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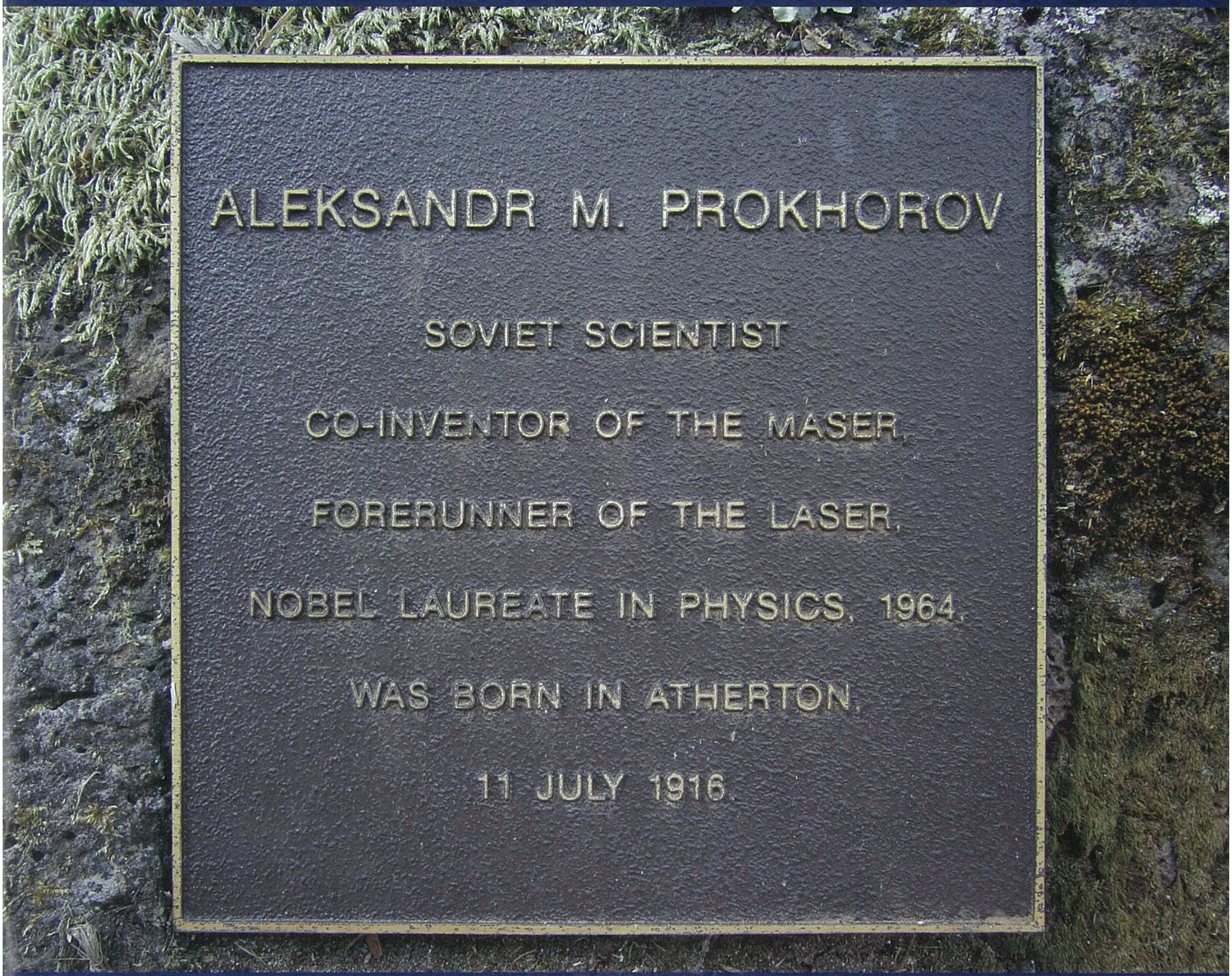

MURCHISON WIDEFIELD ARRAY: FIRST RESULTS

3D X-RAY ART

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3D X-ray art

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The micro-CT facility at the ANU Department of Applied Mathematics has hosted Erica Seccombe as an artist-in-residence since 2006. This article gives an overview of the techniques required to produce the images and a brief art-historical context for the work.

