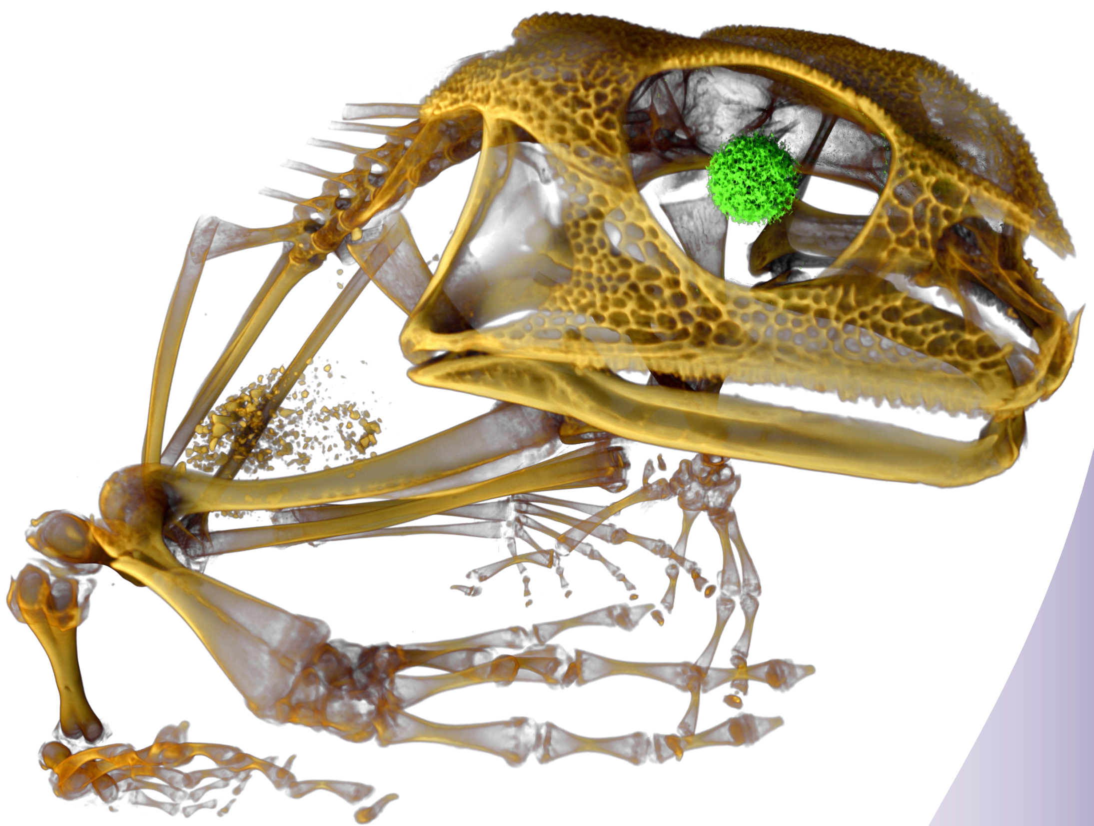
NATURAL HISTORY MUSEUM

ToScA

Tomography for Scientific Advancement

Programme

1st-3rd September 2014



ToScA

Tomography for Scientific Advancement

Welcome to

Tomography for Scientific Advancement

In affiliation with the Royal Microscopical Society (RMS)

The Natural History Museum,
Cromwell Road,
London,
SW7 5BD, UK

1st, 2nd & 3rd
September 2014

BRUKER

CCPi Tomographic Imaging

DEBEN

FEI

Welcome to the second annual Tomography for Scientific Advancement symposium (ToScA). Last year over 100 delegates, from nine different countries, attended ToScA to discuss recent scientific discoveries, applications and future advances in the field of computed tomography. This year we are building on this success by extending the symposium to three days. The meeting will address the growing area of multimodal and correlative tomography, as well as software and hardware developments, applications from a range of sciences and the role of computed tomography in cultural heritage and art. This meeting will consist of keynote speakers, poster presentations, an image competition and a grand dinner in the Hintze Hall under 'Dippy' the Diplodocus. I would like to take this opportunity to encourage representatives from diverse backgrounds to troubleshoot common issues, and actively forge collaborations to advance the field of computed tomography and its applications.

I look forward to seeing you at the symposium

Dr Farah Ahmed

The Natural History Museum

With more than 70 million specimens, ranging from microscopic slides to mammoth skeletons, the Natural History Museum is home to the largest and most important natural history collection in the world.

It all started with Sir Hans Sloane, an 18th century collector, who left his extensive collection of 80,000 items to the nation. Over the years, voyages of discovery such as Cook's epic journey aboard the HMS Endeavour have boosted the collections.

The collections display material from all areas of the natural world, including the ill-fated dodo, meteorites from Mars and a full-size blue whale skeleton amongst others. The specimens cover almost all groups of animals, plants, minerals and fossils and range in size from single cells on slides to whole animals preserved in alcohol.

In addition to that, the Natural History Museum holds the world's finest natural history library, with the largest collection of natural history library materials in the world including books, periodicals, original drawings, paintings and prints, manuscripts and maps.

NATURAL HISTORY MUSEUM

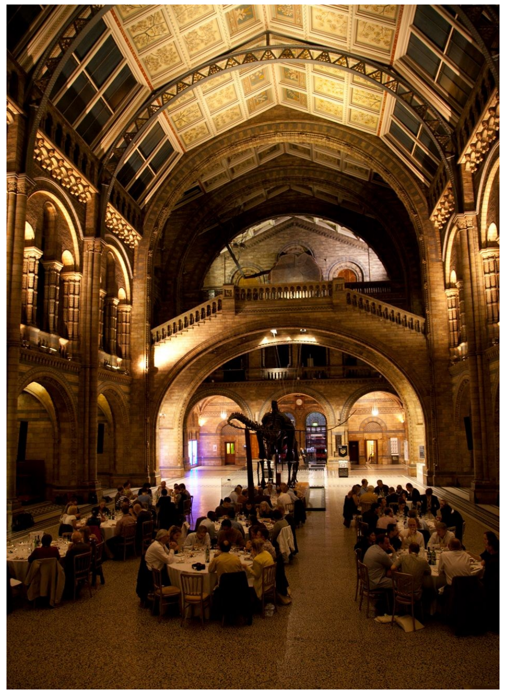
RMS

Social Events

During the symposium talks will be held in the Flett Theatre within the Red Zone. A drinks reception will follow the formal programme on the 2nd September. Refreshments will be served in Lasting Impressions Gallery alongside a display of posters and images from the competitions.

The reception will be followed by a three course evening meal, to be served in the world renowned Hintze Hall of the Museum next to the Museum's most famous resident, Dippy.

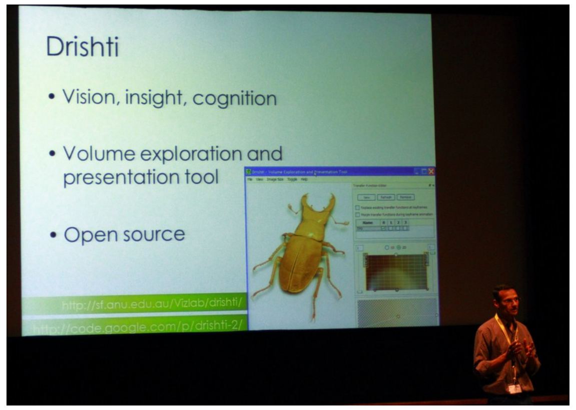
The Drayton Arms will be the pub of choice for post-ToScA socialising on Monday and Wednesday evening.

