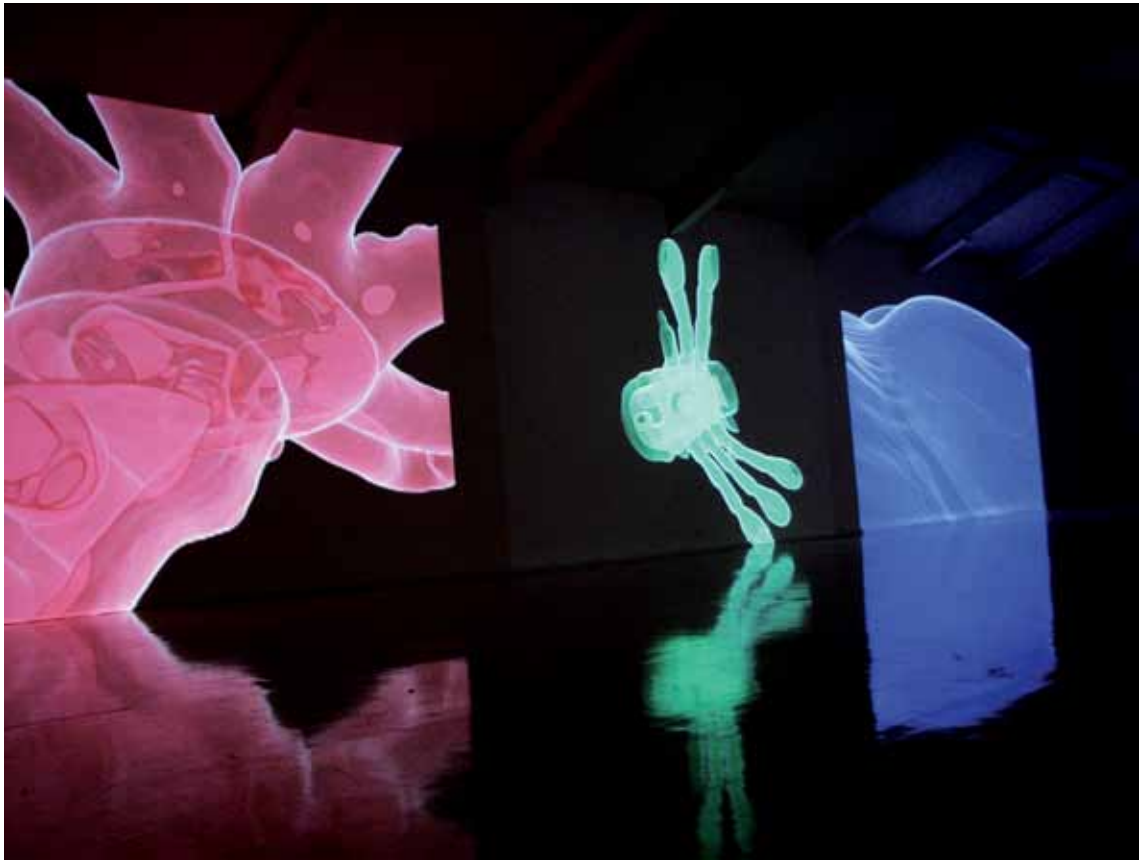


Figure 1 (above): Erica Seccombe, *Nanoplastica*, 2008, (detail) three-channel digital projection installation, first exhibited at Canberra Contemporary Art Space, 2008.

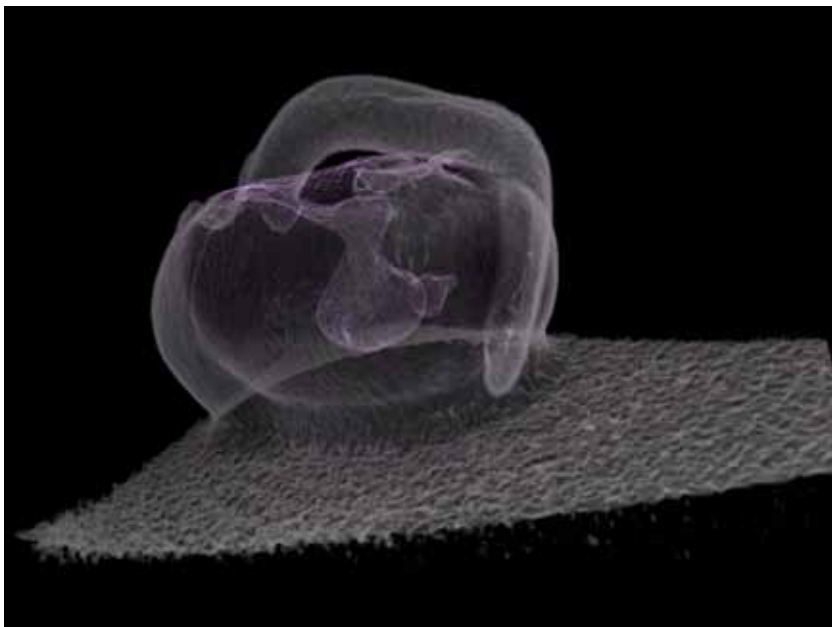


Figure 2: Erica Seccombe, *4D Micro-CT Mungbean sprouting* (work in progress), 2011.

leaf develops, due mainly due to the environment of the Micro-CT lab being uncongenial to plant life. However, though the process of trailing these experiments, I realise that the failure of the seeds to grow to leaf stage should also be considered an equally vital component of this project. These disappointments, the death or failing of the seeds are equally relevant and add to that operatic narrative of life and death. Our emotions are deeply embedded in the hope for new life, a new dawn, a future. If our natural environments become inhospitable then there is a little chance for life to flourish.

In 2013 I completed an animation of virtual seeds germinating entitled *Grow*. The data is from a tightly sown pack of mungbeans and alfalfa seeds. Comprising of 40 volumetric datasets that were acquired over a four-day capture, each set is interpolated so that one discrete moment merges smoothly into the next. The resulting time-lapse animation is just six minutes in duration and it reveals not only the external growth patterns, such as root length and case swelling but the delicate internal structures of the first leaf, the cotyledon as it begins to grow. The mungbeans grew promisingly for the majority of this capture, but their development stalls, whereas the alfalfa shoot quickly from seed to leaf.

I tinted this seed ball with a light-blue hue so as to not to try to imitate the green of plants, but to situate the work with a colour also found in nature, such as in blue sky or water. I then rendered density of the starchy shoots to be as translucent as glass through which incremental stages of growth can be seen to transition slowly as the data rotates clockwise on a vertical axis. I have then divided the black frame up with three panels that provide multiple viewpoints of the one time-sequence in the single projection. The right frame provides a more traditional view of observation from a distance, whereas the other two are more abstracted because the eye is placed in the centre of the data looking out [see fig. 5.].

Grow is interesting to watch when viewed

on the screen of a computer but it definitely works better as a work of art when it is projected to proportionally enlarge the germinating seeds. Playing with comparative scale in the installation process helps to enhance the experience of the work by shifting the position of the observer, placing the viewer within the work. To maximise this sensory experience of looking at virtual data I am also experimenting with various formats for immersive stereoscopic projection installations. This year I have had the opportunity exhibit *Grow* in an exhibition, '*Synapse: a selection*,' at the Powerhouse Museum in Sydney. For this exhibition I trialled a new stereoscopic modulator that projects a 3D image onto a circular preserving polarized silver screen. With this technology the audience is required to wear polarized paper glasses to experience the projection in high definition cinematic 3D. In a dark space the stereoscopic illusion appears to float in front of the screen, far more so than in a public cinema.

The feedback I received about this installation relayed to me that the format of both the animation and the technology worked well to create a meditative and self-reflective space. Some individual accounts described the sensory experience as both mesmerizing and moving and connected the work with the idea of life as being both exquisite and fragile. There were differing opinions about the multiple viewpoints and people had their own interpretations of what they were watching. Many visitors remained for the full duration of the animation to watch the virtual seeds germinating, or stayed for much longer periods of time. Some people preferred to sit transfixed while others played with the optical illusion by moving their body from side to side or sweeping their hands to try and catch the illusory image. I like watching people interact with the work, and it is an interesting image in itself to watch groups of people with black glasses on collectively looking at the same spectacle.

The severance or distance from the subject through the use of virtual data would seem to negate any 'real' or meaningful experience



Figure 3 (above): Erica Seccombe Vault Door, Millennium Seed Bank, Royal Botanic Gardens, Kew, Wakehurst Place, Sussex, UK 2012, digital image, 44.4 x 65.5 cm, inkjet print on Canson rag, edition of five 2012.

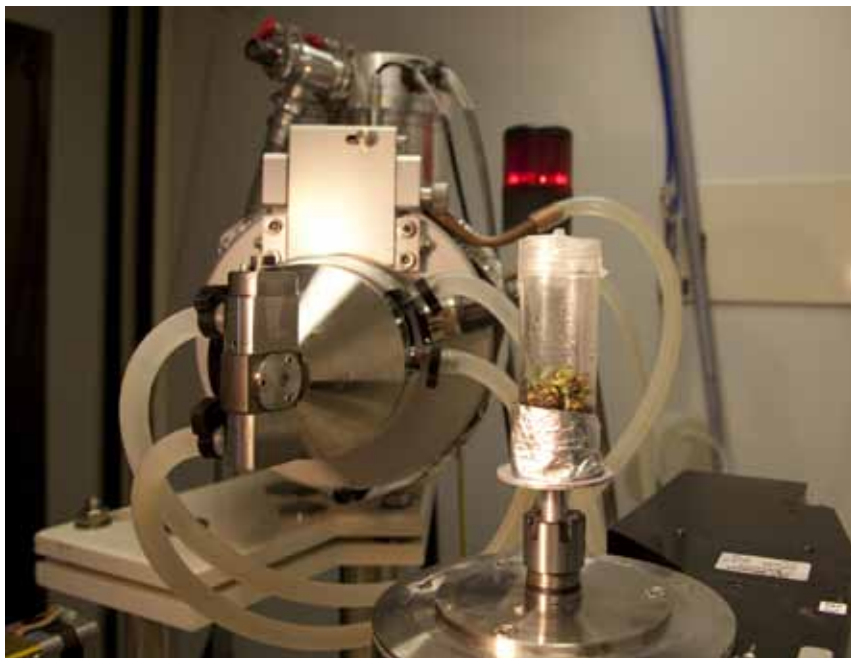


Figure 4: View of bean germinating while being scanned with Micro-CT, Department of Applied Mathematics XCT Facility, ANU, 2012.
Image: Erica Seccombe

of nature that I am proposing in my work. However Sue Thomas writes, 'there is increasing evidence that we respond very similarly to a 'natural' environment, whether it's real or virtual.' [2] Encounters with 'real' nature have long proven already to be psychologically beneficial, and Thomas explores this concept in her recent book *Technobiophilia: nature and cyberspace* (2013). She looks at how the experience of nature in a 'virtual' situation can be just as profound, and how our technologies are named and evolve in reference to nature. But our definition of virtual just depends on what we understand as being 'virtual reality' and this can be confusing.

Marianne Krogh Jensen explains in her essay, '*Mapping virtual materiality*', that this confusion lies in the notion of virtual reality as being a highly abstracted concept, 'in part because it implies total intangibility, and in part because it is most often associated with computers and cyberspace.' [3] For Krogh Jensen, the potential for relocating the real through an imaginative process is linked inextricably with the location of the body. Krogh Jensen suggests by being grounded in a continuous reflective sensation of experience, and that physically locating your own body within the imaginative and sensory state can, 'become something highly material.' [4]

Susan Best proposes that a phenomenological approach to contemporary installation art can be understood through Maurice Merleau-Ponty's 'notion of the flesh of the world, which is continuous with and yet makes possible sensation and the sensate body.' [5] Best explains that the concept of the 'flesh' is about the gaining of true meaning through an individual's sensory experience of an object; an experience that can not be, 'reducible to a narrowly conceived linguistic account.' [6] Best compares this phenomenological practice at the end of the Twentieth Century with earlier minimalist approaches to art. Minimalism sought to reduce the engagement of the viewer as a way of creating a controlled, self-conscious experience through alienation. The move away from considering 'affect' as a mode of

distraction or disorganization began when contemporary installation artists began to adopt this phenomenological approach. These artists intentionally engage the viewer by expanding the sensory properties and affect in the work, as Best writes, to, 'amplify, intensify and motivate aesthetic experience.' [7]

Recent research that investigates these same phenomenological practices looks at how immersive installation art can also be used in models for engaging audiences more effectively with urgent environmental concerns such as global warming, population control, conservation and carbon emissions. At the forefront of this research, Lesley Duxbury is concerned with this social complexity in understanding climate change in context of artistic practice. Duxbury investigates the idea that where rationalism and scientific evidence is working against encouraging any social and political change in society address the problems effectively, certain art practices have the potential to engage society with the reality of climate change emotionally and experientially. She writes that, 'the nonexpert's conceptualizations, values, and experiences may be of significant value, and artists whose fields of expertise are the conceptualization of experiences and emotions have an opportunity to come to the fore.' [8]

As an artist I am underpinning my studio practice with an artistic research question, not a scientific one, and this perspective should be considered equally valuable. Ultimately however, it is not the role of the artist to solve the world's problems, yet we are all part of the same world, the same biosphere. Collectively our emotions are deeply embedded in the hope for new life, renewal, a new dawn, a future. It is through this process of interdisciplinary research and the methodology of making and exhibiting that in turn changes my own viewpoint and helps me understand the complexities of our situation. In turn my work will possibly reflect this consciousness of being in the world through the act of sharing the experiences and observations of my own lifetime.

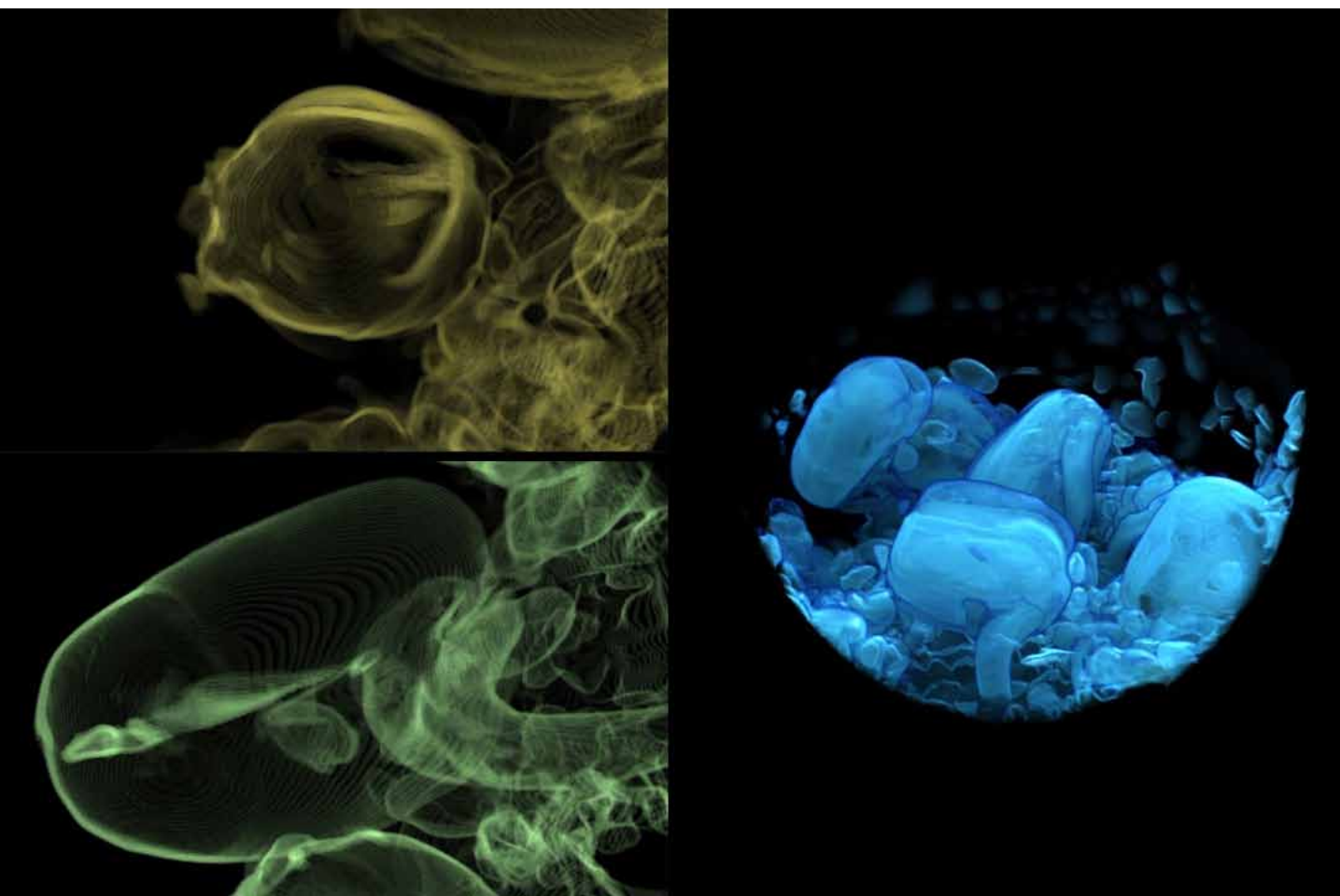


Figure 5: Erica Secombe, *GROW: work in progress*, 2012, (detail) duration 7:12 minstereoscopic digital projection installation, first exhibited in *Synapse: a selection*, Powerhouse Museum, Sydney, 2012.

Speculative Objects: Visual Arts and Science Fiction Futures

Lizzie Muller

Faculty of Art, Design and Media, COFA, UNSW Australia

Awfully Wonderful

This paper is based on curatorial practice-based research surrounding the exhibition *Awfully Wonderful: Science Fiction in Contemporary Art*, which took place at Performance Space, Sydney in 2011 [1, 2]. This exhibition, which I co-curated with Bec Dean, brought together an eclectic mix of science fictional artworks with scientific and technological objects from the collection of the Powerhouse Museum of Science and Design, Sydney. In this paper I propose the idea of the 'speculative object' as a way of understanding how both the artworks and artefacts included in the exhibition function in human experience as philosophical tools that provoke reflection about scientific and technological change, and the relationship of the present to possible futures and alternate pasts.

Science fiction is usually thought of as a narrative genre, primarily experienced through film, television or print. Whether we locate its origins in the Enlightenment or in the Industrial Revolution, there is general agreement that Science Fiction dramatises our deeply ambivalent relationship to the discovery of knowledge about our environment (science), and the means to influence it for our own purposes (technology)[3]. We both fear and revere the immensity of the universe, just as we both desire and revile the augmentation of our own powers through science and technology. Science Fiction has surfed the waves of this oscillation, dramatising utopias and dystopias, helping human beings to think through the ontological and ethical implications of new techno-scientific discoveries [4].

Science Fiction does this through extrapolation and speculation – that is, it projects from the known into the unknown. It

opens up alternative perspectives – whether temporal, spatial, political, interspecies or intergalactic – from which we can see and interrogate our own situation in a new light. In this essay I examine the way in which some objects use or activate this same speculative structure. I ask what happens when science fiction is materialized, when speculative fiction becomes speculative objects [5]. To do this I reflect upon a selection of objects from the exhibition *Awfully Wonderful* – both artworks and techno-scientific artefacts - and try to explain the different ways in which they generate or support speculative thought.

Visualisation and viscosity

Investigating contemporary art (alongside other objects and artefacts) as a materialization of the process of speculation also represents a move away from the question of how science fiction visually represents scientific and technological objects and themes. But it is not necessarily a move away from the rich visual inheritance of Science Fiction imagery. Curator and critic Patrick Gyger wrote in the *Awfully Wonderful* catalogue of the historic interplay between visualization and science fiction, and of the particularly strong and lasting influence of the graphic imagery of the Science Fiction pulp magazines from the mid 20th Century [6]. In an acknowledgment of this inheritance we commissioned artist Deborah Kelly to make a series of works in response to the collection of Science Fiction pulps held in the Fisher Library of the University of Sydney.

In her collage-based practice Kelly has frequently worked with the imagery of the B movie. Her work offers a feminist critique of the futuristic excesses of our visual

Figure 1.: Deborah Kelly, *Dream of a common language in the disintegrating circuit (with thanks to Donna Haraway)* (2011) (© Deborah Kelley. Photo © Performance Space.)



~ F. K. 1972

imagination, without suppressing what is compelling and attractive in these images. What we (and what Kelly herself) expected to emerge from this commission, were pop-esque images of alien creatures and women in seductive space outfits. The results however were a much more subtle and transformative response to Science Fiction's figurative tradition. Fig 1. is one example of a series of 8 collages Kelly produced for *Awfully Wonderful*, collectively titled *Dream of a common language in the disintegrating circuit (with thanks to Donna Harraway)*. They are delicate and exquisite concoctions formed from glamour magazines, erotica, botanical and aquatic imagery. Kelly's artist's statement accompanying the collages connects the fetishized female body of the pulp – in which “lush alien ladies” in “skyscraper heels and skintight spacesuits” teeter into the arms of “reassuringly virile, scientific white men”, to a deep history of female transformation and objectification:

I see fear of monstrous fecundity projected across human millennia from treacherous man-eating seawitch siren lairs through fearsome fairy- and folktales and onto the impossible physiques of fertile future babes.

The speculative structures of Kelly's spliced images, move both forward and backwards in time. They point backwards to myths of human transformation into other kinds of creatures, either through magic, or divine intervention. They explore biological possibilities that are both atavistic and futuristic: invoking our evolutionary inheritance from primordial aquatic forms, and the potential transformation of the human to the post-human through bio-technology. Kelly herself describes them as both pre- and post-mammalian.

Kelly's images imaginatively materialise the potential consequences of contemporary biotechnology, such as genetic modification, biomimicry, and reproductive technologies. Apart from Donna Harraway, Kelly cites Shulamith Firestone as a key influence in these visual experiments. Firestone's extreme and controversial vision of female

emancipation entailed the necessity of “wombless” reproduction. To be truly free, she argued, women would have to jettison that reproductive aspect of female biology. One of our interpretive strategies for the exhibition was to create an audio guide, based on interviews with scientists, that would explore the scientific realities connected with the artworks. In Kelly's case we interviewed Professor Stuart Bunt, the co-founder of SymbioticA research laboratory for Bio-Art. Whilst Firestone's position may seem extreme, Stuart Bunt claimed in the audio guide that “wombless” reproduction is a significant goal in reproductive science, and that current research with calves and mice is relatively close to bringing a live foetus to term outside of the body. In Kelly's case, and in many of the works in the exhibition, what seems like extreme science fiction is actually surprisingly close to science fact, and perhaps more importantly, to scientific developments that are outpacing our capacity for ethical consideration at a societal level.

One of the roles of these speculative objects is to raise these ethical questions that concern our bodies in a bodily or visceral way. Their concrete physical existence demands a physical reaction. How do we feel about these objects, what do they make us want to do? Do we want to go towards them, or do we shy away from them? As such they become tools for embodied reflection on our own attitudes. Kelly herself described her images as visual scenarios, connecting them to influential methods of strategic future planning used in both business and design [7]. Unlike verbal or narrative scenarios, however, they emphasise instinct and ambiguous possibility over explanatory sequences of cause and effect.

Figure 1a (above):. Deborah Kelly, *Dream of a common language in the disintegrating circuit (with thanks to Donna Harraway)* (2011) (© Deborah Kelley. Photo © Performance Space.)

Figure. 2. Barlow's Wheel Electromagnetism Demonstration Device (date unknown), Dr Bodkin Adam's Electromassager (c 1930), Collection of the Powerhouse Museum. (Photo © Performance Space)



The World of Things

Figure 2. shows another object that deals with the shifting ground of scientific knowledge, medical practice and ethics in regard to the human, and particularly female body. The object on the right is Dr Bodkin Adam's electro-massage machine, c 1930, from the Powerhouse Museum collection. This device was widely believed to cure numerous ailments, including female "hysteria", by the application of vibration. One of the uses of this type of machine was probably as an early portable vibrator. This object, like many of the artefacts in the exhibition, speaks eloquently of the scientific fictions of the past, and the way these beliefs are manifested in technologies and practices that can come to seem out-dated at best, and barbaric at worst. It also tells another, more personal story. Between 40 and 160 of Dr Bodkin Adam's patients died under suspicious circumstances in the 1940s and 50s. He was named in the wills of 132 of them. Recent historians are fairly unanimous in describing him as an unconvicted mass murderer, though many at the time believed him to be euthanasiast.

We commissioned artist Jo Law, whose practice engages with the legacy of the Cabinet of Curiosities and the nature and display of objects, to arrange the scientific and technological artefacts that appeared in the exhibition. She placed Dr Bodkin Adam's massager next to an electromagnetism demonstration device called a Barlow's Wheel, which can also be seen in figure 3. There are numerous resonances and connections between the two objects. Like many of the artefacts displayed, they share material and formal properties such as their polished metal and wooden parts and elaborate cursive inscriptions, which are redolent of "antique" technologies. Law constructed bespoke cabinets for the objects with mirrored bases and sides creating infinite reflections that receded into the distance. This optical effect heightened the experience of the formal and visual echoes that resonated between objects and artworks in the exhibition. It also emphasized, through

its repetitive abstraction, the 'objecthood' of the artefacts. Separated from their traditional explanatory contexts (un-labeled and a-historically placed), the objects' relationships to function and period were mysterious. Intriguing, but opaque they became the focus of aesthetic appreciation and a source of speculation. By begging the question 'what might this object be?' the artefacts invited audiences to engage their knowledge of the history of scientific thought and technological apparatus.

As well as arranging the objects we also invited Law to create an interpretive map, *The World of Things* (Fig 3.), which charted both the physical and the metaphysical terrain of the exhibition and. The map provided details of the official provenance and purpose of all the objects in the show, and also situated them in a speculative taxonomical structure. The map moves outwards in concentric circles from the Human Physical Realm at the centre through two axes: The Physical World, The Limits of Human Perception, The Realm of Imperceptible Things and, finally, Boundless Imagination on one axis, and The World of Non-Living Things, The Edge of Human Physical Limits, Logics and Rational Thoughts and Utopias and Dystopias on the other. Thematic trajectories criss-cross the map, connecting disparate objects. The theme of Technologies of the Body connects Dr Bodkin Adams' massager with Deborah Kelly's collages, and the theme of Electromagnetism connects the massager with the Barlow's Wheel and with *The Cloudbusters* (Figure 4), artworks by David Haines and Joyce Hinterding that I will discuss next.

Myth makers and busters

The Cloudbusters, like the electro massager and the Barlow's wheel, speak of the provisionality of scientific truth, the role

Figure 3. Jo Law, *The World of Things* (2011) (© Jo Law. Photo © Performance Space.)

Fig. 4. Haines/Hinterding, *Cloudbuster Number Three: Orgone Energy Cloud Engineering Device (The Black Ray)* 2008/2011. *Cloudbuster Number Four: Orgone Energy Cloud Engineering Device (Starlight Driver 3.1)* 2008/ 2011 (© Haines/Hinterding, Photo © Performance Space)

A. Surveying instrument, circumferential, brass/silver/glass, made by Angelo Turnaghi, Sydney, New South Wales, Australia, 1863-1864.
Lent by the Powerhouse Museum, Sydney. Gift of Mr A McDonald, 1938.

B. Theodolite, copper & brass, William Cary, England, 17th century
Lent by the Powerhouse Museum, Sydney. Gift of WD Campbell, 1922.

C. Musical automaton: bird in cage, maker unknown, Paris, c.1900-1902
Lent by the Powerhouse Museum, Sydney. Purchased 1949.

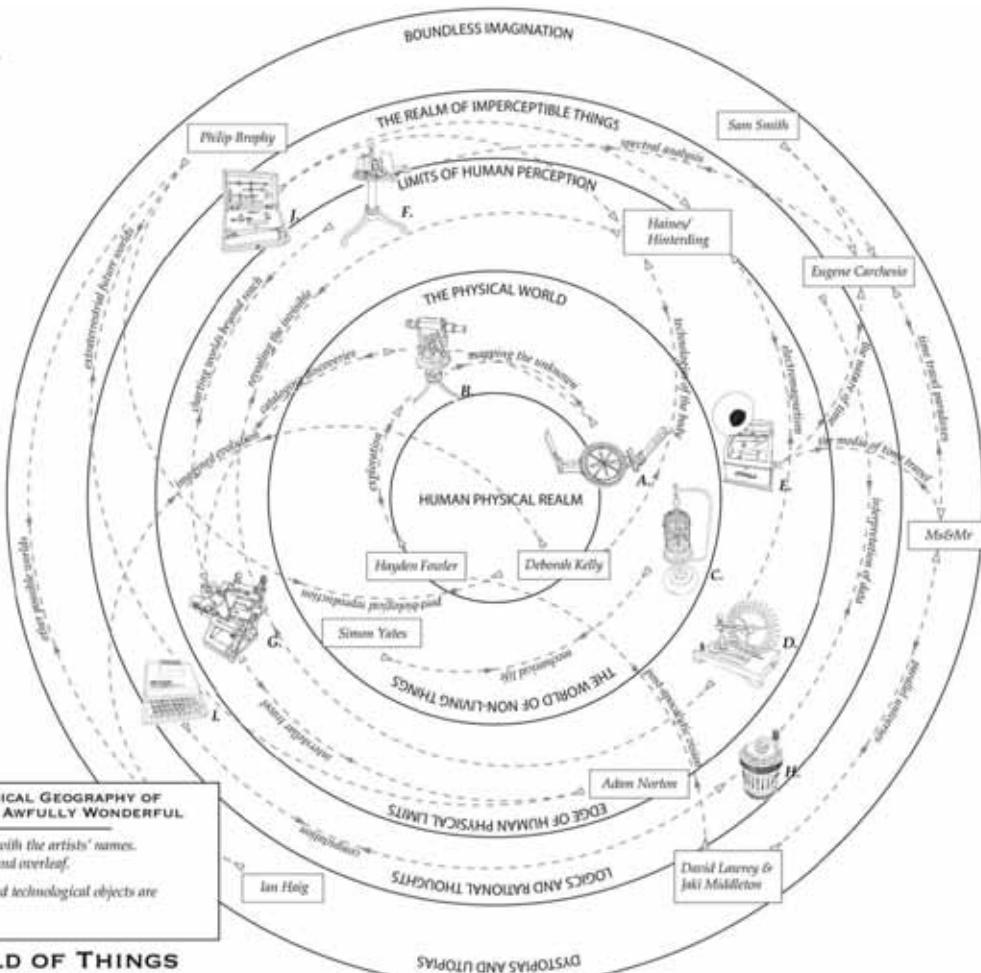
D. Model, Barlow's Wheel, consisting of copper tooth wheel, rotating with lowest teeth in mercury trough set between poles of permanent horse shoe magnet, maker and date unknown
Lent by the Powerhouse Museum, Sydney. Gift of University of Sydney, 1904.
Device for demonstrating electromagnetism.

E. Phonograph, "Bijou" coin-in-the-slot cylinder, glass fronted wooden cabinet, winding handle, serial no. GE37328, Edison, USA, 1908
Lent by the Powerhouse Museum, Sydney. Gift of Thomas A Edison Ltd, 1931.

THE NONPHYSICAL GEOGRAPHY OF THE EXHIBITION, AWFULLY WONDERFUL

- Artworks are labelled with the artists' names. Information can be found overleaf.
- Historical scientific and technological objects are labelled with letters.

THE WORLD OF THINGS



of performance and belief in science and medicine, and the power relations between expert, amateur and audience that are concentrated around technological artefacts.

The Cloudbusters are re-creations of an outlawed technology created by the controversial American Psychiatrist Wilhelm Reich. Reich's published works, including *The Mass Psychology of Fascism* (1933), and *The Sexual Revolution* (1936), were significant texts in the development of left-wing political and social thought. Reich developed the theory of Orgone Energy, which was both widely influential and also widely condemned as a fraud. Reich described Orgone energy as a life force that connects all the beings in the universe together. He attributed to it powerful properties, including the capacity to cure illnesses and influence the weather. The Cloudbusters, which are intended to seed rain, are part of a suite of machines Reich developed, which were supposed to concentrate Orgone energy in particular ways for particular purposes. The American Food and Drug Administration, a deeply conservative organisation in the 1950s, banned the Orgone machines, burned the books that contained instructions of how to make them, and eventually prosecuted and imprisoned Reich for contravening an injunction preventing the distribution of the machines and associated literature.

Haines and Hinterding, whose collaborative practice often includes the manifestation of unseen forces, have recreated these machines from instructions and remaining documentation of the originals. They are to all intents and purposes functioning cloudbusters. The speculative capacity of these objects derives in part from their ambiguous status. Are they tools or sculptures? Are they functional or fantastic? In eluding clear categories these objects question fundamentally the role of belief, respectability and politics in relation to science and technology. They raise the question: what are we allowed to believe?

As with Kelly's collages, the questions raised by The Cloudbusters resonate powerfully with

h contemporary debates about progress, science and technological change. The Cloudbusters speak particularly to the politicization of climate change science and the environment. Geo-engineering (the cause of numerous science fiction apocalypses) is becoming an increasingly likely response to climate change. The idea of engineering interventions to change weather patterns was particularly relevant in Kellerberrin in the Western Australian wheat belt, where these works were made in 2008, as Australia was in the grip of a long drought. Like Kelly's collages these objects raise these fraught issues with a provocative and productive ethical ambivalence.

Macguffins and story engines

All the objects that I have described in this paper vibrate with numerous stories. They act as fulcrums for the intersecting narratives of scientific history, both personal and global. This capacity to generate stories is a key feature of the speculative object. They operate, in Alfred Hitchcock's term, as "Macguffins" the "mechanical element" (as Hitchcock describes it), which propels forward the action of a narrative. The Macguffin has always played an important part in Science Fiction narratives. Generic Science fictional Macguffins include the "BDO" or Big Dumb Object, a thing that inspires awe and wonder through its presence, whilst remaining mysterious (the obelisk in Stanley Kubrick's 2001: A Space Odyssey is a classic example), and the Novum [8], a fictional innovation that is cognitively plausible, and signals the narrative's inhabitation of a world different from that inhabited by the reader. Some of the objects included in Awfully Wonderful were physical examples of Macguffins related to famous sci-fi stories – the Curta Calculator and Sinclair personal computer, for example, are the main object-protagonists in William Gibson's novel *Pattern Recognition*. It is notable that both of these objects are associated with rich real-world stories, and Gibson's invocation of them in his novel

Fig. 5. Simon Yates, *Futura* (2011) (© Simon Yates. Photo © Performamnce Space.)



created a compelling mixture of truth and fiction within the text.

We commissioned artist Simon Yates to materialise, through his signature hand-made wood and paper robots, a particularly famous and provocative science fiction Macguffin – Futura, the evil, seductive, female robot from Fritz Lang’s *Metropolis* (Fig.5). Supported by helium balloons Yates’ fragile and delicate contemporary version of Futura drifted, spectrally around the exhibition. This once powerful and fearful creation was revived in the exhibition as kind of geriatric ghost in the machine. Her haunting presence was a poignant reminder of the way in which the future age.

Anthropocene

Whilst many of the objects and works destabilised our view of the past, others offered destabilising views of the future. Apocalyptic, dystopian and post-human visions are familiar terrain in science fiction narratives, and several of the works materialised this terrain in startlingly physical ways. Hayden Fowler’s work *Anthropocene* (Figure 4, in background.), speaks to the possibility of post-human consciousness, and the relationship that such a consciousness might have to human beings. The Anthropocene is the name recently given to the geological time period during which human activity has had a significant impact on the earth’s ecosystems. The very act of naming this period implies its finitude, and Fowler’s installation allows us to speculate on the possible fate of the human. The work consists of an island covered by grass with a rudimentary cave shelter on top of it. Fowler inhabited the island during the exhibition, wearing a pelt and accompanied, if you looked closely, by three rats.

The installation suggests, at first, a museum diorama of a pre-historic dwelling. It looks like an idealisation of a pre-technological, pre-modern form of existence. When you get closer, however, you can see the complicated technological systems that are maintaining this simple inhabitation. The food Fowler is eating comes from tin cans. CCTV monitors

show surveillance views from within his cave, wires trail beneath the exposed wooden structure of the island. There is a complex technological infrastructure that supports this primitive way of life.

The rats, which audiences may catch a glimpse of, suggest a hint of an ecosystem, but also a laboratory experiment. Whether this is a zoological or museum exhibit, or an experiment, it suggests that the human inhabiting the island is the subject of scrutiny, perhaps even the cause of wonder and enjoyment for another consciousness. What is looking at this exhibit? Something stands in relation to this human in the same position that we humans stand in relation to cave men, zoo animals or laboratory rats. In terms of speculative projection, this is an incredibly humbling perspective to adopt.

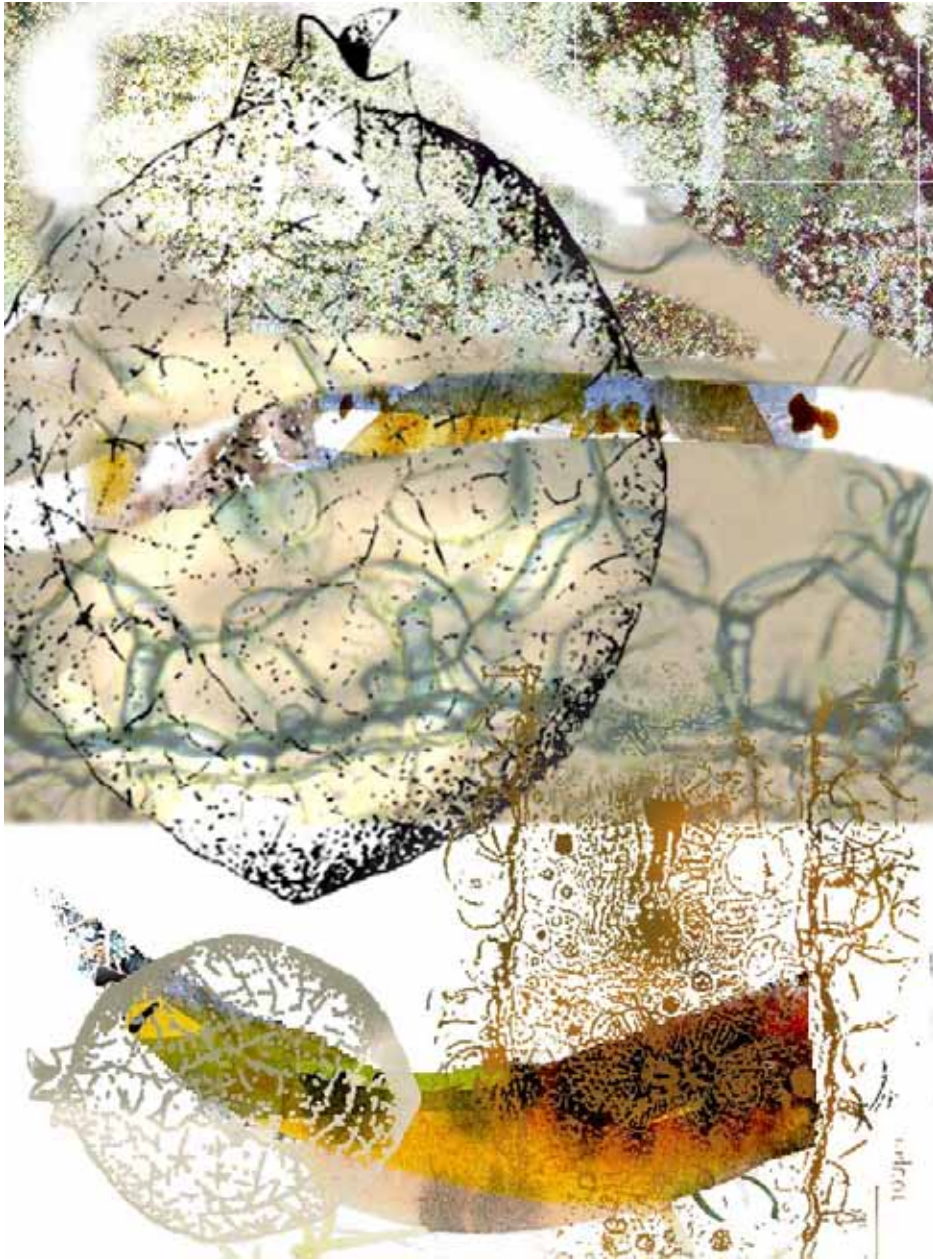
From speculative fiction to speculative objects

Considering the experience of Hayden Fowler’s island illuminates one of the key questions raised by the idea of the speculative object as a materialisation of science fiction. Is the experience of looking at, smelling, moving around and contemplating Anthropocene different from the experience of psychologically inhabiting a science fiction narrative? The Marxist literary critic Frederic Jameson argues that the “deepest vocation” of Science Fiction texts is “over and over again to demonstrate and to dramatise our incapacity to imagine the future.” This, he suggests, is “not owing to any individual failure of imagination but as the result of the systemic, cultural and ideological closure of which we are all in one way or another prisoners.”[9]. Speculative Fiction is, for Jameson, a mirror reflecting our situation but closed off from it, unable to penetrate or shift our reality [10].

In *Awfully Wonderful* science fiction made a three dimensional, and experiential entrance into our own world. The exhibition was filled with objects, like Anthropocene, that suggested alternate realities, but at the same time inhabited, with concrete physicality, our own. It is not by any means the aim of this

essay to argue for the superiority of physical over textual artworks, but it is interesting to note that the nature of the experience generated by the speculative objects I have described offers a possible counterpoint to the impasse identified by Jameson. The experience of speculation

provoked by these objects is visceral and ambiguous. In the interplay of their impossibility, obsolescence and liminality with their tangible existence, these objects act not only as mirrors of our own reality, but also as portals that allow us, if only fleetingly, to move beyond it.



A. spongiosa. 2006. Mary Rosengren. From the print series *fruitingbodies*

Learning through drawing in art and science

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There is increasing recognition of the role of images, and visualization, in creating new knowledge in science, indicating potential parallels between creative processes in science and in art. This chapter presents case studies to illustrate how art has intersected with science ideas, and the commonalities and differences between creative visual processes in art compared to science. The cases are chosen to illuminate the contribution of art to science, the role of visualization in reasoning leading to new theorising in science, and scientific analyses in the service of aesthetic programs in art. The construct of affordances is used to illuminate the differences between artistic and scientific endeavour. We explore a school science pedagogy in which students construct visual and embodied representations, which more authentically demonstrates the imaginative processes through which knowledge is created in science, and the intersections between these two disciplines in knowledge creation. We argue that art and science are both centrally characterised by representation construction, but differ fundamentally in their driving purposes, with corresponding differences in engaging affordance, which we see as a fundamental construct for understanding the nature of reasoning and cognizing in both areas.

Visualization as a major literacy of science

There is a substantial literature, set broadly within a socio-cultural framework, arguing that learning and knowing in a disciplinary area involves a process of enculturation into its discursive practices shaped around a set of discipline specific and generic literacies to build and validate knowledge [1]. Understanding and practical problem solving competency in science, involves the production and coordination of multi-modal representations

to develop explanations and solve problems [2]. There is increasing recognition of visual representations including drawings, photographs, and animations, in science learning and in the epistemic practices of science. Current writing places visualization and the role of visuo-spatial models as important cognitive catalysts of scientific reasoning and knowledge building [3]. Studies have shown the defining, rather than supporting role played by representations [4].