Introduction

One of us, Erica, began working in the ANU Department of Applied Mathematics in 2006 when she was awarded an *artsACT* project [1] for a three-month residency. She had contacted and met Professor Tim Senden the year before and had discussed with him her objectives to explore scientific technology via an artistic practice. Through 2D prints and large-scale photocopy assemblages of small plastic toys she had already emulated electron microscopy and X-ray images (see Figure 1). She predicted the hollow plastic, industrially designed structures would translate interestingly with actual X-ray imaging.

Tim and other members of Applied Maths enthusiastically welcomed the residency. Just two years earlier, the department had completed building a custom X-ray computed tomography (CT) facility capable of imaging materials with a wide variety of densities and sizes from 5 cm cores of rock, imaged at 20 micron resolution, down to samples around 5 mm across imaged with a voxel size of less than 2 microns. Tim saw the collaboration initially as a chance to increase the public profile of the facility. The residency produced a body of work titled *Nanoplastica* (see Figure 2) and was so successful that Erica returned in 2010 with a second *artsACT* grant and a Synapse residency from ANAT [2] to image germinating seeds (see Figure 3), and again in 2013 with support from the Centenary of Canberra [3] to produce renderings and 3D printed objects from a CT image of a woodlouse (slater) - see Figure 4. This essay details some of the technical aspects required to produce the images and the broader artistic context of the work.

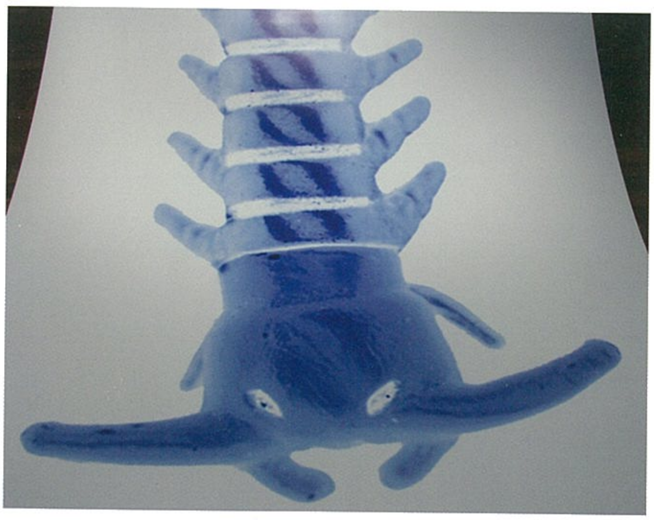

Figure 1: Creaturepede (detail) 2004, inkjet print on satin paper, 90 x 600cm. Image from the exhibition '2x4' of work from the 2004 Masters and PhD graduation at ANU School of Art Gallery 29 April–1 May, 2004.

The ANU X-ray micro-CT facility

In 1967 an idea occurred to Sir Godfrey Newbold Hounsfield (1919-2004), a brilliant English electrical engineer, that one could determine what was inside a box by taking X-ray readings at all angles around the object (these X-ray shadows are called projection data). Prior to this he was involved the development of early computer technology where, in the late 1950s, he led a team that built the first all-transistor computer to be constructed in Britain, the EMIDEC 1100. Combining his knowledge of computer technology and his interest in automatic pattern recognition, Hounsfield's realization led to his invention of the computer-aided tomography (CT or CAT) scanner. 'Tomos' means 'slice'; in the past, three-dimensional structures could only be studied by making physical slices through an object. In CT, the X-ray density at each point inside the object is reconstructed from the projection data using a mathematical relationship called the Radon transform: slices through a specimen are computed by virtual means, rather than being made by the doctor's scalpel.

"...to produce renderings and 3D printed objects from a CT image..."