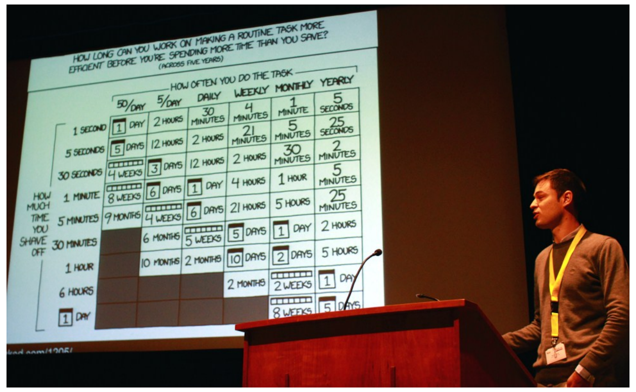


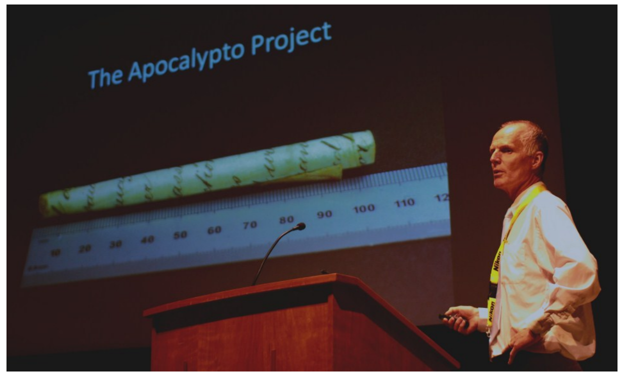
Competition Winners from ToScA 2013

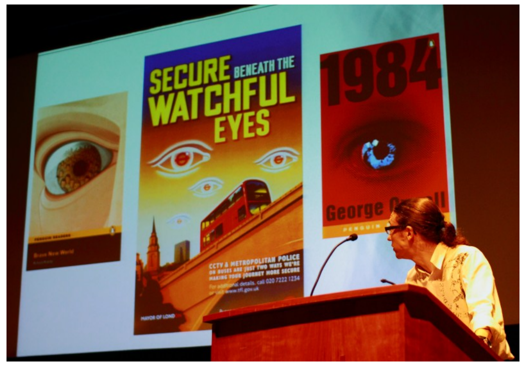
Nikon LaVision We count on Photons simpleware ZEISS SCANCO MEDICAL

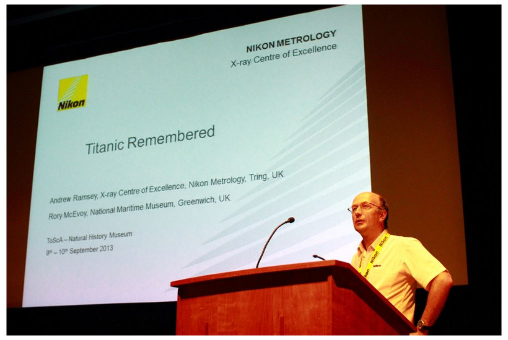
Highlights from ToScA 2013











BRUKER CCPi Tomographic Imaging DEBEN FEI

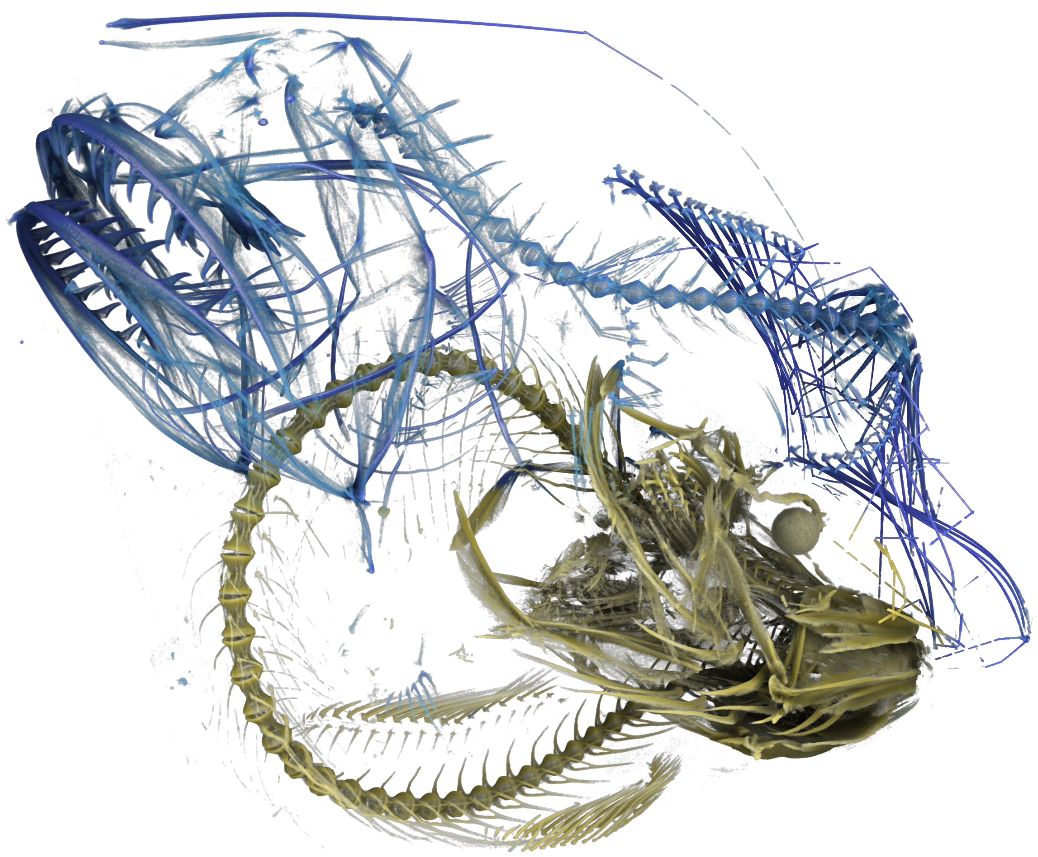
The UKCT Consortium

The United Kingdom Computed Tomography Consortium (UKCT) was established in 2013 to bring together leading researchers in tomography from around the UK. It currently consists of six institutions: The Natural History Museum, Imperial College, Oxford University, Queen Mary UoL, University of Manchester and The British Museum. The key aims of the Consortium are to promote tomography for scientific advancement through the delivery of science via public engagement, facilitating collaborations, organising international meetings and supporting leading research output.

The following members are the representatives of their institutions:

Dr Farah Ahmed, NHM; Dr Graham Davis, QMUL; Dr Richie Abel, Imperial College; Dr Matt Friedman, Oxford University; Janet Ambers, The British Museum; Dr Simon Carr, QMUL; and Prof Phil Withers, University of Manchester.

Please feel free to approach the members during your time at ToScA to discuss ideas, collaborations and the future directions of UKCT.

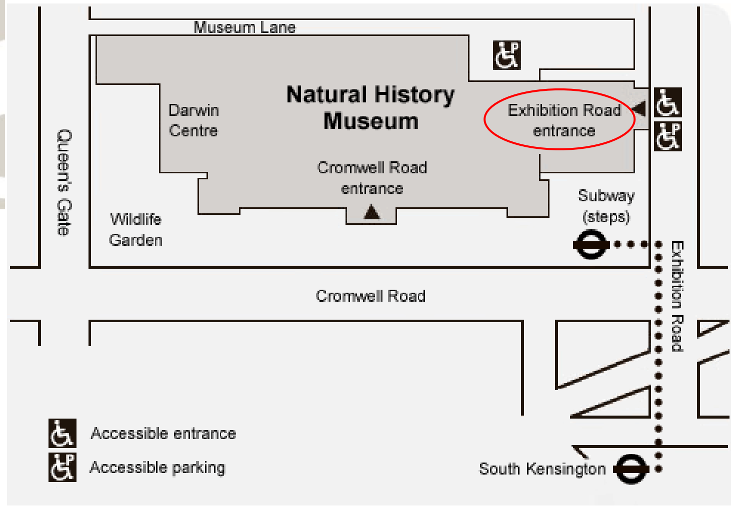


How to Find Us

Natural History Museum

Cromwell Road, London, SW7 5BD, UK

Tel: +44 (0)20 7942 5000



The Museum has 2 entrances, the Cromwell Road entrance and the Exhibition Road entrance. Please use the Exhibition Road staff and departmental visitor entrance for entry during the symposium.

The Museum is within walking distance from South Kensington tube station. See tube map opposite.

Black cabs can easily be found on Cromwell Road, however you can also book a taxi in advance.