This growing recognition of the role of visual and embodied representations in the practice and learning of science raises interesting questions about the relationship and possible productive links with practice and learning in art. This chapter will explore this relationship, drawing on examples from both fields, and on our experience of an approach to school science involving student construction of representations. In particular we draw on the construct of ‘affordances’ [5,6] as providing ‘productive constraints’ on cognition. We argue that the role of affordances in science, and in art, offers productive insights into the distinctiveness of practices in the two fields, and into the appropriate role of imagination in school science learning.

Art in the service of science, and science used for art-making, entail processes in which technology is linked with representation construction. Case studies from each area demonstrate particular interactions between visual representation and idea exploration and theory generation.

‘Scientific method’, variation and adaptation in art

Examples in the literature [7] acknowledge contributions of art to science but let us first examine the converse. Cameron Robbins’

methodology might be 'scientific' but his 'sampling' is distinctly quixotic. Studied longitudinally Robbins' production develops from instruments that produce complex drawn forms from chaotic inputs, to installations elegant in their simplicity. Prodigious from the early 1990s, he creates and deploys a number of drawing machines to record phenomena of wind, tide, and human motion. His 'Heath-Robinson' instruments mimic chart recorders of the kind once used for weather and tide observations. Darwinian adaption is the predominant creative characteristic of this serial production, in the construction of levers, paper drivers and styluses to record the inputs for a specific project. Adaptation and evolution of forms are processes of both scientific and artistic creation [8]. However not just any variation or innovation may be considered creative unless the product is useful to a goal; 'wild ideas' without such coherence may be judged insane rather than creative. Creative effort is appreciated according to practical or aesthetic standards.

In Robbins' case it is not solely the drawing that demonstrates the characteristic, but rather the instrument, its process and product together which are aesthetically pleasing to the artist's audience. Robbins' collaborations, involvement in artist-run spaces and community art works are a demonstration of Gruber's [9] 'evolving systems approach' concept of creative work that reflects the complex interactions of people, processes, and knowledge.



Figure 1: Robbins' smoke room

Robbins' *Smoke Room: 26 Surf Street 2007* (Figure 1) reverses his usual practice of employing random meteorological effects; he controls air circulation in a room to 'draw' with smoke a startling vortex that appears and disappears spontaneously.

A defining characteristic of creativity is novelty. In art and science this may present as a surprise, revelation, manifestation or apparition. Such words share associations also with magical, superstitious or religious experience as being on the 'spooky' outer edge of awareness and intuition.

Art in science: Amplification and reception

Charles Darwin [10] defended the argument that emotional expressions are evolved and adapted. The book was pioneering in its use of photographs (seven heliotype plates) for the collection and analysis of scientific data and effectively communicated it to a bourgeois audience. Julia Voss [11] argues that Darwin "thought with his eyes" ... "to formulate his theories in the first place." Darwin used visualizations, sketched (poorly, he estimated), collected engravings and photographs exhaustively and commissioned wood engravings. Evidently, the compactness of data contained in the portable and physical form of images, readily compared, envisaged the stages between evolved features.



Figure 2: Rejlander's Laughing/Crying

Consider first the illustration of a crying baby that Oscar Gustav Rejlander contrived from a hasty, necessarily unposed, snapshot, enlarging it, redrawing it in chalk, then rephotographing it (Figure 2). This typified

Rejlander's artistic method of montage and image-manipulation to produce narrative, when photography's technical shortcomings then exaggerated the gap between what a photograph would show, and what we think we see. Darwin struggled for records of momentary expression. Being acquainted with innovators in art photography, Darwin could see advantage in employing artistic talent. Given that he required images that would be both 'realistic', and paradigmatic or 'metaphorical', a photographer whose credo "In all picture compositions the thought should take the first place . . . all else [is] the language which is to give it expression" (Rejlander quoted in [12]), provided material better than Darwin himself could produce. Prodder [13] argues that Rejlander was an appropriate choice for Darwin's purpose, against popular modern expectations that the use of the medium in science is oriented toward 'objectivity' for scientific illustration, even though aesthetically mediated and enhanced visual data now necessarily predominates where direct imaging is not possible [14].

Image creation in scientific knowledge building

Image creation and modeling are increasingly recognized as a crucially important aspect of scientific knowledge building [15]. Michael Faraday's approach to scientific discovery provides us with insight into the imaginative processes underpinning a seminal scientific advance. Faraday was a careful documenter of his explorations and ideas, and his diaries allow us a unique insight into scientific reasoning processes. David Gooding [7] analysed the role of Faraday's diarized visualizations in generating and establishing new theoretical perspectives on electromagnetic phenomena. *Figure 3*, based on Gooding, shows a series of entries in Faraday's notebook entries over one day where he moved from observations of patterns of needle orientation around a wire, to 3D enhancement to imagine field lines in 3D, to the imaging of a process in time, and finally to an inference for construction of the first electric motor.

Gooding [7] developed a process model to describe how scientists manipulate the dimensionality of images, moving from particular and situated to more widely accepted facts and laws. He further argues for the central role of visual images, such as those generated by Faraday, in underpinning the formal, rational, written language through which scientific knowledge is secured as fact, law, and theory. The drawings derive from, but act to channel perceptions to drive imaginative acts. They would seem to have much in common with exploratory creation and investigations of new visual languages in art.

From Feynmann's diagrams of particle interactions, the double helix structure of chromosomes, multidimensional modeling of galaxies to computer generated abstracted graphics, visuo-spatial imaging plays a critical generative role in scientific reasoning and knowledge building. Latour ([16], p. 3) argues that the emergence of scientific thought has depended on developing effective representational tools, and that changes over time to procedures for writing and imaging have altered the ways scientists argue and validate their case.

Case studies in art: Embodiment and affordance

Depictions of motion (time/space) are problematic in the still image. Human vision, through binocular and stereo perception, as well as through all other embodied means, enables comprehension of spatial/motion relations to the level of engagement encompassed in Gibson's term 'affordance' [5] and as something which 'points two ways' between observer and environment. He sees pictorial, planar imagery as a construction into which we can build a representation or notation of these relationships with mathematical formulae, or by sectioning space as with a window, so that a still picture might yield an experience of motion and comprehension of spatial/motion relations.

The stereoscope re-positions the observer in visual representation. The observer is no

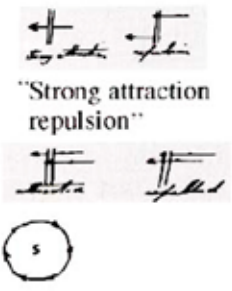
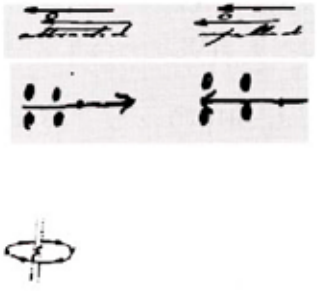
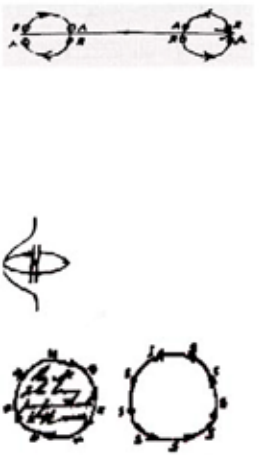

Reduction of complex phenomena to 2D pattern	Enhancement of pattern to 3D structure	Enhancement structure to 4D process	Inference or material derivation
 <p>"Strong attraction repulsion"</p>		 <p>"The N pole being perpendicular to the ring"</p>	 <p>The first electric motor</p>

Figure 3: Visual reasoning by dimensional enhancement and reduction -- a day's work recorded in Faraday's manuscript for 3 September 1821 ([7], p. 16).

Figure 4: James McArdle Pure Pivot (2001), monochrome digital print from scanned large format sheet negatives, 5m x 1.5m



longer separate from the representation; fragments from outside assemble within the body of the observer. Wheatstone or Brewster Stereo viewing apparatuses blend human perception and camera lens imaging in a unique way that exemplifies my concerns; the blend permitting the illusion that we are looking at three-dimensional space.

The stereoscope confirmed that vision is a function as much of the mind as outside stimuli. Patrick Maynard refers to such devices as 'engines of visualisation', industrialising vision and commodifying it [17]. This is useful sociologically and philosophically, and prompts a re-evaluation of these instruments for their characteristics in scientific and aesthetic uses.

Let us use an example that involves movements of the observer, the observed and of the camera. Ernst Mach [18] would have us understand that with our two eyes we stand at two places at the one time, while John Herschel [19] observes: "Let any one traveling rapidly along a high road fix his eye steadily on any object, but at the same time not entirely withdraw his attention from the general landscape, he will see, or think he sees, the whole landscape thrown into rotation, and moving round that object as a centre."

One could see new potential to be derived from that idea; in movement, with our two eyes, we might exist in two moments simultaneously. Further experimentation with photography (*McArdle, Vortex series, opposite page*) seeks to evoke sensations of being in the landscape; working in the environment with the camera to render unique qualities of human vision and perception. (*Figure 4*) Such phenomena result from an 'optic flow' of largely subconscious visceral perception arising from a connection between body and environment, and as Gibson proposes, they are also a sign of mind and attention [5]. Heightened attention is necessary in observing motion perspective, and it is a very human sense of the physicality of the environment. Orientation and order are here

a condensation of space by time, manifested as concentrated still points embedded within the surrounding confusion by the observer (photographer/viewer) themselves. The preparation for the construction of these mural scale montages involves collecting images of the landscape seen on the move (*Figures 5, 6*). A glance on such a journey may pick something up and this place is then visited on foot. Moving and swivelling of body and camera in dance-like and manual gestures re-arranges the chaotic array of near and distant forms; they are registered as streaks and swirls, 'vortices', that form in the foreground and background around still points that remain sharp and distinct.

The process entails systematic investigations, motivated by both scientific and artistic curiosity, that reviewer Dirk de Bruyn proposes "are not random operations but document a bodily relationship to these spaces....Is this an indication of a spent and unsettled landscape, a space in crisis or are these the traces of emotion imparted from the body of the photographer himself?" [20].

Drawing in school science, and science

In our own work we have explored a school science pedagogy based on representation construction. Students draw, and model, their interpretations of phenomena, supported by the teacher to evaluate and refine these to achieve consensus around the scientific representational canon. We advance distinct reasons for actively drawing in learning science [21]. These arguments for active construction of representations in school science mirror the role of representations in the knowledge-building practices of science itself [6].

We analyse the process by which two students in a grade 5/6 class responded to the challenge of representing the movement of a chosen invertebrate. At the start of this lesson Ivan carefully examined representations in his workbook (*Figure 7*) of how an earthworm moved, that he had drawn at home, and discussed them with his partner.



Figure 5: James McArdle Glance (2007) Type C photograph

Figure 6: James McArdle 09:13 (2012) Type C photograph



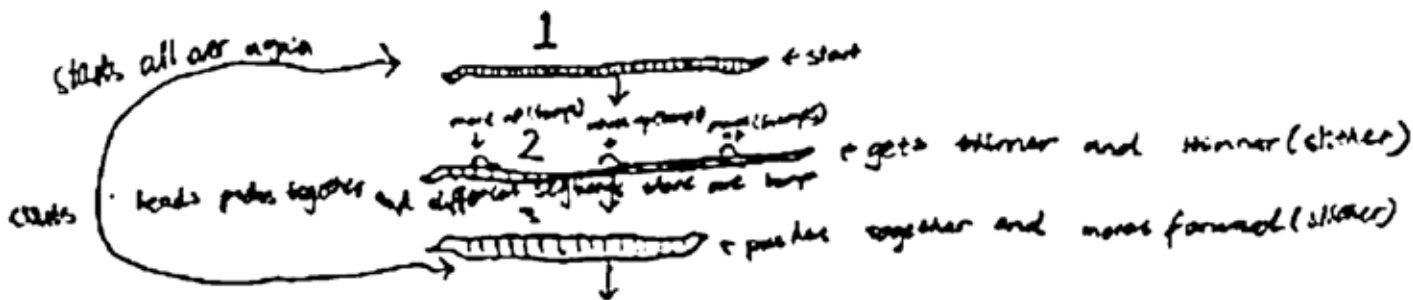


Figure 7: Ivan's workbook entry representing the movement of an earthworm

They then selected meccano pieces, connects, flexi wire and blu tac to build a "techno-worm". They wanted their model to represent as accurately as possible the amount of extension and 'retraction' of the earthworm. They drew up a scale on an A3 paper to help them represent the exact extension and retraction as the earthworm moved along a smooth surface. The boys proceeded to build up a device to enable them to extend and retract the flexi-wire (Figure 8). They described the process of refining their model, which involved trying different materials and connecting arrangements until 'it started to fit ... it made a bit more sense'. They relied on gestures as they described the relationship between the stretch, and the thickness of the worm 'when it shrivels. [palms close] ... it gets fatter [moves the thumb away from the fore fingers]'. The case highlights the multi-modal nature of the students' thinking and reasoning, as they talk, gesture, draw, use measurement artefacts, and construct the 3D model. Their understanding deepens through successive transformations across representations, which act to organize their perceptions at each stage. The drawing sharpens and challenges their observation, the model forces attention on the material characteristics, and on the measurement of retracted/extended length.

We see in this case the successive creation of representations involved the imaginative creation of new visual symbolic tools and artifacts, following the process, described

by Gooding [7], from pattern to structure to process.

Representing in science and in art: Convergence/divergence

From these case studies we argue that the core of the creative process in both art and science is the construction and refinement of representations to solve a problem. Opening up affordances through these representations is key in each case. We can see inspiration and intuition in the way a creative mind from either field makes leaps from one way of seeing to another. In our examples from science and art we are dealing with the problem of representing phenomena, particularly time; how to represent time in a still photographic image, or in a drawing or model. In the science lab, and in the art studio, we distinguish a common pathway from phenomenon>curiosity>discernment of a problem>exploration and analysis>selection and orchestration of elements into a coherent synthesis.

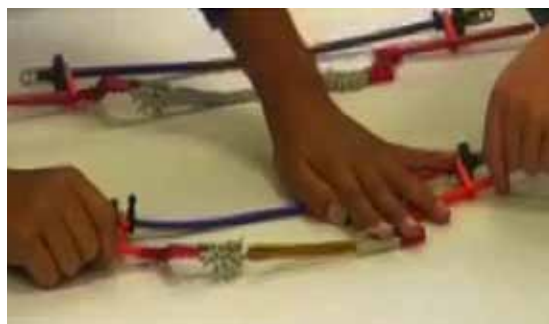


Figure 8: The 'techno-worm' model of the stretch and retraction of an earthworm

The generation, refinement and orchestration of visual and other representations is central to these processes, and the pathway can be discerned in the professional practice of Faraday and McArdle as it can in Jesse's and Paul's exploration of centipede movement or the artistic representation of a forensic investigation.

However, this representation construction process differs in two respects; first, concerning fundamental purpose, and second, the way affordances operate in the two disciplines. First, the different fundamental purposes of representation generation, refinement and orchestration in the two disciplines affect the nature of each element in the process. In art, the burden of the task, and the focus of the analysis, is to create an artefact that for the participant observer offers insight or illumination, renewed or enriched sensibilities and new perceptions. The process aims to achieve new discursive possibilities that advance the field.

Conversely, in science, the exploration and analysis serves to build explanation supported by evidence in an explicit way. We would argue that this is achieved through coordination of the visual representation within explanatory narratives, which allow logical processes to be engaged with, in a formal process of argumentation. The burden of the scientific analysis thus rests on forms of evidence that test and affirm the visual innovation.

Analysis processes are central to both disciplines. We see in McArdle's work the generative nature of analysis of the process of stereoscopic vision and how this affects the images across the field. However, while such insights may, in a science context, have fed into a convergent explanatory depiction of sight, the real aim of the exploration is to a more divergent end – in art, the analysis feeds back into a generative product and concerns the refinement of this to evoke and stimulate insight into perceptual processes. The central concern is to explore the affordances of the medium to achieve this. Affect is a central part of the process,

whereas it is explicitly ruled out of the scientific end product.

Second, in both art and science the construct of affordances is fruitful in providing insight into the nature and purpose of the representation construction. In science, the different representations and different modes offer particular affordances through the way they constrain and focus attention on key features of the phenomenon, to build conceptual insight. Each, however, is convergent in its intent. In art, by contrast, the ultimate purpose of the analysis is to explore and refine the possibilities of the medium. While these may be employed for scientific ends (e.g. Darwin and Rejlander), ultimately for the artist the creation of affordances is the core purpose.

Technology, Illustration and Science

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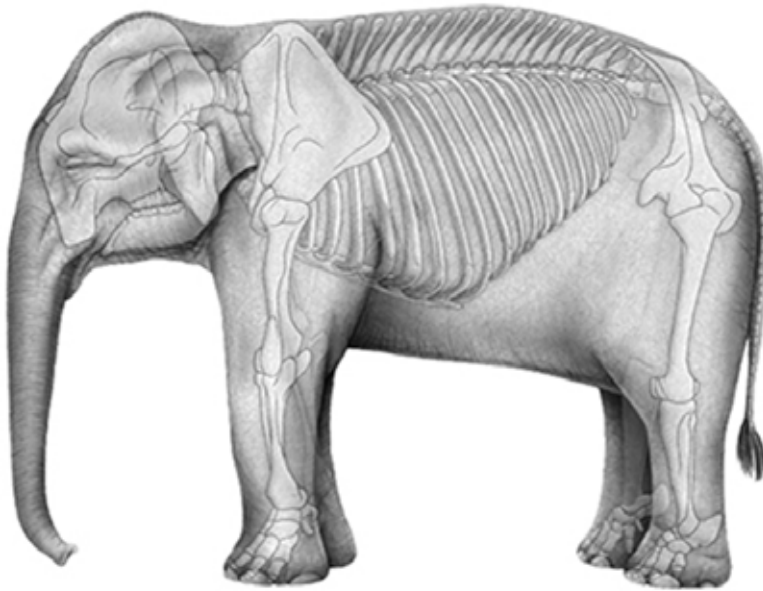


Figure 1: Asian Elephant anatomical reference, Illustration: A. Howells

As a Natural History Illustrator, it is the practice approach or methodology that enables resulting artworks/illustrations to perform a specific function as reference and resource imagery for the sciences. This type of practice and image-based outcome requires a period of contextual research, consultation and observation to inform the studio experience and resulting artworks. As an outcome of research, the artwork, or generated artefact embodies the knowledge acquired in the research process, and communicates the intended knowledge, theme or event that was the catalyst for its creation. It is in this context that technology offers the contemporary Natural History Illustrator considerable scope in studio practice, in collaborative engagement with the sciences and in the diverse forms of publication, exhibition and interaction offered by new and emerging digital media platforms. The traditional collaborative relationship between illustrators and the sciences has

changed with digital imaging technologies. This has opened up new frontiers for observing, recording and representing visual data for both the artist and scientist. The roles in this relationship have not just changed over time but in some cases dissolved. The danger for the sciences in embracing just the functionality of imaging technology and negating the tacit knowledge of the artist visual mind in constructing and interpreting visual data could potentially limit the capacity of captured and constructed images, their interpretation and ability to effectively disseminate knowledge. It is the role of technology in practice-based research as an illustrator for the studio experience, research collaboration and intended forms of publication and interaction that I will discuss in the context of my PhD research titled *Elephant: Art and Science*.

My research was not a scientific study, rather the development of a body of an illustrative

resource based on current scientific methodology. My focus was on the development of illustrations suitable for use as reference in the Body Condition Scoring (BCS) of captive Asian Elephants. BCS formed one aspect of a multi-institutional study titled '*Understanding the interaction between nutrition, activity and reproduction in captive Asian Elephants*'. My contribution to this research was through collaboration with veterinary science researchers at Fort Worth Zoo, Texas. My research was focused on two specific lines of inquiry:

1. The Asian Elephant as subject for illustration and artwork; and
2. The development of illustrated reference for visually assessing the body condition of captive Asian Elephants.

These two lines of enquiry ran concurrently and had a central focus in observing, contextualising and accurately depicting the Asian Elephant. The Asian Elephant as subject for illustration and artwork required extended periods of observation and technical studio experiments to arrive at a process and style that would meet the needs of the required illustrative reference imagery. The development of an illustrated resource to convey the range of possible body conditions defined by the veterinary scientist required collaboration in understanding and depicting specific anatomical content consistently in a body of sequential reference imagery. This process required a multi-disciplinary approach to practice that enabled the resulting illustrations to serve either as individual static reference or as elements of an interactive visual screen-based tool.

Defining Practice

To give context to my work I need to define the processes involved in my practice, these processes are technical, creative and conceptual. I define my practice as Natural History Illustration; the practice is more broadly described or understood as Scientific, or Natural Science Illustration. Gould describes Scientific Illustrators as '*Artists in the service of science. They use specifically informed observational, technical,*

and aesthetic skills to portray a subject accurately. Accuracy and communication are essential. Communication of shapes, anatomy, details and concepts that cannot be conveyed via words, forms the essence of this type of art.'[1] It is important to note that this practice is not defined by a specific illustrative technique or use of materials and media. The practice, although associated with traditional media such as pencil, pen and ink, watercolour and scraperboard, it is defined by a working methodology that requires periods of observation, consultation and studio experimentation in developing visual solutions facilitating the production of imagery with the key objectives of being accuracy and effective communication.

Fieldwork is key to this practice; it is through the process of observational fieldwork that an object becomes a subject. Observation underpins the ability to create representational imagery. In a very similar way to a portrait artist developing a rapport with a sitter, through fieldwork, observation moves from seeing the spatial relationships of form, proportion, structure, and the surface quality of a subject to seeing mannerism, personality and intricacies of form and detail that can only be understood and depicted through periods of intensive observation. It is the subtleties of weight transfer in movement, light describing form and natural posing and stance that needs to be seen and experienced for them to be described. Without these observations a likeness can still be developed from static reference, but it is this intimate knowledge of a subject through fieldwork where a dimensional understanding of a subject is gained to faithfully represent that subject from multiple angles and in many contexts. It was the accurate portrayal of the Asian Elephants anatomy, its natural form, proportion and structure that was crucial in communicating the subtle visual changes between body conditions for the research. Understanding the anatomy of Asian Elephants was crucial to their depiction.

Subsequent knowledge acquired through fieldwork and consultation with specialist is then explored in the studio in context of

the brief, or research objectives. Technical experimentation with materials and media, scale and composition is then undertaken to develop the initial works before further collaborative engagement and the refinement and execution of final illustrations.

Defining the research

The research was specific in its aim to develop a simple system for visually assessing the body condition of captive Asian Elephants. The Texas-based research group had developed an indexed range of possible body conditions for the species. This index range allocated a numerical value to clusters of specific physical characteristics associated with observed body conditions in captive Asian Elephants. They had described the observed physical attributes with each of the indexed classifications and amassed a photographic resource library for each indexed body condition.

So what is BCS? BCS is a subjective visual assessment. BCS is the process of visually assessing a number of anatomical regions of an animal's body and assigning a score, or indexed value based on the described range of possible body conditions for a species. BCS effectively identifies a particular animals body condition in relation to its species broader population. The BCS model used by researchers for a particular species determines the range of possible body conditions. To transition this understanding of BCS in the context of Asian Elephants and to develop a list of illustration requirements to meet the research objectives I needed to redefine BCS in terms that related to the observations I needed to make, and the practice methods needed in designing specific visual reference.

My interpretation of BCS for the purposes of observing, planning and developing practice-based process was; the observation of the variability of visible surface depressions of an animal; visible surface depressions are created and vary depending on the level of fat and muscle condition between an animal's skin and skeleton. It is this relationship between the skin and the skeleton that



Figure 2: Comparative photographic reference of individual Elephants, Photograph: A. Howells.

became the focus of my fieldwork and the basis for developing my preliminary illustrations. *Figure 1* is an illustration I developed as reference of this relationship, and for context when observing the visibility of bony structures as body condition declined.

The exterior of the Asian Elephant and its internal structure became the focus of my fieldwork. This required live specimens and an articulated skeleton to develop reference materials and the understanding I needed to depict visually these two elements when the level of muscle mass and fat changed between described body conditions.

I conducted fieldwork at Sydney's Taronga Zoo, Fort Worth Zoo, Texas, the Australia Museum and the Smithsonian National Museum of Natural History. During these field trips I spent time sketching, photographing, videoing and talking with keepers and scientist in an effort to gather the essential reference materials, and understanding needed to develop meaningful reference images. My research was then transitioned into the studio to translate my understanding of the described index range of body conditions, and reference gathered through fieldwork into artworks.

Why Draw?

At this stage it is important to address the

question that I most often encountered when trying to describe my research. That question is, why draw? In answering this question it is best to understand the context of the origins of the collaborative research relationship and my described illustration practice. The following is a quote that I think explains the strength of the contribution of drawing to cross-disciplinary research. Although the quote directly relates to designers the term can be term directly substituted with drawers/illustrators.

'If designers are to play a constructive role in multi-disciplinary enquiry we need to understand what will be different and helpful in their contribution. One feature of a design-based enquiry is that it can generate artefacts; another is that designers are skilled in organising and representing artefacts. This may not appear central to the idea of scientific enquiry, but it might become very significant if we consider the role that systems of representation have played in the development of thought.' [2]

As with many research collaborations a chance conversation turns into a discussion, followed by a challenge to see if thinking about a problem in a different way may address a need. In my case, while painting a portrait of Sydney University Veterinary Science Lecturer Dr Roy McClements the conversation moved to his latest research and the topic of Elephants. It was his explanation of the process of visually assessing the body condition of Elephants and the way he had planned to instruct and provide reference for the assessment that raised questions in my mind. I was processing his ideas from a purely visual perspective and attempting to understand how someone with limited, to no understanding of veterinary science and Elephant anatomy could see specific physical indicators associated with subtle variations in the physical form of Elephants.

BCS being a subjective visual assessment, the effectiveness of visual reference could reduce the subjectivity in the assessment process by isolating the key visual information and

representing it an idyllic way. Illustrations being completely constructed visuals provided a platform for collaboration, art direction and flexible application for the development outcomes.

The aim in developing illustrated reference was to address the variability associated with photographic reference. The following are the key areas of variability associated with photographic reference that I identified and sought to address with illustration. Variance in photographic reference I grouped to two main categories first was the individual physical characteristics of different Elephants used to demonstrate the scope of nine possible body conditions. *Figure 2* is an example of the variability of individual Elephants, these two Elephants were both subjects that I studied in my fieldwork and would be assessed using the same reference. The noted variances included the following:

- Variation in skin pigmentation of individual animals
- Variation in hair coverage of individual animals
- Variation in the scale of individual animals
- Variation in the stance of photographed animals
- Variation in the surrounding environments of photographic reference

The second main type of variance in photographic reference was to do with technical aspects of photography, including:

- The position of the photographer in relation to the Elephant, this created variation in captured detail, distortion of subject and the amount of contextual environmental content captured.
- The technical proficiency of the photographer, this contributed the composition of the captured reference, the ability to create a focused image and understanding of lighting to capture true form.
- The variation in the technical capacity of the camera including the light sensors, resolution capacity and resulting image quality.

Central to reducing the subjectivity of the assessment was strengthening the reference imagery supplied to make the

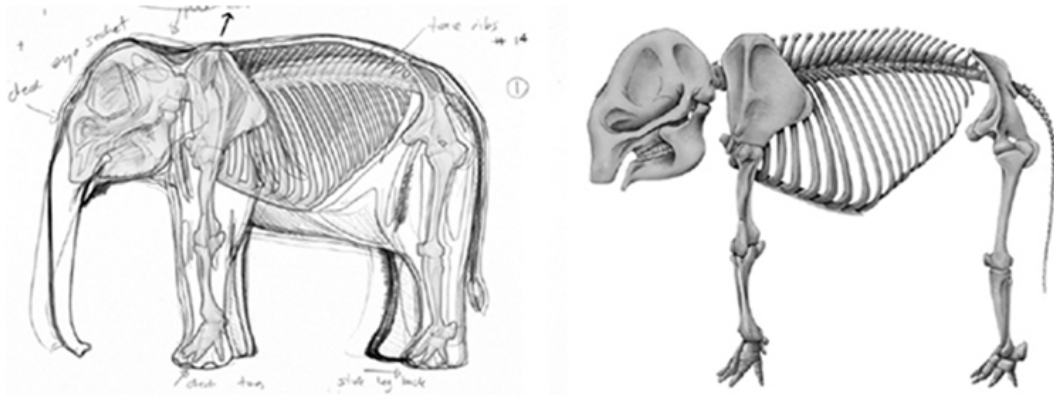


Figure 3: Animation as illustration process, Illustration: A. Howells.

assessment. It is best understood how this could be achieved in the context of the description of BCS that I conveyed earlier, *the observation of the variability of visible surface depressions of an animal; visible surface depressions are created and vary depending on the level of fat and muscle condition between an animal's skin and skeleton.*

Controlling lighting was the most integral part of providing consistent reference imagery that focuses only on the variation of visible surface depressions for each separate body condition. When drawing, light depicted through the use of a tonal range describes form. In a sequence of imagery where the only required visual difference for each image is the depth of a



Figure 4: Morphing body condition of individual animal. Illustration: A. Howells.

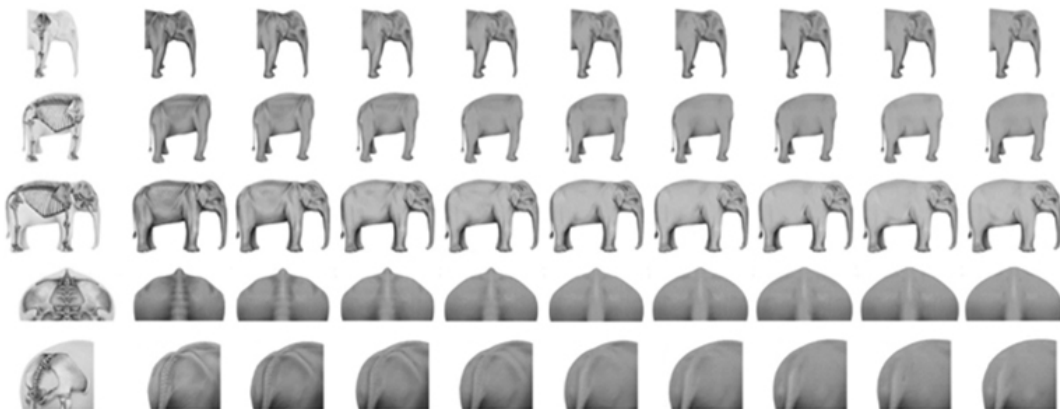


Figure 5: The developed illustrated BCS reference set. Illustration: A. Howells.

visible surface depression, then establishing a consistent light source enables the controlled use of tone to depict varying surface forms. Depicting a single animal in a single stance with a consistent rendering style for all images in the sequence would result in images that only demonstrated and communicated the required observations. This approach to the development of BCS reference imagery in context of an informed understanding of the anatomy demonstrated in *Figure 1* was the basis in establishing illustration requirements.

Illustrating Outcomes

Transitioning fieldwork and contextual research into illustrations required developing studio process that would facilitate the execution of the illustration requirements. The illustration requirements were specifically focused on addressing the anomalies associated with the photographic reference noted above. Each of the requirements reflected a need for specific studio practice that cumulatively formed a practice approach to the development of outcomes. The core requirement for the illustrations was consistency; the development of a generic specimen that would be illustrated in a monochrome style for all nine-body conditions would address the majority of the anomalies observed in photographic reference. This alone would have reduced the subjectivity of the reference, but it was the methods used to develop the sequence of body condition illustrations that added value in controlling the anomalies that could be drawn back into the reference unless there was a system in place to check the morphing of specific physical characteristics between illustrations.

Animation provided a platform for the registration of individual images to each other in a sequence, and therefore a platform to assess the incremental changes in physical features as the body condition changed between illustrations. Although based on traditional light-box animation techniques, widely assessable animation software provided a platform to capture, view and edit the sequence of images as

transparent overlaid images and as a morphing animation of the sequence. On the light-box an illustration of the skeleton could be viewed under the sketch of each body condition as it was drawn, this provided a reference for the bony structures appearing as surface depressions as body condition declined. *Figure 3* demonstrates the development of individual body condition illustrations as overlaid images with the skeletal reference as a point of reference and registration.

Animation was originally used as a way to ensure consistency in the illustration process and to assess the successful morphing of the physical form between illustrations. The process enabled consistency in developed illustrations and additionally a morphing animation of the possible range of body conditions. The process provided outcomes that could be used as static hardcopy reference and played as a morphing animation for screen-based media.

Additional to the role of animation as a process for the development and refinement of the individual illustrations, graphics software provided a platform to control the consistency of tone, surface detail and physical features between illustrations. The illustration process needed to be economical and editable to allow for collaboration in terms of feedback in the development of each illustration. Layered graphics files provided a means to control scale, and the emergence and depth of visible surface depression between illustrations. *Figure 5* demonstrated the complete set of BCS reference, *Figure 5* also demonstrates with greater detail the variation surface depression depicted using variation of tonal depth registered to a skeletal structure.

The role of technology

Technology played a significant role in my research. This role was not just in my practice approach, but also in the collaborative experience and application of outcomes.

The contribution of technology to my

research I have categorised into three key areas:

1. Technology and the studio experience

Software technology allowed me to control the majority of the anomalies associated with the development of a sequential body of traditionally illustrated images, and to share the progress of individual illustrations with collaborators to ensure accuracy in content. Editable illustrations facilitated ongoing collaboration in the re-contextualisation of the illustrations to a number of print and screen-based publication forms.

2. Technology and the collaborative experience

In addition to the role of software in facilitating collaboration in the production of illustrations, animation software provided a platform to demonstrate the morphing of the BCS illustrations as an additional resource that aided in communicating the extent of physical change in the BCS range. Animation was originally a function of the illustration process to ensure consistency, and through collaboration became a resource on its own.

3. Technology and the dissemination knowledge

New media platforms enabled the publication of static and animated content in context of other resources, including: photographic libraries to text-based descriptions. Publishing electronically provided a more comprehensive resource that could be expanded or amended based on the need of the research.

The historically founded link between art and science has greater scope for inquiry and outcomes through the use of technology. The practice-base knowledge of the Natural History Illustrator is technical, creative and conceptual; this knowledge is transferable into technology platforms for image capture, construction and application. It is in the understanding of NHI practice that the sciences can embrace the practitioner and technology in cross-disciplinary research.



The Sixth Shore project: baler twine residue on farming property at Lake Clifton: human complexity and waste (detail)
© Perdita Phillips. Used by permission

Consciousness, quantum mechanics and the Metaphase Typewriter revival project

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I make artwork that engages with quantum mechanics to enable the viewer to doubt conventional reality. Quantum mechanics gives significant cause to doubt conventional reality. Rather than reality being knowable, objective and mind-independent, one quantum theory poses the confronting possibility that reality is brought into existence through observations, even, controversially, by consciousness. My 'mind works' projects, one of which is the Metaphase Typewriter revival project, enables a viewer to doubt conventional reality. Specifically, the 'mind works' projects do this by providing the viewer opportunities to interact with events of quantum superposition, using only consciousness, to arguably affect or even create material reality.

Since 2009, I have been making mixed media artworks based on concepts of quantum mechanics. My PhD research examines how visual art that engages with concepts of quantum mechanics can enable a viewer to doubt knowable, mind-independent, objective reality. As a specific part of that research, my 'mind works' projects [1] make a substantial assault on ideas of conventional reality. They suggest the possibility that there is a primary role for the observer in obtaining information about the world. Further, based on some accounts, they suggest that that the observer's consciousness could be the agency by which fundamental quantum particles move from states of superposition into material reality. [2]

The basis for this claim is that, they provide actual quantum random events [3] with which the viewer can interact to affect or, arguably, create material reality. The viewer has an immediate sense that if their own consciousness can affect or create material reality, then

conventional reality must be more than an objective, material, mind-independent world. The 'mind works' projects represent both metaphorically and, arguably, literally physicist John Wheeler's idea of a 'participatory universe'; that we participate in creating the reality we experience. [4] In this sense, it could be said that conscious observation equates to physical matter. The 'mind works' projects present opportunities for the viewer to directly interact with them, allowing expectations of conventional reality to be potentially ruptured. I have undertaken three separate 'mind works' projects. The first of these, and the subject of this paper, is the Metaphase Typewriter revival project.

Background to the Metaphase Typewriter revival project

Quantum mechanics is the fundamental explanation of how physical matter is created and behaves at the subatomic scale. It is the basis for the explanation of the scheme of things in our universe. However, it is totally at odds with our usual experience of a 'conventional reality' that is knowable, mind-independent and objective. [5] The quantum world forces us to see that reality is a concept much broader than one simply based on our own perceptions; a world that is, possibly, much more subjective and relative than we realise and one that may be interconnected in ways that we cannot yet conceive.

In part, my research into how visual art that engages with quantum concepts, might enable a viewer to doubt conventional reality, aims to respond to a decades-long call from parts of the scientific community for a re-evaluation of 'conventional reality'. [6] This call is based on the fact that quantum mechanics conflicts with the notion of a



Figure 1. Lynden Stone *Metaphase typewriter revival project* 2012, Geiger counter, gas lamp mantle, laptop, program, Perspex cover, dimensions variable, installation view. Photograph by Carl Warner.



Figure 2. Lynden Stone *Metaphase typewriter revival project* 2012, detail of Geiger counter



Figure 3. Lynden Stone *Metaphase typewriter revival project* 2012, installation view

knowable, mind-independent reality in fundamental and shocking ways. In contrast to the macroscopic conventional reality I perceive, in the subatomic quantum world there is no physical matter as I understand it. Rather, according to the accepted formulation of quantum mechanics, pre-material states of connected multiple possibilities (states of 'superposition') exist. These superposed states, according to conventional views, are collapsed and brought into definite states of singular material reality through observation or measurement. [7] Rather than reality being knowable, objective and mind-independent, quantum theories pose the confronting possibility that there is a quantum realm imperceptible to and unknowable by me and that the reality I experience is brought into existence through my observations, even, controversially, by my own consciousness. [8]

In the macroscopic world we live in, we do not readily observe quantum superposition; [9] it appears to have collapsed into single material actuality. The process of how and why quantum superposition collapses (if, in fact, it does) is not presently understood by science. Various theories of how the quantum superposed state of multiple possibilities resolves into a single state of actuality that we experience can be grouped into two propositions: either quantum superposition does collapse or it does not. The main competing collapse theories propose that collapse is caused by either the act of measurement or observation (regarded as the orthodox theory of collapse)[10] or the specific mind or consciousness of the observer,[11] or by mixture with the macroscopic environment (without the necessity for an observer).[12] This last theory of environmental collapse attempts to retain some level of physical objectivity into the idea of quantum mechanics but the mechanism for this collapse theory is yet to be satisfactorily explained and increasing experimental results in demonstrating quantum superposition at scales now readable with the naked eye [13] means the line between superposition and collapse is unclear.

If observation or measurement causes

collapse of pre-material quantum superposition into physical reality, then quantum theory is an empirical theory and there is no physical reality beyond observation and measurement.[14] Some mathematicians, physicists and theorists have extended this theory to suggest that the agency of the observer's mind or consciousness causes quantum collapse.[15] Further still, a highly controversial theory by a handful of physicists proposes that consciousness is the method by which quantum superposition collapses into singular material reality.[16] Accordingly, it is possible that through our consciousness we have a fundamental role in creating material reality.

The Metaphase Typewriter revival project

In the Webb gallery at the Queensland College of Art, Brisbane, a laptop, its keyboard covered with black Perspex, is installed on a plinth. The viewer approaches the laptop screen, drawn in by its sound, a blinking red light and continual lines of green "0"s, "1"s, numbers and text arriving at the bottom of the screen. Eric, one of the laptop's the text-to-voice readers sonorously announces the lines of words that appear against a black background. The Perspex reflects the lines of numbers and text. A constant clicking accompanies the appearance of the '0's and '1's. In front of the laptop, a silver box contains a gadget with a blinking red light. The viewer reads a notice affixed to the wall:

Use your mind to affect the output of words and sentences.

Concentrate on the output of "0"s and "1"s being generated at the bottom of the screen. Relax and be confident that you can affect the generation of these numbers to produce the words you want.

The *Metaphase Typewriter revival project* (2012) (figures 1, 2, 3, and 4) offers an opportunity to the viewer, through interacting with quantum random events, to test the idea that consciousness might collapse quantum superposition to affect or even create material reality.

For the *Metaphase Typewriter revival project*, I collaborated with American physicist Nick Herbert and programmer M.U. Shrooms. In 1970, Nick Herbert built a communication device, the "Metaphase Typewriter", to test the ability of consciousness to probe quantum states to produce material outcomes. It comprised a radioactive source, a Geiger counter, a room of computers and a tele-typewriter. A computer program converted the frequency of random intervals of radioactive decay at the quantum level into an output of letters from the tele-typewriter based on their frequency of occurrence in the English language. I read about Herbert's metaphase typewriter in 2011 in David Kaiser's book, *How the Hippies Saved Physics* [17] and subsequently contacted Herbert, seeking his imprimatur to re-create his device as an artwork using contemporary technology.

My device contains a radioactive source (a gas lamp mantle) and a Geiger counter (figure 3) that is connected to a laptop computer via a USB. Reading the radioactive decay (a quantum event) random bits are generated by the Geiger counter. These bits are then converted, via Shrooms' program, into a number range that represents a word in a word list. The list is a modified version of the *Corpus of Contemporary American English* (a word list compiled by Professor Mark Davies at Brigham Young University for which we sought permission to use). [18] The more frequently occurring words have a wider number range. Less frequent words are represented by a smaller number range or by just one number. Shrooms' program allows for the possibility that, as random words are produced, simple sentence structures may form.

The frequency of decay does not strictly equate to the frequency of the word in the word list. The radioactive decay as read by the Geiger counter is simply a random event that produces a random number. It does not reflect the time interval between each decay event. We would need to know the number of particles available and usual/average rate of decay to add this into the program. So, to

affect the output of a single word, consciousness must, in theory at least, interact with the device at each bit generation to effect a specific result.

During my exhibition *No Singular Reality* [19] in April 2012, where the *Metaphase Typewriter revival project* was exhibited, a viewer told me that, after spending time with the device in the gallery, it had “spooked” her “to the core” and she did not want to go near it again. She had perceived a connection with the output of words and her mind that had terrified her.

When this work is exhibited, the outputs are also streamed live to the Internet via the website www.damon.com/mtrp (where all outputs from the project can still be viewed on that site). One friend in America who interacted with the device over the Internet, reported to me that the words produced by the device had relevance to what he was thinking and intending, and he meditated in a connected state with the device for some time. My own revelatory experience with the *Metaphase Typewriter revival project* was unintentional and unexpected. In April 2012, I worked late into the evening to de-install the exhibition. I left the Metaphase Typewriter running while I was taking down other artwork, patching holes in the wall and re-painting. I liked the sound of Eric reading the words and sentences as they arrived in cadmium green on the black screen of the laptop. As the gallery emptied of work, Eric’s voice became more resonant in the space. He kept me company for several hours. Finally, there was nothing left to do but to shut down the program and turn off the computer. I was strangely reluctant, and maudlin. I did not want to end the process, to shut off Eric. I killed the switch. Reflecting later, Eric’s last output that night was oddly reflective of my own thoughts: it was “i, i the death into”. If the interactive elements of my ‘mind works’ projects do work to direct conscious intention and will to affect physical reality, they defy conventional reality.