Bizarrely Hounsfield's invention is also attributed as a direct result of the Beatles booming record sales in the

Figure 2: Nanoplastica (detail) 2008. Three-channel digital animated projection installed at the Canberra Contemporary Art Space, 23 May–5 July, 2008.

early 1960s. It turns out that the EMI record company, an arm of the EMI Group (Electric & Musical Industries Ltd), also owned the Central Research Laboratory in London of which Hounsfield was an employee. Benefiting from the Beatles lucrative success, EMI was able to fund Hounsfield's pioneering work on this scanning device, for which he was awarded the Nobel Prize in 1979 [4].

Since the 1970s, CT scanners have revolutionized medical diagnostic radiology methods. However the early technology could not support the resolutions required for quantitative analysis of materials. It took the advent of affordable high-performance computing power (GPU computing, for example) and improvements in the components for X-ray generation and detection to make possible studies of structure at the micron scale in sedimentary rocks, bone, composite materials, wood, fossils and insects over the past 10-20 years. The laboratory-based micro-CT at ANU currently uses a transmission-type X-ray source, a large-area amorphous-silicon flat panel detector and reaches a resolution of 1.5 microns with scan times of 10-20 hours [5]. In comparison, the most efficient synchrotron beamlines with their high beam flux can acquire datasets of 2000^3 voxels at 2-5 micron resolution in less than one minute, and have a maximum resolution of 100 nm.

There are three steps involved in creating the volume data that Erica uses for her artistic renderings. The projection images are *acquired* using a helical-scanning cone-beam tomography configuration. This is significantly different to the circular-scanning parallel-beam method first developed by Hounsfield that assumes the X-ray source is a large distance from the sample and detector. The "cone-beam" configuration means the X-ray source can be brought close to the sample being scanned to increase the amount of flux reaching the detector. Projection data from high cone angles can only be transformed accurately into volume data with a helical scanning trajectory.

The *reconstruction* process uses a theoretically exact algorithm based on the Katsevich inversion formula (a generalization of the Radon transform). The group at ANU was the first to implement this method and it involved solving a range of technical issues including thermal drift causing relative movement between source and sample, system alignment, inhomogeneous magnification and secondary radiation sources. The amount of data and computations used to produce these images is staggering. A typical helical trajectory acquisition involves up to 15,000 X-ray projection images, each with 2048x1536 16-bit pixels, amounting to 90 GB of data. The reconstructed 3D volume is approximately 2000x2000x4000 voxels, with 32 GB of data. The reconstruction takes about 3 hours on 192 processors of the Raijin supercomputer at NCI (the National Computational Infrastructure).

"The projection images are acquired using a helical-scanning cone-beam tomography configuration."

The final stage is image processing. Various filtering techniques can help to remove high-frequency noise in the image, and image gradients can highlight boundaries between phases. One of the most important techniques is image *segmentation*, the process of classifying voxels into discrete "phases" such as plastic and air in the case of Erica's first toy objects. There may also be mounts and glue that can be identified and digitally removed. Ideally, the different materials have significantly distinct X-ray densities, so that each phase may be clearly identified. But even for the simplest objects, reconstructed images can be blurred and noisy and voxels representing the boundary between two phases take intermediate values. These factors make image segmentation a labour intensive task.

Erica's second residency was an ambitious project to a capture seed sprouting to first-leaf stage, inspired by new

Figure 3: Grow (detail) 2013. Single channel digital image projection formatted for stereoscopic viewing with circular polarized glasses, silver screen.

research into dynamic CT imaging within the Department. This required Erica to embark on a significant amount of research into types of seeds, growth beds, water content, and containers. The seeds needed to sprout quickly and withstand the harsh environment of the X-ray room, while the container and growth bed needed to provide a stable base that could nurture the seed without any intervention for the duration of the imaging process. After many trials she settled on mung beans and alfalfa growing in a test-tube with a gelatin growth bed containing a small amount of iodine staining to assist with contrasts between different structures in the seeds. She eventually acquired three usable time-lapse sequences of volume images; the longest has 40 volumes taken at regular intervals over four days and nights [6].