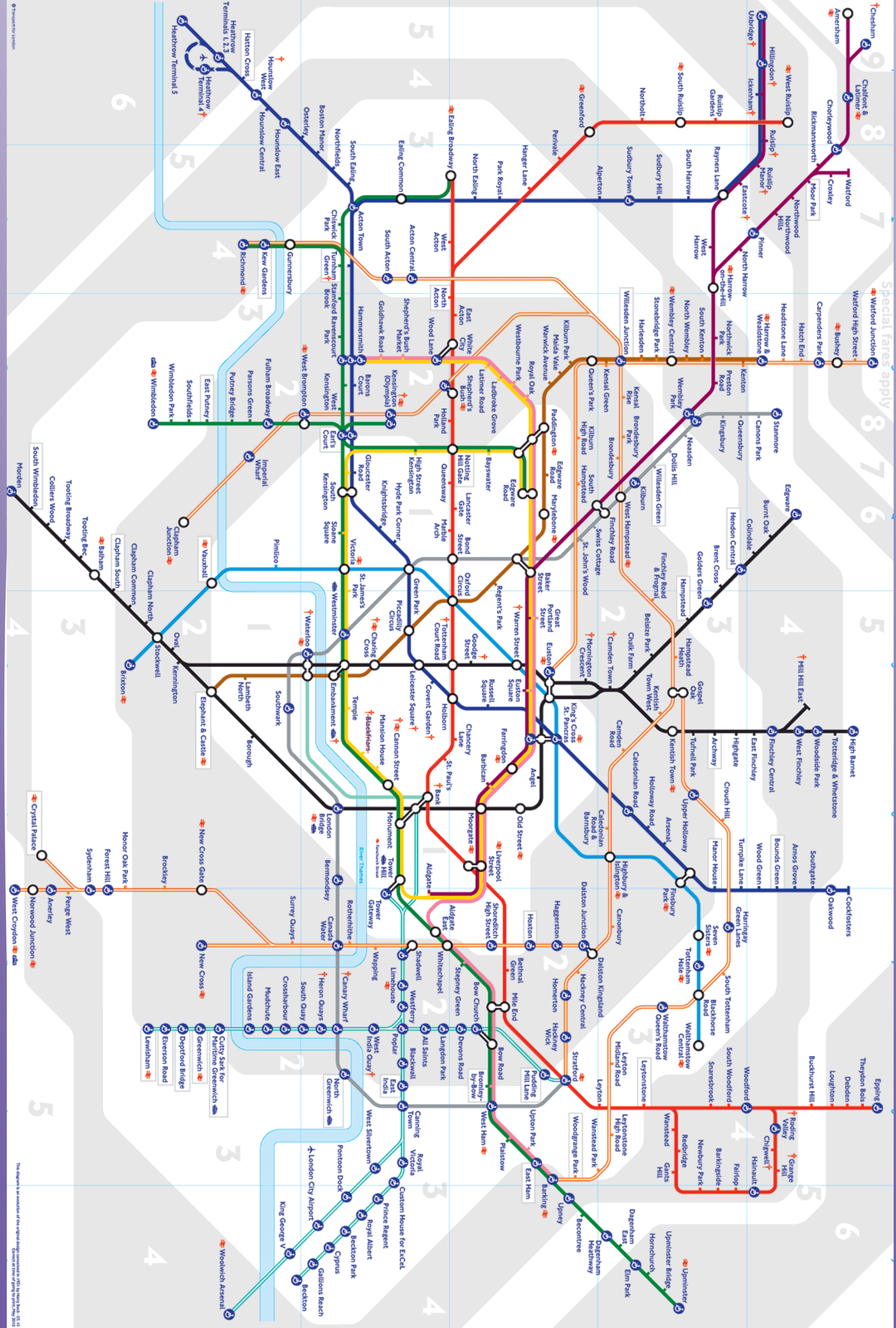
Addison Lee: 0207 387 8888

Call-a-Cab: 020 8901 4444

London Black Taxis: 0203 004 4953

Bus routes 14, 49, 70, 74, 345, 360, 414 and C1 stop near the museum. Bus number 360 stops at Exhibition Road.

There are cycle parking facilities by the Cromwell Road entrance and there are racks along Exhibition Road. The nearest Barclays Cycle Hire docking station is outside the Exhibition Road entrance. Other nearby locations include Queen's Gate and South Kensington tube station



What's on?

At the Natural History Museum

Cocoon *(Entrance is free, Booking not required)*

Interact with the science of nature like never before in the state of the art cocoon building. Take a self guided tour and witness real specimens, incredible displays and thrilling interactive activities. Get up close to scientists at work.

Britain: One Million Years of the Human Story *(run until 28th September, Booking is advised)*

Experience the dramatic story of ancient Britain, its changing landscapes and the people who lived here. This major exhibition showcases more than 200 specimens, objects and life-size models.

Mammoths: Ice Age Giants *(runs until 7th September, Booking is advised)*

Meet some of the largest mammals to have walked the Earth. Fossils, skeletons and huge models tower above you in a mighty display of tusks and trunks. Experience their Ice Age world.

BRUKER CCPi Tomographic Imaging DEBEN FEI

NATURAL HISTORY MUSEUM

RMS

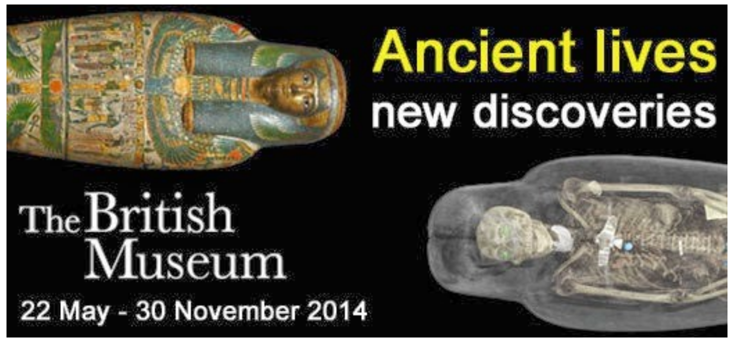
In London

British Museum:

Ancient Lives: New Discoveries *(runs until 30 November 2014, booking required)*

Contemporary Japanese prints: Noda Tetsuya's 'Diary' series *(runs until 5 October 2014, Free)*

The Other Side of the Medal How Germany Saw the First World War *(runs until 23 November 2014, Free)*



Science Museum:

3D: Printing the Future *(runs until 7 January 2015, Free)*

Museum of London:

Christina Broom *(runs until 28 September 2014)*

V and A :

Disobedient Objects *(runs until 1 February 2015)*

Constable: The Making of a Master *(runs until 11 January 2015)*

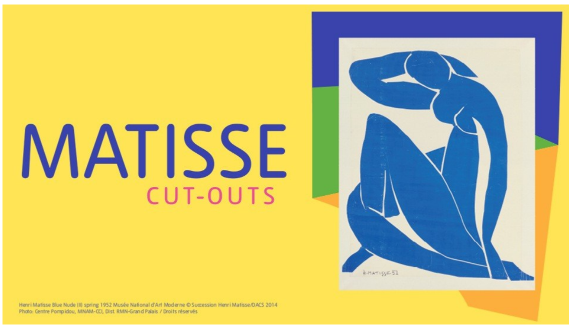
National Gallery:

Making Colour *(runs until 7 September 2014)*

Building the Picture *(runs until 21 September 2014)*

Tate Modern

Henri Matisse: The Cut Outs *(runs until 7th September)*



For other event and exhibit see Timeout

Nikon LaVision WE COUNT ON PHOTONS simpleware ZEISS SCANCO MEDICAL

Day 1

09:00 - 09:30 Morning Registration

09:30 - 10:00 Introduction

Session 1: Software Development I

Time	Speaker	Title
10:00-10:30	Dr Ajay Limaye (Australian National University)	Drishti Prayog is touchscreen enabled "public space ready" version of Drishti
10:30-11:00	Dr Russell Garwood (University of Manchester)	Open source and free software for exploring tomographic data

11:00 - 11:30 Tea Break and Trade Exhibition

Session 2: Software Development II

Time	Speaker	Title
11:30-12:00	Drew Whitehouse (Australian National University)	Voluminous - A web based volume renderer
12:00-12:30	Fabien Arnaud (FEI)	Advanced segmentation using FEI's 3D image analysis software

12:30 - 14:00 Lunch and Trade Exhibition

BRUKER CCPi Tomographic Imaging DEBEN FEI

Session 3: Advancements in Hardware and Design I

Time	Speaker	Title
14:00-14:30	Frederik Coppens (Bruker)	Conventional vs. dual energy microCT scanning: enhancement of material contrast
14.30-15:00	Prof. Marco Stampanoni (Swiss Light Source)	The renaissance of X-rays: phase-contrast imaging on lab-sources

15:00 - 15:30 Tea break and Trade Exhibition

Session 4: Advancements in Hardware and Design II

Time	Speaker	Title
15:30-16:00	Patricia Wils (Paris Muséum national d'Histoire naturelle)	Paris CT lights: The AST-RX platform, an X-ray tomography facility dedicated to natural sciences at the Paris Muséum national d'Histoire naturelle
16:00-16:30	Dr Manuel Dierick (UGCT, University of Ghent)	µ-CT: It's in the details
16:30-17:00	Panel Discussion	

Day 2

Session 5: Conservation, Cultural Heritage and Outreach I

Time	Speaker	Title
10:00-10:30	Dr Graham Davis (Queen Mary's University of London)	Scrolls, films and the borders of possibility
10:30-11:00	Prof. Sarah Hainsworth (University of Leicester)	Forensic applications of micro-computed tomography - Bones, flies and Richard III

11:00 - 11:30 Tea Break and Trade Exhibition

Session 6: Multimodal and Correlative Tomography I

Time	Speaker	Title
11:30-12:00	Dr Philip Schneider	Quantification of 3D ultrastructure orientation: Going beyond conventional CT
12:00-12:30	Dr Jim Swoger (Centre for Genomic Regulation)	Optical Projection Tomography (OPT) – Visible-wavelengths for tomography of mesoscopic biological samples