Does the Metaphase Typewriter work?

If consciousness is an agent in quantum

collapse of pre-material states to material reality, is it possible for a viewer of the *Metaphase Typewriter revival project* to intentionally engage their consciousness in this process? Scientists have nominated specific processes through which our brains and minds might interact with quantum processes to collapse quantum superposition into experienced reality. The least radical of these ideas is that of mathematician Sir Roger Penrose and anaesthetist Stuart Hameroff. [20] Their model proposes to explain how consciousness, as an emergent process, arises from quantum states in the brain and how quantum superposition might be collapsed in the brain. This process, they say, occurs in brain microtubules that remain in superposed states until they self-collapse through a procedure involving quantum gravity. The collapse “creates an instantaneous ‘now’ event. Sequences of such events create a flow of time, and consciousness.” [21] In 2010, a team from the University of Queensland and the University of Sydney claimed to have disproved one of the bases on which the Penrose-Hameroff model was premised but conceded that a revised model might still be plausible. [22] Penrose and Hameroff responded to this and other criticisms but still hold to the general precepts of their model. [23]

The Penrose and Hameroff model (as one of self-collapse depending on quantum gravity processes) does not deal with the issue of volition in superposition collapse. Physicists Evan Harris Walker and Henry Stapp, however, have proposed separate specific methods by which our brains interact with quantum states resulting in chosen material outcomes. In addition, Director or PEAR Laboratory, Robert Jahn, and Lab Manager, Brenda Dunne, propose a model of mind-matter interaction that may be helpful for a viewer interacting with the ‘mind works’ projects. However, all of these models are highly controversial and not readily accepted among physical scientists.

Walker [24] suggests that electron tunnelling, occurring in the brain across synaptic gaps between nerve endings (representing a series of quantum events [25]), is the process that

carries out complex activities that creates our thoughts. [26] Using research on synaptic functioning, Walker took a quantitative approach to identify three separate rates of data processing occurring across these synaptic gaps. The data rate for subconsciousness is one trillion bits per second; for consciousness, one hundred million bits per second; and for intention, the rate is ten thousand bits per second. [27] The final rate of data processing for will or intention in his model serves as a “will channel” for the expression of volition. He proposed that before observation, the state of a quantum system is described as a range of possibilities. In the brain, this range of possibilities arises in the synapses that have the potential to fire. The will channel, in Walker’s view, determines our thoughts and choices. However, much more controversially, Walker says that the will channel is the link between, on the one hand, our consciousness and quantum processes in the brain, and, on the other, the events in the material world external to our minds. Walker asserts: “our mind can affect matter”. [28] The “perfect observer”, he argues, will always get what he or she wants. However, we are not perfect observers because most of us lack “purity of mind” and are unable to distinguish the will channel from all of the other thoughts in our consciousness. [29] The will channel, he asserts, carries much less data than the other channels, and can be drowned out by the “noise” from the conscious channel of the mind. Therefore, there is far less opportunity to manifest intention. [30] However, in his view, it is nevertheless possible.

In a similar vein, Stapp [31] proposes that through quantum processes in the brain occurring around the synaptic cleft separating neurons, we can inject “conscious intentions efficaciously into the physically described world”. [32] Stapp proposes that consciousness in the form of free choices operates outside currently known laws of quantum mechanics or classical physics. However, he proposes a model of how conscious intention of the observer might bridge the causal gap between quantum indeterminacy and material outcome. Ordinarily, he says,

conscious intention of the observer does not dictate the result; usually, “nature” chooses one of the possible outcomes according to statistical rule. [33] While the observer can freely choose the questions to put to nature, an answer is returned subject to classical statistical requirements. In this way, conscious intent gets “washed out by the quantum elements of randomness.” [34] However, according to Stapp, this is not always the case; it is possible for conscious intention to dictate physical outcomes. He proposes a process whereby a rapid sequence of similar intentional acts through mental effort will cause, through the “quantum Zeno effect”, a holding-in-place of a “template for action”. The longer the template survives the more likely it will evolve and defeat other expected statistical probabilities. [35]

If the repetitions are sufficiently rapid then a well-known quantum effect, the quantum Zeno effect, will cause a long string of essential identical [processes]... This rapid sequence of events will, by virtue of the known quantum rules, tend to hold in place the associated template for action, and this will tend to cause the intended action to occur. [36]

Stapp equates the Zeno effect to the “watched pot never boils” idea; that is, that just watching something keeps it from changing. [37] Through this effect, Stapp proposes that the mind can intentionally prevent quantum state changes that occur in the brain by intentionally holding onto desired outcomes and overriding other possibilities. In this way, says Stapp, our willful choices cause specific objective outcomes. [38]

In contrast to Walker’s and Stapp’s propositions that *conscious* intention can affect material reality, Jahn and Dunne raise doubts that physical effects can be produced by direct conscious attention. After two decades of research into anomalous mind/matter interactions, they consider that evidence of conscious intention affecting material output is indeterminate. Instead, they propose that it is the “dynamic”

unconscious mind (also referred to as the subconscious, preconscious, non-conscious or implicit mind) through which anomalous mental influence can be achieved upon otherwise inaccessible material processes. [39] The dynamic unconscious, they say, is to be distinguished from the “procedural” unconscious processes that perform simple physiological and mental tasks. [40] Their research indicates that information exchange between mind and matter was more successful where experimental strategies disengaged the conscious mind but stimulated unconscious connection with the task. [41] In this regard, they propose that the dynamic unconscious may be accessed via a “fuzzy” altered state through methods, such as meditation, dream or trance, “where conceptual boundaries blur, categories fail, space and time evaporate, and uncertainty prevails”. [42]

Conclusion

I do not know if the *Metaphase Typewriter revival project* actually works to allow the viewer to affect or create the material output. I argue, however, that the *Metaphase Typewriter revival project* and my two other ‘mind works’ projects enable viewers to doubt conventional reality. Primarily, they do this in a direct and immediate way as devices that offer states of quantum superposition with which viewers can interact using only consciousness to, arguably, affect or create material output. A willing engagement with the devices brings to the fore, in the mind of the participant, the idea that consciousness might be able to affect the result. Ultimately, the viewer may fall back on, or never alter, their conviction in conventional reality, but the faculty of the device exists to enable the viewer to doubt conventional reality.

(opposite) Documentation and development associated with The Sixth Shore project: microbial mat material in shallow lake © Perdita Phillips. Used by permission

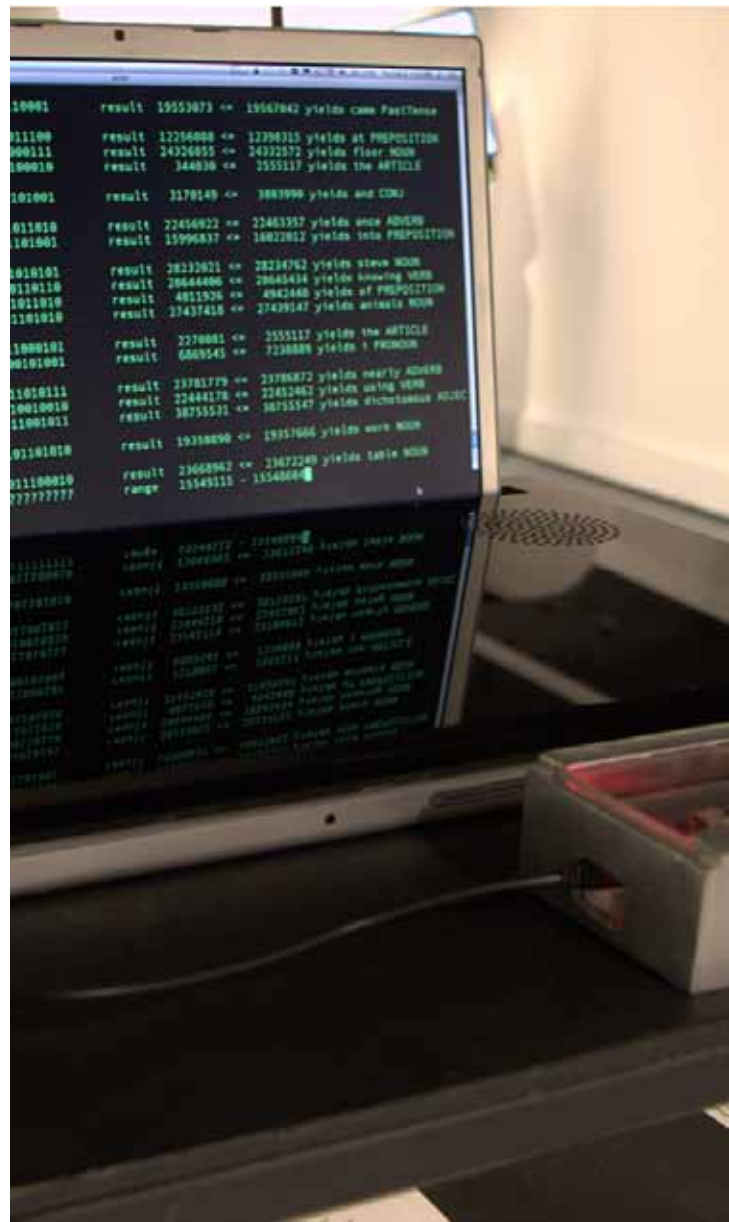


Figure 4. Lynden Stone *Metaphase typewriter revival project* 2012, Geiger counter, gas lamp mantle, laptop, program, Perspex cover, dimensions variable.



Geology, art and imagination: creative propositions for visual representation and cultural narratives

Suzette Worden [1] and Perdita Phillips [2]

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Artists who engage with the earth sciences have been able to explore all kinds of information about the natural environment, including information about the atmosphere, extremes of physical formations across immense dimensions of time and space, and increasingly 'invisible' realms of materials at the nanoscale. The results of this engagement are shown not only through the way artists and designers are developing innovative visual representations but also through the way images are combined with other media and/or through artists challenging the status of the visual through prioritising other media, such as sound. The ways in which artists have worked with geological data are a rich area for identifying the relationship between digital and material cultures. Many artists working with this subject are crossing boundaries and testing out the liminal spaces between the virtual and the real.

The catalyst for this paper was a discussion of historical examples, particularly the formation of a visual language for geology during the formal development of the discipline of geological science from the 1780s to the 1850s. This is represented by an examination of the work of Philip Rashleigh and John Ruskin.

Moving to the present, this will be followed by a discussion of themes being explored in the work of interdisciplinary artist Perdita Phillips, whose project *The Sixth Shore*, explores aspects of geological formations and the natural environment at Lake Clifton, Western Australia. Phillips works with spatial sound, presenting immersive sound environments in galleries and *in situ* (using GPS technology). How connections are made back to the material world and the consequences of meshing the visual and the

sonic will be analysed and discussed.

From this discussion we found contrasts in a move from the representational to the non-representational and changes in the use of classificatory systems. We also found increasing complexity - from belief in accuracy and perfection in beauty to beauty in complexity, resilience and failure. There are also differences in ethical engagement and through the more complex use of simile and metaphor.

Introduction

This paper considers both the development and the re-use of scientific data and imagery from geology and mineralogy. Explorations of geology and mineralogy provide a direct link with the physical environment and our comprehension of scale – the immensity of both of time and space and also the minutiae of elements and particles. Transformations are also dependent on physical change which can be violent and short-lived or slow and beyond the experience of humans. Geology and mineralogy call very quickly on imagination to comprehend both phenomena and explanation.

We propose that artists and critics produce imagery and data that have their roots in scientific processes and in addition emphasise interaction, cultural value and aesthetics for viewers. This is not to say that scientific data and imagery cannot be read and experienced as artistic and cultural, in a 'raw' state, but there may be different intentions in critique and affect where artists have additional cultural agendas.

Through a process of co-authorship for this paper we have considered relationships between the physical environment and mediated representations and how this is reflected

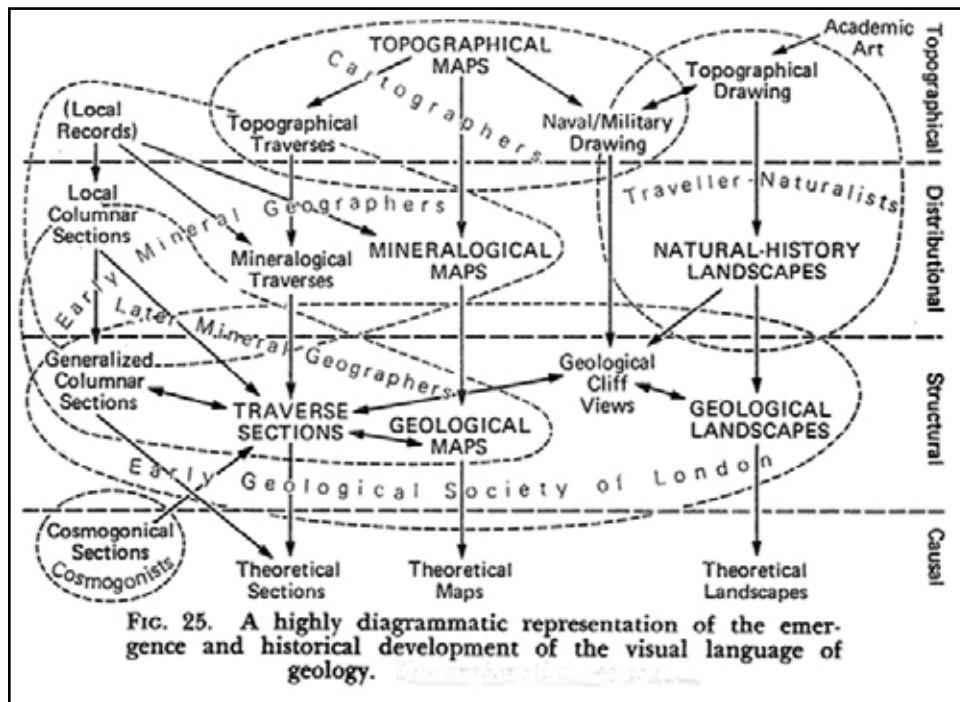


Figure 1. Diagram from M.S. J. Rudwick, "The Emergence of a Visual Language for Geological Science 1760-1840" *History of Science* 14, 149-195 (1976).

Figure 2. Rashleigh collection at the Royal Cornwall Museum Truro.

in choice of imagery and specific technologies for reproduction and presentation, with the starting point, being Perdita Phillip's project, *The Sixth Shore*. This site-specific spatial sound installation was one contribution to a larger project, *Adaptation*, managed through SymbioticA, an artistic laboratory engaged with the life sciences based at the University of Western Australia. Phillips' work combines visualisations of natural phenomena and storytelling being delivered through digital technologies. Besides the site specific sound installation, the *cusp* sound installation was part of the *Adaptation* exhibition at INQB8 in Mandurah, Western Australia, from 6th May to 10th June 2012. [1]

The Sixth Shore affirms the importance of creating a cultural map of an environment and of linking narratives to place. The work also highlights the importance of experience, metaphor and poetics, the concept of the transdisciplinary in the arts and sciences, and possibilities for transformation. It is possible to consider the work from several starting points. Comparison with other historical examples provide opportunities to speculate on enduring preoccupations, changes in emphasis or the specifics of our present preoccupations with ecological and environmental change. Martin Rudwick's overview of the visual language for the geological sciences from 1760 to 1870 shows the emergence of a rich visual language that has continued to expand in response to the growth in knowledge and emerging media forms and technologies.[2] [Figure 1]

Classification and Illustration: Philip Rashleigh (1729-1811)

Philip Rashleigh was a Cornish Antiquarian and mineralogist who, from 1764, collected mineral specimens from local miners and built up a collection of minerals. [3] He corresponded with many other European mineralogists, such as Swedish mineralogist, Axel Fredrik Cronstedt (1722-1765) who developed the use of the blowpipe for the chemical analysis of the composition and chemistry of minerals. Rashleigh never embraced chemical analysis, claiming that his age and

lack of resources prevented him in keeping up with such experimental work. Instead, Rashleigh concentrated on collecting and setting up his own system of classification. He created a significant portfolio of illustrations to educate and inform others about his collection and especially their natural colour. [Figure 2] His collection, which reached over 3000 specimens, passed to a nephew and then became part of The Royal Cornwall Museum in Truro in 1902. [Figure 3]

Rashleigh, like many other mineralogists, assisted in the communication of information, but stayed within the 18th century picturesque tradition of representation. Rudwick prioritises communication through maps in his schema but Rashleigh's work crosses between the arts and science for communication and also feeds into the expanding world of classification, notable in 19th century scientific knowledge and in museum collections which were equally relevant to the arts and the sciences from the 19th century onwards. The collection of minerals is available for viewing in The Royal Cornwall Museum in Truro, and many of his annotations are still associated with the minerals. There is also information on the context of his collecting alongside some information on his personal circumstances. Minerals from his original collection are also part of the display at the Natural History Museum in London. [Figure 4]

Although Rashleigh's collection is part of displays at two institutions, The Royal Cornwall Museum in Truro and the Natural History Museum, it is one of the very few private collections to have survived over two centuries. It therefore provides valuable insights into the juxtaposition of collecting, classification and also how to communicate knowledge, through illustration and display about minerals. Information about connections and comparisons are there to be interpreted through a collection. Rashleigh meticulously collected specimens from local mines that no longer exist and were only worked for a short time so many of the minerals can never be able to be collected again. The value of the collection today is in



Figure 3. Rashleigh collection at the Royal Cornwall Museum Truro, showing illustration and minerals depicted in Specimens of British Minerals selected from the Cabinet of Philip Rashleigh, 1802.



Figure 4. Commentary on specimen collected by Philip Rashleigh in mineral display at the Natural History Museum, London.

the specificity of information. It is highly representational and compared to the following examples, seems utilitarian and even though informed by the picturesque, 'absolute' and realist in its conception of beauty.

Ethical instruction: John Ruskin (1819-1900)

John Ruskin was a highly prolific critic and art historian who was also interested in geology and mineralogy. Like Rashleigh, Ruskin also fits into Rudwick's 18th century picturesque tradition [Figure 1] but he would also have contributed to the topographical drawing section of Rudwick's diagram and would have moved through the distributional and structural sections to look at causal conditions within geology. He provided theoretical interpretations for the arts and the sciences and attempted to integrate both sides of his interests.

Ruskin is well known as a supporter of the art of J.M.W. Turner and then the Pre-Raphaelites. He was also a political economist interested in social issues as well as the arts and crafts. With immense private means, he was able to travel and wrote about the geology and arts of the places he visited in the British Isles and Europe. He was a pupil of Rev. William Buckland (1784-1856) at Oxford. Buckland's theories about geology kept in line with Biblical stories of creation so did not embrace Darwinism. Cramer posits a connection between his studies under Buckland and his formulation of the concept of 'vital beauty.' [4] Ruskin's interest in geology led him to become a Fellow of the Geological Society of London in 1840. Ruskin's work on geology was frequently published and his view of geology was considered alternative to the mainstream, with much of his work considered 'professionally current.' [5]

Ruskin's geological interests are an important part of his five volume study, *Modern Painters*. These volumes were written between 1843 and 1860 and showed his appreciation of painting totally integrated with his love of landscape and particularly of mountains. The second volume was full of description of the Alps and their geology. [Figure 5]

Ruskin considered that Turner's paintings could give factual information on rock types and formations but he suggested that the power of the artist provided further value. For Ruskin, Turner created 'not so much the image of the place itself, as the spirit of the place.' [6] In 1866, *The Ethics of the Dust: Ten Lectures to Little Housewives on the Elements of Crystallisation* was published. This was a discussion of mineralogy with didactic overtones and show Ruskin's attempt to teach political economy and praise virtue using scientific information.

Ruskin used information about crystals, mineralogy and geology to bring moral and religious questions together. For him the quality of mutability was important, with rocks as images of change overtime. Also, rather than organic creation, with artwork being considered to grow from a single germ, his understanding of minerals draws attention to the idea of an array or a constellation, which is ordered in itself and can be extended in infinite ways. There is therefore order within disorder. [7] Ruskin's work had a strong social message and he was interested in education for all. The Collection of the Guild of St George, which was put together under his direction, from 1875, as a creative and educational tool for the metalworkers of Sheffield, UK, included over 2000 mineral specimens. The minerals were part of a collection that also included coins, and drawings and illustrations of architecture art works, and all kinds of natural forms such as landscapes, birds and flowers. Ruskin's ability to make connections between art, people's actions and the physical world are examples of an ethical way thinking that offers useful lessons for the present.

The Sixth Shore

Returning to the *The Sixth Shore*, the project revolved around creating a sound-landscape of the human and non-human worlds that overlap the brackish water ecosystem of Lake Clifton in the Yalgorup National Park in south west Australia. The lake is home to the largest non-marine thrombolite reef in the southern hemisphere, and yet few even know it exists.

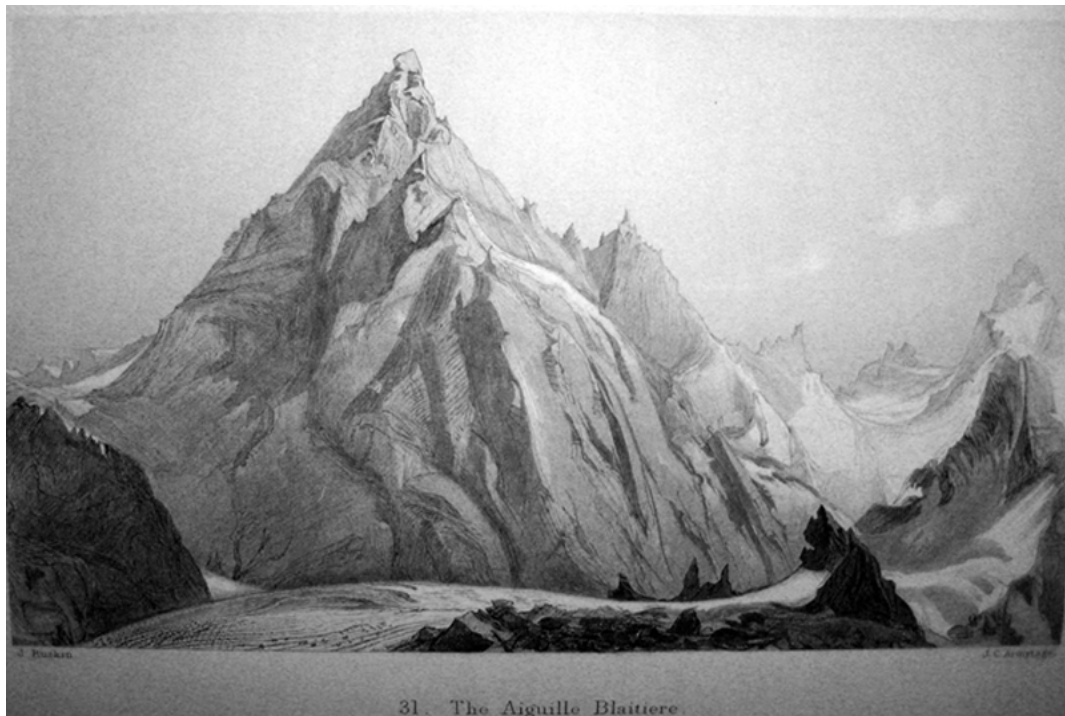


Figure 5. The Aigiulle Blaitiere. c. 1856 by John Ruskin (1819-1900). Drawing with wash. From J. Ruskin. *Modern Painters*, volume 4, (1856).



Figure 6. Thrombolite clotted structure. Image courtesy of Katherine Grey © Geological Survey of Western Australia

Thrombolites are made up of a complex community of micro-organisms, including cyanobacteria, cemented within detritus and other collected mineral sediment.

Cyanobacteria fix carbon dioxide to make their own food source by photosynthesis. Part of the living process is the precipitation of calcium carbonate as the mineral aragonite. The combination of the organic and mineral material gives mass to the colonies. Over time they grow and solidify into rock-like round or conical structures. Other forms of microbial colonies such as stromatolites have been linked to the generation of the Earth's first oxygen atmosphere. Microbialites thus embody the idea of a mineral/vegetable thing that crosses the boundary between the living and non-living worlds. Unlike other microbial structures, thrombolites are distinguished by a clotted structure. [Figure 6]

Phillips used the visual trope of these structures in her work. As part of her investigations she 'drew out' further visual examples of networks and reticulations. [Figure 7] She also investigated the environmental interactions surrounding the current conditions at the lake. Thrombolites have been growing in Lake Clifton for nearly 2000 years, but in recent years the fragile ecosystem has come under increasing threat due to nearby development, clearing, increasing water salinity and decreasing regional rainfall caused by climate change. [8]

In the surrounding landscape, groundwater extraction by turf farms and hobby farmlets affect the lake through changing groundwater regimes. Tuart woodlands are also declining due to these issues and an introduced fungus, *Phytophthora multivora*. [9] Organisms and ecosystems that have survived through thousands of years of change are now under threat from our actions after just 100 or so years of co-existence, and must adapt, or die. Lake Clifton can thus be seen as a hotbed of diversity surrounded by a rich 'human ecology'. It offers a 'microcosmic peek' into the issues and threats that the world faces, and presents a metaphor for the global

systems of a planet in crisis. [10] Phillips expands the notion of the geologic to the level of ecosystems, places and beyond.

In order to express the complex web of issues and timescales and expand notions of agency amongst human and nonhuman actants, the artist formulated six overlapping areas of concern:

Shore 1: thrombolitic time (deep, geological)
Shore 2: shifting shores: lake formation and seashore changes (geomorphological time)
Shore 3: cultivated landscapes: indigenous cultures (older than the lake itself)
Shore 4: settler cultures (since the 1830s)
Shore 5: bird migration and hooded plovers (global in scale and dependent upon annual seasons and longer-term climates)
Shore 6: futures.

Central to this project is the inter-digitation of the shores. The final (sixth) shore, of multiple futures brought together, is about how the previous shores are imbricated with their competing interests. The classification is incomplete. *The Sixth Shore* is unresolved and subject to negotiation: it expresses the potential for transformational futures. Whilst its origins are in the visual, the artist has chosen to manifest the project via overlapping soundscapes. Phillips uses sound recorded at Lake Clifton, local oral histories and interviews, sound samples and the sonification of scientific data such as climate statistics and bore hole data. An important aspect is that the samples and narratives are spatially arranged.

The cusp work exhibited at INQB8 gallery in 2012, was a part-realisation of this project in a gallery space. In this exhibit, listeners heard different sounds as they walked through a 5 x 5 metre area via 12 speakers. In the *in situ* work at Lake Clifton, the audience will wear a backpack with a specialized GPS and headphones with embedded compass in the final artwork. Within a 50 x 50 metre area different sounds will be localized so where the viewer walks and how they orient their heads will determine what they hear. Each walker will determine their own unique experience of the different sounds and



Figure 7. The Sixth Shore (2010) altered digital image of saline lake froth (with additional ink on digital print) © Perdita Phillips



Figure 8. Lake Clifton thrombolites (2009) digital photograph © Perdita Phillips

narratives. Both works engage with the physical and social environment whilst challenging the participants through the conceptual 'interference' of different levels of time and space in the soundtrack. *The Sixth Shore* project as a whole opens an important dialogue and debate surrounding human inaction, intervention, responses and responsibilities to the world at large. The expectation of performativity includes the participation of the audience in an active way. They are not expected to view the work from the 'outside' but become immersed in the experience and its concerns.

By being *in situ* the final work generates a heightened play of dissonance and complementarity between what is seen and what is heard. It is the centrality of walking through the site that adds further richness to the experience and enables the contemplation of a living ecology. Through hinting at an active agency for the thrombolites, the artist questions the 'deadness' of rocks and emphasises the vitality of nonhuman worlds. [Figure 8]

The Sixth Shore works form a complex aesthetic. Whilst it is true that landscape has been a preoccupation of Australian visual artists since colonization, the recent quickening of the intensity of environmental change, points to the need for renewed examination of the perception of, and more fundamentally, the consumption of, landscapes. Place-based art makes use of concepts such as site-specificity but often fail in the level of sophistication of its philosophical or even ecological framework. For example, much environmental art is still based upon the romantic appeal of the idea of a 'balanced nature,' despite considerable evidence of the dynamism and complexity of ecosystems in nature. Recent research into resilience connects complexity theory and ecosystems with communities and social systems. [11] *The Sixth Shore* project actively engages with newer socio-ecological thought.

Phillips takes from Sacha Kagan's exploration of transdisciplinarity as 'the recognition of the existence of different levels of reality governed by different types of logic.' [12]

Science and art are considered different but equal systems. Scientific information is both being critiqued and integral to the work. Phillips critically navigates the power structures of science and society, where existing socio-ecological systems are not sufficiently engaged to bring about change. The aim is to enable and encourage people to be 'imaginatively engaged.' In this sense the work is a form of facilitation and an opportunity to deal with uncertainty, imperfection, risk and opportunity. Phillips has interpreted the scientific knowledge on thrombolites, along with the changing sea levels and coastal deposits, to arrive at metaphorical implications that influence the sound world she is creating. This is a complex story which enriches the 'sense of place' of the area. [13]

Conclusion

Revisiting Rudwick's chart for the emergence of a visual language for geology, it has been possible to draw out the significance of collecting and classification, with the example of Rashleigh working at the cusp of a change, where visual evidence was being augmented by chemical analysis. Ruskin was also highly reliant on visual evidence and direct experience of geological phenomena but to this he also adds the voice of the critic and combines aesthetics and science with morality. Moving to the present, Phillips' *The Sixth Shore* provides the audience with experience beyond the voice of the critic and possibilities for reflecting on and engaging with the cultural aspects of geological knowledge. Ecological questions are raised. Information on geological formations is placed in the wider context of the surrounding environment and complexity, resilience and failure are acknowledged within a viewpoint that offers the viewer/participant a more autonomous engagement. There are similarities in this approach to the interest in human and non-human connections and the 'geologic turn' explored by authors such as Ellsworth and Kruse [14].

These very different examples of collecting, illustration, ethical interpretation and immersive experience of minerals and

geological formations show that understanding the specific and integral cultural narratives are essential to appreciation of the artefacts. The examples can be related to current discussions of the relationship between human and non-human (here minerals and rocks) and also to the emerging debates about responsibility and the 'Anthropocene' where 'Humanity's recent activities can be measured now at a scale commensurate with the geomorphologic narrative of the planet.' [15]

The Anthropocene began approximately in the late 1700s with crucial technical leaps and the Industrial Revolution. Ellsworth and Kruse go as far as to define the 'geologic now' as 'a teaming assemblage of exchange and interaction among the bio, geo, cosmo, socio, political, legal, economic, strategic and imaginary'. [16] If humans are therefore becoming understood as a 'geological' force in an epoch of geology, our ability to 'read' geology, and our understanding of the history of the concept, becomes increasingly important, especially for understanding time.

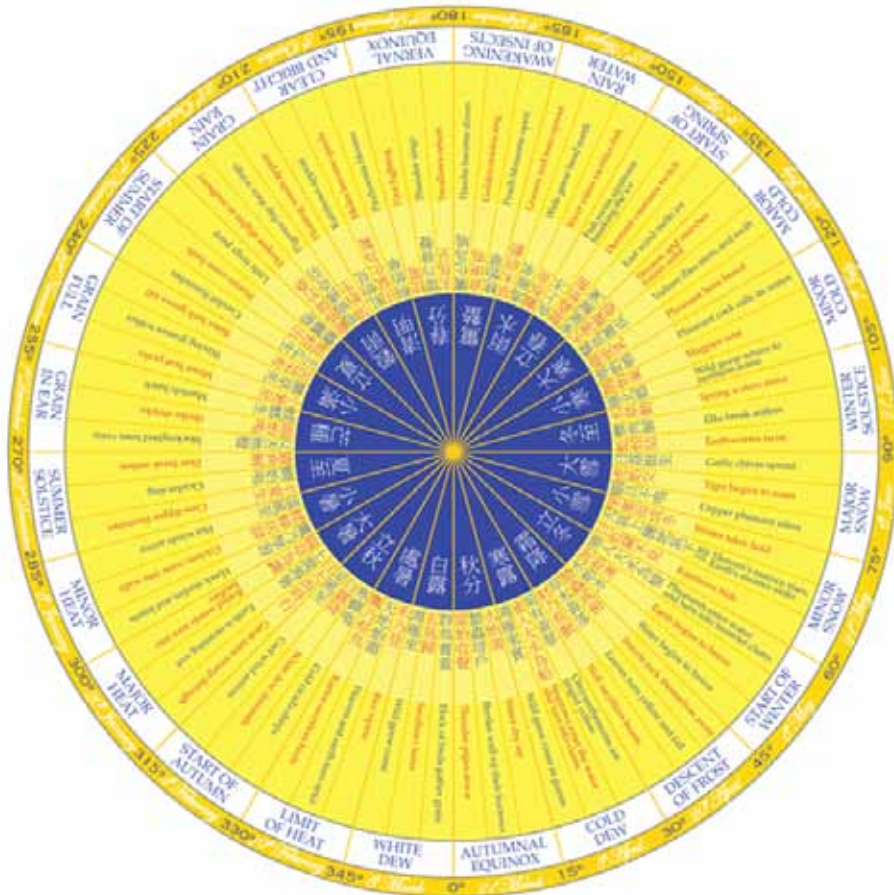


Figure 1. Illustration from The Illustrated Almanac of the Illawarra and Beyond (see overleaf)

Imaging the Seasons: Objects and the Almanac Form

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An almanac is an ancient tool, a scientific instrument for mapping experiences of the physical environments and organising them into familiar and predictable patterns, making sense of past, present, and future. It provides a grounded engagement with the material world and objects through a structure based on observations. One of the earliest almanacs known in Europe was written by Roger Bacon in 1267, where tables showing the movement of astronomical bodies and constellations were used for a whole host of human activities. The Chinese Almanac similarly uses the observed movement of the heavenly bodies for the purpose of time-reckoning. [2] Embedded in the imperial calendar (皇曆), an important official publication, the Chinese lunisolar calendar or agricultural calendar (農曆) advises suitable activities for the emperor and all his subjects. [3] For 'the son of heaven' (天子) it provided a divination reference to all things between heaven and earth. For his agrarian subjects it was an essential 'to-do' list for planting, harvesting, and other related tasks. Still in use today, the Chinese Almanac divides each solar year (歲) into twenty-four solar terms (節氣) as determined by the sun's positions on the ecliptic (figure 2). [4] Each solar term lasts fifteen days and marks a significant point in the season, imminent weather occurrences, or significant agricultural events as observed in ancient China. Their notations connect astronomic and atmospheric conditions, such as rain water (雨水), summer solstice (夏至), limit of heat (處暑), or major snow (大雪), directly to agricultural activities, animal behaviours, and plant growth cycles. Each solar term is subdivided into three pentads (候 or five-day periods), totalling seventy-two (figure 1). [5] These subdivisions make further note of occurrences such as, when 'wild geese arrive' (鴻雁來), 'chrysanthemums tinge yellow' (菊有黃華), or 'earthworms form knots' (蚯蚓結). The almanac pays close attention to

the world of matter: soil properties, topographies, daylight hours, weather conditions, insect reproduction cycles, migratory bird patterns, enabling the effective implementation of agricultural activities. Experiences of cyclical time are thus marked by the direct and active interaction with material constituents in this almanac form.

Ecologist and writer, Aldo Leopold also enacted this direct engagement with the material world in an almanac form. In *A Sand County Almanac*, he provides readers with intimate accounts of activities observed in the plant and animal worlds and their responses to the changing seasons in Wisconsin. [6] In Leopold's almanac, humans are a bit player in this broader world of wilderness. In developing his concept of land ethics, he equalises the status of humans with all things:

The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land... In short, a land ethic changes the role of Homo sapiens from conqueror of the land-community to plain member or citizen of it. [7]

More recently, philosopher Levi Bryant further extends this concept of wilderness ontologically to 'rescue this kernel from the domain of anthropocentric experience and transform it[...] wilderness would signify being as a plurality of agencies, without ontological hierarchy—one that might refuse any bifurcation of being into nature and culture'. [8] Bryant's aim echoes that of Leopold, he continues:

we need to cultivate modes of thinking that help us to become attentive to the alterity of things, the thinginess of things, and the differences that things themselves contribute independent of social construction, human intention, and human meanings. [9]

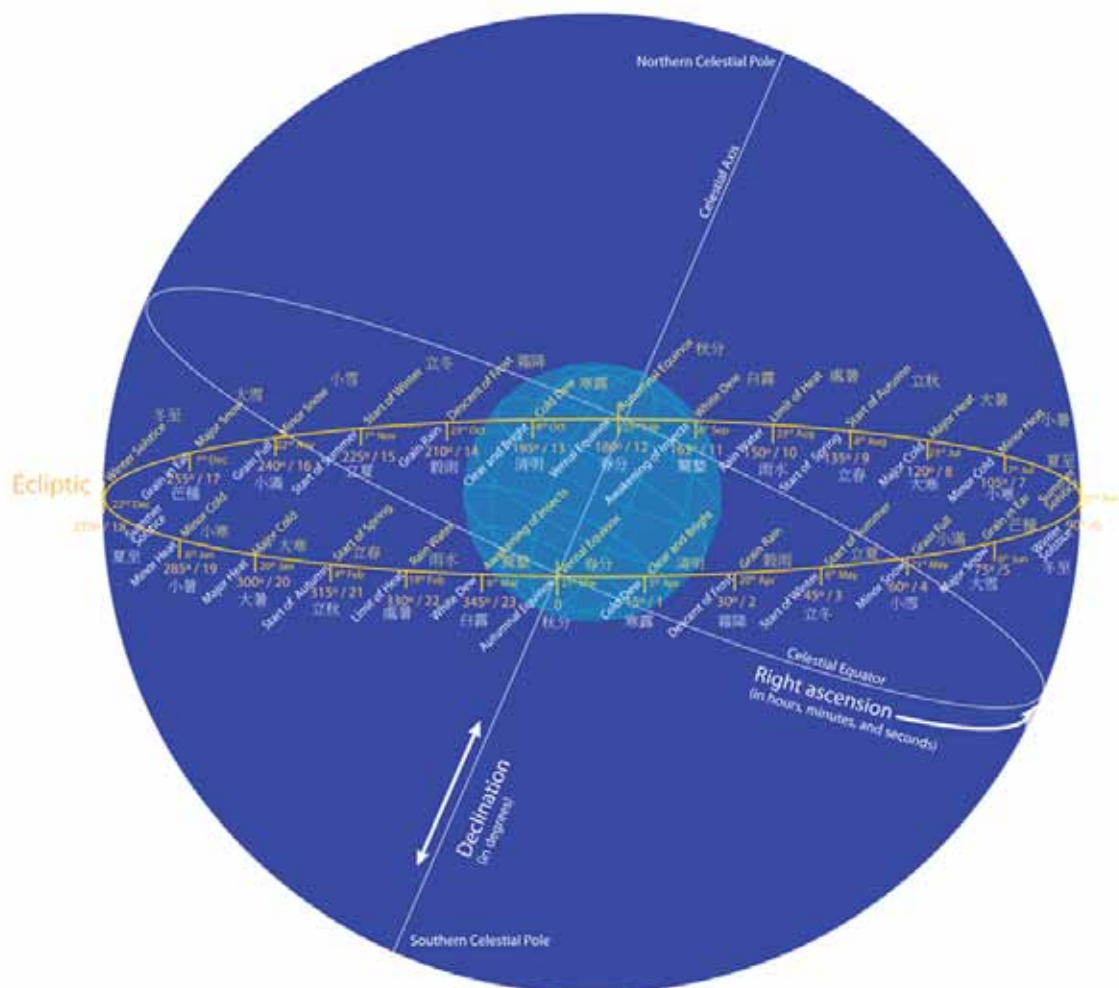


Figure 2. Illustration from *The Illustrated Almanac of the Illawarra and Beyond*

My almanac projects draw attention to the 'plurality of agencies' in each encounter in the material world by paying close attention to everyday objects in their changing surrounds. To date these projects consist of three works: the *Autumn Almanac of Tokyo* (2008), the *Seasonal Almanac of Austinmer* (2009) and the *Illustrated Almanac of the Illawarra and Beyond* (2011–2012). [10] The earliest work was created during my Australia Council Tokyo studio residency that took place between 5 September and 4 December 2008. All projects adopt the Chinese Almanac as a structuring device to affiliate each day with reference to seasonal occurrences. Both the *Autumn Almanac* and

the *Seasonal Almanac* consist of daily online postcards for the durations of the projects while one entry of the *Illustrated Almanac* corresponds to one pentad and seventy-two were posted over one calendar year (from Spring 2011 to Spring 2012). [11] Each post in these almanacs is composed of an image, created using selected materials gathered on the day or pentad: photographs, ephemerals, audio recordings, or video footage, and a textual exposition that drew upon things, objects, characters, experiences, questions, and thoughts encountered in the period of time. The *Autumn Almanac* was conceived as a tool to make sense of the encounter with Tokyo beyond the stereotypical imaginings of the

city. The combined use of visual (sometimes audio and moving) images and texts renders actual experiences tangible and explores the gaps that arise between the generalised perception of seasons and their materialistic manifestations in contemporary Japan, where a modern and modified form of the Chinese Almanac still exists. Rather than illustrating theoretic concepts, the almanac projects meditate on the materiality of our experiences. In contrast to weather data-driven artworks, such as Tim Knowles' *Wind-walk* (2008) and Cam and Yvette Merton's *The Little Optimum* (2003), that feed real-time weather data into the works in ways that affect the artist's or audience's immediate experience, the almanac projects' encounter with materiality is less direct. Rather, the projects make manifest experience as an aesthetic act of perception through encountering the world through things.

By adopting the Chinese Almanac as a structure for discursive entries, the almanac

projects pay attention to the 'plurality of agencies' in everyday encounters and their *zuihitsu* (随筆, literally meaning 'following the brush') approach provides opportunities to bring out narratives immanent within these experiences. [12] In this context, *zuihitsu* as a form of writing focuses on the interaction with seasons and surrounds through observation of objects in time, place, and transition. This practice is exemplified by Sei Shōnagon's *The Pillow Book* and women's diaristic tradition of tenth-century Japan. Shōnagon's work is believed to have been conceived as lists of seasonally and aesthetically appropriate objects to be used in poetic compositions. By layering the Chinese Almanac with the modern Japanese *sekki* (節気) the ninety entries of Autumn Almanac extend ancient categories of things to include objects like daikon, freezing rain, typhoons, kotatsu (a type of heater), water pipes, utagoe kissa (singing cafes – cafes where the customers take turns performing on a stage), trains, omurisu (rice omelette),



Figure 3. The Illustrated Almanac of the Illawarra and Beyond, Minor Heat: Hot Winds Arrive

postcards, laundry, haircuts, junk stores, art, architecture, and so on. Like Shōnagon's lists of poetic objects that situate her readers in specific places and times, things in the Autumn Almanac anchor the experience of contemporary Tokyo firmly to the tangible materials of everyday life through the use of the image.