During this time Erica was commissioned to create a separate body of work for the exhibition 'Science Fiction' as part of the Centenary of Canberra celebrations. She collaborated with Tim Senden using data he had acquired of an *Isopoda*, more commonly known as a woodlouse. This tiny garden-inhabiting crustacean was soaked in ethanol containing 5% iodine for 24 hours. The solution was preferentially absorbed into the muscle tissue with the result that the musculature and exoskeleton had distinct X-ray densities, assisting with segmentation and the rendering process described below.

Volume data rendering using Drishti

After reconstruction and processing the volume data set is still just a three-dimensional array of numbers. The challenge is to display that wealth of information in a meaningful way. The software used by Erica is *Drishti*, a purpose-designed volume exploration tool written by Dr Ajay Limaye at the ANU Supercomputer Facility VizLab [7]. The name *Drishti* was knowingly chosen by Ajay for its multiple meanings in Sanskrit as indicative of a different kind of visual experience. In an English translation of 'drishti' the word can be used to describe vision, seeing, knowledge and intelligence. It can also mean insight as pertaining to mental knowledge, the outcome of perception. The act of transforming data and mathematical relationships into a picture is a vital part of understanding and communicating our knowledge of the world. Scientists create images and diagrams with the primary goal of conveying information. Artists aim to evoke an emotional response to their work, provoking the viewer to make reflective connections between the artwork and their personal experience. *Drishti* is versatile enough to encompass both these objectives.

"The challenge is to display that wealth of information in a meaningful way."

A volumetric image is effectively a function defined over a three-dimensional grid whose value at each point (voxel) is the reconstructed X-ray density. The basic principle in volume rendering is to highlight certain level surfaces (contour surfaces) of this function, or of its gradient, leaving other regions transparent. This is achieved via the *transfer function*: a map from the X-ray density function and gradient values to colour and opacity values (RGBA). *Drishti* projects these contour surfaces to the screen display using a hardware texture-based volume rendering method. The user interactively manipulates the transfer functions to enhance or suppress regions of the data and thereby separate various structures within a specimen. *Drishti* also permits data manipulation through cropping, clipping, lighting and contrast adjustments, and complete freedom to place the software's camera anywhere inside or outside the virtual specimen.

Since its inception in 2004, *Drishti* has improved considerably in terms of its user interface and Erica has played a significant role in this development. When she began in 2006, there weren't many other people actively using the program, but this has changed as the use of 3D imaging technology has increased. One of the main groups now using *Drishti* are paleontologists who can study their fossils with microscopic internal detail without even having to dissolve the rock it has been encased in [8].

Art-historical context

Erica's work references many inter-connected revolutions of invention, discovery and creative developments across optics, physics and computation. The first is Robert Hooke's use of microscopic lenses to reveal previously unimaginable details of objects invisible to the naked eye. His historic book "Micrographia" (1665) contains hand-drawn engravings of insects at greatly magnified scales and inspired wide public interest in the new science of microscopy. The comparative scale of microscopy offered a unique perspective from which to reflect as observers, creating new meanings across time and circumstance. Two centuries later, Wilhelm Roentgen's discovery of radioactive waves and the process of making X-ray radiographs revolutionized the very notion of the physical world where previously solid matter was rendered transparent.

The development of photography in the 19th century also had a profound impact on both science and art, particularly in combination with microscopy and X-rays, as demonstrated in the exhibition and book [9] "Brought to Light: photography and the invisible" by Corey Keller. For Keller, the drive to make pictures of imperceptible phenomena highlighted a major shift in a cultural understanding of the world around us that began with 'an awareness that there was a great deal more to the world than the human senses could perceive'. Scientific photography supported the 19th century movement towards popular science and 'a belief that to have a healthy citizenry you had to have a population that understood the most important ideas in modern science' [10]. But Keller also demonstrates that the creation of X-ray photographs of objects impossible to view with the eye posed a cultural challenge that also led to elements of magic and superstition.

"There is no doubt Science is the new black in Art."