12:30 - 14:30 Lunch and Trade Exhibition

Session 7: Biological Applications I

Time	Speaker	Title
14:30-15:00	Prof. Sacha Mooney (University of Nottingham)	Roots, shoots, leaves and mud! Examples of X-ray computed tomography from the plant and soil sciences
15:00-15:30	Dr Richard Johnston (Swansea University)	The peculiarities of natural form – Hidden structures in nature and their bioinspiration potential

15:30 - 16:00 Tea Break and Trade Exhibition

Session 8: Multimodal and Correlative Tomography II

Time	Speaker	Title
16:00-16:30	Prof. Phil Withers (University of Manchester)	Completing the picture - Correlative tomography
16:30-17:00	Dr Manchechr Soleimani (University of Bath)	Multimodality tomography
17.00-17:30	Dr Rajmund Mokso (Paul Scherrer Institut, Swiss Light Source)	Nature's dynamics under an X-ray microscope
17:30-18:30	Panel Discussion	

18:30 - 19:45 Drinks Reception, Poster and Image Competition

19:45 - 22:30 Symposium Dinner (Central Hall)

Day 3

Session 9: Conservation, Cultural Heritage and Outreach II

Time	Speaker	Title
10:00-10:30	Dr Christina Duffy (British Library)	Understanding book structures: A CT examination of the St Cuthbert Gospel
10:30-11:00	Erica Seccombe (Australian National University)	New dimensions: An artist's perspective on 4D Micro-CT and Drishti

11:00 - 11:30 Tea Break and Trade Exhibition

Session 10: Biological Applications II

Time	Speaker	Title
11:30-12:00	Dr Thomas Simonsen	Non-destructive Lepidoptera genitalia 'dissections' through micro-CT scanning: A step towards virtual taxonomy
12:00-12:30	Dr Brian Metscher (University of Vienna)	Micro-CT diversifies: 3D images in various life sciences applications

12:30 - 14:00 Lunch and Trade Exhibition

Session 11: Advancements in Hardware and Design III

Time	Speaker	Title
14:00-14:30	Dr Andrew Ramsey (Nikon Metrology)	Recent advances in high resolution high energy X-ray imaging – A 750kV microfocus source with a 20μm spot size
14:30-15:00	Dr Michael Drakopoulos (Diamond Light Source)	High-energy imaging at the DLS Beamline I12
15:00-15:30	Dr Andrew Kingston (Australian National University)	CTLab: Tomography downunder

15:30 - 16:00 Tea Break and Trade Exhibition

Session 12: Paleontological Applications

Time	Speaker	Title
16:00-16:30	Dr Mark Sutton (Imperial College)	Tomography in palaeontology: History and the future
16:30-17.00	Dr Zerina Johanson (Natural History Museum)	Teeth inside and outside the mouth? Topographic relationships in sawshark and sawfish dentitions (Elasmobranchii; Chondrichthyes)
17:00-17:45	Panel Discussion and group photo	

18:00 End of Symposium

Abstracts - Day 1

Session 1: Software Development I

Dr Ajay Limaye: Drishti Prayog is touchscreen enabled "public space ready" version of Drishti

Drishti Prayog uses Drishti as the authoring tool. It takes Drishti projects and displays them is a layperson friendly manner. Authors can embed images, movies, text, webpage as well as pdf files in Drishti Prayog projects. Usage statistics is also available for every Drishti Prayog project. This will enable Drishti users in outreach activities. Drishti Prayog requires minimal to no training for use and is ready for public spaces, such as museum, exhibition, institute foyers. It can also help in teaching - allowing students to explore data and access embedded information.

Dr Russell Garwood: Open source and free software for exploring tomographic data

Since its inception, micro-CT has become a widespread tool, with a marked increase in uptake since the turn of the millennium. The many applications and investigatory power of the technique - initially recognised as valuable in industrial, medical/dental and materials research, to choose a few examples - have led to its adoption in settings such as museums, and fields including zoology, archaeology, palaeontology and anthropology. A barrier to even wider adoption of tomographic techniques in these settings and disciplines as CT/MRI equipment becomes ever more accessible and cheap to use, has been the expensive nature of software required to visualise and explore the resulting data. Where budgets are low these costs can be prohibitive, and even when money is available, a large amount of data could be collected with the funds typically spent on proprietary software. Here I will introduce with examples, a range of open source or free software applications that mitigate such cost issues. This will include freely available tools for both the visualisation and analysis of tomographic data, including the SPIERS software suite (surfacing), Blender (ray tracing), Drishti (volume rendering), Meshlab (processing surfaces) and ImageJ/Fiji (processing). I will also provide brief overviews to other software available including Slicer and DrishtiPaint (surfacing), OsiriX (processing and visualisation), and IDAV Landmark Editor/Geomorph R package (morphometric data acquisition). I hope this talk will demonstrate the efficacy and range of freely available software, and highlight that it is possible to tackle a broad range of research questions using tomography and freely available software.

Session 2: Software Development II

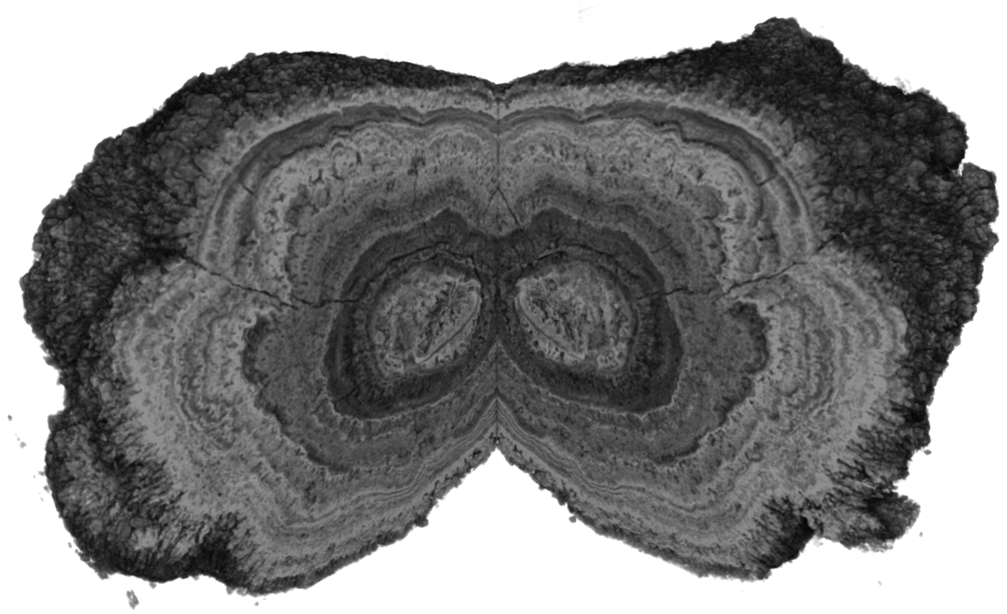
Drew Whitehouse: Voluminous - A web based volume renderer

Rapid advances in modern imaging technology are producing data sets that will soon be prohibitively large to visualise on low powered portable devices and desktop systems. Voluminous is a web based volume rendering application where the GPU based rendering is done on servers in the data centre, close to where the data is reconstructed and archived. Utilizing a central pool of storage and rendering resources provides cost efficient and convenient access to expensive resources. Furthermore, web based visualisation can expedite discovery, publishing and sharing of new scientific results.

Fabien Arnaud: Advanced segmentation using FEI's 3D image analysis software

Amira and Avizo are powerful, multifaceted 3D software platforms for visualizing, manipulating, and understanding data from computed tomography, microscopy, MRI, and many other imaging modalities. With incredible speed and flexibility, they enable advanced 3D imaging workflows for specialists in research areas ranging from biomechanics and palaeontology to neuroscience and bioengineering.

This presentation will show how FEI 3D image analysis software are used to segment and analyse teeth in computer tomography images, using integrated algorithms for separation of teeth and bones.



Abstracts - Day 1

Session 3: Advancements in Hardware and Design I

Frederik Coppens: Conventional vs. dual energy microCT scanning: Enhancement of material contrast.