Here, I turn to Walter Benjamin's development of *Denkbild* (thought-image) as a framework for further analysing the role of objects depicted in my online almanacs. In what follows, I shall digress briefly to explore the *Denkbild* form through Benjamin's writings. In *One Way Street*, Benjamin grasped the elusive experience of the modern metropolis through the *Denkbild* where image plays a central but covert part. [14] Karoline Kirst writes, 'Instead of clarifying a thought by means of an image in linear fashion, or vice versa, the *Denkbild* presents an image as an integral albeit not immediately recognizable part of the thought'.

Benjamin's literary *Denkbild* alters the Baroque emblem's tripartite structure by transforming the visual *pictura* into a textual image. Paul Stephens and Robert Hardwick Weston explain:

The inscriptio is generally preserved in the form of the italicized title, while the pictura, corresponding to the Denkbild's anchor in subjective experience, is collapsed into the subscriptio, making the visual imago a component of the exegetical text that traditionally explained it. On the level of content and style, the collapsing of pictura into subscriptio aims to forge a mental image through persuasive vividness, or anazographesis. [15]

Anazographesis, a practice of evoking emotional impulse through imaging (perceived or imagined), is apposite for framing the complex relationship between word and image within Benjamin's philosophy. [16] Caygill argues that this relationship is defined by Benjamin's concept of experience. Caygill writes:



Figure 4. The Seasonal Almanac of Ausitnmer, Start of autumn: cold cicada chirps

Benjamin's philosophy of the image is best understood through an examination of its place within the speculative philosophy of experience. Just as the critique of the word was transformed by the speculative concept of experience, so too was the critique of the image. The analysis of the image within a philosophy of speculative experience had considerable implications for the critique of the experience of images in the guise of art criticism and of art history. Benjamin argued that images should be understood as a technology for organising experience, and that visual art was a way of speculating upon the limits of experience from within. However, the technological organisation of experience through the image did not necessarily agree with the political organisation of experience through the word. [17]

In relation to the technological organisation of experience, Esther Leslie writes in reference to Benjamin's 'Work of Art in the Epoch of Technical Reproducibility' that, 'The

photographic object brings objects closer for inspection, providing an imprint of traces of the world. It reveals traces (*Spuren*), not of the potter's handprint, but of the objective modern world'. [18] This imprint is not a reflection but a trace, a texture, a material presence of the world that remains in the artwork. This translation of tactility into photographic form is important in thinking about how images function within the almanac projects. In what follows, I analyse three entries using the *Denkbild* form as a framework.

In a brief entry in the *Seasonal Almanac*, the *inscriptio* reads: 'Start of Autumn: cold cicadas chirp', 'February 15th, 2009'. The *pictura* shows a pair of dampened shoes in the bottom left-hand corner standing on an assortment of black pebbles; on the speckled ground are rocks, shell fragments, remnants of blue bottles (jellyfish), strands of seaweed, flotsam and jetsam; the shoes point towards the centre of the image where a



Figure 5. The Autumn Almanac of Tokyo, Shuubun: Beetles wall up their burrows/ Adzuki beans ripen

dead fish lies (figure 4). The *subscriptio* speaks of the experience of walking on the beach, the observation of rain, previous high tide, washed-up strap weeds and blue bottles. The diaristic form of an almanac is conducive to transference of actual experience into speculative thoughts for both writers and readers. These thoughts remain *unsaid* and subjective. They may suggest memories or imaginings of an Australian seaside, the weather of New South Wales' South Coast in February, or ocean temperatures that encourage the dominance of jellyfish species. Furthermore, the materiality of objects as depicted within the visual image recall unsaid sensations: the crunchiness of pebbles, the discomfort of wearing wet shoes, the texture of dead fish, the 'popping' of blue bottles' swim bladders underfoot. Instead of the 'collapsing of *pictura* into *subscriptio*', the *pictura* returns to a visual form and stands apart from the textual *inscriptio* and *subscription*. [19] On this open yet concrete platform, the *pictura* brings out

the alterity of things visually through anazographesis.

In a post from the *Autumn Almanac*, the *inscriptio* reads: 'Shuubun: Beetles wall up their burrows/Adzuki beans ripen, October 1st, 2008'. [20] The *pictura* shows a large body of fast-flowing water; it is night, the water is dark and reflects surrounding coloured lights (figure 5). The *subscriptio* presents a simple scenario in suburban Tokyo as tropical cyclones dissipated, and an unexpected encounter with an urban animal species—*tanuki* (*Nyctereutes procyonoides viverrinus*). [21] Many thoughts emerge from this assemblage that are *unsaid*. Non-human animals lose their habitats to the encroaching suburban development and seek refuge in the human-made environment. During the Autumnal Equinox in October, cyclones still pass through Japan, bringing with them heavy rainfall. Densely built areas need carefully planned drainage to channel storm water quickly and effectively.



Figure 6. The Autumn Almanac of Tokyo, Shousetsu: Heaven's essence rises, earth's essence sinks/ north wind, freezing rain

The *Kandagawa* provides the main waterway to take the rainwater out to Tokyo Bay. The tripartite fragment teases out the interconnectedness of the weather system, geography, and urban environments through physical things: Cyclones 0815 and 0817, neighbouring China, the *Kandagawa*, the neighbourhoods of *Takadanobaba* and *Shima-Ochiai*, rainfall, drains, busy roads, railway, and *tanuki*. The gushing water in the visual *pictura* occupies a central node in this enmeshed network of things. Its pictorial qualities: blackness, glassy surface, patterns of undulations, silence, enhance the materiality of things and suggest their agency without naming it. Within the image, to quote from Jane Bennett's *Vibrant Matter*, 'objects appeared as *things*, that is, as vivid entities not entirely reducible to the contexts in which (human) subjects set them, never entirely exhausted by their semiotics'. [22] The *pictura* provides an *other* path for thinking about temporal contexts framed by the *inscriptio* and the subject's experiences described in the *subscriptio*.

In one of the last entries in the *Autumn Almanac* under the *inscriptio* of 'Shousetsu: Heaven's essence rises, earth's essence sinks/ North wind, freezing rain' dated 'December 1st, 2008', the *pictura* presents an impressive pile of junk that fills the entire frame, lit by a strangely warm yellow-green glow. [23] The *subscriptio* describes a pleasant expedition to visit a new acquaintance in the *Akikawa* valley of Tokyo's far west. The written text describes what one may imagine to be typical of modern Japanese architecture and design: clever house renovation, stylish Japanese-Italian restaurant by the river, new *onsen* facilities, sharply contrasting the disorderly orderliness of the pile in the image. In the last paragraph, the reader discovers that the astounding pile is, in fact, the goods of a second-hand store run by a Korean migrant. The photographic image captures each and every object in sharp focus: in the bottom left-hand corner the bronze-colour folding chair casually leans on the pile, congregating nearby like stacks of kindling are neatly folded clear plastic umbrellas with curved white handles, a round

white tub wrapped in plastic sits prominently at the bottom centre of the frame, to its right is an orange enamel cook pot, above is a pale blue rectangular waste paper basket, to its left are an old-fashioned cypress and copper water bucket and its smaller counterpart for rice; the right of the image is populated by video tape decks, disc players, fax machines, and drawers of different types, the flat rectangular shapes cascade into a deep valley where a flattened white sports shoe with missing laces sits at its base. In the image, the objects emanate an innocence; in retaining their pristine appearances, their functions are clearly discernible. These photographed objects are no longer desirable commodities nor are they refuse; they sit somewhere in between, perhaps as desirable refuse. This clarity of the image captures the materiality of the junk pile.

The visual image in the almanac entries extends the contemplative process and draws out *what is unsaid* in the textual image. Specifically, the *pictura* transposes the materiality of objects into visual form, bringing out 'profane existence' of everyday experience.[24] Stephen and Weston write:

This element of everyday experience is central both to the Denkbild form and to denkb(u)ilding as discursive practice. As a mode of writing, to denkbild is to build up thought, to construct [bilden] thought, criticism, from the images of everyday life. [25]

Pictura in these almanac entries bring out the 'alterity of things' through observations, estrangement, and ambiguities. These ambiguities and uncertainties within the image make room for speculations, allow the 'thinginess of things' to proliferate as individual narratives. Unlike Benjamin's literary *Denkbild*, where the *pictura* is collapsed into the *subscriptio*, the generation of emotions and affects through *what is not said* in the almanac projects puts an emphasis back on the image. These narratives may illuminate the 'profane existence' of everyday experience and allude to an 'enigmatic form of something [that is] beyond [their] existence'. Objects within these images in the almanac

projects revealed everyday experiences in a new light. As Bryant argues:

art seems to carry the capacity to break with meaning, to bring the alterity and thingliness of things to the fore, to allow us to see them both from their point of view and independent of our own meanings and intentions. [26]

In conclusion, the almanac projects as art-works generate structures that interpret experience through encounters with objects. Aspects of these encounters are captured visually and textually. This framing de-familiarises the objects and 'allows an encounter [with...] the familiar things of our everyday

life in their independent thinginess' by bringing them closer for inspection and 'seeing them, perhaps for the very first time'. [27] By analysing the almanacs' entries using Benjamin's Denkbild as a framework, I reveal the role of objects within images in these works. In doing so, I hope to realise images' potential to illuminate subjective everyday experiences.

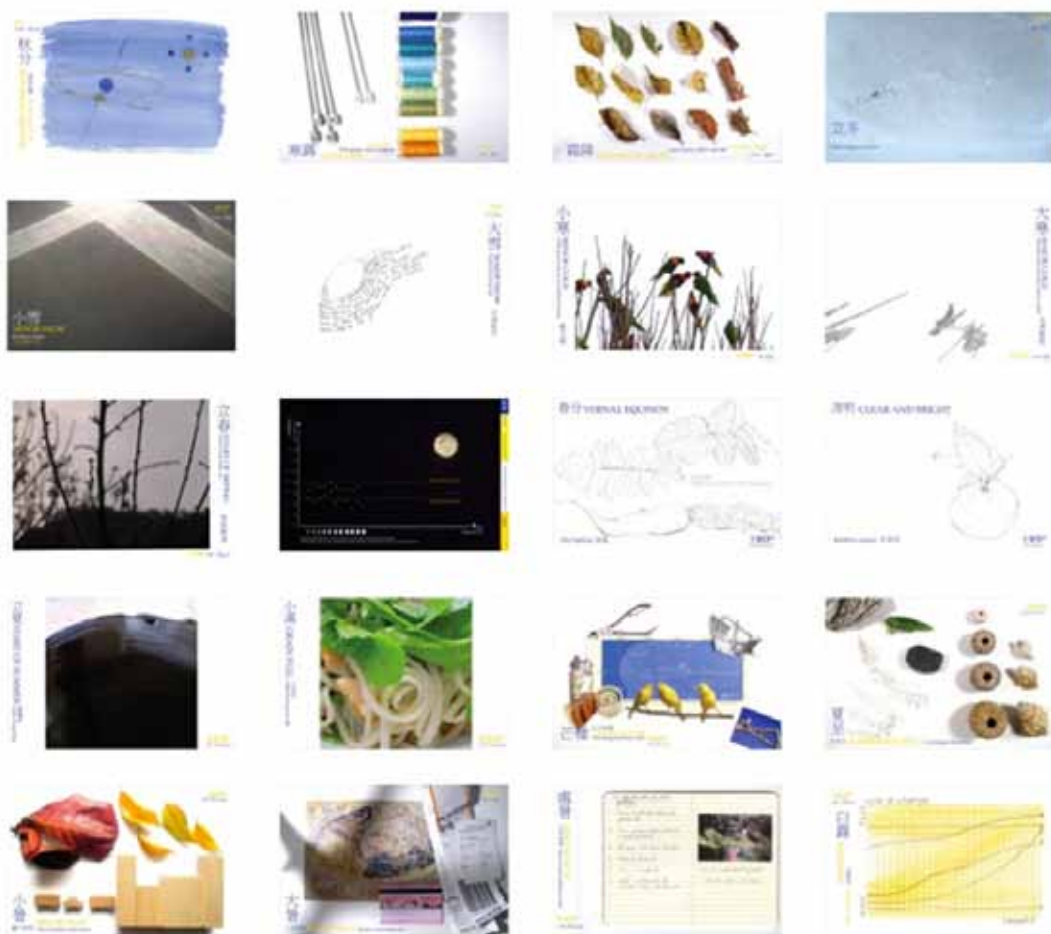


Figure 7. Collage of entries from The Illustrated Almanac of the Illawarra and Beyond

The Anonymous Photographers of Animal Ecology

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Science advances through the combination of theory and data; yet, it is often technological advancement that facilitates this relationship. When Galileo Galilei turned his telescope to Saturn in 1610, he claimed to have seen three bodies rather than a planet with rings. Although Galileo was lacking theory, as there was not a theory of planetary rings at the time, he was let down most by his data. Due to inadequate telescope technology, Galileo simply could not see Saturn clearly enough. Thirteen years after Galileo's death in 1655, Christiaan Huygens used a superior telescope to collect clearer data and concluded that Saturn, indeed, has rings. The history of science is replete with similar stories of new technologies or methodological advancements, which subsequently lead to the collection of superior or new types of data that in turn confirm or advance theory.

Wildlife research has not been excluded from this narrative. In the 18th century, the Italian scientist Lazzaro Spallanzani postulated that bats used sound to navigate; however, it was not until the 1930s that Donald Griffin was able to demonstrate bat echolocation with newly available ultrasonic sound detectors. This trend has accelerated over the past 20 years. As the price of robust digital technology has decreased, the modern wildlife researcher has begun to ask old questions in new ways, and ask new questions that traditional methods were not capable of answering. For example, satellite remote sensing techniques allow researchers to map and model species distributions that pre-20th century naturalists like Alexander von Humboldt or Alfred Russel Wallace would only dream, and advances in genetic methods have seen the development of whole fields of science like phylogeography. While these and many other technologies are great for scientists, one device in particular, the camera-trap, has led to changes that

transcend wildlife research.

Camera-traps consist of a camera, often housed in a weather-proof box, and a trigger mechanism to activate the camera. They are slightly misnamed in that camera-traps do not “trap” anything. Instead, the device captures a picture of whatever animal happens to trigger it without the researcher activating the camera or even being present. As is often the case when a new piece of technology emerges, it advances the field of science it is applied to; and the camera-trap is no exception. The difference with the camera-trap comes when we consider how it has, and continues, to affect culture more broadly. Thus, in this paper I will briefly discuss how the camera-trap is advancing wildlife research, how it is changing the way people engage with science, and how its development changed the world.

Advancing Wildlife Research

Answering questions in wildlife ecology requires an obvious though often challenging task of the researcher: to “sample” the target species. In this context, “sampling” may refer to collecting tissue samples, recording physical measurements of the limbs and/ or body of the target animal, or simply confirming that a specific species is present at a specific site through observing the animal directly or its signs such as scats and tracks. The type of sample required and the technique employed to collect said sample depends upon the question the

(Top) Figure 1: Camera-traps allow researchers to peer into the lives of animals and reveal events not captured using traditional techniques. Here a mother Swamp Wallaby “grooms” her joey. (Bottom) Figure 2: The use of camera-traps has traditionally been on mammals and birds, but recent developments have meant that they can now be used to survey reptiles. A major advantage in citizen science programs where potentially dangerous animals, like this Red-Bellied black snake can be encountered.

2011-06-03 9:11:13 AM M 5/10 9°C



2012-03-24 4:09:12 PM M 2/10 26°C



investigator is attempting to answer. While there are often multiple methods that one could employ to collect identical or similar data, no single device exists, including camera-traps, which can collect all types of data to answer all ecological questions. Thus, to differentiate between various methods that may provide suitable data, the wildlife researcher must assess resource constraints, ethical considerations, and methodological assumptions to maximise research success while minimising financial and environmental costs.

In light of the aforementioned sampling considerations, camera-traps have become an invaluable tool for the wildlife researcher. Firstly, while some studies have shown that the camera flash can cause some species to avoid camera-traps [1], they are ethically superior to live-trapping due to the well documented problem of trap mortality associated with live-trapping techniques [2]. Secondly, as an automated device, and despite the high initial cost, camera-traps are less resource intensive than other methods in both financial and personnel terms [3], only requiring researchers to deploy and retrieve equipment, and identify photos. Techniques such as live-traps, sand-plots, and active searches all require numerous researchers to be in the field for the duration of the study to collect data and maintain sampling devices, which greatly increase financial costs. Finally, measured in both number of animal detections and in providing positive identification of wildlife, camera-traps have been shown to be more efficient than alternative methods [4]. These advantages have solidified the use of camera-traps in wildlife research; yet, it is the photographic aspect that has opened the wildlife researchers eyes most.

Unlike all other sampling methods, the camera-trap is the only method that operates much like a human observer would; it “watches” the environment, recording events in the form of images. As we are familiar with photographic technology in the 21st century, this does not sound that impressive, but to the ecologist, this is a major change from traditional techniques.

In a sense, until the camera-trap, wildlife research has been conducted in the dark. For example, using live-traps the researcher would only make the observation at the time they check the trap. But, finding an animal in a trap tells us nothing of what happened prior. We do not know whether the animal was alone when it was caught, if it was foraging with another individual, or if it was attempting to escape a predator. Similarly, in the case of predation events at birds’ nests, predators would be inferred by piecing together the available evidence in and around the nest. Camera-traps cut through much of the uncertainty to reveal expected and surprising animal behaviour.

In the aforementioned cases, cameras have shown that live-trapping does sometimes separate adults from young, a significant problem if those young are dependent upon the adult. Bird nest predation studies have greatly benefitted from the camera-trap as the camera confirms exactly which predator was responsible and at what time of the day; on occasion revealing unexpected predators, like the brushtail possum. Camera-traps even tell us something about our sampling techniques more broadly, such as the use of baits when we are live- or camera-trapping. Baits are often used in wildlife research to bring the target species to the sampling device. The use of attractants has long been understood to bias results as some species are preferentially attracted to the sampling device; in fact, recent studies have shown that baits affect detection and capture rates at the individual level [5]. Additionally, it has long been hypothesised that baits may influence predators of target species too. By attracting target species to a location, predators of that species may “stake-out” the bait, waiting for prey. Camera-traps have revealed that this may be the case with observations of predators such as snakes and dogs being present at the bait site for long periods of time.

Sampling wildlife is at the heart of wildlife research, and improving the way in which researchers collect data often leads to more ethical and more efficient research outcomes.



Figure 3: As a device, camera-traps are considered far less intrusive than most other methods; still, animals do notice unnatural objects in their environment.

Over the history of wildlife research, many techniques have been developed that have made the researcher's job easier, allowed them to ask new questions, and ask old questions in a more efficient manner. However, camera-traps provide a bigger, clearer window for the researcher to look through. They, of course, allow ecologists to conduct more ethical, efficient research, but camera-traps also reveal surprising new details about fauna, and about how ecologists conduct research. While there are still methodological issues to resolve with the deployment and technical application of camera-traps; arguably, they have been one of the most important methodological developments in the history of wildlife research.

Public Engagement with Science

As a sampling device, camera-traps have two inherent advantages over other sampling methods, beyond the aforementioned, that the public can take advantage of. Firstly, the raw data from a camera-trapping survey is in the form of images. Almost all other wildlife research methods such as live-trapping, active searches, or using scats and tracks to survey wildlife are recorded on observation sheets. Data about the event, such as the time of day, weather conditions, and relevant details about the animal are written into a logbook or digital device. Camera-trap images however, as will be discussed, can inspire and bring research to life in many forms of science communication. Secondly, the technical skill

required in deploying and retrieving camera-traps, and to process the data, is much lower than that of other research methods. This has facilitated the rise of citizen science programs, which allow members of the public to directly participate in the scientific process.

Science communication is the process of taking research or a scientific phenomenon and repackaging it in a way that the public can understand and appreciate. In this context, the public is everyone that is not a researcher in the field being communicated about. Science communication takes the form of television programs, radio broadcasts, magazine articles, and live talks and for the most part, it falls to the communicator to describe and interpret the data for the audience. Those fields that capture data in images (e.g. optical astronomy) clearly make the communication job much easier as the actual data can be presented, but more importantly, the images connect the public with the scientific topic in a much more visceral way than a simple description. This is well understood, which is why communicators of wildlife sciences often use images shot by professional photographers to illustrate the science. However, despite these images being aesthetically beautiful, there is often an artificial feel to the final product, whereas images from camera-traps present wildlife in a raw, almost untouched state.

Animals in camera-trap images do not often appear interested in the camera-trap, so animal behaviour is as close to natural as we can observe. This makes science communication with camera-trap images spectacular and powerful. One great example of this took place in 2012 with the capture of close to two minutes of footage of cross river gorillas [6]. At approximately 250 individuals they are the rarest gorilla species and are seldom seen even by wildlife researchers. The camera-trap however, brought this spectacular animal to the smart phones and computers of the public. The footage shows eight individuals moving somewhat leisurely through the forest. A large silverback breaks the serenity by charging past the camera beating his chest. A female gorilla hobbles

past; she is missing a hand, likely an injury caused by an animal snare. The footage needs little description to enhance its worth; viewing it is all that is needed. Several organisations, such as the Smithsonian, have taken advantage of this raw beauty that camera-traps deliver by creating virtual zoos, collating thousands of camera-trap images and making them available to anyone with an internet connection.

The interactive documentary *Bear71* takes science communication with camera-trap images even further [7]. *Bear71* tells the story of human-wildlife interactions by following a grizzly bear that, at age three, was radio collared and watched via camera-trap for her entire life. The film plays out on an interactive map of Banff National Park, Canada, that viewers can navigate while listening to narration and watching set story pieces. Across the map various icons, representing camera-trap stations, can be selected to give the viewer a glimpse of other species that occur in the park. *Bear71* is an amazing piece of work that has won numerous awards; any further description of it here would not do it justice, I can only beseech you to watch it for yourself. While this is the first documentary created almost entirely from camera-trap images, it may not be the last. Numerous professional photographers, including the National Geographic photographer Michael Nichols, are now using camera-traps and other technology to bring a new flavour to wildlife photography.

Citizen science is, as the name suggests, science undertaken by citizens, or non-experts. While a relatively new term, it is not a new concept as interested and passionate amateur scientists have always participated in the scientific endeavour. In fact, pre-20th century scientific investigation was often undertaken by amateur and self-funded researchers. In modern science, citizen science is often restricted to fields where risks can be minimised; thus, wildlife research has generally been excluded. An exception to this has been in ornithological research. Sampling is often conducted through recording

sightings of birds, or noting bird calls, at survey locations; hence, bird watching interest groups often provide invaluable assistance to academic researchers by providing extra people on the ground to undertake observations. Yet, in wildlife research more broadly where live-trapping and animal handling has been the norm, the risk of exposing citizens to injury has been seen as too great of a risk.

Conducting wildlife surveys with camera-traps pose little risk to the researcher, and so, have made way for citizen science programs to progress. To deploy cameras, researchers stake the camera into the ground or attach it to a tree, pointing it in the required direction, then simply turn the device on. At the end of the study period, cameras are switched off and retrieved and memory cards downloaded so that images can be identified. Every part of this process can be undertaken by amateur scientists and a number of programs have begun to experiment with citizen science initiatives to collect scientific data. In the United States, researchers from the North Carolina Museum of Natural Sciences and the North Carolina State University conducted a study of backyard predators in 2012 known as The Great Chicken Coop Stakeout [8]. Volunteers from the community were provided with a camera-trap and shown how to deploy and operate them, with the researchers being responsible for identification. The program was a success, and lessons learned from it have shaped a new research project, eMammal, which will use cloud computing technology and allow volunteers to also identify the photographs [9].

There are many examples of camera-traps being used in science communication and citizen science projects. Camera-traps, of course, were not designed for these purposes but their ease of use and photographic data collection, which make them invaluable tools for wildlife researchers, are also perfect for public engagement. As our world continues to become more technologically connected it is clear that camera-traps will continue to play a vital role in engaging the public with wildlife. Indeed, it is easy to envisage a time when

images from all forms of camera-trap research will be uploaded to the cloud, and members of the public, amateur researchers and professional scientists will investigate the data to find which animals occur around them, or to answer novel questions. Open data of this form, as has transpired in other fields such as genetics and astronomy, may in fact lead to new types of scientific questions and drive new ways to engage the public with science. Hence, camera-traps may not only be a great tool for engaging the public in science, but may also lead to great new forms of public engagement.

The Camera-Trap that Changed the World

Claiming that camera-traps have changed the world certainly seems pretentious, maybe it is, but bear with me. Consider movie technology. I suspect that you have watched the television or a movie in your life. In fact, just take the consumption rates of YouTube, a video hosting platform launched in 2005. It has become one of the biggest websites on the internet, according to YouTube's vice president by early 2013 the site had achieved a billion unique monthly visitors resulting in over six billion hours of video being consumed per month [10]. YouTube in fact has been a launching platform for the careers of numerous performers like Australia's Cody Simpson, and of course, Justin Bieber. While we cannot claim that YouTube specifically is a result of camera-traps; surprisingly, the development of the camera-trap, and its first uses as a scientific instrument, lead us directly to the moving picture. And, there is no denying that movies have had a huge impact upon the world.

Since its emergence in 1839, photography has been inextricably linked with science. The photograph offered scientists a level of objectivity and fecundity that the scientific illustrator could not match; and this was especially the case with biological organisms. Take Dürer's rhinoceros as an example. Broadly, it captures what an Indian rhinoceros was, but it was embellished and exaggerated beyond the living animal. Dürer had never seen a rhinoceros, his wood cut

was created from a description and drawing provided to him. Indeed, a quick look at the history of scientific illustration finds that it is fraught para-scientific representations. This is simply due to the human filter that information passes through. The observation being made is recorded after it has passed through the experiences and perceptions of the individual making the observation. However, the camera observes and records simultaneously, and not just the information of interest at the time, but all detail within its field of view. Thus, once technical problems of exposure length and portability were resolved, the camera became an invaluable scientific device, and especially for events too fast for the human eye.

In the 1870s, the camera was aimed at the problem of animal locomotion, and specifically, the issue of whether a horse's feet, as it ran, were free from contact with the ground. Eadweard Muybridge, a landscape photographer, endeavoured to answer the question by devising a mechanism that did not require a camera operator to manually open and close the shutter. Instead, the subject of the photo activated the shutter via a mechanical and electro-magnetic trigger attached to the camera; it was the first camera-trap. Muybridge, initially, lined up a dozen cameras side-by-side that were all activated by the horse tripping the shutter mechanism as it ran past, and demonstrated conclusively that horses are free from the ground at certain parts of the stride. This might seem trivial, but at the time, it was a question that had not been answered, though it was asked even as far back as the ancient Egyptians. In fact, until Muybridge, illustrators and artists would often depict horses with legs outstretched, fore and aft, as if leaping.

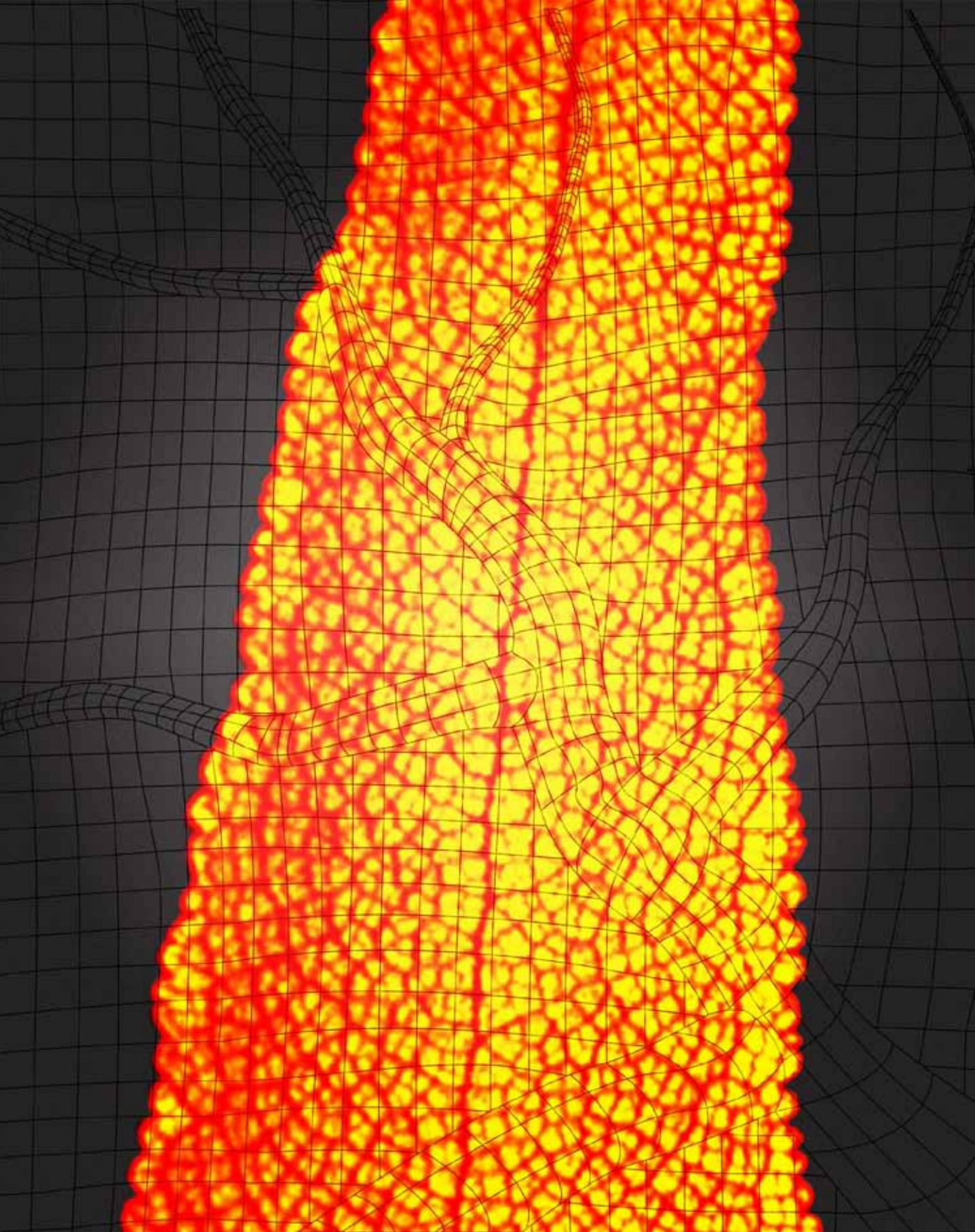
Eadweard Muybridge's work did not stop with just one horse, he increased the number of cameras and went on to have numerous other animals, including humans, trot, walk, canter, jump, and so on past his cameras. In order to view the images, one could merely look at each photo individually, but in 1879, Muybridge solved this problem by inventing the zoopraxiscope. The zoopraxiscope

was a modification to the praxinoscope, a device used to animate individual images. Muybridge aligned his images on to the edge of a disc that, when light was shone through, it would project the images onto a surface. By rotating the disc, the still images would create the illusion of a single moving image; and thus, the "movie" was born. Muybridge's work is the earliest account at creating moving pictures, elevating him to the title of 'Father of Cinema'. I facetiously suggest here that camera-traps changed the world as its invention led us to movies; but I have merely done this for sake of telling the story of the origins of the camera-trap. Other inventors of Muybridge's era were close to developing movie technology, and would have thus been crowned as such otherwise. The true value of Muybridge's work was in his contribution to animal locomotion as little has been learned, even today, that he did not discover.

Conclusion

In many ways the history of the camera-trap repeats the history of the telescope. Just as the telescope allowed Huygens to confirm the rings of Saturn, camera-traps are allowing wildlife researchers to make discoveries that other methods did not. Indeed, it is true for all of science that every time a new window on the universe is open, we discover something new. Camera-traps duplicate the researcher, allowing her/ him to be in multiple places simultaneously and make new discoveries. But its use has also reached beyond the ivory walls. As images from the Hubble Space telescope have given the public a portal upon the visual splendour of the universe, camera-traps allow the public to engage with wildlife in a safe but still spectacular way. It is now possible for people to take part in wildlife research in almost complete safety; and it has given storytellers and consumers a taste of nature in the rawest form. Camera-traps have made a tremendous impact upon wildlife research and science communication and have the potential, with new technologies, to continue to advance these fields of human endeavour.

Opposite: Untitled image from Erica Seccombe



Learning Science in School through Constructing Representations

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Visualizing in Science

New discoveries in science have often drawn on visual modes and increasingly do so. As noted by Wise [1, p. 75], much of the history of science has been about “making new things visible, or familiar things visible in new ways”. Scientists use optical instruments, maps, plots, drawings, scans, graphs and simulations to generate images that can justify scientific claims or argument about new knowledge. This is evident historically in Newton’s prisms, in Bunsen and Kirchhoff’s spectrometers, and also in current use of X-rays, CAT and PET scans, and MRI, where images “form both what and how we know” [1, p. 82].

However, this capacity to think with and through images is often down-played in traditional approaches to learning science in schools. While students are clearly expected to interpret and construct diagrams, graphs, and charts, the main focus is on learning concepts that are characterized in linguistic terms. Students are expected to know what “energy”, “equilibrium” and “adaptation” mean, and be able to apply these concepts to explain different phenomena. We recognize that learning science entails verbal reasoning and formal logic, but also claim that students need to engage in informal visual and creative reasoning as used by scientists. We report here on an approach to science learning in school that seeks to integrate both kinds of reasoning. Our approach focuses on students constructing, justifying and refining their own representations, where teachers guide students to develop conceptual understanding through this process. We first elaborate on what we mean by reasoning.

Reasoning in Science Learning

We recognize that an extensive range of cognitive theories casts humans as adaptive information processors, who use perception, memory, categorization against norms, and logical inferences to reason [2]. We also recognize sociocultural and embodied-cognitive theories that cast humans as players, who reason through participating in collective activity, simulation, visualization, rehearsal, engagement with tools, enactment, reflection, embodied understandings, pattern-spotting, and aesthetic preferences [3,4,5].

Accounts of reasoning to learn in science have generally drawn on the first set of theories around formal reasoning processes. For example, the Trends in International Mathematics and Science Study [6] characterizes reasoning as analyzing/solving problems, integrating/synthesizing, hypothesizing/predicting, designing/planning, drawing conclusions, generalizing, evaluating, and justifying. Reasoning can also be understood as a two-step mental process [7], where the first stage of imagining and representing solutions is seen as automated, intuitive, and based on past knowledge and personal preferences. By contrast, the second phase of assessment/judgment is viewed as analytical, linguistic and evidence-based, and thus aligned with formal logical processes outlined in the science education literature on reasoning. We think this version of a two-step process oversimplifies the kinds of reasoning that occur when students create solutions, but agree that both creating and critiquing representations are crucial to rich science learning.

Our approach seeks to focus on informal and formal reasoning processes when students

construct, justify, assess the adequacy of, and refine their own representations. This approach aligns with other calls to focus on students' representational competence [8,9,10,11]. Reasoning processes/strategies here include informal, contextual practical reasoning based on observations and data collection, perceptual pattern-spotting, object manipulation, approximations, enactment and re-representation of experiments. Other processes include classroom conversations and elaboration of contested perspectives to clarify claims, inductive reasoning from examples, deductive reasoning from principles to new cases, abductive reasoning or "guessing" from logical inferences, logical analyses of the adequacy and coherence of students' own and others' representational and re-representational claims.

Support for this approach from scientific practice is evident in Gooding's [12] analysis of Faraday's notebooks. Gooding persuasively claims that science knowledge-making does not proceed solely by semantic logical formulations but builds heavily on visualization. According to Gooding [12, p.40], visualization in science involves objects "that combine visual and non-visual elements because scientific work requires representations that are hybrid (that combine verbal or symbolic expressions with visual and other sensory modalities)". This enables the meaning of an image, word or symbol to be at first negotiable before it is fixed. In this view standard accounts of the nature of science based on verbal formulations (facts, laws, formulae) that obey semantic rules, do not capture how new knowledge is made. The more complex thinking based on perceptual, usually visual patterns, draws on two features of human cognition: "our ability to recognize regularity in visual patterns, and our ability to integrate different types of sensory information into a single representation" [12, p 42] .

A Representation Construction Approach in Science Classrooms

In this approach to learning science in school, students are expected to respond to a

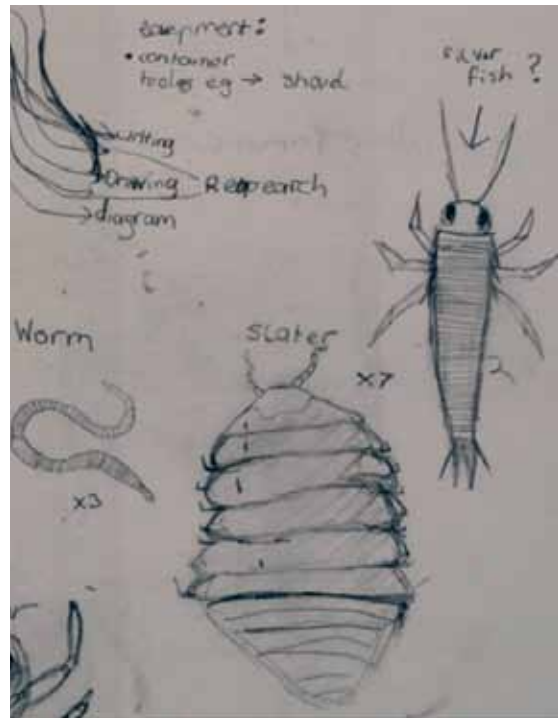


Figure 1a and 1b - Student notebook sketches.

representational challenge where they explain features or changes in natural phenomena. This approach entails teachers guiding students through a sequence of representations and re-representations on a science topic. In the following example, two year 5/6 teachers in a shared primary classroom planned, implemented, and evaluated a unit on Animals in the School Environment that included a rich range of teacher and student-generated representational challenges, investigative activities, discussion, and re-representation. Major concepts to be learnt included: ecosystem, habitat, diversity of animal populations, interactions between plants and animals in an ecosystem, animal structure and function, and the adaptive purposes of behaviour. Students were expected to learn about methods for studying animals, and generate their own representations to explore ideas and develop understanding of target concepts.

The students were taught how to sample and draw representations using tables, graphs, diagrams and cross sections in relation to animal diversity and animal classification, which they then applied to studying mealworms. Students collected data on animals and plants in the school-ground habitat, and gathered animals for small-group study. They were required to describe the diversity of these animals in their logbooks, characterise their structure and behaviours, and explain how these were adaptive to their habitat (see *Figs 1 and 2 for examples*).

The specificity of detail in these logbooks points not only to the students' high levels of engagement, but also to the ways in which writing and other modes are necessarily interdependent in meaning-making and reasoning as the students integrate visual, verbal and mathematical modes to clarify and communicate emerging understandings. The types of drawing, the level of detail, the count of animals, and the use of a graph to characterise the population, all reveal how the students integrate meaning across modes, to reason about animal diversity. Teacher and peer verbal and other inputs are also clearly critical to this process.

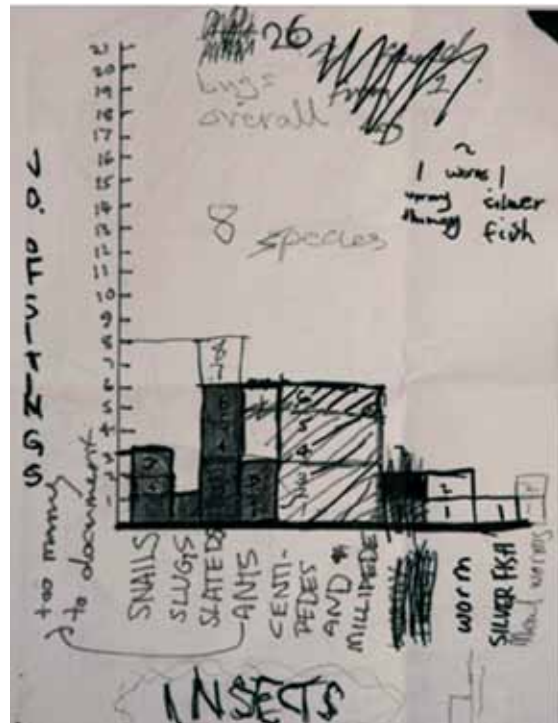


Figure 2 - Student graphical representation of animal population

Learning the languages and reasoning moves of science is embedded meaningfully in an inquiry where students are addressing the challenge of how to represent adequately their understanding of this diversity. The changing annotations flag how the students used the graphs to guide both data collection and to prompt new reasoning processes and conclusions.

Two boys in this class observed centipede behaviour closely and then constructed a jointed model with elastic connections to attempt to capture the animal's undulant movement. As with all the representational challenges in this class, the students were expected to draw on and extend their current representational resources to address this problem. The 3D model that they produced (see *Figure 4*) indicates a strong understanding of the nature of the jointed body and the sequence of leg movement. The two boys made preliminary drawings of the arrangement of the centipede's legs, as well

as a close-up of the animal cleaning its antenna (*Figure 3*), and these observations were subsequently reflected in the constructed model, and in the verbal descriptions made by the boys to the class in explaining this model.

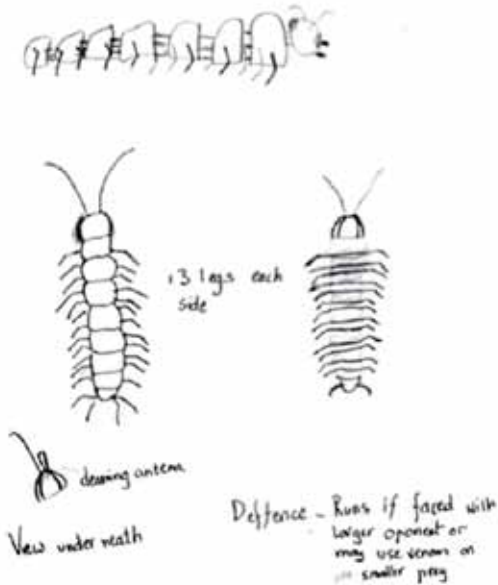


Figure 3: Centipede notebook entry

The two boys drew on many resources to reason about how centipedes move, and how to design a model that explains this movement. They used past knowledge and experience in constructing objects, their understanding and experience of their own bodily movement and the movement of other animals, as well as symbolic resources such as learnt verbal, visual and mathematical representations from past science lessons. They also drew imaginatively on perceived qualities in their raw materials and their capacity to visualise a product or a possible outcome as they tackled this non-routine task. Their reasoning processes varied across different stages of the process. Initially their talk, sketches, and decisions on model design enabled them to organize perceptions of the precise nature of how the legs and body moved. Constructing drawings involved identifying key centipede parts important to movement, and abstracting these elements in a creative visual reasoning process. This



Figure 4: Centipede model showing elastic attachment of segments

then led to successive transformations across multiple representations, from labelled drawing, ongoing talk, a design drawing focusing on joints, model construction, and then embodied characterization in a spontaneous role-play of the centipede's movement when they later demonstrated their understanding to the class.

