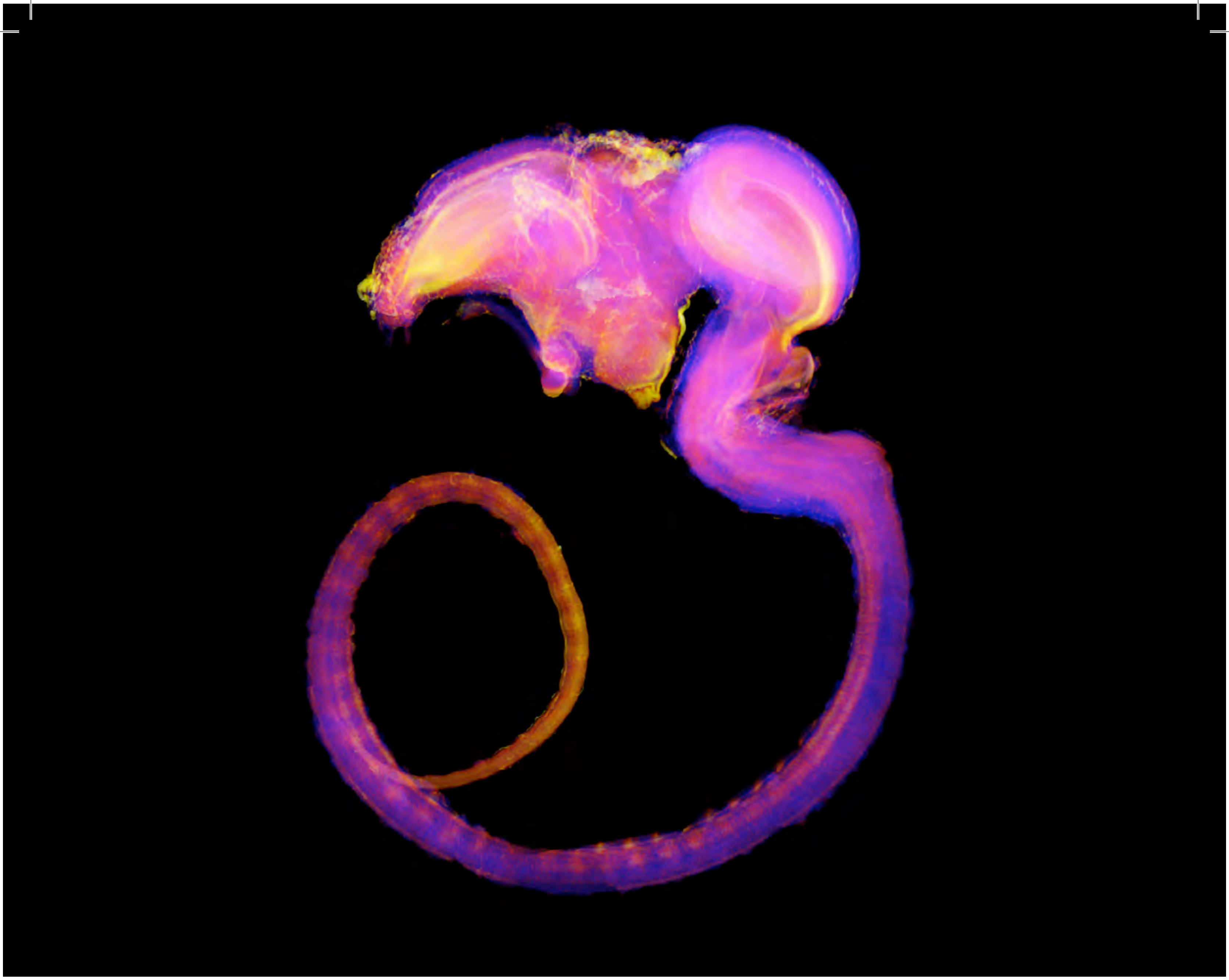


ToScA

Tomography for Scientific Advancement

ToScA North America

6 – 8 March 2019, University of Florida, Gainsville, FL

Program

FLORIDA MUSEUM

UF Research Service Centers UNIVERSITY of FLORIDA

NATURAL HISTORY MUSEUM

Event Management by RMS


thermoscientific

Welcome

ToScA President: Dr Farah Ahmed, *Exponent International*

A huge welcome to the North American Tomography community! With ToScA International in its seventh year and the success of the launch symposium at University of Texas, Austin, I am pleased to announce the second meeting at University of Florida. ToScA was established to bridge the gap between academia and industry, and to enable knowledge share and innovation. I hope you all use this platform to share your knowledge, exchange ideas and further advance the use of tomography in your respective fields. I look forward to hearing about all of the collaborations as a consequence of attending ToScA!

On behalf of the board, I would like to whole-heartedly thank Dr Maisano, who has embraced her position as chair and committed to bringing together the community in North America. I would also like to thank Dr Stanley(co-chair), and his amazing team, who have put together an incredible programme.

Chair: Dr Jessie Maisano, *The University of Texas, Austin, TX*

Welcome to the second ToScA North America Symposium! Following on the success of the first symposium, held at the University of Texas at Austin in June 2017, this gathering brings together students, researchers, and industry representatives from six countries, four natural history museums, two federal institutions, 11 companies and more than 20 universities. Over the course of workshops, posters, talks, and an image competition, this dynamic community will exchange ideas and form new partnerships across diverse fields from materials science to paleontology using imaging modalities from neutron to diffraction contrast tomography.