X-ray microCT provides 3D information about the local attenuation within a sample. Whilst the attenuation coefficient of a chemical element at a certain energy is a clearly defined quantity, the complexity of a realistic micro-CT configuration makes the connection between the obtained scan information and the atomic composition non-trivial. To visualize and quantify different features of a sample a sufficient amount of relative contrast is needed. In certain cases different materials produce highly similar and/or overlapping x-ray opacity profiles making segmentation difficult or even impossible. By scanning an object at different energies and combining the information from these, a more efficient segmentation can sometimes be obtained. This technique exploits the difference in attenuation of X-rays at a certain energy for a given material. We use the DEHist software which plots an X-Y intensity map based on the attenuation values of two reconstructed slices with an identical position in a sample but acquired at different energy. The area is divided in to three zones and the reconstructed dataset can be segmented according to these zones. We discuss a number of examples were we compare segmentation based on conventional and dual energy results.

Prof Marco Stampanoni: The renaissance of X-rays: Phase-contrast imaging on lab-sources

Coherent X-rays as available on third generation synchrotron facilities are intrinsically able to transfer phase information from a sample to a proper detector system. During the last decade, phase-contrast imaging has been proved to be a powerful tool to image low-Z materials and, as a consequence, it is considered as a very promising technique for medical applications and non-destructive, high-sensitive material characterization. But, how to get phase contrast efficiently on common X-ray tubes while keeping geometrical and physical constraints under control? The talk will illustrate how grating-based interferometry can address this challenge. Further, I will present results from a first clinical study based on phase contrast mammography, show the potential of the technique for early breast cancer detection as well as some preliminary data from our high-energy phase contrast prototype.

Abstracts - Day 2

Session 4: Advancements in Hardware and Design II

Patricia Wills: Paris CT lights-The AST-RX platform, an X-ray tomography facility dedicated to natural sciences at the Paris Muséum national d'Histoire naturelle (MNHM)

The MNHM as been hosting an X-ray tomography facility for 3 years now. The system (vltomelx L240, GE Inspection Technologies PhoenixlX-ray) combines a microfocus and a nanofocus X-ray sources and a large-sized movable detector in a vast radiation cabinet. Therefore, specimens from a wide range of sizes (from a millimetre to about 60 centimetres tall) can be safety imaged.

The AST-RX platform is accessible under conditions for everyone wishing to digitalize natural science specimens both from MNHN collections and outside collections. The access conditions depend on the origin of the sample and the funding sources. Since May 2011, we CT scanned specimens from a wide variety of collections such as palaeontology, palaeoanthropology, comparative anatomy, meteorites, entomology or marine environments. Examples of different collections will be illustrated.

The AST-RX facility produces CT data for many different research projects every year. Users are guided in their projects by the CT engineer who is in charge of every CT acquisition. Free software training is also offered, which allows users to become independent in CT data post-treatment. The session will show some of these projects to highlight the fascinating results achievable with this equipment.

Dr Manuel Dierick: μ-CT: It's in the details

X-ray microtomography is becoming a well-know technique for non-destructive investigation in a wide range of scientific and commercial research applications. This brings along increasing expectations from end-users in terms of resolution, contrast, speed etc. The physics of X-ray tomography however are more complex that may appear at first sight, and this puts limits on what can be done. It is important that end-users are aware of those limitations, so that they can correctly interpret the images they get from their scanners.

UGCT is a user facility which develops custom micro-CT scanners for scientific research applications, with a strong focus on the underlying physics and how this affects the end-results. This presentation will give an overview of how the applications that come to the facility drive the technological developments at UGCT. We will elaborate on some of the main issues users should be aware of in order to correctly use micro-CT. This includes hardware related issues such as X-ray tube technology, but also image artefacts which come from the physics of X-ray propagation itself, as well as the mathematics of CT reconstruction. We will show the extent of these issues, how they can affect the results, and how we address them in our lab through modifications of the existing hardware and development of the necessary algorithms for image correction, reconstruction and 3D analysis. This will be illustrated with a selection of applications from various fields.

Session 5: Conservation, Cultural Heritage and Outreach I

Dr Graham Davis: Scrolls, films and the borders of possibility

In science, the concept of what is possible has two aspects. There is what is technically possible and what is physically possible. Research is continually pushing the boundary of what is technically possible, but we must be aware that there is physical possibility boundary that is immovable. In medical tomography, for example, resolution and image quality has improved as detectors and computational methods have got better. But resolution and image quality are also tied in with the number of X-ray photons that are used to generate the data. The technical limit on resolution at around 300 μm is probably pretty close to the physical limit because higher resolution requires more photons (higher dose) and that causes damage to the patient. I can conceive of a technical advancement that would have 30 micron resolution, but the dose would have to be 10,000 times higher and the patient might just get vaporised. Recently, we have had some success in recovering text from an ancient scroll that was damaged to the extent that it could not be unrolled. A similar problem occurs with old film reels that stick together as acetate breaks down to form acetic acid. Here we demonstrate the feasibility of reading a reeled film with a small sample. Scaling this up to read a full-size film reel is not technically possible now, but is it even physically possible or should we abandon all hope?

Prof Sarah Hainsworth: Forensic applications of micro-computed tomography - Bones, flies and Richard III

Multi detector X-ray computed tomography has gained widespread use in forensic pathology. The technique allows non-invasive or near virtual autopsies to be performed where the cause of death can often be determined without having to resort to the traditional invasive autopsy. The maximum isotropic spatial resolution in a medical postmortem CT (PMCT) is approximately 0.4 mm which is limited by the pixel size of the detectors. A major advantage of medical CT for forensic pathology is that the usual constraints associated with X-ray dose for "live" patients are not an issue. In forensic cases related to dismemberment and other cases where tool marks are present, micro-computed tomography offers considerably better resolution than medical PMCT. A Nikon Metrology XTH 225 micro-CT scanner, with a Paxscan detector has been used for imaging a range of tool marks on bone. The resolution micro-CT is influenced by a number of factors, including; the inherent resolution of the X-ray detector, focal spot size, geometric magnification, stability of the rotation mechanism and the filtering algorithm utilized for CT reconstruction. However, resolutions of 6-10 μm are achievable. The images obtained from micro CT are compared to the details available from stereo optical microscopy and scanning electron microscopy and the advantages and disadvantages of each technique for imaging tool marks in forensic applications is discussed. The talk will be illustrated with examples from dismemberment cases, imaging of blow fly larvae and the micro-CT imaging used for analyzing tool marks on the skeleton of Richard III.

Session 6: Multimodal and Correlative Tomography I

Dr Philip Schneider: Quantification of 3D ultrastructure orientation: Going beyond conventional CT

The arrangement and orientation of the ultrastructure plays an important role for the mechanical properties of inhomogeneous and anisotropic materials, such as polymers, wood, or bone. However, there is a lack of techniques to spatially resolve and quantify the material's ultrastructure orientation. In this study, a new method is presented, which allows deriving the ultrastructural 3D orientation in a quantitative and spatially resolved manner. The proposed 3D scanning small-angle X-ray scattering (3D sSAXS) method was demonstrated on a trabecular bone specimen of a human vertebra. A micro-focus X-ray beam from a synchrotron radiation source was used to raster scan the sample for different rotation angles. Furthermore, a mathematical framework was developed, validated and employed to describe the relation between the SAXS data for the different rotation angles and the local 3D orientation of the bone ultrastructure. The resulting local 3D orientation was visualized by a 3D orientation map using vector fields. Finally, by applying the proposed 3D scanning SAXS method on consecutive bone sections, a 3D map of the local orientation of a complete trabecular element could be reconstructed for the first time. The obtained 3D orientation map provided information on the bone ultrastructure organization and revealed links between trabecular microarchitecture and local ultrastructure. 3D orientation maps will help to quantify and understand structure-function relationships relating bone ultrastructure to bone mechanics. Beyond that, the proposed method can also be used in other research fields such as materials sciences, with the aim to locally determine the 3D orientation of material components.

Dr Jim Swoger: Optical Projection Tomography (OPT) –Visible-wavelengths for tomography of mesoscopic biological samples

OPT is the visible-wavelength analogue of X-ray CT. To implement OPT an optical system is designed to image the sample of interest (typically samples fall into the 100 µm to 1 cm size range) as it is incrementally rotated through 360°. The optics are designed so that the depth of field is similar to the dimensions of the sample; the images acquired are therefore, to a good approximation, equivalent to projections through the sample. A 3D volumetric reconstruction can then be performed on the acquired set of projections, e.g. by filtered back-projection.

OPT can function in both transmission and fluorescence modes. In transmission it is equivalent to transmission X-ray CT, and can be used to reconstruct either the intrinsic 3D absorption properties of a sample or extrinsic label-based contrasts such as 3D gene expression patterns stained by in situ hybridization. A fluorescence OPT system is similar to a traditional wide-field epi-fluorescence microscope, with the addition of a sample rotation stage to capture multiple views. Fluorescence OPT allows the use of the enormous range of specific fluorescent markers that have been developed for optical microscopy, e.g. multi-channel antibody labelling or genetically encoded fluorescent proteins.