Different representational tasks within this process provide different affordances that constrain and productively focus the students' attention. Drawing enables the relation between segments and leg attachments to be specified, with the design drawing requiring an account of the characteristics of the joints. Annotated writing enables them to categorise parts and specify the exact nature of their claim about the movement. Creating a 3D model forces consideration of the material properties that would allow appropriate movement, such as the choice of elastic over hard sections. The 3D model shows the boys' close awareness of the nature of the jointed body and the leg movement sequence.

In presenting the model to the rest of the class, one boy moved the model so that individual sections undulated. He gestured,

moved the model, and commented that “instead of moving in straight lines it moves like a snake”. The other boy gestured to signify the undulation, and added, “so we used elastic so it could move properly”. Their 3D representation combined with their verbal accounts functioned as reasoning tools. As one boy said:

How we found out, how it moves is (moves the model) it went like (uses right hand to simulate the undulating movement). I also think it did this (moves hands) one set of legs forward and the other (raises both hands and moves them in a left-right, left –right motion). At this point he moved very close to and just behind the other boy in order to represent the next consecutive segment. Both students then used their hands and their entire body, gesturing and moving in complete synchronicity as an embodied account of their understanding.

This example of primary students addressing a representational challenge highlights the complexity of factors and strategies that contribute to quality learning in primary school science, where talking and writing are two of many resources that contribute to the processes and products of learning. The students, as in all science learning, have to make durable links between past knowledge, new experiences, manipulation of objects and other inquiry processes, as they invest all their available representational resources, including writing, into personal meaning-making about the target concepts. What the students can know or learn through writing in this topic, and from linguistic resources more broadly, depends on their ability (and motivation) to make strong links across all these elements. Whether student talk and writing can serve informal and formal reasoning processes in this context also depends on these linkages.

Rethinking Reasoning in Science

Our approach to learning in school science also raises interesting questions about the relationship between image-making, reasoning, and knowledge production in science. As noted by Wise [1], rather than

perpetuate dichotomies between art and science, intuitive image-making and analytical abstraction, geometric pictures and algebraic logics, new accounts of knowledge-making in science, and in science classrooms, point to necessary intersections between these approaches rather than binary exclusions. Gooding [12, p. 60] makes a similar point in his analyses of Faraday’s research:

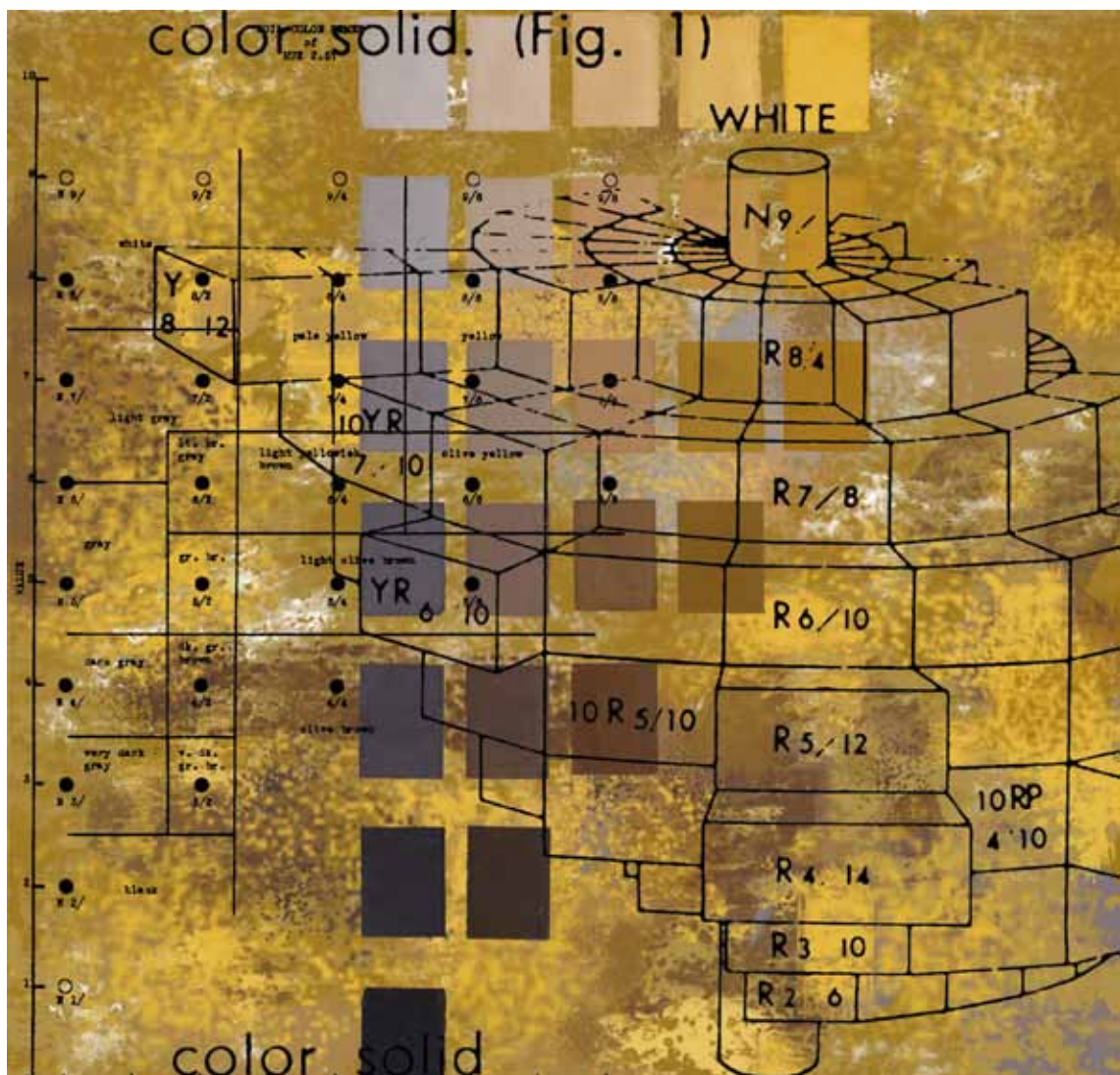
The received view of scientific inference is that it is accomplished in language capable of preserving consistency, both in the use of signs and in relationships between propositions. Does this mean that Faraday’s visual and material manipulations were not really reasoning, or that what these produced was not knowledge? On the contrary, while successful science does require a stable linguistic formulation, creative research cannot be conducted solely with well-formed linguistic representations. There are nonvisual ways of forging an isomorphism of words, images or symbols to what they denote, but images are particularly conducive to the essential dialectical movement between the creative stages of discovery and the deliberative, rational stages in which rules and evaluative criteria are introduced to fix meanings and turn images from interpretations into evidence.

This is a compelling attempt to explain the relationship between creating and critiquing representations in making knowledge in science, as well as the cognitive, cultural and material resources that enable this feat. We consider that our research on student science learning in school confirms the broad plausibility of this account [13]. In this sense, the evidential linguistic post-hoc account of a new scientific break-through masks the means by which it has been accomplished. We also think “the creative stages of discovery”, to judge from our classroom example above, indicate that the students (as well as scientists) use informal, deliberative, inventive reasoning processes as they construct representations to explain phenomena.

By implication, science teachers need to

recognize that student reasoning in science includes both formal and informal processes, and that when students are guided to address representational challenges both kinds of reasoning can be developed and integrated. As noted in our classroom example, student construction, review and explanation of images are crucial to these reasoning processes. Our research points to effective learning tasks and teacher/student roles where students' attempts to visualize and justify accounts of phenomena can lead to quality learning in science.

Below: Spectra 2 (2011) Mary Rosengren



The Montage: a working space for interdisciplinary discourse

Victoria Cooper

Artist and independent researcher, Toowoomba, Qld, Australia.

Interdisciplinary projects that connect the artist with the visual potential of scientific knowledge and images often require a flexible and inclusive space for the development of visual concepts. Using examples from her recent study, the artist discusses how the photo-montage provided a supple medium to create her visual narratives where improbable relationships were explored. In this work, scanning electron microscope images of invisible aquatic life forms inhabited the larger social spaces of Australian freshwater environments. A feature of this investigation was the observation of unexpected and unnatural phenomena arising from this fertile space and how these informed the artist's work. After reflecting on the results of this work the artist recognised a broader potential for the montage as a methodology for dynamic thinking processes. This paper seeks to promote the montage as a tool enabling a provocative and stimulating visual parliament for interdisciplinary discourse.

Re-colonising the Narrative

This research explored the re-contextualisation and repurposing of scientific images to create visual narratives of freshwater places in Australia. Aquatic fungi were featured in these visual stories as a representative for the more-than-human inhabitants of these aquatic environments, that lie mysteriously, like the Bunyip, beyond normal human perception. These fungi and their place in the ecosystem not only underpinned the construction the visual narratives but also expanded the narrative space to beyond the human experience of fresh water. Appearing as apparitions, these natural recyclers metaphorically de-compose the detritus of the colonial freshwater narratives to assert the presence of the non-human.

Many issues arose from the interdisciplinary work as the objectivity of science collided with subjectivity of a physical and meta-physical experience of place. In this contested space, preconceptions of scientific knowledge and values were challenged and then reconciled. In this discussion I refer to Gaston Bachelard's deliberations in *Poetics of Space* [1] and Donna Haraway's discussion: 'science is cultural practice and practical culture' [2]. Rather than Edward O. Wilson's *Consilience* [3], where interdisciplinary discourse flows in unison, I discovered an unpredictable and surprising space. Throughout my visual research I explored the new pathways formed arising from the inclusion of different voices and lived experiences within site-specific, place-narratives of fresh water.

The work was created in the inclusive and flexible space of the montage where rigid structures and familiar places were decomposed and recombined into an unexpected diversity of ideas. Intentionally, the reader is not offered yet another eco-political environmental narrative of water and rivers. These stories flow from one site to another, from colonial perceptions of progress and production to a natural recognition of absence and presence, and from scientific fact to mythical reality.

The fieldwork was carried out in three sites of fresh water:

1. *Rio Vista*, Mildura, Victoria. William and George Chaffey, the engineers who pioneered irrigation in this district, originally owned this grand colonial homestead situated near the Murray River. This house is now part of the Mildura Arts Centre and was undergoing renovation during my residency.
2. *Bundanon*, near Nowra New South Wales, originally Arthur and Yvonne Boyd's Australian residence and studio, is situated beside the Shoalhaven River. In 1993 The

Figure 1 The collection process: Three images showing the collection of leaf litter and foam samples at Bundanon from the Shoalhaven River. The samples were then incubated in an aerated freshwater bath for two weeks. During this time samples from the baths were processed to detect, monitor and photograph the microscopic aquatic fungi from each site.

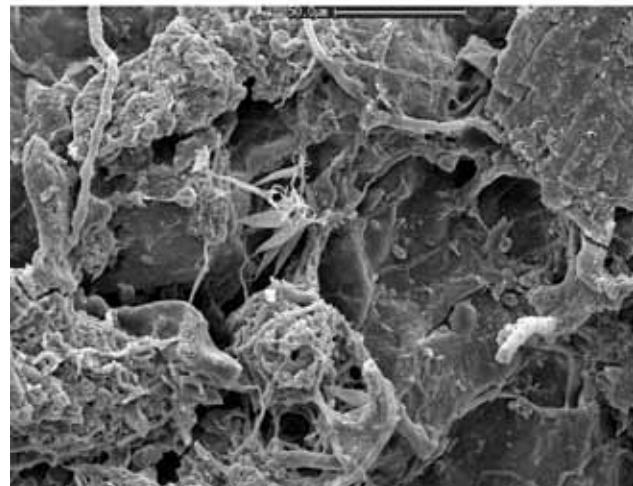
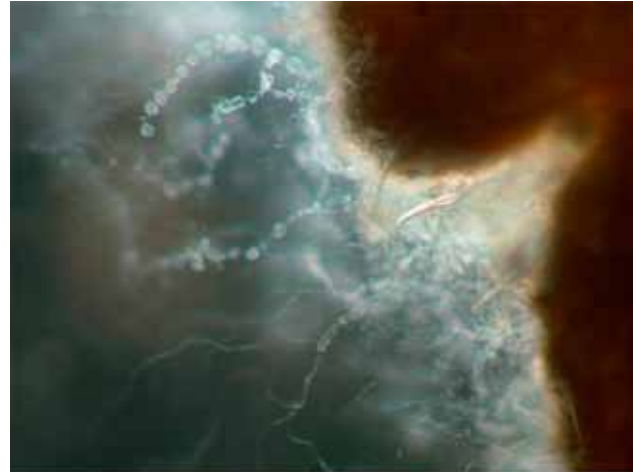
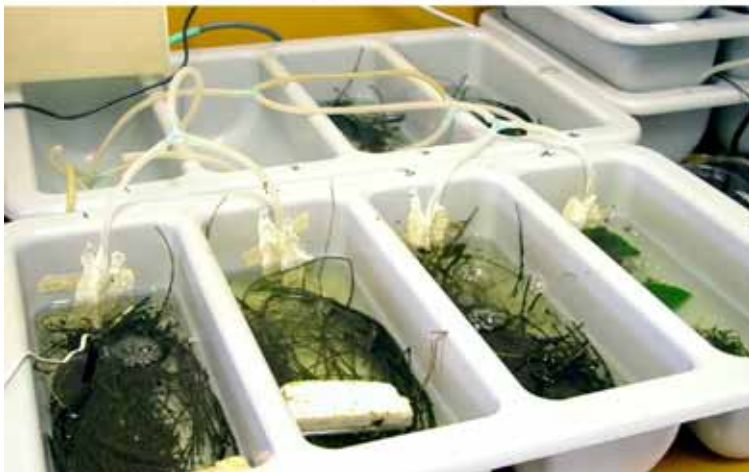


Figure 2 The specimens were observed and imaged through three different microscopic technologies. Top: Samples from the baths were micropore-filtered and placed under a stereo-microscope for initial observations. Middle: After aquatic fungi were observed under the stereo microscope, samples were stained with lacto-phenol cotton blue solution and wet mounted onto slides for viewing and imaging under the compound microscope. Bottom: Many samples were then imaged within an electron microscope. These electron micrographs were found to have the images qualities

Boyd's donated all their properties in this region to the Australian people. Bundanon is now used for artists in residence programmes and to conserve, along with an extensive collection of the Boyd family art; the modern architecture and colonial buildings; and native bushland reserves.

3. *Myall Park Botanic Garden* (MPBG) near Glenmorgan, Central Southern Queensland. Situated near the confluence of the Condamine, Balonne Rivers with Dogwood creek, this botanic garden has a reputation for both its living collection of Australian plants, established by David Gordon (1899-2001) and the botanical art of Dorothy Gordon (1928-1985). To ensure that the garden's legacy and focus on the fostering of the environment and art would continue David Gordon gifted the garden in 1994 to the committee of volunteers that now keep the dream alive.

Over the duration of the fieldwork I made many images including: the topographical and architectural forms of place; and the microscopic environment of aquatic fungi. I collected small samples of water and leaf litter to culture, observe and record the aquatic fungi gathered from each site (*Figure 1*). From each collection I would create light and electron microscope images as a resource for my photomontages (*Figure 2*). The fieldwork at the historic home, Rio Vista, on the Murray River was connected with the collection of the microscopic environment I made at the headwaters of the Condamine River in Queensland. This work brought together two sites separated by over thousand kilometres but connected by the waters of two great Australian river systems, the Murray-Darling River Basin. At the next two sites I collected water samples directly from the Shoalhaven River at Bundanon and at the Condamine River near MPBG.

In the creation of the visual work, I utilised the photographic documentation as 'quotes' rather than 'translations from appearances' [4]. In this mode they became narrative elements or language within the compositional space of the photomontage. Spatial boundaries and surfaces of each site had to be transgressed in order to widen the

potential for new discourses on water. The renovation of Rio Vista had uncovered early forms of wallpaper, leadlight windows and painted decorations from the colonial period [*Figure 3*]. The renovation and the stories of ghosts and apparitions became the foundation inspiration for including the aquatic fungi into the narrative of this site. In the spirit of renewal in the homestead and in my water narrative, the fungi metaphorically performed their recycling role, deconstructing and reclaiming the space. I created three visual narratives in the form of artists' books (*Figures 4-6*): Book 1: *The Apparition*, Books 2a and 2b: *The Excavation and the Restoration* and Book 3: *The Exploration*.

The montage space in these books included scientific images and collections, human and non-human habitation. The mythical presence of the aquatic fungi created from the Mildura site motivated the next field study at Bundanon. Much of Arthur Boyd's work at the Shoalhaven River at Bundanon deals with human nature within the context of Australian environment. Boyd used the classical and mythical metaphor of Narcissus as part of a collaborative book of the same name with the poet Peter Porter. These haunting images along with Boyd's concern for environmental issues in Australia resonated with my own work. The aquatic fungi collected from this river returned again but as they crossed the impossible spatial boundaries of scale, mythology and poetry now entered the space of the montage. My visual work for this site was again three artists' books (*Figures 7-9*): *Images of Metaphor*, *The House* and *The River*. This place and the river for me will never be the same...

At the final site, Myall Park Botanic Garden, dams and irrigation pipes are the visible evidence of fresh water. The collection made at the nearby confluence did not yield identifiable forms of aquatic fungi. The narrative of this site was about the search for the evidence of the mythical fungi and uncanny nature of the Australian experience of the bush. The montage space was extended to include the ever present but not always visible fungi as a metaphor of the



Figure 3

Rio Vista was a rich visual resource of colonial history and stories of the Murray River its irrigation and the human lived experiences. These examples were inspiration for my visual narratives. The leadlight windows had details of river life, rather like the river had been captured and wrought into the fabric of the building. I observed and documented details from the excavation and renovation (the edges and cracks) of this richly detailed colonial wall decoration.

absence and presence of fresh water. This place is a collaborative space where art and science, human and non-human, myth and daily experiences are defined by the narrative of water. The three books from this site are (Figures 10-12): *Day Garden*, *Night Garden* and *7 Gates*.

The Photomontage: Questions of Objectivity

Although I was open to any outcomes, the resulting composite images still challenged my scientific conscience. They seemed unreal and incongruous. I began to question my intent for this work. As I reassigned the purpose of the scientific document, would this concept then lose its narrative strength? What was the balance between subjectivity and objectivity when using photographic information in an interdisciplinary discourse? Roland Barthes' critical discussion on photography has a relevance to this contemporary issue. Barthes observes: 'the image is not the reality but at least it is its perfect analogon.' He then adds that the photograph in isolation is 'a message without a code' [5] – its meaning is dependent on the viewer or its context explained in the accompanying text. Importantly for my project, Barthes then questions the duality of the meaning implied in the photograph: 'How then can the photograph be at once "objective" and "invested", natural and cultural?' [6].

In *Camera Lucida* [7], Barthes further suggests that rather than looking at the photograph we enter into a subjective visual discourse, which is dependent on the viewer's preference or conceptual framework 'some technical', 'others are historical or sociological' [8]. So Barthes' discussion had consequences for my work, not as a criticism but as an enabler. I sought to utilise this visual paradox to bring together the 'objective' and the 'invested' – the 'natural and the cultural'. This was open-ended, a collaboration between my scientific and artistic curiosity and intent. Can both share in the inventive and an unrestricted playful creation of new narratives within these alternative or metaphorically uncharted waters?

Since the growth of the digital medium these questions and challenges to the traditional notion of the photograph as a captured reality have only been amplified. In a publication critiquing the history of photography Joan Fontcuberta proposes that in the digital paradigm:

Photography has now become information in the pure state, content without matter . . . Issues of meaning will take precedence over issues of representation . . . in the realm of artistic expression digital photography should be unfavourable to certain developments of a formalist nature while accentuating others of a narrative and conceptual nature. [9]

His salient comment regarding the changed physical state and perception of photography in the digital medium releases the image from its social requirement to record and allows for new potential visual discourse; and provides for the author/artist the articulation of methodology. The photomontage thus became a space where the imagination can be free to invent new concepts and question obsolete traditional beliefs. Here both subjectivity and objectivity can co-exist where imaginative or original thoughts are developed and understood. As Gaston Bachelard proposes in his phenomenology of the imagination that to 'receive the psychic benefit of poetry':

... [the] two functions of the human psyche—the function of the real and the function of the unreal—are made to co-operate. We are offered a veritable cure of rhythm-analysis through the poem, which interweaves real and unreal, and gives dynamism to language by means of the dual activity of signification and poetry. [10]

As visual 'quotes' made from the microscopic investigation, the documentary photographs were set free from their scientific purpose. The space of the montage enabled a dynamic visual thinking process: the posing and pondering of questions and relationships in the research. The narratives of fresh water then evolved through the 'co-operation' of the 'real' and the 'unreal' within the space of photomontage.



Figure 4
Rio Vista; Aqua Vista. Details
from the artists' book, Book 1:
The Apparition
Artists: Victoria Cooper and
Doug Spowart
Collection: Mildura Arts Centre
and The National Library of
Australia's Rare Book and Manu-
scripts Collections



Figure 5
Rio Vista; Aqua Vista. Details
from the artists' book, Book 2a:
The Excavation, Book 2b: The
Renovation
Artist: Victoria Cooper
Collection: Mildura Arts Centre
and The National Library of
Australia's Rare Book and Manu-
scripts Collections



One Voice or Many?

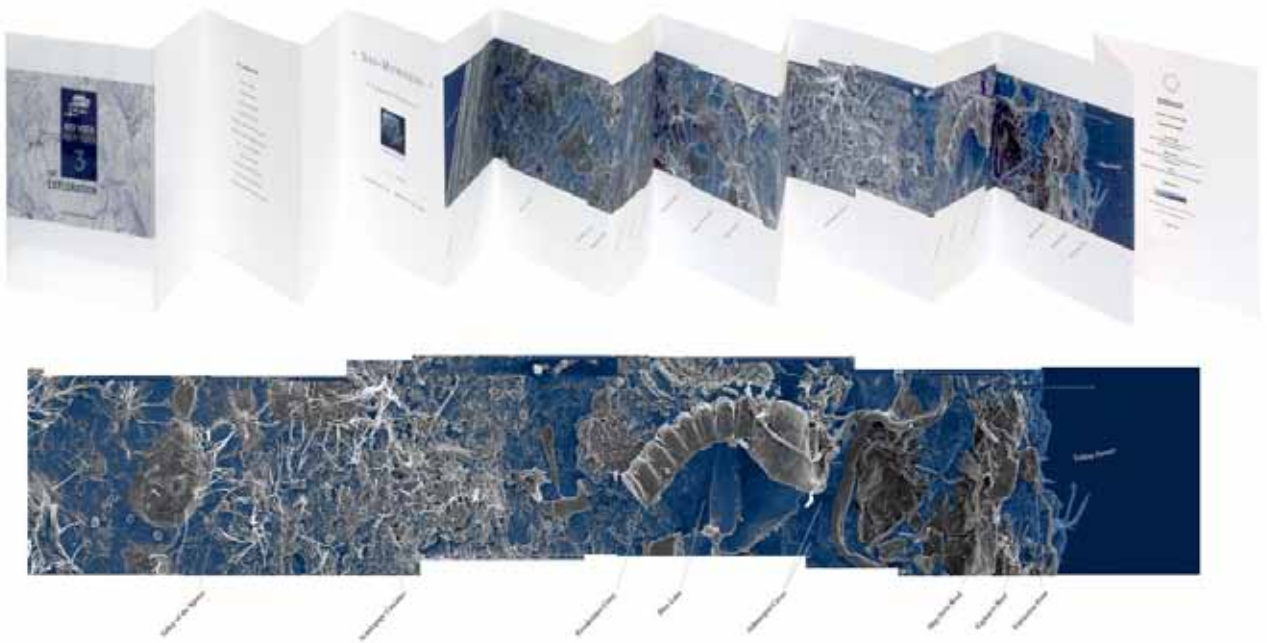
Through the montage I created a space for visual thinking, where science, nature and culture were equal contributors. This space is a metaphorical 'soil' rich with organic and inorganic matter. But this mode of research is open and chaotic rather than the consilience as Edward O. Wilson presents: *The central idea of the consilience world view is that all tangible phenomena, from birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible.* [11]

In this discussion, Wilson presents an interdisciplinary discourse, where the humanities and the sciences can work together but in terms seeking a targeted result from a mission driven research. As an important part of a knowledge gaining and testing process, this model by its nature reduces the potential for anarchy and chaos. Although guided by the aims of the research, I chose to extend the field to include divergences and instabilities that emerged as they also assisted the development of an alternative narrative of fresh water. As Siân Ede comments in her book *Art and Science* (2005) that advocates of the ideals of unity, even though 'well-

meaning' and present compelling cases, can overlook the fact that: *Very many different groups of people in the world also seek a Unity of Knowledge and a mending of misconceived gaps, but on their own terms, through different religious beliefs, spiritual, fundamentalist or otherwise, or through varieties of totalitarian rule, or paradoxically, through visions of anarchy and disorder.* [12]

Notions of unity and consensus may seem initially seductive but as Ede points out there also needs to be recognition of the importance of diversity, difference and instability in this debate. Social scientist and theorist Donna Haraway places science as a cultural practice where there should be no hierarchy, no sacred cow: all is open to be questioned; context and content require constant revision. The humanities and the social sciences are equal partners with the natural and physical sciences in this open epistemological environment. Here, many new voices can be heard, as Haraway states: *The fantastic and the ordinary commingle promiscuously. Boundary lines and rosters of actors—human and nonhuman—remain permanently contingent, full of history, open to change. To be meaningful, the universal must be built of humans and nonhumans.* [13]

Figure 6 (below) Rio Vista; Aqua Vista. Details from the artists' book, Book 3: The Exploration Artist: Victoria Cooper
Collection: Mildura Arts Centre and The National Library of Australia's Rare Book and Manuscripts Collections
Figure 7 (opposite page) Site Bundanon. Details from the artists' book Images of Metaphor Artist: Victoria Cooper
Collection: The National Library of Australia's Rare Book and Manuscripts Collections



A collection of decomposing leaf litter was made at a site in the shallow waters along the Shoalhaven River's shoreline at Arther Boyd's Bendamon.

A different destiny now lay ahead for these fragments of decaying matter . . .

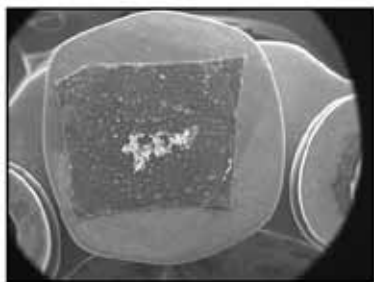
Upon removal from the river the dead leaves were placed in a water bath, a simulated river, with nutrients and a bubbler to supply fresh oxygen. In this controlled environment, generations of microscopic life forms are generated from the processes and products of decomposition.

After 3 to 4 weeks carefully selected samples of the decaying leaves were dissected and air-dried in a science lab in preparation for the next stage.

These desiccated leaf fragments were then carefully placed onto a support to keep them secure during crucial stages of the imaging process. Following this step the specimens were then finely coated in gold. Finally they were placed under a vacuum to be microscopically scanned and imaged with an electron beam.

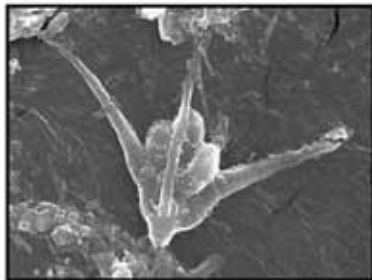
The surface was now ready for a trans-dimensional exploration into the microscopic landscape of the Shoalhaven River.

Victoria Cooper August 5, 2007



Contents in a drop of water from the Shoalhaven River Bendamon, near Nowra, New South Wales, Australia

i



Tetractadium sp.
Bendamon, near Nowra, New South Wales, Australia

There have been some unsubstantiated records of mysterious sightings of this aquatic fungi emanating from the river and buildings on the Bendamon property

viii



"We must, in fact, not divorce the stream from its valley in our thoughts at any time.

If we do we loose touch with reality . . . Some where, in Australia there must be a stream with a channel like a gutter, fed by runoff from a landscape paved like a parking lot.

There, I predict, will be found the legendary river creature of the Aborigines - the Bunyip."

In his 1952 book, *The Ecology of Aquatic Hyphomycetes*, Prof. DeFolia Alphonse includes this quote made by renowned freshwater ecologist Prof. Dr H.E.B. Rykes in the conclusion of his 1975 Edgar & Davis Lecture at the 19th International Limnology Congress in Winnipeg.

Thus in my montage spaces voices of the natural environment were 'commingling promiscuously' with the familiar human narratives of place. I created spaces where: aquatic fungi reclaimed their history, they moved across spatial and ecological boundaries, fungi and human merged and through this mythical hybrid perhaps the non-human has asserted its presence. Sociologist Bruno Latour's *Steps Toward the Writing of a Compositionist Manifesto* (2010) [14] advocates a compositional space that empowers each contributor, however disparate and regional, 'Even though the word "composition" is a bit too long and windy, what is nice is that it underlines that things have to be put together while retaining their heterogeneity'. [15]

The Montage: More than just an Image

The montages in the work, *Viral Landscapes* (1991) [16], by British artist Helen Chadwick (1953-1996) visualises a virus entering the 'body' of a landscape. Viewing her photo-montages was analogous to observing the viral invasion of the landscape through a microscope. Chadwick's work passes beyond the superficial into a philosophical space. Is this then a spatial proposal where science and art appear to cohabit independently in two distinct spaces? The use of montage then presents the notion of flow of viral and cellular information crossing both the cellular and the body walls that separate the internal from the external metaphorical landscapes. Australian artist Lin Onus (1948-1996) presents the unseen or hidden Indigenous presence, where both human and non-human are layered within, and over, a painted landscape. By crossing the boundaries of the traditional European landscape topographical painting with the Indigenous landscape narrative, Onus created a montage of visual languages that critiqued the contemporary cultural landscape of the late 20th century in Australia. Through the layered meanings and visual messages in the paintings of Onus shows a different way of understanding the Australian landscape [17].

The montage was also used to contrast

concepts as in the 'value added' landscapes [18] of Australian artist Ian Burn (1939-1993). In this work Burn critiques the context of Australian landscape painting through a visual interplay text and image. These installations are a combination of text overlying the found-object amateur landscape painting both contesting for space in the reader's imagination and their search for meaning in both. In this way these works challenge the viewer to reconsider the landscape image and the text in a dynamic interplay of meaning. Burn stimulated my imagination to explore and question alternative meanings through this visual 'reading' between the lines.

Additionally the development of the contemporary digital environment has provided the tools so that artists and photographers could weave and seamlessly blend unnatural or unexpected elements into the fabric of image or narrative. As such these elements are naturalised into the image and—rather than disrupt or disturb, as in the cut or tear of the collage styled montage—have a more subtle and subversive impact on the reading of the narrative. Both forms create different approaches each working with ideas towards a point where space for questioning and thinking about problems.

There are also emergent forms of the montage in the form of a mashup utilising elements from movies and video, music, non visual or textual concepts from human history and the natural environment. In January 2011 Australian and New Zealand libraries opened up part of their archives for a digital mashup competition where the general public was invited to create montages of history, news, images, texts and narratives. This enabled the broader community to reinvent themselves and create new histories and identities

Through my interdisciplinary research into freshwater narratives I have come to know the montage as a dynamic collaborative space, where materials and minds contest, contrast and combine to construct and then transform the visual message. More than the familiar interdisciplinary approach I have found the montage, as in Latour's



Figure 8
 Site Bundanon. Details from the artists' book *The House*
 Artist: Victoria Cooper
 Collection: The National Library of Australia's Rare Book and Manuscripts Collections

Figure 9
 Site Bundanon. Details from the artists' book *The River*
 Artist: Victoria Cooper
 Collection: Bundanon Trust and The National Library of Australia's Rare Book and Manuscripts Collections



composition, an egalitarian recombinant space where chaos and order can ‘commingle’ and unexpected outcomes can evolve, while the individual participation remains vital and methodologies—infinately varied. Although this kind of research is not mission driven, the extended perception gained can in many ways be more productive than pursuing outcomes.. Through this space the potential of thinking visually can be realized, as artist Gerhard Richter [19] presents:

The thinking that aesthetic presentation can open up for us is thus not meant to explain and, by extension, to explain out of existence, what in fact remains irreducible, singular, and resistant within the work. Rather, learning to think aesthetically, to think with and through

the work of art, means learning to see what exactly the enigma or riddle is . . . We could say that the photograph offers us an unexpected mode of seeing that aids us in our task to learn to see the difficulty of thinking. [20]

In the pursuit of wide ranging issues affecting broad human and non-human, I have found the digital montage as a space not just for the visual arts but as a cultural and social medium where the ‘difficulty of thinking’ and ‘thinking aesthetically’ enables a provocative and stimulating visual parliament of ideas.

Figure 10
Borderlines. Details from the
artists’ book Day Garden
Artist: Victoria Cooper
Collection: The National Library
of Australia’s Rare Book and
Manuscripts Collections



Figure 11
Borderlines. Details from the
artists’ book Night Garden
Artists: Victoria Cooper and
Doug Spowart
Collection: The National Library
of Australia’s Rare Book and
Manuscripts Collections



Figure 12
Borderlines. Details from the
artists’ book 7 Gates
Artist: Victoria Cooper
Collection: The National Library
of Australia’s Rare Book and
Manuscripts Collections







Rio Vista; Aqua Vista. Detail from the artists' book, Book 1: The Apparition Artists: Victoria Cooper and Doug Spowart
Collection: Mildura Arts Centre and The National Library of Australia's Rare Book and Manuscripts Collections

Site Bundanon. Details from the artists' book The River Artist: Victoria Cooper
Collection: Bundanon Trust and The National Library of Australia's Rare Book and Manuscripts Collections



TWITCH: translating microscopic fast motion to a musical composition

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‘TWITCH’ is a musical composition derived from two sources: images of the movement of monocytes, and the author’s aesthetic response to these images as represented through a musical rendering. It considers microscopic imaging, data sonification, and mathematical interpretations/representations in the creation of an algorithmic process for generating an indefinite number of musical works. This short paper presents a very brief overview of the Art/Science nexus, the making of art, and the processes used by Myers and Alsop in developing an approach to music creation.

Science/Art - Art/Science

Leonardo Da Vinci is attributed as recommending these principles *“for the Development of a Complete Mind: Study the science of art. Study the art of science. Develop your senses- especially learn how to see. Realize that everything connects to everything else.”* [1]

Isidor Rabi [2] then Charles Snow [3] considered art/science differently to Da Vinci, seeing that there was a divide, not just of tools but in ways of thinking, indicating a schism and consequent dichotomy that is mutually detrimental and need not exist. Their positions have been vigorously discussed, developed and extended as technologies have developed [4-8]. These discussions generally focus on the development of a more holistic, catholic approach to inquiry and societal development, but, as Gibson puts it, the ““gulf of incomprehension” not only grows between science and non-science, but it can also be observed between, let’s say, biochemistry and

astrophysics.” [9]. There are many, often successful, efforts to bridge this gulf, the SPECTRA 2012 symposia attests to this. But perhaps scientists and artists have different styles, thought processes, and approaches to creative and inquisitive acts.

A search limited to peer reviewed papers between 1924 and 2014 of my university’s on line library catalog revealed 54,016 hits for the phrase “creative thinking”, 23,499 for “scientific thinking”, and 726 for “artistic thinking. Scientific thinking has well developed histories and methods for developing it in young people [10, 11] and in later education [12]. Artistic thinking has more diverse methods and history regarding developing it in young people and later education. This is demonstrated by the majority of the 54,016 discussions on creativity being based on creativity in the arts. Balkis et al [13] overview this regarding vocation and inter-personal attributes, but the majority of writing focuses on creativity within disciplines and approaches [14], and possible cross-disciplinary interactions [15].

Visualization and Sonification

Much of the Science/art-Art/Science relationship is expressed visually, *Figure 1* and *Figure 2* are examples from the Art of Science 2011 Gallery, Princeton, where the images are described as “not art for art’s sake. Rather, they were produced during the course of scientific research [and] chosen for their aesthetic excellence as well as scientific or technical interest.” [16]. *Figure 1* shows a simulation of geomagnetic reversals, *Figure 2* shows an arsenic sulphide dissolved in solution, and *Figure 3* shows a still image

from the monocytes film used to develop TWITCH. Drew Berry's animations of the extremely small and fast [17], Géryk's [18] and Ruiz et al [19] discussion of analysis and education via computer animation, and Haglund et al's [20] discussion of potential issues are examples of illustrative uses of visualisation in different disciplines. These are visualizations of usually invisible objects or data that may be arcane and esoteric, complex, diverse, or require extremely long or short times to gather and mentally process. Manovich [21] and Marsella [22] encapsulate and comment on these processes.

Currently sonification seems less discussed, perhaps due to the cultural "centrality of the eye" [23]. However, it is an equally useful process in making information as diverse as the very long or short-term motion of fluids, behaviour of stock markets or immigrants over time, the presence of disease [24-27] available through a modality that highlights and gives access to different aspects to the visual. Both processes use various applied algorithms to translate the data from one form to another via a set of abstractions and algorithms. It is also possible to invert such abstractions and algorithms to generate, test, and then explore theories regarding the behaviour of such things, and to then develop new understandings; it is also possible to apply these approaches in ostensibly unrelated areas for the creation of new and diverse works and understandings.

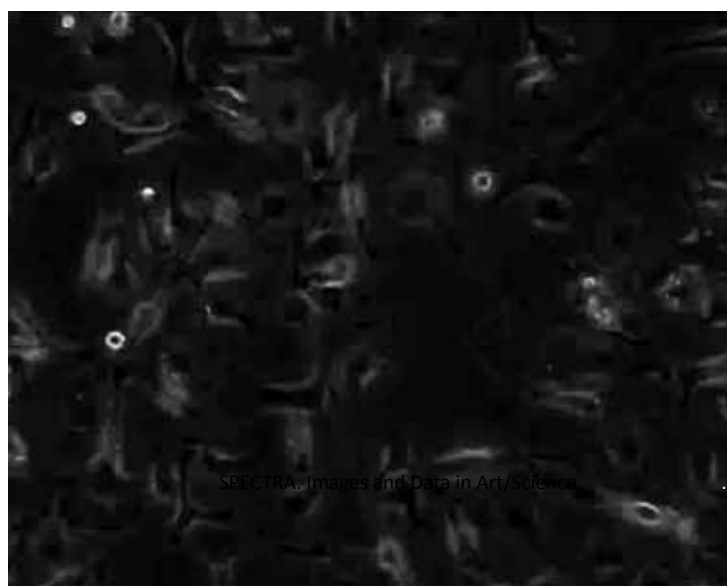
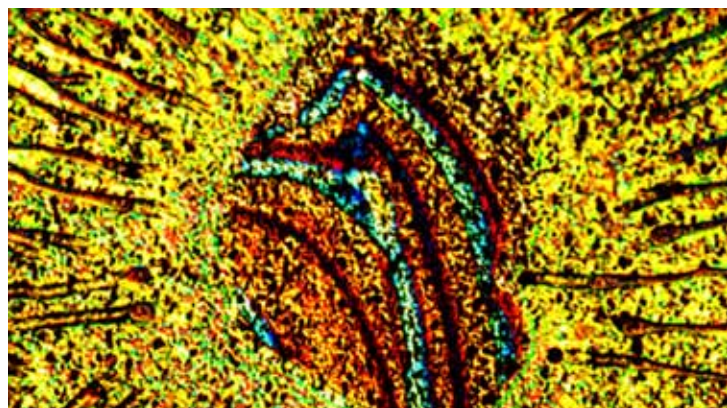
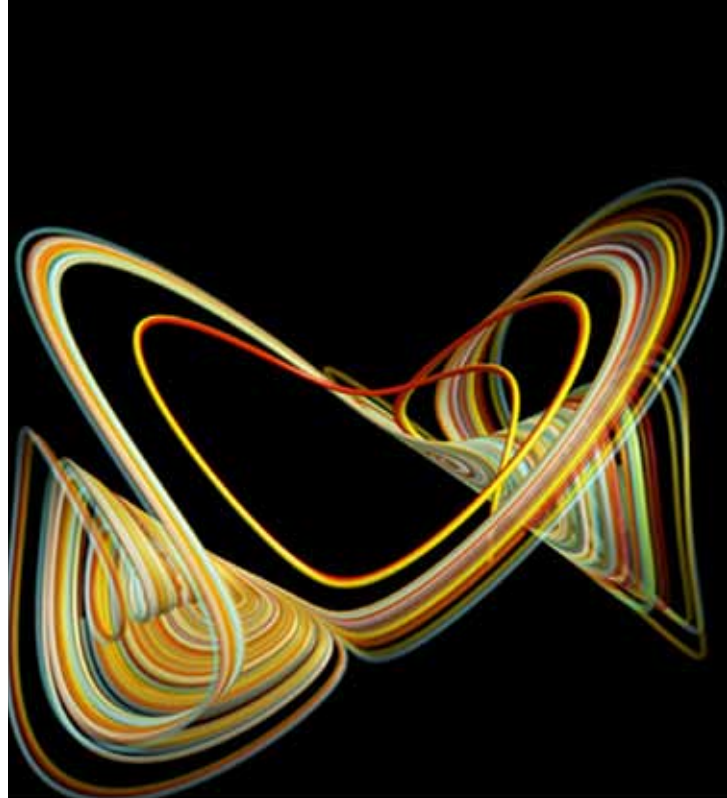
Authenticities

In *The Work of Art in the Age of Mechanical Reproduction*, Walter Benjamin discussed what makes an authentic artwork, saying "The authenticity of a thing is the essence of all that is transmissible from its beginning, ranging from its substantive duration to its testimony to the history which it has experienced", which is eliminated through reproduction. He continues: "One might subsume the eliminated element in the term

Figure 1 (above): Illustrating the geomagnetic reversals

Figure 2 (middle): Arsenic sulphide dissolved in solution

Figure 3 (below): Image from the monocyte film used to develop the musical piece discussed here



“aura” and go on to say: that which withers in the age of mechanical reproduction is the aura of the work of art.”[28]. But the age of mechanical reproduction allows the sonification and visualization discussed above.

In their accompanying gallery statement, Zwicker et al describe the images in *Figures 1* and *2* as “not art for art’s sake. Rather, they were produced during the course of scientific research [and] chosen for their aesthetic excellence as well as scientific or technical interest.”[16]. This indicates the application of an “aura” to the images, even though the images were not created with a similar intention or context to the artworks Benjamin was referring to. Instead, the images were seen and then interpreted as having an aesthetic value extra to and distinct from the original reason for creating them. This is a case of an “aura” being applied to an inherently “aura-less” image by the perceiver and for that aura to then be “reproduced” in the transmissions via a medium extra to the image. This process of creating an artwork from a non-artwork is reflected in Duchamp’s statement that the “creative act is not performed by the artist alone; the spectator brings the work in contact with the external world by deciphering and interpreting its inner qualifications and thus adds his contribution to the creative act” [29]. Duchamp’s *Fountain* is an example of the artist instilling a value or “aura” on a non-

artwork, and that “aura” being agreed to by many.