Similar tensions exist between science and superstition today. The urgent environmental concerns of our time: global warming, population growth, conservation of biodiversity, tend to be discussed in a polarizing, di-

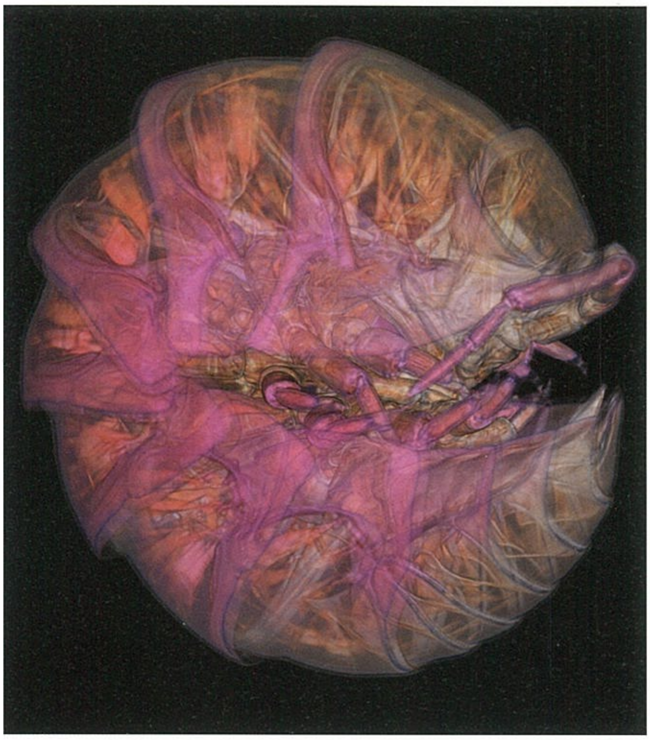

Figure 4: Monster (still) 2013. Print exhibited as a finalist in the image competition at Tomography for Scientific Advancement, Natural History Museum, London.

dactic fashion, leading to public disengagement. RMIT artist and academic Lesley Duxbury has proposed that certain art practices have the potential to engage society with nature emotionally and experientially [11]:

Erica is using cutting-edge 21st century technology to induce awe and wonderment in the viewer, a subjective experience of being in the moment watching a seed as it begins to grow, or by taking a bug and making it beautiful on a gigantic scale. We are lightly encouraged to reflect on our place in the natural world at this precarious point in human history.

Science-Art Collaboration

"There is no doubt Science is the new black in Art." This was the opening statement from Vicky Sowry, Director of the Australian Network for Art and Technology (ANAT), at a recent Vivid Ideas event [12]. Discussions between the panel members and the audience revealed that the most successful collaborations have a genuine personal connection at their core, with mutual respect for the perspectives and methodologies of one another's disciplines. Scientists must acknowledge the artist as more than an illustrator and artists must engage with the scientists and laboratories as more than service providers.

The collaboration between Erica, Tim, Ajay and other members of Applied Mathematics has certainly been successful in artistic terms. The scientific benefits are less tangible perhaps, but in addition to her influence on the development of *Drishti*, the presence of an interested outsider stimulates discussions: hidden assumptions are exposed, ideas are clarified under force of explanation. Exhibitions of scientifically engaged artworks, such as Erica's, help to engage the public with what can be an otherwise mysterious and impenetrable discipline.

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AUTHOR BIOGRAPHIES

Erica Seccombe is a visual artist with a printmaking background who explores ideas of authenticity, replication and simulation of the natural world and has always been interested in the influence of scientific ideas on 20th century art. Since 2006 she has been working with scientists in the ANU Research School of Physics and Engineering, primarily Tim Senden in the Department of Applied Mathematics and Ajay Limay in the VizLab. She is currently completing a PhD in visual art practice at the ANU School of Art.
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Vanessa Robins is an applied mathematician at the ANU, recently awarded an ARC Future Fellowship. She works on the quantification of shape from data and the role of topological and geometric structure in the physical properties of materials. She has a life-long love of the visual arts.
http://physics.anu.edu.au/people/profile.php?ID=75