Our lab focuses on the developmental biology of vertebrates, especially mouse and chick. This talk will outline how OPT works, and in particular its similarities to and differences from other tomographic techniques. I will then discuss some examples of how OPT has advanced our understanding of how genes and tissue morphology interact to shape embryonic development.

Abstracts - Day 2

Session 7: Biological Applications I

Prof Sacha Mooney: Roots, shoots, leaves and mud! Examples of X-ray computed tomography from the plant and soil sciences

Understanding how roots interact with the soil environment is crucial to support the efforts into phenotyping crops to reveal their behavioural traits; a key challenge for global food security. The biophysical environment where roots and soil interact has frequently been ignored because of the difficulties in observing it in any meaningful way. This important volume of soil is fragile, dynamic and opaque and is a crucial zone for plant development through the transfer of water and nutrients, but we know very little about how it is structured and functions. Non-invasive techniques such as Computed Tomography (CT) have shown great promise, especially in recent years, to visualise root architecture in situ within undisturbed soils largely due to us overcoming limitations in segmenting roots from soil in X-ray images e.g. RooTrak, (Mairhofer et al. 2012). As such CT has been demonstrated as a tool that can be used to help us understand how the soil physical and biochemical environment impacts on plant development. The talk will provide examples on the impact of soil stressors such as compaction, drought and soil-borne pathogens on root growth and also illustrate how CT is rapidly becoming a tool for exploring the aerial tissues of plants. Understanding the interaction between soils and plants is vital for maximising inputs from the available land and assisting with the problems associated with its degradation. With a rapidly increasing global population and the threat of a changing climate, developing sustainable soil management strategies has never been more important.

Dr Richard Johnston: The peculiarities of natural form – Hidden structures in nature and their bioinspiration potential

There are many lessons we can learn from nature, from the way a gecko can hang from smooth surfaces, to the water-harvesting forewings of the Namib desert beetle. Bioinspiration is the understanding of systems in nature and how we can modify and replicate these for human design and engineering. Classic biomimicry of natural shapes has focused on the surface or overall structures. X-ray microtomography (µCT) has the potential to reveal hidden internal microarchitectures, as well as generating 3D representations of complex surface structures. Using X-ray µCT, we've investigated a number of species including cuttlefish (*Sepia officinalis)*, woodlice (*Armadillidium vulgare*), and barnacles (*Semibalanus balanoides*). Imaging has revealed complex internal architectures only visible using non-destructive methods. Understanding the organism's behavior is essential to consider the functions of these complex forms, requiring first-hand observation or collaboration with species specialists. The overall architecture of cuttlebone, unique to cuttlefish, provides function to by regulating the buoyancy, and ultimately depth in the sea, but the finer internal $CaCO_3$ structure revealed by µCT is even more enigmatic. Woodlice use their articulating armour plates for defense. µCT imaging showed how these structures interact and move, with a combination of soft and hard tissue. We also visualized in 3D the interlocking plates secreted to encase barnacles. Rapid prototyping was also used to gain greater insight into these structures, and to consider their bioinspiration potential. 3D imaging reveals a new dimension, opening up a myriad of structures, forms and functions in nature to be discovered, studied, and adapted for engineering applications.

Session 8: Multimodal and Correlative Tomography II

Prof Phil Withers: Completing the picture - Correlative tomography

Correlative microscopy has proven itself as a powerful tool in bridging scales and providing complementary insights in 2D, for example combining florescence imaging with optical microscopy. Here we present the concept of correlative tomography linking together information across different scales and collected by different imaging modalities for the same volume of interest. Co-locating a submerged volume of interest across different instruments is challenging but the spatial correlation of images and 3D data recorded at multiple provides rich multimodal data and ensures the context is retained through all scales.

In this presentation I will describe the multiscale 3D characterization workflows combining macroscale X-ray computed tomography (CT), micro X-ray CT, nanoscale serial section FIB/SEM imaging and analysis, and scanning transmission electron microscopy to study a range of materials degradation and repair processes. This approach allows us to travel down the scales to better understand macroscale damage in terms of the underlying microstructure and to co-visualise structural, crystallographic (EBSD) and chemical (EDS) information. Future workflows and visualization software advances will enable the materials scientist to bring together multiple scales and information or undertake high resolution imaging with a high degree of knowledge of the local context.

Finally, the three pillars of materials science (microstructure-chemistry-performance) are traditionally studied separately in the microscopy suite, the chemistry lab and the mechanical test facility on different samples. Correlative techniques currently allow one to bring them all into registry in three dimensions.

Dr Manuchehr Soleimani: Multimodality tomography

Tomographic imaging is one of the most important innovations of the 20th century. Medical imaging is the most advanced area of tomographic imaging. According to world health organisation report more than two third of world's population don't have access to any form of medical imaging. Specific attentions will be given to new and emerging tomographic methods that can be low cost. Various methods for tomographic imaging are being developed for many applications areas from medicine, to material science to geophysical and space science. For a better understanding of materials and processes, it is often required to augment one type of tomographic data with complementary data – this will create a new algorithmic framework that requires state of the art data fusion. In this talk we will present state of the art multimodality tomography considering implication such as cost, computational time, complexity of the instruments and more importantly the complimentary aspect of the two or more imaging modalities used in particular multimodality setting.

Abstracts - Day 2

Session 8: Multimodal and Correlative Tomography II

Dr Rajmund Mokso: Nature's dynamics under an X-ray microscope

Visualizing fast micrometer-scale internal movements of small animals is a key challenge for studies in functional anatomy, physiology and biomechanics. Recent advances in synchrotron-based X-ray imaging techniques proved to reach micrometer resolutions and thus opened completely new insights into micrometer-scale biology. However, combining high spatial with sub-second temporal resolution, especially considering radiation dose, still remains a challenging task. To address this challenge we work on new concepts for 4D synchrotron imaging. In the first example we combine single-exposure phase retrieval with optical flow guided retrospective gating. The resulting tomographic time series enable us to visualize the fast internal movements of the blowfly flight motor on sub-millisecond and micrometer scales. In the second example we describe how to achieve a compromise between spatial resolution and radiation dose for in-vivo experiments for investigating air-recruitment mechanisms and overextension patterns at the micrometer scale on mice and rats lungs. Both studies were conceived with the aim to reach a 3D isotropic resolution bellow 10 μm and a temporal resolution down to 300μs.

Abstracts - Day 3

Session 9: Conservation, Cultural Heritage and Outreach II

Dr Christina Duffy: Understanding book structures: A CT examination of the St Cuthbert Gospel

The non-invasive and non-destructive nature of Computed Tomography (CT) has proven to be a robust method for the structural examination of the St Cuthbert Gospel, an early 8th-century pocket gospel held at the British Library. CT technology enables unique and restricted items to become digitally accessible, thereby contributing to the long-term preservation of rare and historically significant collections. The British Library holds over 150 million items in most known languages, with 3 million new items added each year.

Our conservation team is responsible for the preservation of the collection, encompassing materials which vary from 3,000 year old Chinese oracle bones to modern-day newspapers. Over 200 of our most precious items are on public display in the Sir John Ritblat: Treasures Gallery. Amongst these Treasures is the St Cuthbert Gospel, acquired by the Library in 2012 for £9 million. The gospel has an incredible history: it was found in the coffin of St Cuthbert, Bishop of Lindisfarne, North East England (d. 687), when the coffin was opened in Durham Cathedral in 1104.

The gospel's contemporary decorated leather binding is the earliest known Western bookbinding to survive. Other contemporaneous manuscripts have lost their original bindings, either through degradation, or replacement over the centuries. No earlier Western binding has survived. In October 2013, the St Cuthbert Gospel was CT scanned to fully document the structure of the binding, and specifically to provide clarity on the raised plant-motif decoration. Previous to this, knowledge of the binding has relied on a publication from 1969. CT results have yielded unprecedented clues to the starting point for the history of bookbinding in Europe.

Erica Seccombe: New dimensions: An artist's perspective on 4D Micro-CT and Drishti

I am a visual artist investigating the aesthetic possibilities of 4D Micro-CT. I am conducting my project in the ANU Department of Applied Mathematics and at VizLab, the ANU Supercomputer facility, NCI. With this science I am capturing the transformation of seeds as they germinate, from embryo to first leaf stage. I am visualising this data in the direct volume rendering application Drishti with the intention of exhibiting these virtual time-lapse datasets as immersive stereoscopic projection installations. The tradition of scientific modelling provides a rational and objective way to represent objects and processes while communicating theories and concepts. In this presentation I will talk about how I am modelling time-lapse data of germinating seeds in order to investigate the potential for a subjective experience. I am looking at how this science and technology increases the opportunity for the observer to make new determinations, observations and predictions, while also creating new imaginative possibilities and cultural infusions. I will discuss these aspects of this interdisciplinary project along side work that I have created with Micro-CT for public exhibitions.