This creative act is not just the domain of man-made/contrived objects or events; there is a sense that natural objects or events, when contextualized and interpreted as having an extra qualification or authenticity, can be interpreted as having the qualities of art; these qualifications and authenticities are applied in Zwicker et al’s statements.

Musical structures and Organic structures

Western music has the inbuilt abstraction of musical notation, which describes the temporal arrangement of sounds in order to create harmonies, melodies, rhythms, and textures, and number of innovations to the canon came about in the twentieth century. While keeping relevance to the music and inherent structures, the changes that came about were radical. Schoenberg’s twelve-tone approach ‘emancipated the dissonance’, forming a new way to consider musical structure at the core of a musical composition [30, 31]. This approach created a system that allows algorithmic creation and manipulation of harmonies, melodies, rhythms, and textures exposing consequent tensions and resolutions. Examples of this can be seen in various approaches to compositional design [32-38], [39-42], however there are a number of issues with this approach to the organisation of sounds [43, 44].



Figure 4: Four pitch sequences

In the arts, an organic structure is often felt to be one in which an ad hoc approach in the processes and development of an outcome is used. In the sciences, an organic structure may be a more finite and applied term.¹ In the creation of TWITCH an organic structure is considered to be generative within set paradigms to produce outcomes recognized as fitting that structure.

The background pitch structure used here, created by Myers, is shown on the previous page in *Figure 4*. It can be accessed and interpreted in many ways, and when using and adhering to it, any heard iteration is redolent of the structure, regardless of the sounds heard.

Figure 5: MIDI numbers of note used

SEQUENCE A	27	28	32	33	36	37	39	40	43	44	48	49	52	53	55	56	59	60	64	65	68	69	71	72	75	76	80	81	84	85	87	88	91	92	96	97
SEQUENCE B	34	35	37	38	41	42	46	47	50	51	53	54	57	58	62	63	66	67	69	70	73	74	78	79	82	83	85	86	89	90	94	95	98	99	101	102
SEQUENCE C	32	33	37	38	41	42	44	45	48	49	53	54	57	58	60	61	64	65	69	70	73	74	76	77	80	81	85	86	89	90	92	93	96	97	101	102
SEQUENCE D	39	40	42	43	46	47	51	52	55	56	58	59	62	63	67	68	71	72	74	75	78	79	83	84	87	88	90	91	94	95	99	100	103	104	106	107

These four pitch sequences are arranged thus: 9 pitch classes per sequence with multiple octave doublings, which results in a high level of resonance; 3 unused pitches per sequence – the set 0, 4, 8, (an augmented triad), the four complements of which constitute a 12-tone aggregate. As we are working in a computer based music system the pitches are represented as MIDI² numbers, seen in *Figure 5*, above.

Intervals in Sequences A & C

1 4 1 3 1 2 1 3 1 4 1 3 1 2 1 3 1 4 1 3 1 2 1 3 1 4 1 3 1 2 1 3 1 4 1 3 1 2 1 3 1 4 1

Figure 6 (below): Interval sequences of the four sequences

Intervals in Sequences B & D

1 2 1 3 1 4 1 3 1 2 1 3 1 4 1 3 1 2 1 3 1 4 1 3 1 2 1 3 1 4 1 3 1 2 1 3 1 4 1 3 1 2 1

These pitch sequences then form the interval sequences shown *Figure 6*; they are arranged in groups of the seven intervals between eight adjacent pitches in each of the groups seen above, top.

These interval sequences form palindromes. In Sequences A & C above, the first cell of seven interval distances (numbers) are 1 4 1 3 1 2 1, and the last cell of seven distances (numbers) are the reverse, 1 2 1 3 1 4 1, and the third and fifth cells have the interval distances of 1 4 1 3 1 2 1 and 1 2 1 3 1 4 1; this is so for all 16 cells. Therefore the sequences have multiple iterations of the same set/cell, and multiple inversions of sets (for example transposition and the

interval retrogrades shown above), this results in palindromes within palindromes. Sequences A and C are related by octave and B and C are 4th and 5th transpositions of A³ forming a closed, self-referential structure from simple expanding and contracting interval sequences.

¹This should be read as coming from an artist's perhaps ignorant perspective.

²Musical Instrument Digital Interface, a protocol used to communicate between electronic musical instruments, in which each or 128 attributes are given 128 possible degrees of difference.

³(Seq A - 27 28 32 ... + 12 semitones results in, Seq C - 39, 40, 42 ...). Sequences B and D are a fifth and a fourth transpositions from sequence A (the 5th: + 7 semitones, and 4th: + 5 semitones) transpositions being inversion of each other.

Process of forming music from the monocyte film

Alsop's program for interpreting Myer's pitch sequences and the film is shown in *Figure 7*. The four grey boxes containing numbers are in the top right contain Myers' four sequences, and these are triggered sequentially at equal divisions of the film duration ⁴.

As the film is being played the average RGB values of 72 small squares superimposed over the monocyte film set the velocity (or volume level) at which a pitch is played. The duration of the pitch is directly related to the pitch MIDI number shown in *Figure 5*. Looking at the top right hand corner of the right

darkened area at the bottom left of *Figure 7*, the velocity, pitch, and duration played is shown, in this image the values in area A are 40, 17, and 1400, causing the pitch 40 to be heard at an amplitude of 17, for 1400 msecs, and in B are 40, 16, and 4400, causing the pitch 40 to be heard at an amplitude of 16, for 4400 msecs.

The speed at which the film is played influences the number of notes struck simultaneously, in *Figure 7* the film, takes 1209 seconds to complete triggering each of its 1199 frames. It is also possible to set the

⁴When using the program contextual pop help is available for each object on the screen.

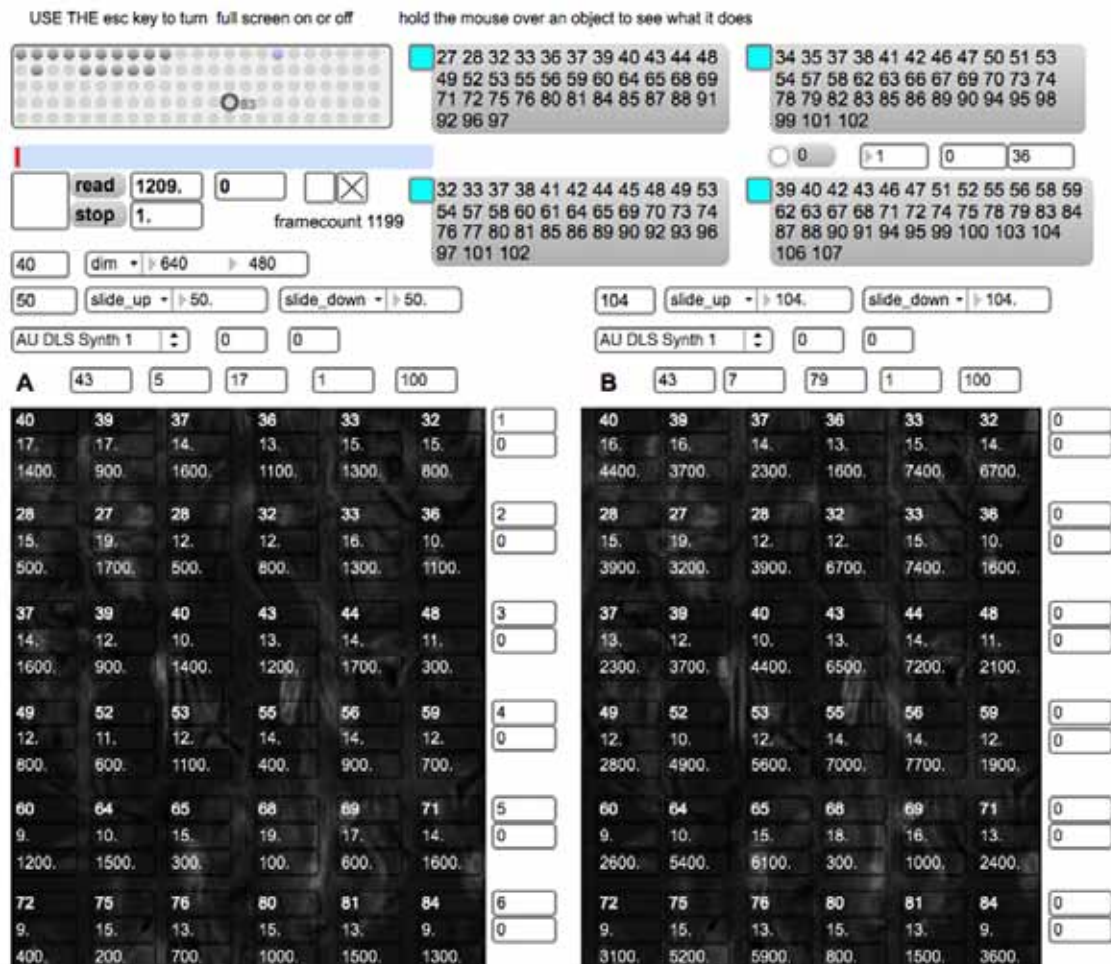


Figure 7: Example of the process for forming music from the film

rate at which the film is played, allowing play from particular frame at a certain speed and then revert or move on to the next frame when that frame is triggered. These processes allow a great deal of flexibility by the composer/program user in interpreting the film, which originally takes 49 seconds to play at 24.5 frames per second.

It is possible to blur the film, which creates gradual variations in the RGB values of each area, creating gradual variation amplitudes at which each note is played.

Conclusion

The monocyte film, Myers' note sequences, and Alsop's process are inherently devoid of Benjamin's 'aura' or Duchamp's 'inner qualification', however each can gain these through an artistic intervention. This process of sonifying a visual image may be used in many formats and for many purposes. The outcomes may fit expected music traditions or not, and there is the potential for calibrating both Myers and Alsop's structures to fit desired musical outputs. These approaches to reinterpreting data show possible ways to re-encounter, and then re-contextualize, re-understand, these or any other visual event, through an actual transductive process.

At the museum by Barbara Maria Stafford



A Feeling for the Image: Hands, Body and Visualisation of the Invisible

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Visualising the Invisible

A fundamental issue in much scientific imaging is that the object of our investigation is invisible to the naked eye. Indeed, the whole aim of disciplines such as microscopy or astronomy is to reveal the appearance of the invisible. In the case of microscopy, the objects of interest are too small to be seen without the aid of some kind of instrumentation. Modern microscopy can now visualise structures down close to atomic level. Powerful instruments use lasers (confocal microscopy), electron beams (electron microscopy) and even incomprehensively small inter-molecular forces (atomic force microscopy) to determine the microscopic structure of biological structures such as cells and their intracellular molecular machinery, and, in some cases, the molecules themselves.

Since the earliest days of optical microscopy, microscopists have struggled with the interpretation of the images they generate [1]. Even in the case of optical microscopy, the magnified image is heavily mediated, generated by surprisingly complex interactions between light, the specimen, the way it has been prepared, the optical system itself, and, ultimately, the visual system of the viewer. When we consider image generation by a scanning laser confocal microscope, many types of modern electron microscopes or atomic force microscopes, there is no raw optical image to see directly. The images are generated by complex technology controlled by sophisticated computer software, resulting in a display where each pixel represents some form of information encoded into an visually-

-appreciated analogue. From the beginnings of microscopy, the technical literature has discussed the processes involved in the transformation from original specimen to the magnified image [2]. Correct interpretation of the image requires knowledge of the source of the specimen, how it was prepared, the viewing conditions, and underlying operational principles of the microscope and its image acquisition paradigms.

But something else is also going on, especially with experienced microscopists, or indeed, the users of any imaging instrument. It is readily apparent that such users develop a deep intuitive feel for the nature of the material they are observing. Such intuition arises from two sources: familiarity with the specimens under investigation, and familiarity with the mediation processes of the imaging instrument. But how does this intuitive “feeling for the image” arise? Most microscopists, if asked to explain what they have been observing, will describe their images via some combination of drawing and gesture. Why do they use their hands to configure something that cannot be seen, let alone grasped and manipulated? Is this any different from the way we explain anything we cannot see, such as the internal structure of our own bodies?

Scanning Laser Confocal Microscopy

Confocal microscopy is an optical microscopy technique that became widely available around 20 years ago and is now a mainstay of modern biological research [3]. In the most common form of confocal microscopy, an extremely narrow laser beam

is scanned across the sample using the same lens that is used to capture light re-emitted from the sample. The optical path is set up in such a way that only a very thin slice of the specimen is in focus at any time (an “optical section”). By scanning through the specimen at a series of different focal planes, the microscope produces a series of adjacent optical sections of the specimen. The microscope software then can build up a data-set to generate a high-resolution virtual three-dimensional representation that can be viewed and measured in many different ways.

The technology underlying laser scanning confocal microscopy is formidable [3]. Laser sources come in a variety of modes and wavelengths (colours), with some capable of being tuned to deliver a variety of wavelengths as required. Control of the laser beam intensity and colour selection may be achieved using acoustic-optical filters that do not use any glass. The laser beam scanning is accomplished via a pair of mirrors that oscillate up to 8,000 times per second. Detectors can respond to single photons of light allowing hardware-software modules count them, and assign their origin in multi-dimensional space.

To maximise the utility of an instrument like this, an expert operator ideally needs a decent working knowledge of the relevant aspects of quantum mechanics, optics, photochemistry, and computing, not to mention all the biochemistry and cell biology necessary to understand the behaviour of the specimen itself.

At the extreme, when only single photons are being gathered to generate the image, there is nothing to see in real time. The image plane is sampled for only half a millionth of a second at a time (ie 0.5 microseconds per pixel), and most samples do not contain any photons. However, when this process is continued repeatedly in space and time, the single photon data can be integrated to generate a high-resolution image of the specimen. But given the large amount of intervention between the original specimen and the final image, how do we know if it is “real”? Of course the image itself is a real object, or at least it can be rendered into one from computer memory. The more relevant question is how well this construct mirrors the underlying structure of the specimen, in particular the components of the specimen

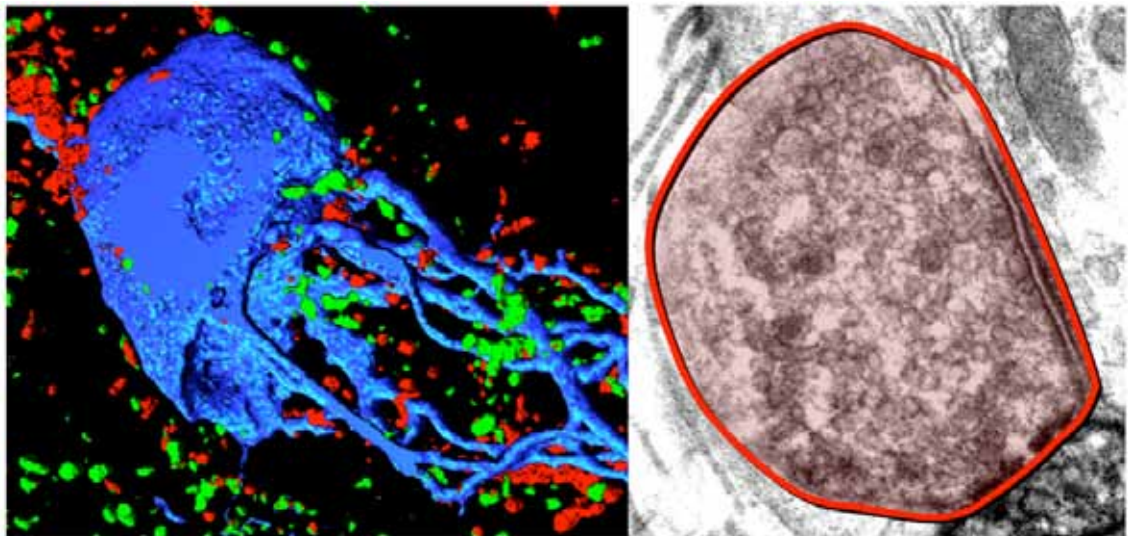


Figure 1: (Left) Computer reconstruction of a confocal microscope image of a single neuron (blue) and its potential synaptic connections (red and green). This image contains several artefacts of the reconstruction process that could not possibly exist in a living neuron. (Right) An electron microscope image of a synaptic connection, outlined in red (from [10]). A synaptic connection is about 1 micrometre in diameter. The electron microscope image shows internal structure that cannot be seen with a confocal microscope.

specimen that we could not “see” otherwise. The answer is relatively simple conceptually, although it may be difficult in practice. What you observe with the microscope in any specific instance is compared with what you (or others) have seen previously, especially if similar material has been imaged with a different technique or at a different magnification. So you might compare your confocal images of a particular type of living cell with electron microscopic images, which provide much higher magnifications, albeit not of living tissue (*Fig. 1*). You also might compare your confocal images with what you know about the behaviour of comparable cells in intact organisms.

While such comparisons may take considerable time and effort in a rigorous scientific context, we do this kind of mental processing routinely in the rest of our lives. What we know about the nature of external objects in our worlds is informed by multiple modalities of sensory input: typically visual, tactile, auditory, and where appropriate, olfactory or gustatory [4]. Remarkably, we are able to visually recognise familiar objects in the absence of touch, colour, realistic three-dimensionality, sound, or most other senses, as when we see a black-and-white photograph of our house or dog or sister. The critical importance of familiarity is obvious if we are given a photograph of an object we have never seen before: not only will we fail to recognise it, to give it a name, but we may not even know which way the image should be oriented.

Use Your Hands

Most scientists are delighted to explain their work to you. If you ask a microscopist to show you what he or she has been observing with their instrument, you’ll almost certainly be given a look and an explanation. Nevertheless, if you are not a microscopist yourself, you probably will find it difficult to understand what is actually before your eyes. What do the colours mean? Which bit is which? How big (or small) is it? Before long, most microscopists will be explaining the images to you, taking advantage of two key sets of

props, namely, some sort of drawing implement, and their hands.

There are several remarkable features of such a performance, yet they are so natural, we take them for granted [5]. Your microscopist will sketch outlines of cells, or organs, or molecules as required, all within the confines of the page that happens to be available. And, almost certainly, he or she will indicate with their hands the general shape of whatever it is, spatial relations with its neighbours, how it interacts with other components of the system.

In order to do this, your microscopist clearly must have an internalised mental image of whatever is being explained. This image somehow exists in a scalable state: the drawings will be different in some way if they were made on a typical laboratory whiteboard compared with a sheet of A4 paper. At very least the drawings will be bigger on the whiteboard, and they necessarily will be constructed via a different set of muscles and movements, as befits the larger scale and standing posture. More than that, this internal image can be represented from different points of view: from above, from below, a zoomed view of a detail. How is this achieved? Where in the brain is such an image stored? We will discuss this question further below.

Under Your Skin

We have investigated a closely related set of questions in what initially seems to be a completely dissimilar situation. How do students studying human anatomy come to form an understanding of the internal structure of the living body? The relative sizes and positions of the various internal organs, the muscles, blood vessels and nerves?

There are many resources available for students trying to learn anatomy, most notably well-illustrated textbooks, anatomical atlases, and, increasingly, computer-generated animated virtual models of the body and its constituents. But these are all overtly artificial representations, flat on the page or screen. Regardless of how

skillfully or interactively the illustrations are rendered, no one could ever confuse them with the real thing.

At the Flinders University School of Medicine, we are fortunate to have a well-equipped Anatomy Teaching Laboratory. Here, students have the rare opportunity to study directly the three-dimensional topography of the human body, either using anatomical specimens prepared by our skillful technical staff, or by doing their own dissections, as part of the medical course. Although learning anatomy at the detail required to practise medicine is a daunting task, most students find the experience enjoyable overall.

What are the advantages of learning anatomy from real specimens? The method by which the specimens are preserved means that they have neither the colour nor material texture of the living body. Nevertheless, differences in elasticity, flexibility, and hardness of the organs and their parts persist in the preserved specimens. Unlike a plastic model or a computer-generated representation, a real anatomical specimen differentially gives as it is handled: it is deformable; it has mass and volume that vary from region to region, specimen to specimen. While some of this information can be gained by simply looking at the specimens, so much more is obtained by physically handling them, exploring the feel, the heft of them. This tactile information is gathered largely subconsciously, while the students are providing explanations to each other, looking up their notes or other nearby teaching materials, or as an element of curious enquiry.

We expect the students to have a deep knowledge of human anatomy. But whose body have they learnt? How do they rescale between the life-size specimens and the textbook or smart-phone diagrams? Clearly, the students (and their anatomist teachers) must form a generalised set of images of the internal structure of body. As practitioners, they must access this mental model of details they cannot see whenever they physically

examine a patient, review a radiograph, or carry out an operation. And just like the microscopists, most will explain what they know with a combination of sketch and gesture.

A Model in the Brain

In recent years, there has been astounding progress in understanding how the brain forms internal representations of the both the body itself and the physical world that surrounds it. A substantial amount of the cerebral cortex (most of the parietal cortex) is devoted to the mapping of sensory information from the body, converting that into knowledge of the appearance, mass and texture of the thousands of external objects we can recognise and manipulate [4; Fig. 2]. Another large area of the cortex (the motor and premotor regions) develops, stores and continuously updates our knowledge of how to move our body and manipulate external objects [6].

Several cortical areas interact to generate our conscious experience of inhabiting our own body, most critically, the inferior parietal cortex. This construct is suprisingly malleable, as seen most dramatically in the rubber hand illusion, in which a subject can be easily convinced that they can feel an obviously artificial limb as being part of their body [7,8].

As bizarre as this may appear, we make these modifications to our body schema all the time. For example, if we are writing with a familiar pen, we only think about the text we are trying to generate; we are at best minimally aware of the pen itself, and then, probably only the pen tip as it scrawls across the page. In line with anecdotal experience, there is good evidence showing that our knowledge of familiar objects becomes incorporated into our internal body schema. Thus, familiar objects feel “natural” because they are interpreted to be extensions of the body by the cerebral regions responsible for recognising and controlling their activity [4,6-8].

A Feeling for the Image

Although the precise experiments have not

been done, it is clear that microscopists and anatomists alike must generate detailed internal representations of what they have seen. Notwithstanding inevitable factual errors and conceptual holes, these representations become more “life-like”, ie have greater fidelity and accuracy, with increasing familiarity and experience. They are at once both generalised and particular: they provide a template for commonality and a base level for recognising difference. They are intrinsically scalable: in principle, they can be drawn or recognised at any size, but they feel most comfortable, most natural, when reproduced at normal body scales.

But we must return to the critical difference between the mental images of a microscopist and an anatomist. When all else fails, the anatomist can check up with the real thing, largely unmediated by technology, chemistry and physics. However, the microscopist’s image is forever invisible to the naked eye; no matter how familiar it feels, it is always mediated by instrumentation.

So what does the invisible feel like? How can you describe the familiarity of an object you cannot touch, that has no weight or texture, no aroma, no natural colour? Science can provide some formal language of analysis, but ultimately, perhaps poetry best approaches the essence of the feeling.

“The space between my hands.

Like whiskey-tongued fishermen, shore-bound by Force Ten gales, I dream about the ones that got away: snapper, mullet, ocean trout, hammerhead, fins slicing the sea into sashimi, carpaccio, butterfly fillets, jettisoned, spinning and flipping and floating far from any dimly recollected grasp.

The gaps between my fingers,

as if they were feathers, as if they should span the imbalance dividing this updraught from that, this diminishing shadow from its source, this invisible calculation defining lift and drag, streamlined flight and unrecoverable freefall, from this total, irredeemable, loss of sensibility.

The space between my hands, the gaps between my fingers:

only now can I describe the shapes that fill my memory; only now can I describe the holdfasts, the hefts, the weights, the locks and latches, the keys misplaced forever; only now, can I describe, for you, a tattoo needle, a wedding ring, collisions, inadequate light, unbidden, insufficient narcosis.” [9]



Figure 2: The left side of a human brain, with the brainstem and cerebellum towards the lower right of the image. Area 1 (red) is the superior parietal cortex, which stores information about the physical nature of objects we handle. Area 2 (green) is the inferior parietal cortex, which is essential to forming the feeling of owning our own body. Area 3 (blue) is the temporal cortex, which stores semantic information that we use to verbally describe objects.



Dancing up a Storm: Interactions Between a Dancer and the Surrounding Fluid Medium

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² Canberra Dance Theatre / CSIRO Discovery

Dance is, in its outreach to the audience, primarily a visual form of artistic expression. The graceful and aesthetic motions of a dancer can be readily observed and appreciated. Invisible to the naked eye, however, and therefore usually far less appreciated, is the interaction of the dancer's body with the surrounding air. We explore two aspects of this interaction.

Any motion of the dancer creates motion in the air, a kinematic interaction. In fluid dynamics parlance, a dancer may be considered a “bluff body”, or an un-streamlined shape. The velocities of the dancer's torso and limbs are in general small enough that the fluid motions engendered fall into the regime of “low Reynolds Number (Re) aerodynamics”, where the flows will be laminar or moderately turbulent. Such low Re flows over bluff bodies are dominated by vortical motions, in which the air swirls off the body and continues to rotate as it moves away, in “miniature tornados”. These motions of the air can also be very aesthetically appealing when made visible, as in the sinuous waving of a dancer's apparel (see *Figure 1*) or the ribbon in rhythmic gymnastics.

A well-documented example from the natural world is in the play of dolphins and whales (cetaceans). They are able to create bubble-filled vortex rings (“bubble rings”) from their blowholes, where the many small bubbles from an exhalation merge into a single large annular bubble. In this case the rings are clearly visible due to the sharp interface between the air in the bubble and the surrounding water. The vortex rings are self-advecting, and are long lasting and coherent due to the relatively low viscosity of water, until their velocity reduces below a critical value and they become unstable and break down. Dolphins and whales do not just create these rings, but play and interact with them in a way that could easily be described as dancing. The rings can be nudged, rotated and flipped, steered and pinched into smaller rings, and seem to serve as analogues of physical toys.

Figure 1 (left). The waves that can be seen propagating along a dancer's apparel (here: white silk) are related to the motion of the dancer. The image shows dancer Alison Plevy in Liz Lea's *InFlight*. Photo taken by Lorna Sim.

Figure 2 (below). Beluga whales playing with bubble rings .



The motion of the cetacean and the motion of the vortex are both aesthetic when considered separately, but the ability to see the fluid flow, both for the animal and for the human observer, make the effect greater than the sum of the parts and quite simply wondrous to behold.

A second type of interaction of a dancer with the surrounding air is via the heat given off by the dancer's body. A ball-park figure for the thermal power output of a moderately active human is 100 watts. During strenuous exercise, this output can be several times higher. This results in a heating of the air adjacent to the dancer, leading to slightly less dense air which rises in a buoyant plume. The motion of this plume depends primarily on the density ratio that creates the buoyancy and how the buoyancy force compares with the other forces that shape the flow, primarily friction and inertial forces. The latter two forces are introduced by the motion of the dancer, which moves the surrounding air and as a consequence modifies the thermal plume. The resulting kinematic interactions generate a flow shaped by the interplay of buoyancy, friction and inertial forces.

A visualisation of such a flow can provide an insight into the mechanisms of these interactions, but as air is transparent and thus invisible to the naked eye, special techniques are required to observe such flows. Fortunately, density differences in air or other (transparent) fluids can be detected with relative ease as a change in density changes the speed of light through the fluid. If the changes are large enough they may be observed without special equipment – take, for example, the distortion of a background if viewed through the exhaust of an engine or simply through the hot air above a candle – but if these changes are subtle, one needs special optical equipment to detect them. One such method used to see and measure density changes in a transparent medium is the so-called “schlieren” technique. Light is sent through the transparent medium of interest, and if the light beam encounters density variations, it is refracted by different amounts depending on the size and direction

of the variation. These refractions are optically amplified and give rise to patterns of greater or lesser light intensity (or different colour) on a viewing screen or camera. This technique was used here to visualise a few small-scale flows that contain the previously mentioned motions of buoyant plumes.

Figure 3 shows examples of such visualisations: In the left image, a table tennis ball balancing on a gaseous stream (visible in the schlieren system, but not to the naked eye) is being pushed by the girl, which gives rise to changes in the flow (incidentally, the girl's breath and the warm air surrounding her face and her hand also become visible inside the visualisation system). The middle image shows how the hot column of air above a candle flame is blocked by a hand. As a result, the warm air moves to the side and forms a larger vortical structure in the process – a typical behaviour of a low Reynolds number flow as indicated above. Finally, the plume of warm air surrounding the skin of a hand is seen in the image on the right – note that this air flow is only visible above the hand while only a thin layer of warm air can be detected on the lower side of the hand.

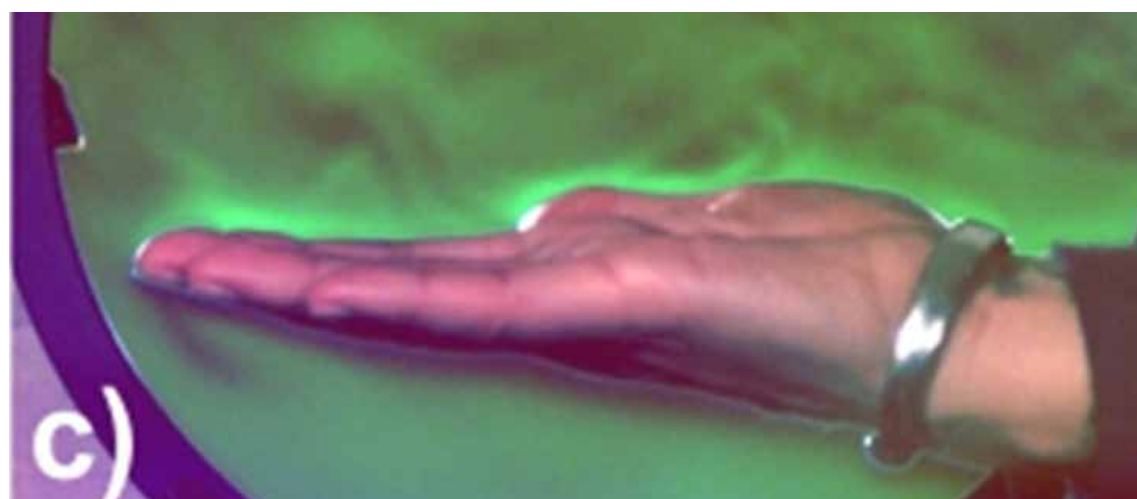
Making visible both the kinematic and thermal interactions of the dancer with the surrounding air provide a heretofore unexplored way of changing the visual experience of dance. Our eventual aim is to create a visual analogue of the “light harp” (where a performer creates sound by interacting with a series of light beams linked to a synthesiser). In our envisaged system a dancer, being able to see the flow patterns created by their movement, is able to modify that movement to create an aesthetic flow pattern or a particular desired effect, and the visualisation system lets the audience see this interaction.

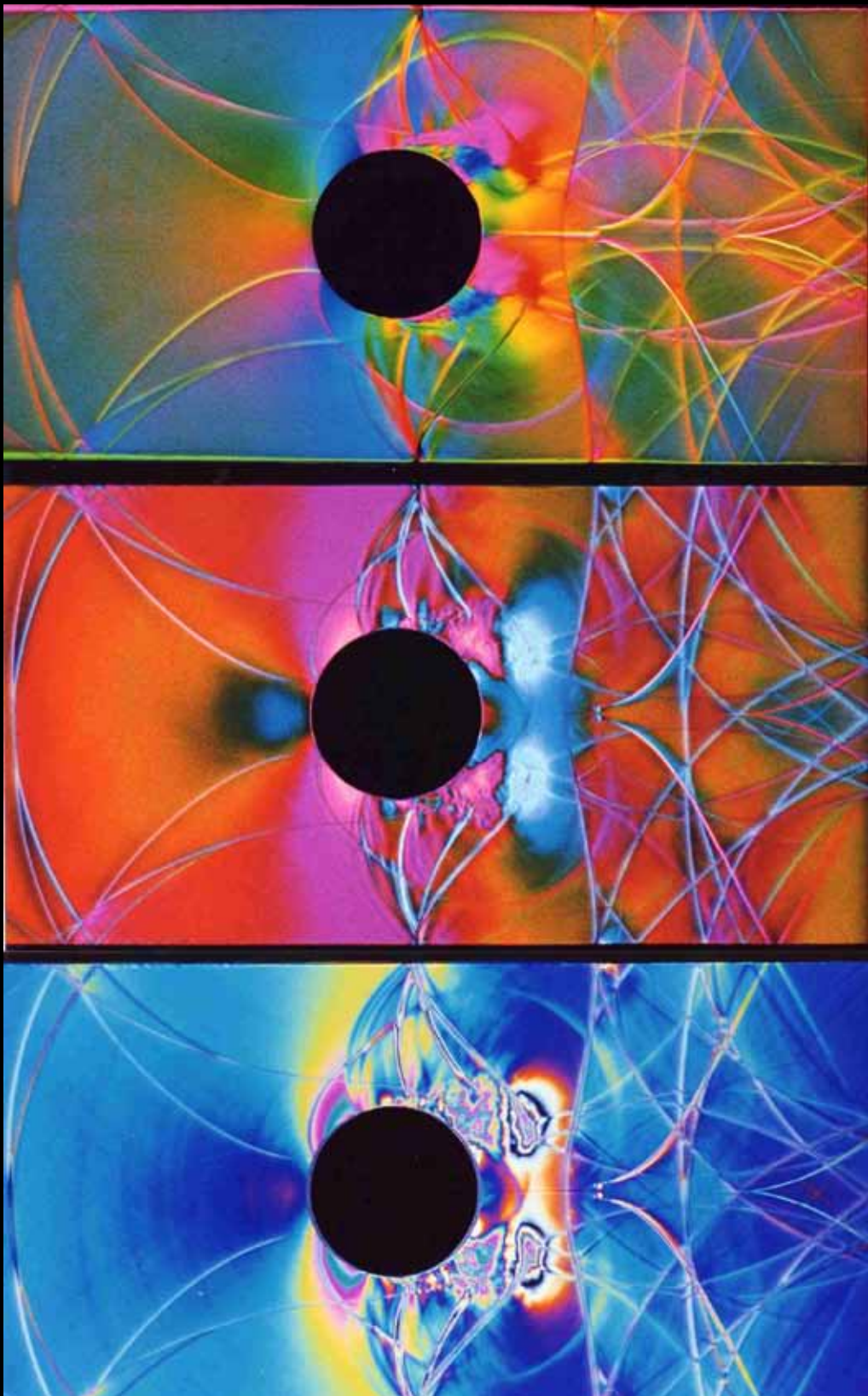
Figure 3. Colour schlieren flow visualisation with front lighting. Details of the used setup are described in [1].

a) Visualisation of the gas flow keeping a table tennis ball suspended in mid-air. Elements of the girl's thermal plume from her forehead and breath are also visible.

b) Developing vortical structure within the thermal plume of a candle flame blocked by a hand

c) Warm air rising from a hand





Fluid flows. Image: Harald Kleine, UNSW

StellrScope

Eleanor Gates-Stuart

Australian National Centre for the Public Awareness of Science, Australian National University, ACT
Computational Informatics CSIRO, ACT, Australia

StellrScope builds on a story connecting the Canberra region to Australia's major crop in delivering a science artwork for the Centenary of Canberra (2013). It celebrates a 100 years of wheat innovation from the days of William Farrer through to the present day research undertaken at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), namely in the Future Foods Flagship and Computational Informatics. In coining the term, *StellrScope* (Gates-Stuart, 2012) to describe *translating information complexity into a simplistic visual rendering of meaning*, it is significant in such a project where the volume of scientific information is possibly overwhelming for non-scientists and requires a comprehensive visual interpretation. In tackling such a project, the processes involved are not always predetermined and respond much more to the direction of ideas, content building, researching and an aesthetic understanding and construct for creating the artwork. That being said, the question of "how to represent a 100 years of meaningful content in a singular artistic outcome for the Centenary of Canberra as well as an artwork with equal value and understanding for CSIRO?" was the challenge (Gates-Stuart, 2013).

Context

Commissioned by the Centenary of Canberra (2012), the Australian Capital Territory Government (ACT), the *StellrScope* project was also the basis for Gates-Stuart's residency as Science Art Fellow at the CSIRO, as the successful recipient of the Science Art Commission. The CSIRO and has a long history of Science Art (c. Kennedy, 2013), the Food Futures Flagship exemplifies this kind of effort with its Future Grains Theme as a key supporter of *StellrScope*. In 2008, CSIRO initiated its Transformational Capability Platform (TCP) program with the explicit intent of fostering vital cross-organisational science areas; the Transformational Biology TCP that provided the residency for Gates-Stuart. The CSIRO residency bridged the Divisions of Computational Informatics, the Food Futures Flagship and the Australian Plant Phenomics Facility.

The breadth of *StellrScope* research and the geographic spread of its researchers made this a challenging aspiration; communication within the organisation, between the research disciplines and its houses certainly fostered a creative catalyst (Gates-Stuart et al., 2013) and was critical to its success. The



Figure 1. StellrScope Science Art Commission: the *StellrLumé Domes*

final commission piece, *StellLumé Domes* as shown in *Figure 1*, respectfully pays homage to this successful partnership.

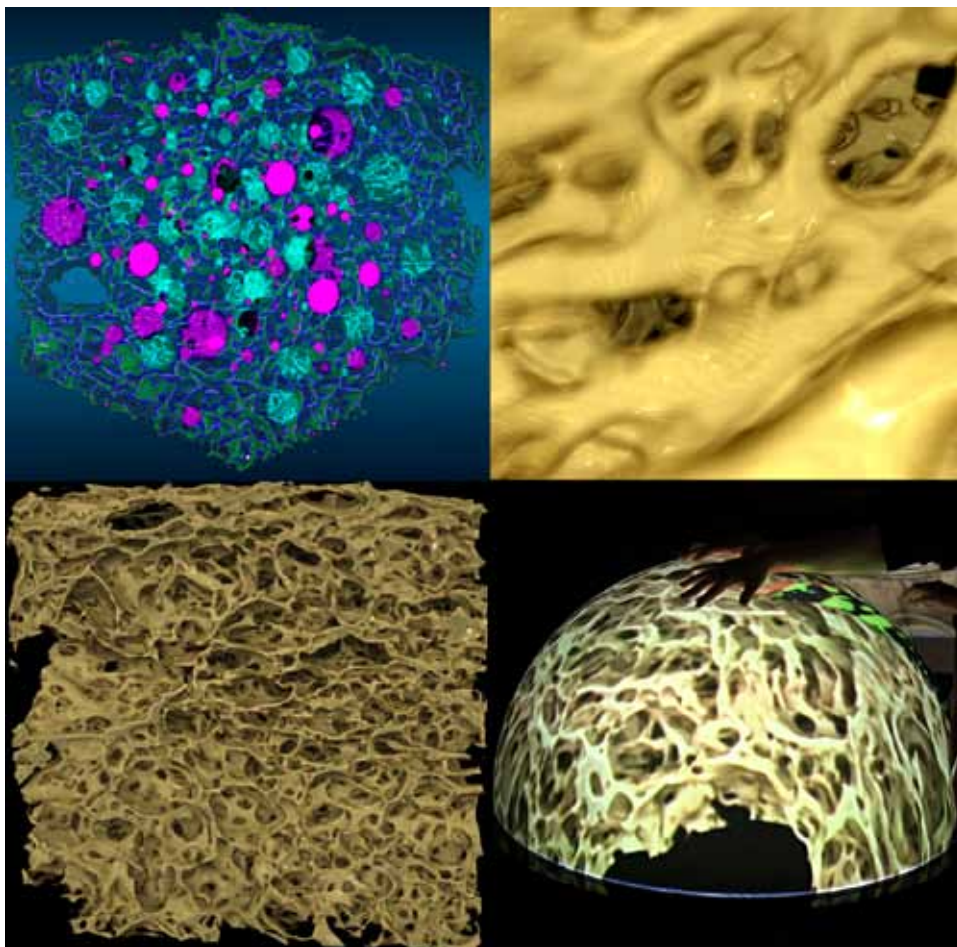
Making the work

Uniquely, the premise in creating *StellrScope*, beyond just using of elements of science within the work in this project, Gates-Stuart used art to illuminate the science for the purposes of research. This proved to be a model for mutually beneficial science/art explorations in related fields across interdisciplinary practice (Gates-Stuart & Nguyen, 2014), particularly in this collaboration between scientists and artist, and of significance within a national research organisation (Gates-Stuart et al., 2013). This synergy between scientist and artist enveloped other collaborators at CSIRO as the *StellrScope* project generated the opportunity to enhance other research areas. For example, when Gates-Stuart presented images at a Future Grains workshop,

Dr Sumana Bell (Research Director at the Centre for Grain Food Innovation) saw the potential to apply these ideas to the “invisible bubbles” of gas inside bread. Links were made to Dr Sherry Mayo who has since used X-ray CT to gain insight into the voids that form during dough development, and which determine texture, consistency and baking properties. This joint research between Bell and Mayo neatly illustrates how Art can catalyse Science and foster interactions across research domains (Gates-Stuart et al., 2013) and is just one of several throughout the *StellrScope* project. (See *Figure 2*)

It is these explorations that informed and led the direction of the *StellrScope* Science Art Commission artworks, especially as the final works were to be shown at the Questacon

Figure 2. Invisible Bubbles: X-Ray Phase Contrast Scanning in collaboration with Dr Sumana Bell and Dr Sherry Mayo



(National Science and Technology Centre) and at the CSIRO Discovery Centre. The artworks certainly reflect Professor Durrant's catalogue statement; *Genuine partnerships between artists and scientists represent a new form of interdisciplinary practice that can have a significant influence on the public's engagement with science. Such partnerships with respectful exchange of ideas and perspectives can also help both artists and scientists see things in new light* (Durant, 2013).

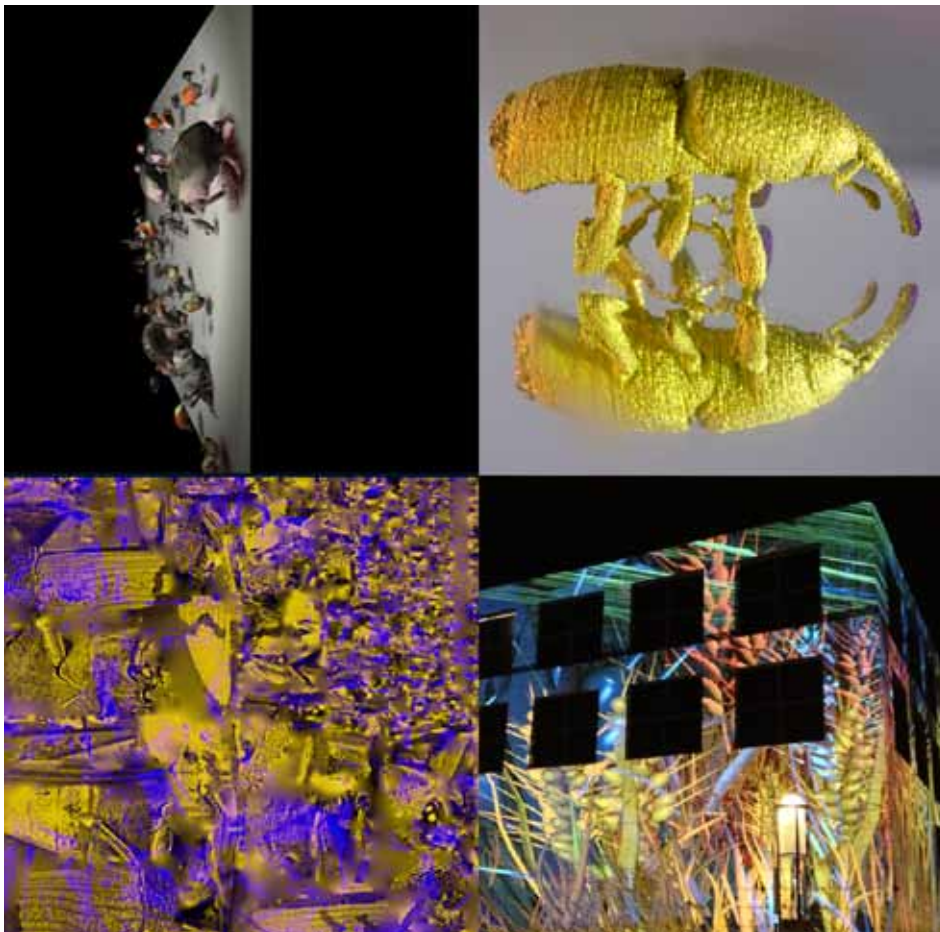
Testing the limits and extending the scope, both in content and experimental techniques were presented in many forums and public exhibition leading up to the final corresponding exhibitions, *StellrScope*, and *Hot Seeds*. An opportunity to discuss the research and preview a live screening of the 3D insects had been presented at Spectra that showed 3D animated insects crawling around the CSIRO Entomology building. The Enlighten Canberra Festival (ACT Government, 2013) included large scale architectural projections on Canberra's

National Institutions of 3D insects and plants on the Questacon building, whilst the 3D titanium Insects (Davis, 2013) were exhibited at *Embracing Innovations Vol. 3* (Hely, 2013) at the Craft ACT Design. Such interactions and public art opportunities served as an important information loop and positive feedback in terms of the research and development of new works. Figure 3 details the images used in these artworks.

Focus on Wheat

Connecting the Canberra region to Australia's major crop, celebrating a 100 years of wheat innovation from the days of William Farrer through to the present day research undertaken at the CSIRO, *StellrScope* takes a step beyond the biological fingerprint and is a deep and intense scrutiny of the remarkable

Figure 3. (Top Left) Animated Bugs at Spectra; (Top Right) 3D Titanium Insects; (Bottom Left) Detail of 3D Mapping on the Questacon Building; (Bottom Right) Wheat Field on Questacon.





physical and biochemical traits of organisms in physical plant structures. Despite first appearances, quantitative sciences like mathematics, informatics and statistics have long-standing and deep connections to biological science. Modern molecular biology is awash with data from instruments that tell us about the DNA of living organisms – informatics, particularly computational science, is an essential part of dealing with this deluge of data.

This work is a result of collaboration at CSIRO, working with scientific leaders Dr David Lovell and Dr Matthew Morell including many other valued scientific researchers and linkage partners such as the William Farrer Trust. This innovation of national significance certainly extends the early research achievement of William Farrer who no doubt would be immensely proud of this research legacy and inspiration towards StellrScope.

The focus of StellrScope has been centred on various themes, such as growth and development, pest and disease, technology and bioinformatics, including health and future food. Situated with the department of computational Informatics, the influence of using numerical data, or code as visualisation extracted from data, such as algorithm or more typically, data sets is an underlying basis for the transformation away from traditional two dimensional representation. Lovell introduced Gates-Stuart to the multiple dimensions and multivariate methods underpinning aspects of experimental design and analysis in field trials and wheat

breeding. With the help of Abbot (Abbott, 1992) and Lovell, this entrée into the nth dimension was motivational in exploring 2D visuals into 3D interactive artworks. The first steps were to assimilate the numerous artifacts, data and scientific content ready for content delivery and production, see examples in *Figures 4 and 5*.

StellrScope, the *StellrLumé Domes*, provide an opportunity to encompass visual dialogue using multiple references and technical data within the artwork itself. These results have in fact been encoded into the artwork, embedded as visual layers, accessible via human interaction revealing multifaceted scientific information and historical findings (including William Farrer's field diary) that is the

Figure 4 (above). 'Splendour' by Eleanor Gates-Stuart. X-Ray Phase Scanning by Dr Sherry Mayo

Figure 5 (below). 'Bio Wheat' by Eleanor Gates-Stuart. Heat Map Data by Dr David Lovell



intention of artwork. As with science, it is not always what appears on the surface that tells the story but the means to explore the evidence, or in this case, the visual narrative within the beauty of the aesthetic.

StellrScope simplifies this complexity into stunning images of aesthetic analysis and graphical interface, extracting complex visualisation data with image to construct narrative via interactive hemispherical displays, named *StellrLumé Domes* as an installation artwork for the Centenary of Canberra.

Conclusion

The process for each exhibition, *StellrScope* and *Hot Seeds*, were interesting in that the exhibitions were connected in content, although the environments were very different. The *StellrScope* exhibition was kept under wraps until the opening day as the work involved the commission piece, *StellrLumé Domes*, and three other large pieces, including an interactive floor piece, nicknamed 'Disco Floor' because everyone wanted to dance on it, artwork shown in

Figure 6. This exhibition at Questacon emphasised the spirit of play and learning through discovery as key factors to the make and build of the work.

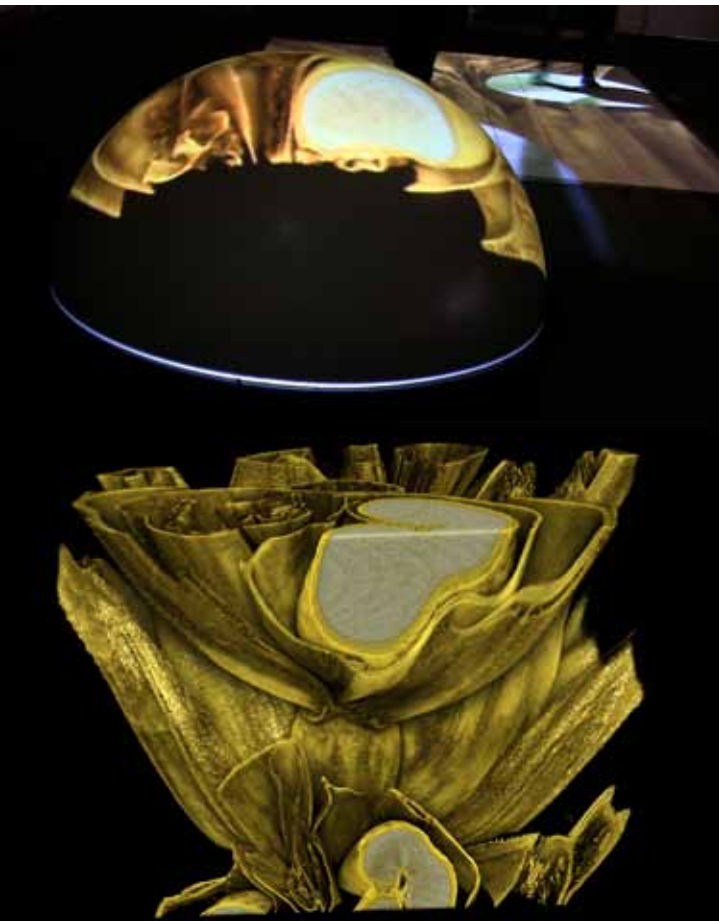
The CSIRO Discovery Centre focused on the images created during the residency as the exhibition space suits large wall based works and is also located near the science labs, ideal for linking the artworks as a direct result of working with many of the scientists. As a summary to *StellrScope* and conclusion to the research project, it is complimentary to finish this paper with an extract of Dr Morell's catalogue statement:

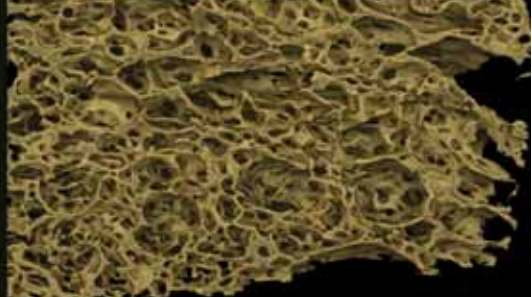
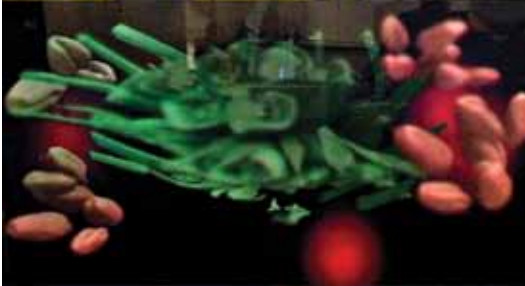
Eleanor's contribution has been multi-faceted and challenges us to re-evaluate our subject from a range of perspectives. She undoubtedly relates to the wheat plant and crop as a source of artistic inspiration, reminding us of the beauty and elegance of the underpinning biology. Eleanor has also challenged us to explain the more abstract aspects of our work. How would you visualise for a lay audience the processes of genetics principles and statistical processes that allow the association of particular regions of the wheat genome with key production traits? Her images seek to capture not only the concrete but the abstract aspects of our science.

Eleanor captures the excitement of the research and of the scientists and makes images that invite enquiry and further engagement. However, in addition to these specific outcomes, an enduring and yet intangible legacy from working with Eleanor has been to explore the similarities and differences between artistic and scientific creativity and expression, and this has been an eye opener for both the scientists and the artist. (Morell, 2013)

Figure 6. (Top) *StellrLumé Dome* and 'Spotlight' interactive floor installation. (Below) Wheatear Plant Section by X-Ray Phase Contrast Scanning

Figure 7. *StellrScope* Collection: (Listed from the top row) *StellrLumé Domes*; Wheat Weevils; 3D Holograms; Collection of Prints; Spotlight on Wheat; *StellrLumé 'Slices of Man'*.





The StellrScope project includes the following artworks (Shown in *Figure 7*):

StellrLumé Domes

The StellrLumé Domes use Spatial Augmented Reality (SAR) techniques to bring computer graphics into the human-scale physical environment. In order to facilitate interaction between the graphics and visitors, overhead depth cameras are used that sense red, green and blue as well as distance for every pixel. Custom software then extracts the human form, such as hands, over the top of the projection surface and elements of the digital content (video images) are selected and shown based on where 'virtual shadows' land and a composite video is projected through a fish-eye lens onto the dome. This creates a two-layer, 2D video on a 3D surface.

Stellr'Lumara

The Stellr'Lumara installation is a volumetric display for seeing 3D images and motion. It consists of a frame with multiple strings placed in a grid formation. Custom software creates an image in a series of vertical strips which are a few pixels wide and each strip corresponds to a single string on the Stellr'Lumara. The strings are precisely aligned to the projector to create the 3D images and motion.

Spotlight on Wheat

The Spotlight on Wheat installation use Spatial Augmented Reality (SAR) techniques to bring digital video content, a wheat field and micro CT seed scans, into the human-scale physical environment. In order to facilitate interaction between the graphics and visitors, overhead depth cameras are used that sense red, green and blue as well as distance for every pixel. Custom software then extracts the human form, body shapes, over the top of the floor projection surface. Elements of the digital content are selected based on where 'virtual shadows' land. The audience must become active participants in order to experience the floor spotlights.

StellrLume 3D Holograms

The StellrScope holograms use 3D data as the foundational component of the hologram. Using CT scans of wheat, seeds and animated

images, the 3D model data is broken down into subsets for each hogel (a three dimensional pixel). Each digital hologram is composed of thousands of hogels. The hologram of the 3D model is created by recording interference patterns of two laser beams. Interference patterns are composed and recorded in the photo polymer film. This completes the process for just one hogel, so it is repeated for each subsequent hogel until the hologram is complete. The hologram records and processes the film and is ready to be viewed.

StellrLume Collection of Prints

StellrScope images have been digitally composed from original documentary video, photographs, drawings and text produced during the Science Art residency at CSIRO, based at the Computational Informatics Division and the Food Futures Flagship. Information was drawn from the National Library of Australia, the Farrer Memorial Trust, National Film and Archives of Australia and in collaboration with CSIRO scientists. The images are produced with archival inks on Hahnemuhle paper from an a large format printer. See more: <http://www.stellscope.com>

StellrLume 'Slices of Man'

The 'Five Slices of Man' wall based sculptures are life size in scale and consist of light resin based material showing large bubble type holes. This work relates to the health benefits of eating bread and draw interest in the research of texture in commercial baking processes, in particular, air holes.

Wheat Weevils

A series of 3D Printed Titanium Insects are a result of researching the weevil insect as part of the StellrScope Wheat Science Art Commission at CSIRO. Creating the 3D insects brought together expertise across CSIRO, including the Australian National Insect Collection, Computational Informatics and Future Manufacturing. The insects were achieved by using advanced scanning techniques and X-Ray Phase Contrast Scanning by Dr Sherry Mayo and Quantative Imaging by Dr Choung Nguyen, CSIRO. 3D Titanium Printing by Dr John Barnes, Lab22, CSIRO

ONE

Rebecca Cunningham

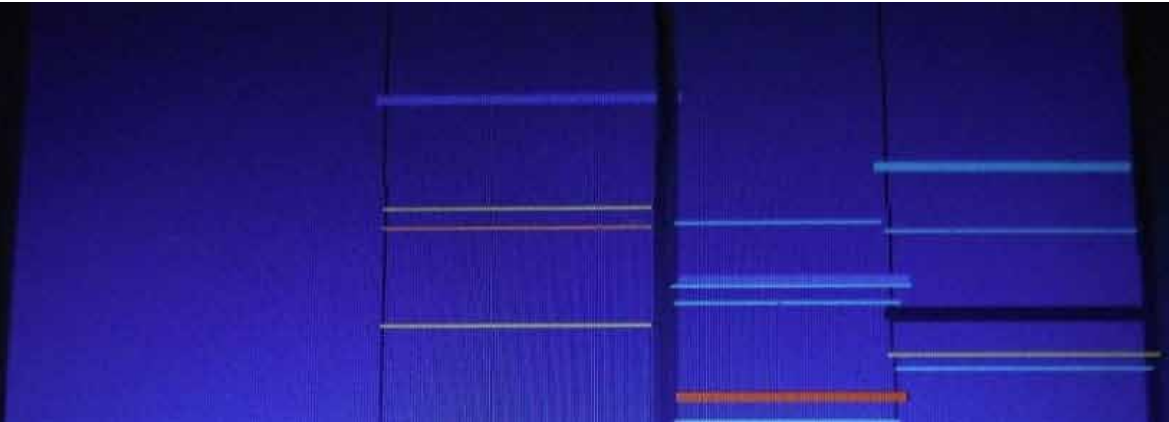
Arts practitioner, Brisbane, QLD www.oneperformance.wordpress.com

**ONE is a durational performance by
Rebecca Cunningham and “all of you”.**

ONE is a performance that may take
ONE lifetime
ONE person sitting opposite
ONE person
there is ONE exchange
ONE sample of DNA is collected
if desired ONE sample of DNA is exchanged
this will happen ONE million times
until ONE million samples have been collected
once ONE million samples
from ONE million people have been collected,
each DNA sample will be imaged
and from ONE million DNA images
ONE will be made
a composite of all becoming
ONE

ONE is a bio portrait of 1 million people
This work began in 2010 as an idea
I will now continue this work for the rest of
my life.
I was thinking about trust, and community.
I was wondering what it would look like if we

could get the smallest parts of ourselves and
put them as close together as possible.
What would this mean?
What would this look like?
Would it be interesting?





ONE first performed at Brisbane Festival
UNDER THE RADAR 2011
image credit: Gerwyn Davis

ONE consists of 2 components

- 1) DNA Collection
- 2) DNA Visualization

1) **DNA collection** This occurs in a performative context : 1 x table 2 x chairs. We sit, talk, exchange DNA
The DNA is a hair sample.
I aim to undertake this act with 1,000,000,000 people. ONE currently has 120 participants.

The performance was first made in Brisbane in 2011, and has now been presented in Australia, the USA, with documentation presented in Poland, and the work will tour to the UK and Europe end 2012.



Brisbane Emerging Artist Festival Metro Arts,
18 February 2012



EMERGENCY INDEX LAUNCH @ THE KITCHEN,
NEW YORK 20 March, 2012 <http://emergencyindex.com/index.html>
Image credit: Emergency Index

4 Festiwal Sztuka i Dokumentacja / 4th Art & Documentation Festival 12 April - May 6 2012
Łódź, Poland www.doc.art.pl

2) DNA visualization

Originally when I asked "What is the BEST way to image DNA?" The response was TEM (Transmission Electron Microscopy) - Although this is true, TEM does have some setbacks

- a) This process is expensive and time on these machines is precious.
- b) I would require assistance for this process. I thought it would be nice to be able try to find a way to image the DNA DIY, so that only I will come in contact with the samples, and I could hypothetically do this imaging in my home or studio.



DIY DNA research

In April – June 2012 I was fortunate to be Artist in Residence at the Queensland State Library The Edge. During this residency and with the help of many friendly scientists a DIY method for imaging DNA has been collated, and soon will go into production.

Three steps have been identified for the DIY DNA visualization of a human hair sample.

Step 1 – DNA extraction

Fortunately there is an existing protocol documented online <http://www.protocol-online.org/biology-forums/posts/760.html>

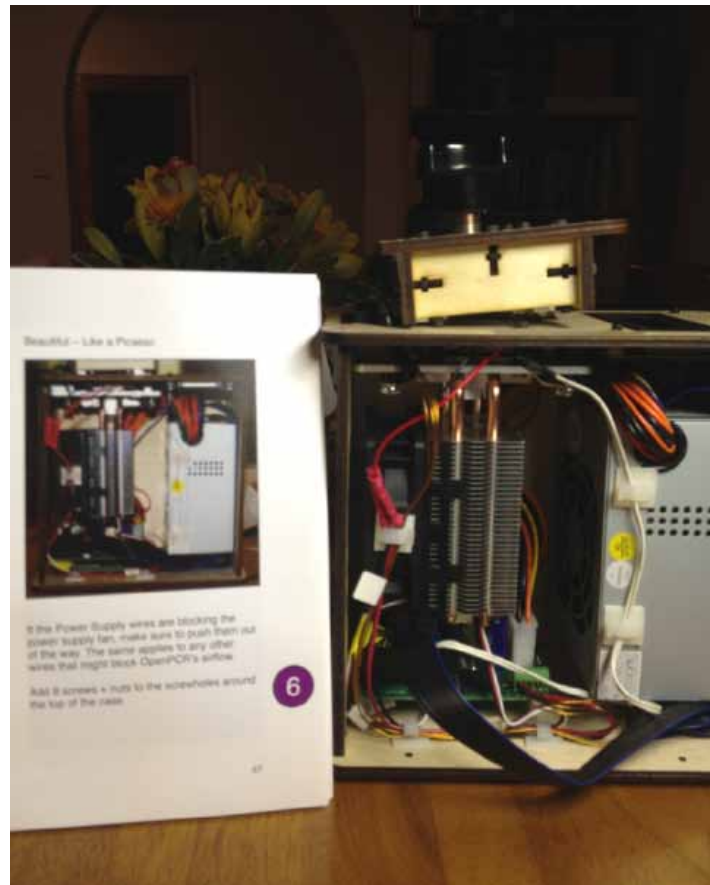
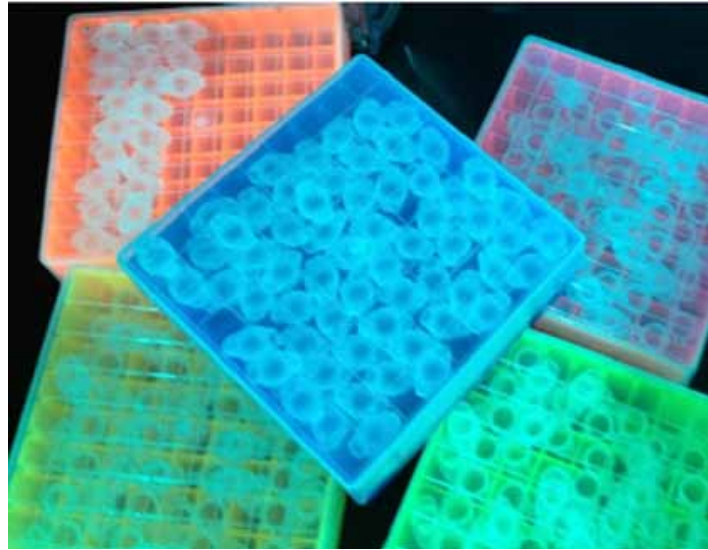
- Cut 10- 15 hair roots about 0.5 cm into a 1.5ml eppendorf tube.
- Add 50 ul of 200mM NaOH solution. [sodium hydroxide]
- Boil the tube in a water bath at 94oC for 10 minutes.
- Cool at room temperature and add 50 ul of a solution containing 200mM HCL. [hydrochloric acid] +100mM Tris-HCL pH 8.5. [buffer]
- Your DNA is ready for PCR.

Step 2 – DNA amplification

PCR or Polymerase chain reaction will multiply a sequence of DNA many millions of times; making visualization possible. Initial issue with this method was that PCR machines – thermal cyclers - can be expensive and difficult to access. But not with OPEN PCR. Thanks to Bio Hackers everywhere: You too can have your very own PCR machine for \$599 USD [plus postage and handling] Arriving in 'kit' form, it takes approx 3 hours to assemble. (<http://openpcr.org/>)

I purchased my very own OPEN PCR online and true to form, it did take about 2 hrs to assemble. I did have a little help. There were a few parts left over which was disconcerting however... It works! PCR success!

The extracted samples are put into PCR tubes, and a primer is added. The primer tells the PCR which sequence of DNA to amplify. The OPEN PCR device easily connects to a laptop and comes with software so you can program its cycles. Once the sample with primer are



Building the DIY "OPENPCR" machine

run in the OpenPRC, approx 3 hrs later you have samples ready for visualization.

Step 3 – visualization with gel electrophoresis

For gel electrophoresis you will need to get your hands on a gel electrophoresis machine and a low voltage power supply. Again, these can be expensive, but just keep looking. I bought mine off ebay – electrophoresis chamber \$80, power supply \$100 ish. You will also need a swag of dyes, buffers and agarose; these are trickier and far more expensive to acquire.

Gel Electrophoresis prep

(many of you will be familiar with this process, but for those who are not).

First you must make the gel with chemical grade agarose – made similar to regular jelly – with one significant difference.

A dye is required so that the DNA will be visible. The common dye used is ethidium bromide [EtBr], however, this dye is a known mutagen and is not safe to use in a DIY setting. There is SYBR Safe, however I have been unable to access this chemical in Australia.

SYBR Green is used commonly in gel electrophoresis and bonds to DNA. SYBR Green is a known carcinogen. As such SYBR Green is again prohibitive in many DIY scenarios. SYBR Green usage requires a minimum of a “clean bench” or Level 1 Lab Safety space, and must be kept in refrigerated storage. To remove SYBR Green it must be subjected to activated charcoal and disposed of as solid chemical waste. I have been able to access SYBR green through a supplier. However, it is expensive - approx \$600 for 5 mls.

Once the gel is made with dye, it is placed into the gel electrophoresis chamber. The chamber is filled with buffer with a pH 8.5 – sort of like sea water. The samples from the PCR are then put into the gel. Low levels of voltage is applied which pushes the DNA through the gel. Small pieces of DNA move faster than large pieces of DNA. This process can take 8 – 12 hours

Once the gel has completed its run, it is removed from the chamber and placed on a dark reader. This device pushes blue Ultra Violet light through the gel, illuminating each sample. Dark room and safety glasses must be used for this process. An image of this illumination may now be taken.



The pictured mini Dark Reader was purchased from BioScientific for \$700 AUD.

Once the samples have been visualized, each participant receives a copy of their DNA for their interest [along with a sound track as I will be converting the image of their DNA into sound]. The individual images are then compressed and compiled, compressed and compiled until there are 1 million people's DNA visualized as a single image.

Next steps, hurdles and moving forward

SPACE

I am working on making a clean bench so that I may run samples at my leisure. Prior to this I hope to use a lab to practice and refine my skills on a pilot batch of samples prior to commence imaging on ONE samples proper.

COST

The cost of imaging each sample is approx \$50 per person with the outlined method. \$50 x 1M = a very expensive art project / hobby indeed. As most of the required equipment I now have in my possession [current outlay circa \$5K] the primary cost are consumable chemicals. I am looking into and hoping to develop inexpensive alternatives.

We know that human DNA is mostly the same. And we have many aspects in common with other species as well. As the outlined method would be looking at a particular sequence rather than the whole DNA strand, the outcome of the image is likely to be uniform - which would be pretty boring for people with a science/bio background.

What might be more interesting is to image non-coded / regulatory / junk DNA that has variation in length. Coded DNA is represented by approx 5% of our sequence with non-coded/regulatory or junk DNA comprising the remaining 95%

There are 2 obstacles going down this path

1) A primer will need to be designed and created to amplify this non-coded DNA sequence. ENCODE will be an important resource in the initial stages of design. I am not a scientist nor geneticists, so much more research and collaboration will be required for this primer design and implementation. In 2007, after the Human Genome was sequenced the Encyclopedia of DNA Elements or the ENCODE project commenced. <http://genome.ucsc.edu/ENCODE/>

2) Ethical and legal implications

In 1989 Genetic Technologies, an Australian company formed and soon after was successful in their application to patent all non-coded DNA in humans and animals. United States Patent number 5,612,179 ('179) Any person or researcher wanting to investigate non-coded DNA must request a licence from Genetic Technologies Ltd. Personally, I feel it unequivocally unethical that a company may own 95% of every human being's DNA. How can they own a licence to my body?

Participants in ONE sign a document – a contract – to say that they are offering their DNA to this project. It is a project of trust, whereby participants are willing to trust me with their most intimate data, and I offer them mine in return. As participants are offering their material to me personally, I am currently in conversations with legal and patent professionals to see if it is possible to bypass this patent.

Conclusions

It is certainly possible to image DNA DIY. However there are considerable technical, practical, ethical, legal and financial issues to be taken into consideration. If you have any questions, concerns, contributions please do feel free to find me. I look forward to working with ONE and in this field for many many decades to come.

www.oneperformance.wordpress.com



Innovation synapses: transgressive movements in working with knowledge

Lorraine White-Hancock

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The Australian Government's most recent policy on innovation outlines the reasons for encouraging innovation in terms of declining productivity and global economic competitiveness (DIISR, 2009, p. 11). This policy and reports informing it talk about the importance of collaboration, knowledge building and creativity to innovation. Reasons given for collaboration include bringing together diverse "perspectives, experience, skills and knowledge; breaking down specialist silos and restrictive organisational boundaries and fostering cross-disciplinary interactions; encouraging skills and knowledge transfer" (O'Kane, 2008, p. 2). Cutler argues against "segmenting innovation into... silos that split the creative arts and humanities from the physical sciences" and calls for understanding the "connections and commonalities" between the arts and science (Full Report, 2008, pp. 47-48). Yet much more detail about mechanisms such as funding for supporting innovation in science and technology is provided in the policy document, and the focus is still tied to these fields.

More and more people work collaboratively across knowledge boundaries in local and global contexts. Yet there is little research about the conditions that support cross-disciplinary, collaborative work or about the experience and effects of in this way. The research question that guides my writing is: *What are the features of workplace learning in art-science collaborations that produce innovative and transgressive knowledge practice?*

Innovation is commonly defined as building processes and products anew or "creating value through doing something in a novel way" (Cutler 2008, Overview). Government and business tend to emphasise economic out-

comes. In the arts, the focus is more on social value and human impacts (White-Hancock 2006). In this paper, innovation is conceptualized as learning that moves ways of thinking and doing in new directions; innovation challenges or crosses boundaries and brings change.

The theoretical framework that scaffolds this study is explained in the next section. The Synapse cases are then introduced, identifying how they were innovative. The paper is then organised around three interfacing elements that are found from reviewing literature across different knowledge traditions to make up innovation: management; innovation enabling environments and learning in practice.

Transgressing boundaries and workplace learning

Literature informing this study extends across knowledge traditions in the social sciences including organisational development and management, workplace learning, innovation, globalization and the social organization of work and occupations. Donna Haraway's writing in the philosophy of science tradition and her socialist-feminist perspective, particularly inform this study. Her notion of situated knowledge (1991) helps me explain social, political and disciplinary boundaries and hierarchies. Situated knowledge, dealing with the 'facts' of a situation, recognises that to others, the facts might be quite different. This concept helps me understand how people who work together from different knowledge traditions might see things differently, and how these different perspectives might affect each other. The concept of boundaries is of particular significance across a range of knowledge traditions in the literature reviewed. Haraway argues that boundaries are less distinct than

we think and are permeable surfaces. It is the interactions between things across boundaries that are crucial for evolution and innovation. Haraway challenges the concept of 'I' and writes:

I love the fact that human genomes can be found in only about 10 percent of all the cells that occupy the mundane space I call my body; the other 90 percent of the cells are filled with the genomes of bacteria, fungi, protists, and such, some of which play in a symphony necessary to my being alive at all... (2008).

Haraway's notion of transgression sheds light on the potential and dangers of engagement with other situated knowledges for people who work across disciplinary boundaries. Haraway explains how the process of transferring genes between species in biotechnology is argued by its opponents to be an "act that transgresses natural barriers, compromising species integrity" (1996, p. 60). In other words, transgressive border-crossing pollutes lineages.

In a similar way, cross-disciplinarity is treated with some suspicion in academia where disciplinary knowledge traditions are seen to be challenged. Gieryn (1983), writing on the social organization of work, suggests that as the since the industrial revolution the way we define ourselves, our identities, have been tied to disciplines and professions – I am a doctor, I am a baker, and so on. Globalisation and the world-wide-web are changing that. Multiple identities emerge through social media networks and global mobility that break down institutional and social boundaries across cultures. Disciplinarity with its monocular focus is argued to be inadequate in a world of complexity that characterizes contemporary life, and cross-disciplinary approaches are needed to solve complex global problems (Land, 2010).

More recently, ideas of 'situated learning' rather than situated knowledge emerge in relation to innovation in workplaces. Lundvall (2008) argues that knowledge is becoming obsolete more rapidly than before in the age of the world-wide-web, so that

firms and employees constantly have to learn and acquire new competencies. This involves forms of learning through experience, which are as important as those learnt through exposure to teaching in formalised school settings (Lundvall et al, 2008, p. 681). Furthermore, spontaneous learning and the ability to improvise at work arise from unexpected events and problems and improvising requires situated learning rather than theoretical 'school learning' (Høyrup, 2012, p. 22). Recent research on workplace learning which is rooted in the socio-anthropological-cultural tradition focuses on how the structuring of current workplaces and practices impacts on collaborative work, learning and on innovation (Felstead et al, 2009). The authors argue that dysfunctions and blockages in the productive system shape patterns of learning at work, sometimes stifling it, sometimes leading people to find innovative ways to solve problems. In some workplaces the terms and conditions of work allow and even encourage innovations that run against established rules, conventions and norms. This characteristic describes an 'expansive' workplace (Felstead et al, 2009). Felstead's ideas help explain how the structuring of the Synapse program as well as the project workplaces and practices, together impact on learning and innovation.

Research Design

The broader PhD study employs a comparative approach, drawing on grounded theory. My strategy of inquiry is qualitative and employs a mixed-method approach, including:

- Discourse analysis of Australian Government policies on innovation and collaboration.
- Auto-ethnography, reflecting on my experience of a cross-disciplinary workshop called Crosslife conducted in Malta in 2008. This workshop brought together lecturers and PhD students from 6 universities from 6 different countries. The focus was on cross boundary work, travelling ideas and transformations in lifelong learning and work that have resulted from globalization. I also draw briefly from my

own professional work as an artist that led to a collaborative project with an expert in optics and laser holography at RMIT University's Physics Department. These lived experiences provide me with an 'insider' perspective on cross-disciplinary, collaborative work and learning.

- Case studies of 3 Synapse Residency Program projects conducted from 2010-2011 provide me with an 'outsider' perspective of collaborative, cross-disciplinary work. Case study methodology highlights work practices, terms and conditions enabling innovation. This involved conducting interviews with artists and their partners working together on collaborative projects. Audio recordings and full transcriptions were made of interviews. The study gained ethics committee approval from Monash University.
- The Synapse Residency program, funded by the Australian Network for Art & Technology (ANAT) and the Australia Council for the Arts, provides grants for artists to undertake residencies in science and research settings, both within Australia and internationally. (<http://www.anat.org.au/synapse/>).

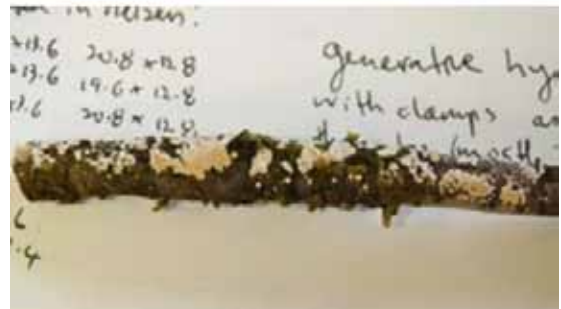
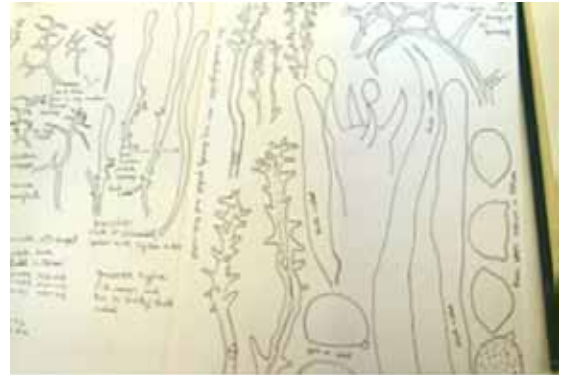
Synapse Residency project sites were selected for investigation because they can be considered as 'hotspots of knowledge flow' (Sassen, 2008) or 'liminal', in-between spaces (Durrsschmidt & Taylor, 2007). They are sites of intersection for cross-boundary, cross-disciplinary work that reveal evidence of transgressed boundaries, learning and innovation.

Spaces of innovation

This part introduces the three Synapse projects selected as case studies. Due to space restrictions, this paper focuses its report on the work of one project conducted by Catherine Truman and Ian Gibbins but also draws on the stories of other project partners.

Dr Mary Rosengren worked with Cris Kennedy, Director of the CSIRO Discovery Centre (Canberra, ACT) and the scientists who manage and study CSIRO collections in order to "investigate and articulate the connections

between different aspects of CSIRO research and to extend professional thinking about interdisciplinarity and the appraisal of images within science and art contexts" (<http://www.anat.org.au/synapse/>).



Drawings by Heino Lepp, mycologist. Specimens from Australian National Herbarium's Cryptogam collection (ferns, mosses, liverworts and lichens, algae and fungi) housed at the Australian National Botanical Gardens. Photograph by Mary Rosengren. <http://rosengren2011.anat.org.au/>

The artist has visited a number of collections, interviewed the scientists who work with them, "finding out what they're about, how they work and how they could be connected through the imaging technology", and identifying how visualisation is used in the collections. This approach was used in order to connect "the old science of classifying, ordering and organising things with contemporary science methods and processes and technology". The Synapse program manager explained in a phone conversation that from ANAT's perspective, Rosengren and Kennedy's project was innovative because there were different dimensions that were to be investigated and it

was the interconnections that were critical. For both Kennedy and Rosengren, what is innovative about their project was the idea of science-art collaboration or working beyond one's own disciplinary boundary. Rosengren also considered innovation in her work in terms of "looking at not just the methodology but the way in which the technology and the imaging is utilised and valued within both those disciplines. So this is an attempt to see science differently". The artist investigated CSIRO collections as a complex system rather than bounded categories.

Artist Chris Henschke worked with scientists at Australian Synchrotron (Clayton, Melbourne), particularly Dr Mark Boland, Principal Scientist in Accelerator Physics. The synchrotron is a machine about the size of a football field that accelerates electrons at almost the speed of light to experimental workstations. Their Lightbridge project was conceived of as "a kind of a portal" where data that's usually only available to scientists is made available to an artist (Boland, 2012).



Chris Henschke created 100+ GB worth of synchrotron-light based test animations for multi-projector setup (15 August, 2010). The animated version can be viewed at <http://henschke2010.anat.org.au>

The term 'lightbridge' suggests a phenomenon that links environments. The work is considered innovative because it is the first time in Australia an artist has worked in this kind of physics environment. Henschke

wanted to experience the 'frontier' of the machine itself in the spirit of the pioneer, going where no artist had gone before. In Boland's view, the project is also innovative in its transgressive knowledge sharing across disciplinary boundaries of "data channels that are usually reserved and tightly guarded". The concept pushed the boundaries of what was permissible by the organisation in terms of access to data "that's just solid gold ...you don't just give that away ... that's a kind of a boundary that scientists wouldn't cross". Artist Catherine Truman makes objects for and about the body. Her work has been exhibited widely in Australia and internationally and recognized with an Australia Council for the Arts Fellowship (2007).



Catherine Truman, *Hybrids*, 2011, Carved English lime, wood, paint; largest dimension 150mm; wood, paint (<http://truman2011.anat.org.au/>)



Catherine Truman, *The fine bones of the hand*. Anatomy Lab, 2011

She worked with Professor Ian Gibbins, Head of Department: Histology and Anatomy at Flinders University in Adelaide. Truman explained that: *We were interested in how the body is learned by medical students, and the role that the instructor plays, also the role that the objects in the room, the teaching anatomy room, play. That kind of led us into a really distinct interest in the interrelationships that occur between students and the tutor as well in terms of learning the body. So we became fascinated with the role of touch and gesture in learning.*

This collaborative work is innovative because it has developed new pedagogical methods and practices that have refined the way medical students learn about the body at Flinders University. These new approaches have been recognized by the University with a teaching and learning Innovation Award. Truman also pointed out that their ability to communicate through shared languages - through poetry, writing, images and objects, both scientific and artistic, and through shared earlier experience, transgressed the disciplinary divide and was innovative. It was Truman's understanding that "it's unusual to develop a relationship between a medical educator and an artist in this context ... initially it was about this kind of education, about medical education and how science perceives the body and how artists perceive the body or communicate the body. It's about communication. Gibbins also highlighted that that it's unusual for a scientist to also be a practicing artist as it is for an artist to be familiar with 'the way the place works' and with some elements of his practice. In fact, Truman had joined in Gibbins anatomy classes for three years to learn more about the area and Gibbins practice. Gibbins had a background in writing poetry, composing and performing electronic music and sound-scapes and making experimental film prior to his work with Truman and has also produced an impressive body of work during their years of collaborative engagement.

Both Truman and Gibbins said that what they learned from their partners and their different disciplinary practices was that there was less difference than they thought. I found myself asking, 'Who is the artist? Who is the scientist?' These interviews surfaced the idea and the tradition of the artist-scientist. There were similarities in the methodological approaches of the artists and scientists interviewed – research, planning, observation, experimentation, documentation and interpretation. In contrast, Henschke found the distance between disciplinary languages, and accessing and using technology troublesome barriers. Boland explained his belief that despite similarities, scientists have to be more outcomes and evidence-driven than artists: *There are certain beliefs and principles and rules that you have to stick with ... the scientists are working in a framework where the fundamental philosophy is that there is an underlying truth that you're nutting out, and then in order to discover that you can't go down a linear path. You have to be creative and go all over the place to find the trapdoor that will lead you into the next ... So there's a certain framework or certain mystery that you're trying to unravel as a scientist that requires similar techniques as an artist [but] the artist framework is far more ephemeral So that although similar techniques and similar working environments exists, ultimately they're poles apart in terms of what they're trying to achieve or what they do achieve or what comes out of that same approach.*

Yet they are both creative. Distinctions between artists and scientists are blurred, yet the framework that artists' work within are perceived as being less governed by rules and laws, and have different aims and outcomes. Projects were innovative in their attempts to 'see science differently', to see interconnections and transgress different kinds of boundaries.

The next three sections consider what supported and constrained collaborative, cross-disciplinary learning and innovation in this project.

Management

There has been no shortage of products and outcomes from these residencies though they were not expected by ANAT (beyond blogs and a project report) since the aim of residencies is to generate research and share knowledge. This approach differs from many other funding organizations that expect products in order to fulfill funding requirements. The Synapse program manager at ANAT recognizes that outcomes can take some time to occur. Participants felt that this freedom supported their ability to 'free range'. ANAT had a 'hands off' approach beyond the selection process which also afforded participants freedom to conduct their work as they saw fit. However, two of the three organisations where residencies took place had some expectation of products.

Some internal organisational or bureaucratic obstacles were experienced in Truman and Gibbins project. Although these were not perceived as being particularly problematic, other partners reported more troublesome issues with their organisation's management or with internal politics being played out at the time. Artist Chris Henschke described a confrontation, or a 'blockage in the system' (Felstead et al, 2009), that had quite an impact on him. It occurred at his meeting with the Co-director on the first day of his first residency at Australian Synchrotron:

He said, like totally serious, "So where's your easel and your paints, paint brushes?" ... I pointed at the giant particle accelerator and I said, "Well, you're right in a sense, but that is my paintbrush." The Co-director just got bright red in his face and stood up and went, "You're not going to go anywhere near that bloody thing. If you touch that thing I'll come after you with a hammer."

Negotiating the disciplinary divide was a challenge for Henschke, restricting progress of his earlier project. However, he worked for the most part with Boland on his second project who dealt with problems, as did the other artists' project partners. Boland later facilitated Henschke's access to the particle accelerator. The artists partners were critical 'boundary brokers', to use Wenger's (2003) term, within their organisations, negotiating and enabling access to facilities and smoothing the passage of residencies. Boland explained the process of getting the Synapse application through his management: "I knew my way through the bureaucracy and I knew enough about the place to not press the wrong buttons and say the wrong things like give away data or access being mandated". The project may not have seen the light of day without Boland who understood the issues, sensitivities, structure and the personalities in his workplace.

To summarise, supports to learning and innovation in these projects are identified at different levels of the system from ANAT to the organizations involved. Projects were generally characterised by a flat management structure without interference from the organizations management or from the Synapse program manager. Supports were characterized by an emphasis on freedoms afforded by the flat management structure, discretion in determining how and what work was done and less emphasis on outcomes which provided the ability to 'free range'. Where there were problems, these were dealt with by Gibbins and the other artist's partners. The presence of 'boundary brokers' who understood how their workplaces worked, enabled access and smooth passage of projects was significant. However, Henschke's case shows that workplace activity can only realise innovation when endorsed by the management that authorises the work.

The next section examines the projects in terms of how the workplace environment supported learning and innovation.

Innovation enabling environments

The environment of his organisation at Flinders University, described by Gibbins as 'open', emphasising participation and freedom of access. Gibbins said "Anybody can come here and work here if they've got the right credentials and background ... good science is open environment".