Abstracts - Day 3

Session 10: Biological Applications II

Dr Thomas Simonsen: Non-destructive Lepidoptera genitalia 'dissections' through micro-CT scanning: A step towards virtual taxonomy

Morphological studies and documentation of characters are of singular importance in Lepidoptera taxonomy and systematics despite the increasing popularity and importance over the past decade of molecular methods such as DNA barcoding. In particular, genitalia dissections of type material are often crucial in revisionary taxonomic studies. However, type material is not always readily available as the institutions holding the material may be reluctant to send it on loan, and even more reluctant to allow such material to be dissected. Here we demonstrate how a standard micro-CT scanner in conjunction with freely available can be used to carry out highly detailed, non-destructive virtual dissections of Lepidoptera male genitalia. Furthermore, we propose a workflow by which data can be shared for analysis by workers across the world.

Dr Brian Metscher: Micro-CT diversifies: 3D images in various life sciences applications

The use of x-ray microtomography in life sciences is expanding rapidly to include applications in development, taxonomy, functional morphology, and anywhere else a detailed 3D framework is needed as a complement to other kinds of data. I will show some examples from my group's recent projects.

In a comparative study of snake pulmonary development, we have scanned PTA-contrasted samples and segmented the images with Amira to analyse differences in development of the left lung, which varies in different species. An ongoing study of horse embryology is using microCT imaging of resin blocks followed by sectioning for histology and TEM, with subsequent registration of histological and ultrastructural sections with the 3D images. We have recently shown that acrylic corrosion casts give clear microCT images, and we are now testing microCT imaging of Mercox-perfused samples without tissue maceration to visualise the vascular along with other tissues.

The size-calibrated 3D images data generated by tomography are a natural basis for models of morphological structure and function. Our recent applications in this area include modelling the feeding suction pumps in flies and butterflies, finite-element analysis of developing fish jaws, and qualitative analysis of penis bone function in bats.

Virtual specimens can be useful objects of study, both in their digital form and as 3D-printed simulacra of original specimens. We are currently working on 3D atlases of development for two model animals, zebrafish and the squid Eupryma scolopes. Future work will aim to produce a high-detail 3D atlas of human development for teaching and research.

Session 11: Advancements in Hardware and Design III

Dr Andrew Ramsey: Recent advances in high resolution high energy X-ray imaging – A 750kV microfocus source with a 20µm spot size

Industrial CT scanning can show intricate details inside small components and can measure very accurately very small dimensions even when these are completely hidden from view. When components are denser it becomes more difficult not only to penetrate the object with X-rays, but to maintain a small focal spot in order to get high resolution images.

With Nikon Metrology's 450kV source up to around three inches (75mm) of steel can be penetrated and details below 100µm can be seen and measurements with an accuracy of 25µm can be obtained. For smaller denser castings and machined parts it is difficult even with this source to get good images.

Nikon Metrology can now demonstrate a 750kV X-ray source with a focal spot even smaller than its previous 450kV source. Being able to see details down to 10µm the new source can penetrate up to 120mm of steel. Small aluminium wires (less than 1mm) can be seen even through about an inch of lead. This source will surely help obtain high resolution CT images of even very dense samples.

Dr Michael Drakopoulos: High-energy imaging at the DLS Beamline I12

I12 is a not exactly a new but still a young beamline for imaging and diffraction at the Diamond Light Source in Oxfordshire. Using particularly hard x-rays from 50 keV to 150 keV, the beamline is well suited for tomography on dense or large specimens and for samples that reside inside an in-situ chamber to undergo various processing.

Since its first light late 2009, we have studied samples from scientific disciplines such as material and engineering science, chemical processing, biology, medical research and palaeoanthropology.

The synchrotron light we use has high intensity and enables rapid scans for dynamic studies or for the imaging of a large number of samples. The strictly monochromatic x-rays produce contrast still at most subtle features. The brilliance of the radiation reveals refraction contrast in samples that otherwise exhibit very little attenuation.

Our design concept makes the beamline easily accessible for research teams bringing complex sample environment or processing instruments. Amongst the large variety of in-situ apparatus used during imaging experiments were mechanical test rigs, furnaces, cooling chambers, welding rigs, shock guns and even a running motor-bike.

NATURAL HISTORY MUSEUM

RMS

Abstracts - Day 3

Session 11: Advancements in Hardware and Design III

Dr Andrew Kingston : CTLab– Tomography downunder

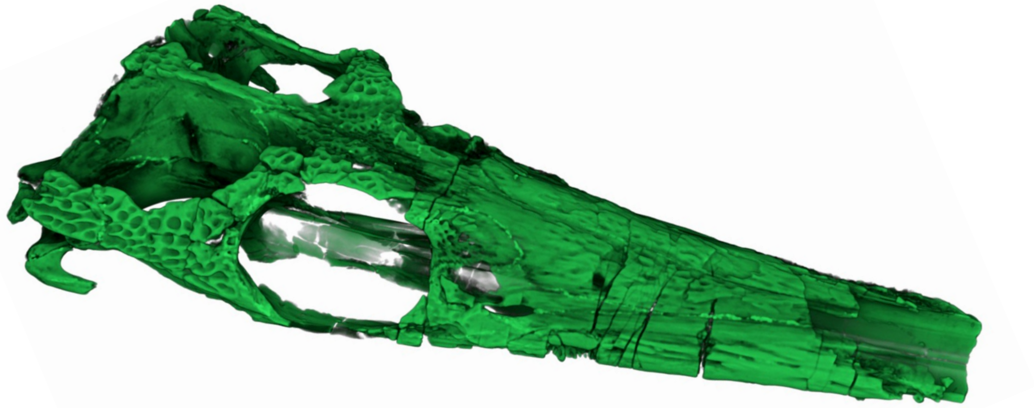
Last year we talked about the broad range of applications and collaborations that the ANU Micro-CT group (CTLab) is involved with. This year I will focus on some of the specifics of achieving high quality tomograms in our group by a combination of software and hardware solutions (e.g., component alignment, thermal component drift correction, ring-removal, etc.). These innovations have enabled us to routinely implement the "theoretically exact" Katsevich reconstruction algorithm at the micron scale using a helical scanning trajectory. I will also present our current research directions in iterative reconstruction, dual-energy scanning, X-ray beam-hardening correction and X-ray source deblurring.

Drishti Workshop

Dr Ajay Limaye, creator of the highly successful 3D visualisation software Drishti, will be running a workshop at the Natural History Museum 4th September. Created in 2006, Drishti is an open source volume exploration and presentation tool, which can be used for visualising computed tomography data from a range of techniques (X-ray computed tomography, SEM, CLSM). The word Drishti is Sanskrit for insight, which is exactly what Drishti provides it users with; its intuitive interface allows researchers to produce renders that cross the art-science boundary and can communicate complex scientific stories in ways that are accessible to all.

This is a chance to see Drishti in action, with Dr Limaye performing a series of demonstrations that will highlight the basic functions (importing data, exploring the histogram and transfer functions). Attendees will then replicate these using simple test datasets (e.g. a tooth); finally applying this new found knowledge to their own datasets, and explore more advanced rendering techniques.

The workshop is open to students, researchers and people from industry. Please speak to a member of Team ToScA for more information.



Session 12: Paleontological Applications

Dr Mark Sutton: Tomography in palaeontology: History and the future

Tomography, in the form of serial sectioning and similar techniques (collectively 'Physical Optical Tomography'), has a long history of use in many branches of Palaeontology. However, while the utility of tomographic methods for the study of three-dimensionally preserved fossils has long been recognized, physical-optical work tomography is laborious and destructive, and the approach has hence only been used sporadically. Physical-optical work, now combined with digital reconstruction techniques, has continued into the Twenty-first Century (e.g. the study of the Silurian Herefordshire Lagerstätte), but has increasingly been overtaken by a flurry of X-ray tomographic studies, which are faster, cheaper, easier, and non-destructive. CT work began in the 1980s on vertebrate fossils large enough to fit within medical scanners, but with the advent of micro, nano and synchrotron CT have become increasingly common in the study of smaller invertebrate fossils as well. Other tomographic techniques (e.g. optical tomography) have also appeared; while less broadly applicable they can in some cases recover more data than CT-based approaches. A toolkit of tomographic techniques now exist, with the potential to reconstruct almost all fossils regardless of scale or composition. It is reasonable to characterise the increasing adoption of these new techniques as a revolution for the science; not only have they provided a new influx of morphological data, but they are also bringing opportunities to change the ways in which palaeontologists work and think. These opportunities also provide challenges, the most pressing of which is the need to develop an infrastructure for (and a mind-set for) the widespread sharing of tomographic data. Technical developments in the field continue; the most important for palaeontologists is probably simply the increasing availability of high-resolution equipment, but techniques that promise chemical characterization of rock composition in three dimensions have the potential to provide a second revolutionary advance.