Time working together helped to establish trust, respect and a 'safe' environment for collaboration. A safe environment is argued to be necessary for learning and innovation to occur because it is risky to present work that is different or transgressive (Quinlan et al, 2010). Truman commented on the challenges to her personal ethics relating to the practice of vivisection in scientific research and in Gibbins' workplace. However the artist's way of addressing the conflict was to step back and respect the scientific approach of the workplace that she was invited into, even if she didn't agree with it. Apart from this, Truman felt comfortable in Gibbins' environment. Gibbins felt comfortable about Truman's presence in the department because they had already established a rapport through several years of collaborative work. This is seen to be critical to the success of these short term projects by participants, and this is also an important criterion for Synapse residency selection.

Truman showed me the tearoom on my tour of the facility at Flinders University, commenting that it was a place where ideas emerged and critical discussions took place through more informal interactions. This was a space that supported the openness that Gibbins and other participants spoke about. Physical and intellectual spaces and environments that support openness, freedom of thought, freedom of access to information and resources, and spaces for conversation are seen to support innovation among the artists and scientists interviewed.

How collaborative learning progressed in these projects is now considered.

Learning in practice

Both Gibbins and Truman pointed to the necessity for finding some kind of common ground, or shared object, that enables communication in effective collaborative, cross-disciplinary work. Truman felt that reading some prose called *A Morning's Anatomy* to a group of scientists including Gibbins, and written after observing one of his classes, was a critical catalyst for finding that common ground. Truman said "I read it to Ian in particular. He didn't react all that much, but since I discovered that it was the first time that those kinds of things had been reflected back to him. And we just took off from there".

Gibbins' teaching 'performances' and the role of touch, gesture and movement in learning became a focus of their recent project work.



Catherine Truman,
Talking hands

The awareness that was surfaced by Truman's prose, her observations and documentation led Gibbins to highlight the gestures he uses, nuancing his approach to teaching the body. Gibbins said:

Over the years I've learned a whole bunch of movements to illustrate particular muscles and particular actions. So this year I've been much more precise about the way I do those demonstrations, either in a lecture or in a practical class. So much more precision... instead of just putting my hand up and waving it around like that, you know, so this is the flexor digitorum for the third finger... So very decisive.

Gibbins explained that this information is also shared with students, expanding their understanding and engagement in learning about the body.

Truman's interest in the way gloves are used both in the teaching classes and in the laboratory for different purposes led to an idea about filming one of the lab technicians dissecting a glove from her hand with a pair of scissors. She then got Gibbins to perform the same procedure. The film was reversed in fast motion, giving the appearance of the hand being 're-skinned'. Replaying the film, Truman observed that people performed the process differently, despite procedural conventions. The experiment showed Truman that there was subjectivity in 'objective' science, an idea the artist developed through her observations in her first residency in a Darwin hospital. Truman pointed out that this idea "was a very, very controversial thing to suggest in a scientific environment" and in this way, the experiment was transgressive. Gibbins said that this experiment "triggered the writing that I've done so far" and switched the focus of the project very clearly onto the hands as a way of mediating experience. Truman cast a fresh eye over the way these gloves, such commonplace, everyday artefacts in Gibbins work, are used and what they can mean. This idea evolved from an 'outsider', artist perspective and generated discussion, new thinking, learning and work for both partners. The glove dissection story illustrates how an

idea travelled across disciplinary boundaries, enabling people to reconsider taken-for-granted assumptions or routine processes involved in their work and how collaborative learning at work progressed.

Ideas evolved and learning occurred not only through interactions with people but was also mediated by an array of technologies and artefacts, or 'boundary objects' (Wenger, 2003; Felstead et al, 2009) used in the workplace. Truman's observations were not only of Gibbins's teaching performances but also the ways both low and high technologies were used. Truman explained what she had learned was that: *Science was more about the technology of how we can see things more clearly. By that I literally mean how we can place things in front of our eyes so that we can understand better. So all the technology that gets developed in science is about that; simply for a human being to lay their eyes on something and then understand it.*

The artist later elaborated: *I've been down in the microscope room (on) several occasions with Ian. He'll be jumping around the room, this dark room with this machine that takes up the whole room which is the microscope, and Ian will be saying, "Nobody's ever seen anything like this before. It's so exciting".*

Imaging technologies and artefacts for data visualisation also played a critical role in science-culture as they mediate knowledge building and learning, enhancing ways of seeing, making the invisible, visible. The focus on data visualization is critical to Henschke's project at Synchrotron and Rosengren's work with CSIRO collections (<http://henschke2010.anat.org.au>; <http://rosengren2011.anat.org.au/>).

As Truman highlighted in her interview, their projects are deeply rooted in the "burning curiosity in both of us about each other's practice. Really wanting to understand a bit more, and not only understand, but experience it. So understanding through experience". This was an important theme that emerged from the interviews and supports Lundvall's (2008) argument. Truman's need to experience the lab and the classes was for the "promise of learning something

new”, gaining some insight into another practice and environment.

Participants had a reasonably clear idea of what they wanted to do but their ideas evolved organically through observation, reflection, and having time and space for ongoing conversations and interactions between project partners and others working with and around them but all were prepared to ‘roam’. The way these projects evolved was not linear, with predetermined outcomes. Such openness to new possibilities enabled ‘expansive’ learning (Felstead et al (2009) which involved experiential, ‘situated learning’ (Lundvall et al, 2008). The idea of ‘not knowing’ in a world that focuses on outcomes and acquiring knowledge emerged as a critical way to learn and move forward in these projects. Truman commented that: *We’ve often said that it’s more about the stuff we don’t know than the stuff we know. It’s much more about that, the stuff that we don’t know, and the acceptance of not knowing something. That’s what drives both of us in our practices.*

None of the artists or scientists interviewed felt that their formal education equipped them particularly well with the skills for stepping into collaborative, cross-disciplinary work practices; rather this was learned through practice in the workplace. However, the nature of scientific research requires this way of working and it is performed as a matter of routine in the workplace, though less often in cross-disciplinary settings. Gibbins assumed that “it’s more of a challenge for artists to work collaboratively than it is for scientists because we do (it) all the time”.

Yet there is an age-old tradition of artists and craftspeople who work collaboratively that has been traced to medieval European guilds and classical Greek corporations (Wenger, 2003). Truman noted the influence of Clemente Susini whose anatomical models made in collaboration with the Italian scientist and academic Felice Fontana in the 1770-90s are recognised to demonstrate extensive scientific knowledge (Riva, 2010). Rosengren

referred to the work of the Swedish botanist, physician, and zoologist, Carl Linnaeus, attributed with pioneering modern taxonomy and ecology and who collaborated with the botanist-illustrator Georg Ehret from 1735-36. Kennedy highlighted the work of the English botanist-illustrator Joseph Banks on Captain James Cook’s voyage from England on the Endeavour (1768-1771). More recently, the studio-labs of the 1960s where artists engaged with science and technologies were inspired by the German Bauhaus school (1919-1933) as a model of cross-disciplinary practice (Century, 1999). Such models influenced the development of programs like the Synapse residencies.

Despite the history, the perception is that much art is still studio-based where the artist works in isolation in a cold little garret. Project participants were all well aware of the myths and stereotypes of ‘bohemian’ artists who all use brushes and paint and ‘mad’ scientists. Rosengren spoke of being “guided by people who have their own prejudice about what artists are really interested in as well as their own perceptions of what those things are as well”. Collections of colorful butterflies were perceived as something that would appeal to her and the soil collection was merely “a whole lot of plastic cups with soil in it”. However the soil collection, Rosengren said, “was so [much] more interesting because of the problematic of it not being ... a highly visual object. A soil collection is conceptually a very different thing because it’s more of a phenomenon. It doesn’t have a boundary usually in your mind”. Soil links ecologies.

Assumptions, myths and misconceptions about different disciplines had the potential to divert attention and narrow the focus of learning unless those engaging in cross-disciplinary collaboration are mindful of the issue. Truman pointed to the value of cross-disciplinary collaboration in changing misconceptions through “gentle interactions, daily interactions, particularly in that centre room. Everybody comes there and goes away. We sit down at lunchtime, we do crosswords together and eat and talk”.

In summary, 'gentle' interaction in informal settings helped to change disciplinary misconceptions which could restrict learning. The glove dissection story illustrates how an idea travelled across disciplinary boundaries, enabling people to reconsider taken-for-granted assumptions about routine processes and objects involved in their work and how collaborative learning at work progressed. Understanding through experience was critical to this process. Learning occurred through interaction with people and was mediated by technologies and other artefacts in the workplace. Learning also occurred through 'not knowing'. Ideas were allowed to evolve and all participants were prepared to 'roam'. Formal education did not prepare people well for engaging in collaborative work practices, this was also learned through practical workplace experience.

Conclusion

Ideas and knowledge flowed in new and transgressive ways across boundaries in these workplaces and was supported in a number of ways in terms of the workplace environment and learning through work practice. Physical and intellectual spaces and safe environments where trust and respect were established, freedom of thought and access to information and resources, and spaces for conversation and informal interaction supported innovation in these projects. Expansive learning occurred through interaction with people and was mediated by technologies and artefacts. A flat management structure where participants were also afforded discretion to determine their own work was a key aspect of the organizational culture that supported innovation in these expansive workplaces. However, this activity can only realise innovation when endorsed by the management system.

The distinctive contribution of arts practice to innovation in these projects lies in seeing, interpreting and communicating science in a unique way. Creative perspectives can offer new understandings and insights about taken-for-granted practices and assumptions. The processes involved can be transgressive, challenging and complex. All of the artists interviewed experienced personal challenges or confrontations at some stage of their cross-disciplinary practices. Yet all choose to continue with this way of working, arguing that collaborative, cross-disciplinary work is their practice— it is their identity. Transgressing personal boundaries, putting herself into what she describes as "challenging situations" for the promise of learning something new, is a recurring element of Truman's work. It can be argued that confronting and transgressing boundaries are the very things that enabled unexpected, expansive learning and were critical to innovation in the cases studied.

The findings of this study have implications for Government policy on education and training that needs to prepare people for learning and work in new, complex and re-emerging cross-disciplinary contexts. The idea of not knowing and arts praxis emerge as ways forward in education for innovation in an era where much education is knowledge and outcomes-driven. There are recognized benefits for the Government's innovation agenda in encouraging creativity at work. This study finds that creative arts are a valuable but underdeveloped resource for supporting cross-disciplinary workplace learning and innovation. Further research needs to be done to establish the policy settings that can better support creative arts involvement in cross-disciplinary organisational learning contexts.

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1. For the work True Stories and the ongoing project Re-imaging Nature. Rosengren, M. Re-imaging Nature. University of Wollongong, Faculty of Creative Arts. 2008.
2. Rosengren, M. Re-imaging Nature. University of Wollongong, Faculty of Creative Arts. 2008.
3. Refer to "Inter/disciplinarity" Carlo Ginzberg, James D. Herbert, W.J.T. Mitchell, Thomas F Reese and Ellen Handler Spitz. The Art Bulletin Vol 77 (Dec 1995): 534-552.
4. Mitchell, W.J.T. *Picture Theory*. Chicago: University of Chicago Press.1995. (11-13).
5. Anton Von Leeuwenhoek's (1632-1723), Maria Sibylla Merian (1647-1717) and Robert Hooke (1635-1703), and by collaborations such as Georg Dionysius Ehret (1708-1770) and Carl Linnaeus (1707-1778), Robert Brown (1773-

- (1858) and Ferdinand Bauer (1760-1826), and for over forty years Walter Hood Fitch (1817-1892) worked with both Sir William Jackson Hooker (1785- 1865) and his son Sir Joseph Dalton Hooker (1817-1911).
6. On Astronomical images produced by NASA see Kessler, Elizabeth A. *Picturing the Cosmos* Hubble Space Telescope Images. Minneapolis: University of Minnesota Press, 2012.
 7. The terms- true/false colour and an example can be viewed <http://www.nasa.gov/mission_pages/voyager/pia00032_prt.htm
 8. "Cells may also be stained to highlight metabolic processes or differentiate between live and dead cells in a sample. Cells may be enumerated by staining cells to determine biomass in an environment of interest." Bruckner.
 9. As in Plate 1 *The Plant Cell* (1) in Gunning, Brian.S. and Steer,Martin, W. *Ultrastructure and the biology of plant cells*. London: Edward Arnold,1975) 185.
 - 10.1920s Cell diagram Edmund Beecher Wilson from Flannery, Maura C. "Images of the Cell in Twentieth-Century Art and Science". *Leonardo* 31 (1998) No 3: 195-204.
 11. Drawing eukaryotic animal cell Bunji Tagawa *Scientific American* 1961 Cell Drawing from Flannery, Maura C. "Images of the Cell in Twentieth-Century Art and Science". *Leonardo* 31 (1998) No 3: 195-204.
 12. Pigmentation can be assessed using other methods such as High Performance Liquid Chromatography (HPLC) but the sample is dead.
 13. A Helium Argon laser 680 nanometres (near infra red).
 14. Value of seeing an indication of specimens' health allows for monitoring of environmental conditions –refer "Impact of changes in natural UV radiation on pigment composition, physiological and morphological characteristics of Antarctic moss." S Robinson, J Turnbull, C. Lovelock.
 15. Refer to Confocal video microscopy stills from Cleary, Anne. "Actin in action." *Biologic: The interactive cell*. Research School of Biological Sciences Institute of Advanced Studies ANU. No. 10, May 1995 (3-6)
 16. Photographic manipulation has always been possible but as Mitchell states "extensive reworking of a photographic image to produce seamless transformations and combinations is technically difficult, time consuming, and outside the mainstream of photographic practice."
 17. Refer Chapter 3 of Rosengren, M. *Re-Imaging Nature*. 2008, University of Wollongong
 18. Or in fact heard. Drew Berry's animation "Apotosis" has an accompanying sound track by Franc Tetaz, who does sound design for feature films.
 19. See David Goodsell, *Black and White Drawing* *Simulated cross-section of bacterium Escherichia coli drawn at the magnification of one million times*" rpt. *A Look Inside the Living Cell* FlanneryMaura C. "Images of the Cell in Twentieth-Century Art and Science". *Leonardo* 31 (1998)
 20. For Goodsell and Berry, Robertson and others artists wowing "the audience" is also significant intention and they are part of the enlightenment tradition of captivating, enthralling and educating.
 21. "I can't wonder at it ... since 'tis difficult to comprehend such things without getting a sight of 'em." Van Leeuwenhoek in Nabors 28.
 22. An artifact in an image refers to the presence of features that result from technical aberrations; in a biological specimen something that is not naturally present but has been introduced or produced during a procedure such as staining or sectioning.
 23. Refer techniques, confocal microscopy, also far/near IR- microscopy and other techniques Australian Synchrotron.
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2. P. Feyerabend, *Against Method*, Humanities, 1975, p. 28
3. K. Popper, "Selections from *The Logic of Discovery*", in R. Boyd, P. Gasper, & J. Trout (eds.), *The Philosophy of Science*, MIT Press, 1993, p.106

Page 38 - Erica Seccombe

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3. Thomas, Sue. 'Technobiophilia: We surf the net, stream our films and save stuff in the cloud. Can we get all the nature we need from the digital world?' *Aeon Magazine* www.aeonmagazine.com/nature-and-cosmos/can-we-get-all-the-nature-we-need-from-the-digital-world/ (Published, 24 September 2013)
4. Jenson, Marion Krogh, 'mapping virtual materiality', in Olafur Eliasson, *Surrounds Surrounded*, Neue Galerie, Graz and MIT Press, Cambridge on the occasion of the exhibition, p.302 (2000)
5. Ibid, p.302.
6. Best, Sue, 'What is Affect? Considering the Affective Dimension of Contemporary Installation Art' in *AAANZ Journal of Art*, vol. 2, no. 2, 2001 and vol.3, no.1, p.219 (2001)
7. Ibid, p.219.
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9. Duxbury, Lesley, 2010: 'A Change in the Climate: New Interpretations and Perceptions of Climate Change through Artistic Interventions and Representations'. *Weather, Climate & Society*, Volume 2, p.295 (2010). (Published, 24 September 2013)
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Page 46 - Lizzie Muller

1. A later version of the paper presented at SPECTRA was presented at ISEA 2013 in Sydney. This published version contains elements of both presentations.
2. For a discussion of my particular approach to curatorial practice-based research see Muller, Lizzie 'Learning From Experience: A Reflective Curatorial Practice' in Candy, L. & Edmonds, E. (Eds), *Interacting: Art, Research and the Creative Practitioner*, Libri Publishing, Faringdon, Oxfordshire, U.K, pp. 94-106 (2011)
3. See both Anne Cranny Francis (20-24) and Andrew Frost (24-27) in Dean, B. and Muller, L. (Eds) *Awfully Wonderful: Science Fiction in Contemporary Art: Catalogue of the Exhibition Performance Space: Sydney* (2011)
4. My argument here builds on previous work I have done in explaining the aesthetic experience of interactive digital art, which draws on the pragmatist philosopher John Dewey, see Muller, Lizzie (2009) *The Audience Experience of Media Art: A Curatorial Study*, PhD Thesis, University of Technology, Sydney.
5. The term "speculative fiction" is used to describe the family of literature that includes both science fiction and fantasy fiction. This essay, and the exhibition it is based on, are concerned particularly with the nature of science fictional speculation that engages with the implications of scientific discovery and technological change.
6. Gyger, Patrick (2011) "In a Strange Land: A Tour Through the Worlds of Science Fiction Art", in Dean, B. and Muller, L. (Eds) *Awfully Wonderful: Science Fiction in Contemporary Art: Catalogue of the Exhibition Performance Space, Sydney* (2011)
7. One of the most influential users of future scenarios is the Shell Oil company, who have famously been producing energy related scenarios since the 1970s. Since 2000 the Intergovernmental Panel on Climate Change

- (IPCC's) Emissions Scenarios have been hotly debated, showing speculation on future events as a powerful ideological battleground.
8. Suvin, Darko *Metamorphoses of Science Fiction: On the Poetics and History of a Literary Genre*, Yale University Press, New Haven and London (1979)
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10. It is perhaps unsurprising that, as the embers of Marxist revolutionary politics fade, Jameson should claim that it is structurally impossible, within a fictional text to represent an alternative future. Other critics have more recently pointed to the practical and measurable effects of science fiction on individuals and society.

I would like to thank the anonymous reviewer who provided feedback on this essay as part of the peer review process for ISEA 2013 for suggesting the following references to support this point:

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34(17), 2751-2773 (2012).

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11. J. Voss, & L. Lantz (Translator), *Darwin's pictures : Views of evolutionary theory, 1837-1874*. Yale University Press, New Haven [Conn.] (2010).
12. A.H. Wall, *Artistic Landscape Photography*. Bradford: Percy Lund & Co. (1896).
13. P. Prodger, *Darwin's camera : Art and photography in the theory of evolution*. Oxford, New York: OUP (2009).
14. C. Tourney, *Truth and Beauty at the Nanoscale*. *Leonardo* 42(2), 151-155 (2009).
15. J. Elkins, *Visual practices across the University: A Report*. In O. Grau (Ed.) *Imagery in the 21st Century*. Cambridge, MA: MIT Press (2011).
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21. S. Ainsworth, V. Prain, & R. Tytler, *Drawing to learn in science*. *Science*, 333 (26 August), 1096-1097 (2011).

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Page 71 - Lynden Stone

1. The 'mind works' projects are: *the Metaphase Typewriter revival project*, 2012, *the Mind Lamp project*, 2013 and *the Mind Dispenser*, 2013.
2. For example: Eugene Wigner, "Remarks on the Mind-Body Question," in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek (Princeton New Jersey: Princeton University Press [1961]), 168 (1983); Stuart Hameroff and Roger Penrose, "Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness," *Mathematics and Computers in Simulation*, 40: 453-480 (1996); Amit Goswami, "Physics Within Nondual Consciousness," *Philosophy East & West*, 51 no. 4: 535-44 (2001); John Archibald Wheeler, "Law Without Law," in *Quantum Theory and Measurement* ed. John Archibald Wheeler & Wojciech Hubert Zurek (Princeton: Princeton University Press), 182-213 (1983); Henry Stapp, "Quantum Interactive Dualism: an Alternative to Materialism," *Zygon*, 41, no. 3: 599-615 (2006), doi: 10.1111/j.1467-9744.2005.00762.x; Henry Stapp, "Quantum Interactive Dualism: II: The Libet and Einstein-Podolsky-Rosen Causal Anomalies," *Erkenntnis*, 65: 117-42 (2006), doi: 10.1007/s10670-006-9017-y; John von Neumann, *Mathematical Foundations of Quantum Mechanics*, trans. Robert T. Beyer (Princeton: Princeton University Press [1932]) (1955); Evan Harris Walker, *The Physics of Consciousness: The Quantum Mind and the Meaning of Life* (Cambridge: Perseus) (2000); Eugene Wigner, *Symmetries and Reflections*, (Bloomington, Indiana: Indiana University Press), 171-84 (1967); Dean Radin, *Entangled Minds: Extrasensory Experiences in a Quantum Reality* (New York: Paraview Pocket Books) (2006).
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11. John Archibald Wheeler, "Law without Law," 182—213; Stapp, "Quantum Interactive Dualism: An Alternative to Materialism," 599—615; Stapp, "Quantum Interactive Dualism: II: the Libet and Einstein-Podolsky-Rosen Causal Anomalies," 117—142; von Neumann *Mathematical Foundations of Quantum Mechanics*; Walker, *The Physics of Consciousness*; Wigner, *Symmetries and Reflections*, 171—84; Goswami, "Physics Within Nondual Consciousness," 535—44.
12. Giancarlo Ghirardi, Alberto Rimini and Tullio Weber "Unified Dynamics for Microscopic and Macroscopic Systems," *Physical Review, D* 34: 470—91 (1986).
13. Pain, "Breakthrough of the Year."
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17. David Kaiser, *How the Hippies Saved Physics: Science, Counterculture and the Quantum Revival*.
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20. Hameroff and Penrose, "Orchestrated Reduction of Quantum Coherence in Brain Microtubules".
21. Ibid., 456–57.
22. Laura K. McKemmish, Jeffrey R. Reimers, Ross H. McKenzie, Alan E. Mark and Noel S. Hush, "Penrose-Hameroff orchestrated objective-reduction proposal for human consciousness is not biologically feasible," *Physical review* 80: 021912-1—6 (2009).
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24. Evan Harris Walker was a physicist at Ballistic Research Laboratories, United States Army, Aberdeen Proving Ground, Maryland.
25. Electron tunneling is quantum process whereby electrons successfully cross negatively charged barriers, a feat not possible according to classical physics.
26. Walker, *The Physics of Consciousness*, 72.
27. Ibid., 263–64.
28. Ibid., 265.
29. Ibid., 266.
30. Ibid., 265-66.
31. Henry Stapp is a senior staff member of the Lawrence Berkeley National Laboratory.
32. Stapp, "Quantum Interactive Dualism: An Alternative to Materialism," 601.
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- different dynasties in imperial China. The very similar pronunciation of the two terms has blurred their distinct histories and both seem to be attributed as the predecessor of the now common 通勝 *tōngshèng* (in Mandarin) or *tung sing* (in Cantonese).
4. As opposed to *sui* (solar year), which is defined as the period between two consecutive vernal equinoxes, a lunar year is (年 *nián*), defined as the period between two consecutive lunar new year days. The solar-based calculations reckon seasons astronomically; that is, seasons are defined by apparent positions of the sun on the ecliptic rather than meteorologically by average air temperatures.
 5. This calendar was adopted in Japan, Korea, and Vietnam, where the solar terms remain unchanged but the pentads were modified in accordance with local observations and conditions.
 6. Aldo Leopold, *A Sand County Almanac*, New York: Ballantine, 1966.
 7. Leopold, 239 – 40.
 8. Levi Bryant, 'Wilderness Ontology' in *Preternatural*. Ed. Celina Jeffery, New York: Punctum, 2011, p. 21.
 9. Bryant, 23.
 10. The project title of the Autumn Almanac of Tokyo in Japanese is 東京の秋の生活暦 (www.photonicsmedia.net/about-autumn). Both the Seasonal Almanac and the Illustrated Almanac have Chinese titles, which are 季節年鑑 (<http://www.photonicsmedia.net/about-seasonal>) and 插圖年鑑 (<http://almanac.photonicsmedia.net/>) respectively.
 11. The first almanac project addresses both the Chinese solar terms and Japanese pentads, while the subsequent projects use solar terms and pentads adjusted for the southern hemisphere.
 12. The Japanese technique of *zuihitsu* (or following the brush) developed in tenth-century women's diaristic writings, most notably Sei Shonagon's *The Pillow Book*. This way of writing responds to everyday events with contemplation in the form of short prose, or often unconnected fragments.
 13. Walter Benjamin, *One Way Street and Other Writings*, tr. Edmund Jephcott and Kingsley Shorter (London: Verso, 1992).
 14. Karoline Kirst, 'Walter Benjamin's "Denkbild":

Page 88 - Jo Law

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Rebecca Clunningham is an Australian curator, sound, and performance artist. Rebecca holds a Bachelor of Music, Performance from the Queensland Conservatorium of Music, Griffith University and Bachelor of Creative Industries 2A Honours, Interdisciplinary from QUT and is currently undertaking a PHD in Business [Griffith University] exploring the operation of trust in the global performance art network. Cunningham is a founding member and co-director of the Artist Run Initiative – exist <http://existenceperformanceart.wordpress.com> and has curated a number of events in Brisbane including *MUSICIRCUS* (2004), *FLUX-US* (2006) and *CHAMBERS* (2007), “exist in 08: an international live art event” (2008) and “exist-ence” (Jan & Nov 2010, Oct 2011, June-July 2013). Rebecca has also performed locally and internationally; most recently Rebecca has made work for the *DAScienCE* festival (Canberra, 2013), *12~12~12 Humanity* (Manchester, UK 2012), *Dimanche Rouge* (Paris, France 2012), *Cage in US* festival (Brisbane, 2012), *Kesher Festival* (New York, 2012), the *Emergency Index Launch* (New York 2012), *Brisbane Festival* (2008, 2011), *POW! POW! POW! ACTION Art Festival*, San Francisco, USA (2010), *IN:ACT* festival, Hanoi, Vietnam (2010), *National Review of Live Art*, Glasgow (Feb 08 & Feb 09), *Ipswich City Square Mall* (2008), *The Other Film Festival* (Brisbane, Nov 07), *Once Only* (Brisbane, Sept 07), *Fetter Field festival* (Singapore, Sept 07) and has presented digital work in a range of other events, from Indonesia to Russia. “I see performance art as a way of living utopia in the moment, offering a space of pause, a place for personal meta-physical transformation.” <http://rebeccacunningham.wordpress.com/>.

Victoria Cooper is an artist with a PhD in Visual Arts researching the intersections of art and science. This interdisciplinary research is informed and inspired by her previous career in Human and Plant Pathology along with current interest in local and regional issues of land and water. During her 23-year arts career she has also worked across many forms of photographic technology—analogue to digital imaging; site specific documentation of performance; and artists’ books. In a collaborative practice with Dr Doug Spowart, she explores the post technological paradigm of photography as a cultural communication and a site-specific visual medium. This multi-methodological approach is applied in their current *Place Project* work in many regional communities. Cooper has exhibited in Australia and internationally and her work has been much published. Cooper’s artists’ books are held in most significant national and private collections including the rare books and manuscript collections of the National Library of Australia and the State Library of Queensland. *Acknowledgements from Victoria: Dr Doug Spowart – artist and independent researcher, Toowoomba Queensland; Dr Malcolm Ryley and Dr Gary Kong – formerly Principal Plant Pathologists and Dr John Alcorn – Former Curator, BRIP Plant Pathology Herbarium Department of Agriculture, Fisheries and Forestry, Queensland; John Reid, School Of Art – Australian National University; Dr Sally Stowe and the Electron Microscope Unit – Australian National University; Julian Bowron – Currently Director Bunbury Regional Art Galleries, Western Australia; Bundanon Trust – Nowra, New South Wales; Myall Park Botanic Garden (MPBG) – Glenmorgan, Queensland; Carol and Ed McCormack – Glenmorgan, Queensland; Kerry Brett – former owner of property located at The Head Queensland; Les and Penny Sheahan, Rob and Tammy Irons, former and current owners of Balcondo, Queensland; and Dr Felicity Rea - Toowoomba QLD.*

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Chris Henschke is an artist who works in the areas of media including fine art, illustration and imaging, interactive art, video and animation, graphic design, sound design, music, installation art and performance. *Acknowledgements from Chris: The Australian Synchrotron Artist In Residence program was developed by the Australina Network for Art & Technology, and supported by Arts Victoria Arts Innovation. Beamline experiments were conducted with the assistance of Mark Tobin, Mark Boland and Tom Caradoc-Davies.*

Dr Andrew Howells is a lecturer in Natural History Illustration at the University of Newcastle. With a professional background in animation, graphic design, fine art and Illustration Andrew takes a multidisciplinary approach to his practice-based research. Andrew's research focus is on contemporary illustration practice, visual resource development and the collaboration between art and science. *Acknowledgements from Andrew: I would like to acknowledge the contribution of the late Dr Roy McClements to my research and to thank him for his belief in the strength of a cross-disciplinary approach to research between the arts and sciences.*

Jo Law lectures in media arts at the University of Wollongong, Australia. "From my early videos that draw out the layering of intercultural currents to my more recent online almanacs that examine lived experiences in temporal segments, I find myself consistently returning to the task of mapping the everyday. I incorporate divergent media and materials in my works: films, videos, animations, collages, drawings, diagrams, maps, prints, books, online works and objects. My works have been exhibited widely across Australia and internationally and received awards including the Silver Spire Award at the San Francisco International Film Festival. Following a book chapter in Walter Benjamin and the Architecture of Modernity, I continue to publish my research such as a forthcoming co-authored article in Ozone: The Journal of Object-orientated Studies."

Harald Kleine received his degrees in Mechanical/Aeronautical Engineering at the Technical University of Aachen, Germany. During his postgraduate studies he began to design and build advanced optical systems for the visualisation of unsteady high-speed gas flows as observed in shock tubes and super- and hypersonic wind tunnels. He continued to work in this field during a postdoctoral fellowship at McGill University, Montreal, Canada (1995-97). For two years, he worked on the design and testing of blast protection equipment at the Ottawa-based company Med-Eng Systems, and subsequently followed an invitation of Tohoku University, Sendai, Japan, to continue his studies in high-speed flows. After the end of his contract with Tohoku University in 2002, Dr. Kleine became a staff member of the University of New South Wales at the Australian Defence Force Academy in Canberra, where he currently holds the position of Associate Professor. His work focuses on the development of improved time-resolved visualisation techniques and associated applications in shock wave research. On several occasions, he has also engaged with the artistic aspects of flow visualisation, a topic on which he has given a few presentations and published two papers. Many of his images are featured in exhibitions on scientific photography.

A performer and choreographer **Liz Lea** trained at London Contemporary Dance School and Akademi in London and Darpana Academy in India. Based between London and Sydney for many years she is now based in Canberra as Artistic Director of Liz Lea & Co and Canberra Dance Theatre and Associate Director at QL2 Dance. In 2013 she was Choreographer in Residence at CSIRO Discovery and Directed DANscienCE, a dance and science symposium held in Canberra for National Science Week, August 2013. She also presented InFlight at the National Library of Australia and Seeking Biloela at The Street Theatre – two new solo works; Magnificus Magnificus inspired by the red tailed black cockatoo for Indigenous dance artist Tammi Gissell and Kapture, inspired by Ahmed Kathrada, imprisoned alongside Nelson Mandela for 26 years. As a dancer Liz has worked for the Royal Opera House, Ranjabati Sircar, Imlata, Sankalpam, English National Opera and English Bach Festival as a Baroque specialist. Liz's research into the early modern dance movement and non Asian dance pioneers inspired by India such as Anna Pavlova and Ruth St Denis have led to the forthcoming documentary 'Dance Detective', filmed in India. She one of very few artists who has reinterpreted the early 1906 solos of Ruth St Denis, inspired by India.

James McArdle is Associate Professor in the Image at Deakin University and previously Head of Visual Arts and Design at La Trobe University. His research is devoted to art, visual thinking, creativity, and art education and has sustained thirty-three years of community service, teaching and curriculum development in secondary, adult, University and professional art, design and media technologies education, and ongoing artistic practice in photography, exhibiting nationally and internationally since 1974. Teaching and practice is constantly refreshed by regularly publishing and exhibiting research into visual attention, affordance, phenomenology and visual communication which he critically reappraises through photomedia fundamentals, adapting selective focus and binocular vision. *Acknowledgements from James: Figure 1 Cameron Robbins 'Smoke Room: 26 Surf Street 2007', reproduced with his kind permission, was part of his 'Appartion' installation (see <http://cameronrobbins-merricksbeach.blogspot.com> for more information and illustrations). Figure 4 is from James McArdle's solo show 'Vortex' at Bendigo Art Gallery, 29 September to 28th October 2001; Figure 5 is from James McArdle, 'Azimuth', Phyllis Palmer Gallery, Bendigo, 6 July – 6 Aug 2007; and Figure 6, from 'Second Nature', a joint solo exhibition by James McArdle and Lorena Carrington at Stephen McLaughlan Gallery Melbourne, Level 8 Nicholas Building 37 Swanston St, Melbourne, 14-31 March 2012.*

Lizzie Muller is a curator and writer specialising in interaction, audience experience and interdisciplinary collaboration. She is Senior Lecturer in the College of Fine Arts, UNSW Australia. Lizzie's primary research interest is the audience experience of art, particularly media art, interdisciplinary collaborations and participatory and interactive artworks. Her research draws together curatorial practice based research with theories and methods drawn from participatory design and interaction design. Her work with audience experience extends to the fields of preservation and archiving, particularly experiential documentation and oral histories of media art. Her current research explores the relationship between curatorial practice and shifts in contemporary disciplinary structures. *Acknowledgements from Lizzie: With thanks to Bec Dean, co-curator of Awfully Wonderful and all the staff at Performance Space, and to all the artists involved in the exhibition.*

Andrew Parker is Research Leader, Natural History Museum (London) and Green Templeton College, University of Oxford. The author of Seven Deadly Colours, Andrew Parker is the head of Green Templeton College's Photonic structures and eyes: evolution, development and biomimetics research team. Parker has been described by Time Magazine as "one of the three most important young scientists in the world for his work in investigating and answering the great riddle of the Cambrian explosion." *Acknowledgements from Andrew: This work was funded by The Royal Society (UK) and The Australian Research Council.*

Perdita Phillips is an Australian artist with a wide-ranging and experimental conceptual practice. She works in walking, mixed media installation, environmental projects, sound, sculpture, photography and drawing. Whilst materially diverse, underlying themes of ecological processes and a commitment to a resensitisation to the physical environment, are apparent. She often works with scientific knowledge systems and her binaural soundwalks extend the senses, combining real and imagined terrains and generating sonic/spatial dissonances. Recent works include .- / - / - (the penguin anticipatory archive) (2013) and the Shy (*dissolution + exchange*) conceptual mail art project (2012-2014). www.perditaphillips.com.

Vaughan Prain is Professor of Education at La Trobe University and is the author of *Writing, Thinking and Learning in Science*. His 2014 exhibition Get-Together exhibited at the Phyllis Palmer Gallery in Bendigo.

Mary Rosengren's installations and media works explore overlays between visual art, science and technology. Her research of images, natural phenomena and dynamic systems has taken her to the extreme environments of Lake Mungo NSW, Cairngorm Mountains Scotland and the Antarctic Peninsular and into significant scientific collections and contemporary research facilities in Australia and the UK. A recipient of the ANAT Synapse 6 residency in 2011, Mary lectures in visual arts at La Trobe University. *Acknowledgements from Mary: I would like to thank and to acknowledge the significant role and aspirations of Cris Kennedy, Director- CSIRO Discovery Centre for his continuing efforts and support for SPECTRA 2012, begun with the ANAT 2011 Synapse 6 Residency award. Cris Kennedy initiated and organized the SPECTRA2012 symposium and with staff at Discovery Centre managed the event itself. It is due to Cris Kennedy's energy, commitment and curiosity about art/science culture that the publication of the SPECTRA2012 papers has been realized. Thanks to the artists and scientists who presented at SPECTRA and those who contributed their papers here. Thanks to Vicki Sowry at ANAT, CSIRO for hosting the project, Anne and John at the Discovery Centre and the curators and technicians of CSIRO Biological Collections for supporting my research during the Residency in 2011. This paper is dedicated to Hugh McNicholl 1945-2012*

Erica Seccombe's project GROW: visualising nature at nanoscale was supported by an artACT project grant and a 2010 Synapse Residency in the ANU Department of Applied Mathematics before being accepted into the ANU PhD program in 2011. Erica also exhibited a major body of work 'Monster' in collaboration with Tim Senden and Ajay Limaye curated by David Broker, for Science Fiction at Canberra Contemporary Art Space in 2013. This work explores the volumetric data of an Isopoda through a stereoscopic digital projection and a 3D printing installation. For more information on Erica's activities visit her website www.ericaseccombe.com.au and watch excerpts of her animations on Vimeo. *Acknowledgements from Erica: This paper is based on Erica's PhD Exegesis research GROW: Visualising Nature at Nanoscale, ANU School of Art, and is also a condensed version of a peer reviewed essay 'Relocating the real: experiencing nature in the fifth dimension,' to be published as part of the 2013 AAANZ conference proceedings in 2014.*

Barbara Maria Stafford's research focusses on the intersection of the visual arts with the physical and biological sciences as well as the evolution of optical technologies. Author of ten books, her recent work [Echo Objects: The Cognitive Work of Images [2007] and A Field Guide to a New Metafield: Bridging the Humanities-Neurosciences Divide [2011] investigate emerging cross-disciplinary entanglements. Recently, she served as critic-at-large in the College of Architecture at the Georgia Institute of Technology where she initiated an Art/Science Salon by curating two exhibitions [the Salon for Vision [2011] and the Neuro-Salon [2012] and organized their accompanying conferences. [See barbaramariastafford.com]

Lynden Stone is a fulltime visual artist and PhD candidate at the Queensland College of Art, Griffith University, Brisbane. Her current studio practice investigates how visual artists can explore and represent the enigmas that quantum physics presents to conventional reality. Her primary practice is in painting but she also makes videos and installation work. She has exhibited in solo and group exhibitions in Australia, Philadelphia and London. *Acknowledgements from Lynden: I acknowledge the support and advice of my PhD supervisors Professor Mostyn Bramley-Moore and Dr. George Petelin. I wish also to thank Nick Herbert for his support and advice on the Metaphase Typewriter revival project as well as my collaborator and programmer on that project, M. U. Shrooms. In addition, I thank Evie Franzidis for her comments and suggestions whilst editing sections of this paper that formed part of my PhD exegesis.*

Eleanor Gates-Stuart is a Researcher with the Australian National Centre for the Public Awareness of Science (CPAS) at ANU and associated with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Eleanor's research in Science and Art is diverse and collaborative. Specialising in visual media communicating her artistic practice in new and innovative ways, questioning and engaging audience in art, science and technology, working with major research organisations, museums, business and local government. Her recent project, StellrScope, was awarded to Eleanor by the Centenary of Canberra as a major Science Art Commission, that was supported by the Australian Capital Territory (ACT) Government and the Australian Government. CSIRO was the host for this research, engaging Eleanor as the Science Art Fellow with the Food Futures Flagship and the Computational Informatics (CIS) Research Division. Eleanor's interests firmly crossover arts, science, design, technology and communication. Having received numerous awards, grants, and commissions in her career, Eleanor's international artistic profile and research includes roles such as associate professor, curator, exhibitor and director of media and science arts events. She is a regular contributor to numerous professional associations, enjoys working on collaborations, publishing and presenting papers at conferences in the UK, USA, Taiwan and Australia. *Acknowledgements from Eleanor: The Centenary Science Art Commission StellrScope is a Centenary of Canberra project, supported by the ACT Government and the Australian Government. Gates-Stuart's residency at CSIRO has been supported through the CSIRO Transformational Biology initiative and in association with CSIRO's Future Grains Theme. Huge acknowledgment of all those who have contributed to, or collaborated on the works described in this paper, including Matt Adcock, Chuong Nguyen, David Feng and Dulitha Ranatunga who played key roles in implementing software and display systems for StellrScope, including the input of CSIRO's Lab 22 and the Australian National Insect Collection. An additional thank you to Professor Sue Stocklmayer, Australian National Centre for the Public Awareness of Science, ANU, for her generous support with this project.*

Russell Tytler is Professor of Science Education at Deakin University. He has been involved over many years with system wide curriculum development and professional development initiatives. He has researched and written extensively on student learning and reasoning in science, and science investigations. His recent research interests include the role of representation in reasoning and learning in science, teacher and school change, and international perspectives on science and environmental education. He has undertaken a number of influential studies concerning student engagement with science and mathematics, and STEM policy. Russell has held visiting professor positions in Europe and Asia. He is deputy director of the very active CREFI strategic research centre at Deakin.

Dustin Welbourne is a PhD candidate with the University of New South Wales whose research is on the development of non-invasive research methods for terrestrial vertebrates. In 2012, Mr. Welbourne devised and published a method to use camera-traps to surveying terrestrial reptiles, the first of its type in the world, which has proved to be more effective than some traditional methods. Wildlife research however, is only part of his interest as Mr Welbourne has recently completed a Masters in Science Communication with the Australian National University where he studied the use of YouTube as a platform for science communication. Mr. Welbourne has written numerous articles for the popular press, given a variety of public talks including at TEDxCanberra 2013, and was one of the national winners of “I’m a Scientist, get me out of here”. Mr. Welbourne currently lives in Canberra, but he is on the lookout for upcoming post doc opportunities to satisfy his breadth of scientific interest. *Acknowledgements from Dustin: Thank you to UNSW Canberra for providing me with the time and resources to attend SPECTRA 2012, and to the organising committee of SPECTRA 2012 for putting on such an interesting and inspiring event.*

Lorraine White-Hancock is a PhD candidate in the Faculty of Education at Monash University, Melbourne, Australia. Her background is as an artist and object designer. Until recently she was a teacher and Course Coordinator of the Adv. Dip. Engineering Technology – Jewellery and Metalsmithing at Box Hill Institute of TAFE, Victoria, Australia. In 2013 White-Hancock worked as a research assistant at Monash University. *Acknowledgements from Lorraine: Thanks to the Synapse grant recipients - Dr Mary Rosengren and Cris Kennedy, Catherine Truman and Professor Ian Gibbins, Chris Henschke and Dr Mark Boland - who agreed to be interviewed and so generously gave their valuable time to this process. Thanks also to Vicky Sowry at ANAT who kindly helped me contact project partners and discussed the Synapse program with me.*

Suzette Worden’s current research interests include mining, aluminium and wool under the theme of materiality and design. This research links craft and design with heritage, material culture and science technology studies. She has extended this to include research into art-science collaborations. From 2002-2011 she was Professor of Design at Curtin University, Perth, Western Australia. Besides teaching and researching the history of design she has co-curated exhibitions and been involved in the organisation of conferences on digital media.

Acknowledgements from Suzette: The Sixth Shore project has been assisted by the Australian Government through the Australia Council, its arts funding and advisory body. Perdita Phillips also acknowledges assistance from SymbioticA at the University of Western Australia and the Sidney Myer Fund. Figure 6 courtesy of Katherine Grey, Geological Survey of Western Australia.

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