Session 12: Paleontological Applications

Dr Zerina Johanson: Teeth inside and outside the mouth? Topographic relationships in sawshark and sawfish dentitions (Elasmobranchii; Chondrichthyes)

Sharks and rays have been studied extensively to address the origin and evolution of teeth in jawed vertebrates. They possess a micromeric dermal skeleton in which odontodes form as separate placoid scales (skin denticles) in a pattern distinct from teeth on the jaws. Extended rostra are present in taxa of both sharks and rays including the sawsharks (Pristiophoridae; Selachiomorpha), sawfish (Pristidae; Batoidea) and the fossil Sclerorhynchoidea (Batoidea). In these taxa, tooth-like structures on the rostra differ from both oral teeth and placoid scales, presenting a challenge in understanding the morphogenesis of this rostrum pattern, and whether it is related to that of the dentition.

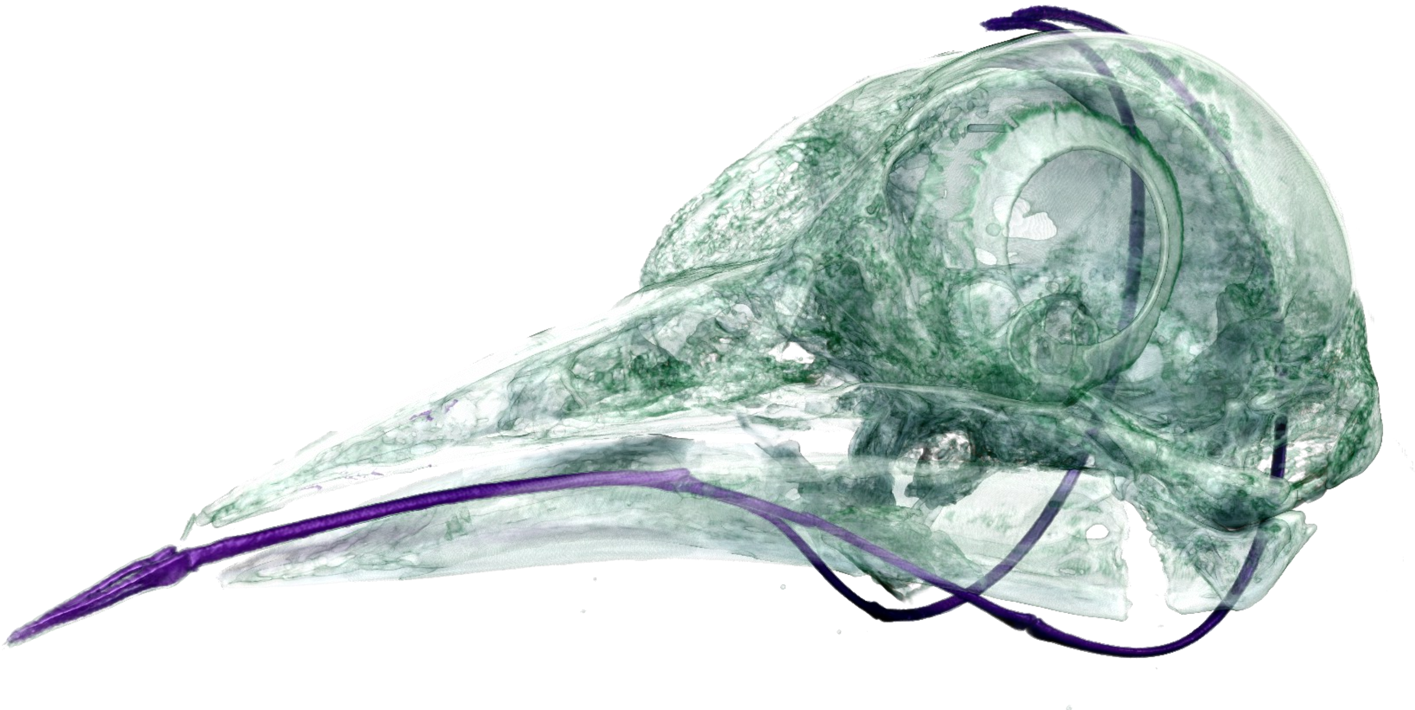
Sawshark, sawfish and sclerorhynchid rostra are convergently evolved feeding and/or sensorial structures. Sawfish retain the same set of rostral 'teeth' during their whole life, each growing from the base via the deposition of dentine. These 'teeth' are of equal size and equal spacing, located in deep sockets on the lateral side of the rostrum. In contrast, sawshark rostral teeth are of different sizes and include three distinct topographic series; it is notable that sclerorhynchids such as Sclerorhynchus present the same morphological pattern, the rostral 'teeth' being replaced in both groups.

X-mCT provided rendered volume densities of 3D models that were used to study growth, replacement and patterning of these 'teeth'. For example, in the sawshark, new additions to lateral rostral 'teeth' and their positioning along the rostrum appear to be the result of rostrum growth, while replacement 'teeth' occur irregularly, only after 'tooth' loss. These characteristics are more comparable to placoid scales rather than oral teeth. Nevertheless, some degree of patterning is present as replacement is in a size-specific manner, and in size-dependent locations on the rostrum. Our hypothesis is that these rostral 'teeth' represent modified placoid scales, patterning having been co-opted from areas showing patterned placoid scales, for example along the dorsal body just behind the head. These rostral denticles, along with a range of other dermal structures, demonstrate the considerable developmental plasticity of the external odontode.

Poster Competition Finalists

Author(s)	Title
Jason M. Warnett[1], P. Denissenko[2], P. J. Thomas[2], D. Norman[1], M. A. Williams[1] ([1]Warwick Manufacturing Group, [2]School of Engineering, University of Warwick)	Investigating axisymmetric granular collapse using X-ray CT
Krishan Bhanot,[1] H. Downes[1], E. Humphreys-Williams,[2] C. Petrone.[2] ([1]Birbeck University, [2]Natural History Museum)	CT scanning of spinel-pyroxene clusters in mantle peridotite xenoliths from the Massif Central, France and Lanzarote, Canary Islands
Ronald Seidel,[1] D. Knoetel[2], D. Baum,[2,] J.C. Weaver[3], M. N. Dean[1] ([1]Max Planck Institute, [2]Zuse Institute Berlin, [3]Harvard University)	Material and structural characterization of mineralized elasmobranch cartilage – Lessons in repeated tiling patterns in mechanically loaded 3D objects
Lidia Sonakowska[1], M. Rost- Roszkowska[1], M. Binkowski[2], J. Śróbka[2], M. Czaja[2], M. Kszuk-Jendrysik[1], K. Kamińska[1], A. Włodarczyk[1] ([1]Department of Animal Histology and Embryology, [2]Department of Biomedical Computer Systems, University of Silesia)	X-ray microtomography and TEM in the analysis at the digestive epithelia in freshwater shrimp *Neocaridinia heteropoda* (Crustacea, Malacostraca): autophagy

Author(s)	Title
Alex Marter, F. Pierron, M. Mavrogordato, S. Nobakhti, A. Dickinson, M. Browne (University of Southampton)	The influence of a metal implant on achievable bone strain resolution of Digital Volume Correlation (DVC)
Robert S. Stephenson[1], J. Zhao[2], S. Kharche[3], G. Hart[3], P. Withers[3], J. Jarvis[1] ([1]Liverpool John Morres University, [2]The University of Aukland, [3]University of Manchester)	Contrast enhanced micro-computed tomography reveals the microanatomy underlying electrical and contractile function in the atria of the heart
Laura North[1], E. Pope[2], R. Johnston[1] (College of Engineering[1], Department of Biosciences[2], Swansea University)	4-D imaging by X-ray microtomography of the failure behaviour in cuttlebone
Fergus McCorkell[1], R. Bromphrey[2], G. Taylor[1], M. Doube[2], A. Boyde[3] ([1]Oxford University, [2] Royal Veterinary College, [3]Queen Mary's University London)	Iodine vapour staining
Peter B. Swart[1], Martina Wicklein[1], Farah Ahmed[2], Holger G. Krapp[1] ([1]Dept. Of Bioengineering, Imperial College London, UK; [2]Imaging and Analysis Centre, Natural History Museum, London, UK)	Characterising the neck motor system of the blowfly



We would like to extend our thanks to the UKCT Consortium, The Natural History Museum, The Royal Microscopical Society, our sponsors, our speakers, everyone involved in the preparation and organisation of ToScA and all the delegates.

-Team ToScA