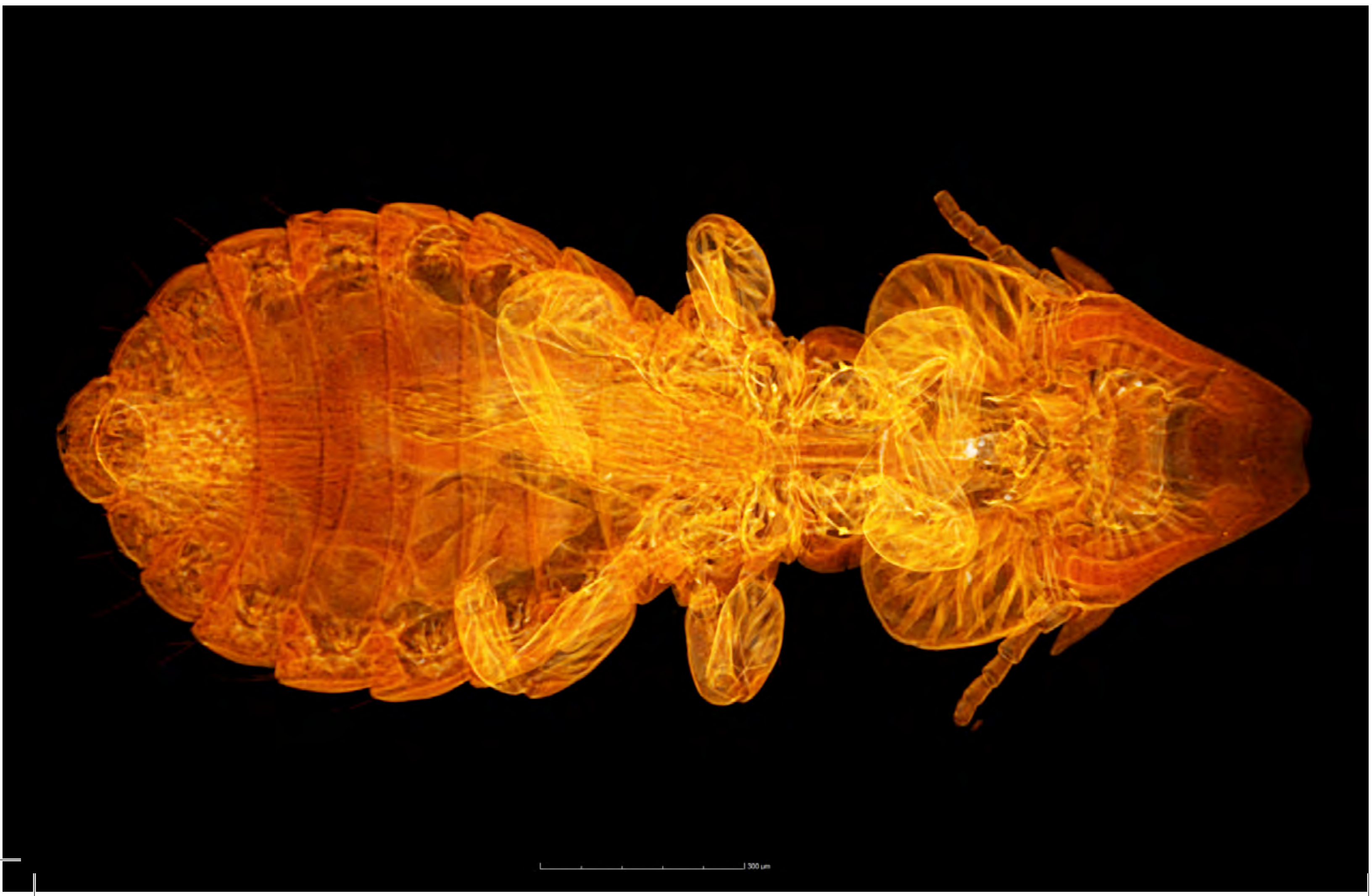
As Chair of ToScA North America, I extend a heartfelt thank you to the local committee at the University of Florida (Ed Stanley, local chair) and to the Royal Microscopical Society for all of their hard work to ensure the success of this meeting. Thanks also to Farah Ahmed (President of ToScA International) for exporting her very successful endeavor 'across the pond', and to our wonderful Sponsors whose support makes this meeting possible. I look forward to interacting with each of you while here in Gainesville, and at the next ToScA symposium in 2021!

Local Chair: Dr Edward Stanley, *Florida Museum of Natural History*

On behalf of the local committee, it is my great pleasure to welcome you to the University of Florida and the second ToScA North American Symposium! We are excited to host such an eclectic and inspiring group of researchers, educators, students and industry experts, and look forward to meeting each and every one of you. The North American tomography community continues to grow apace, and the ToScA meetings are a fantastic forum to network and learn about the diverse applications of this exciting methodology. In addition to the five workshops and two full days of talks and posters, we are pleased to share the delights of the Florida Museum of Natural History with you for the evening event on Thursday, where we can drink, dine and socialize among the mammoths, giant sloths and terror birds!

For those of you who have acquired a taste for bat-watching from previous ToScA meeting, the University houses its very own bat houses, with nightly mass exoduses at dusk. The nearby Ichetucknee springs, and Paynes Prairie also offer excellent wildlife viewing, and for those that prefer talking animals, Walt Disney World is only a two-hour drive away!

We hope you will enjoy your time in Florida; please let any of the UF hosts know if we can be of any assistance during your stay.



Organising Committee & Invited Speakers

Organisers

Dr Farah Ahmed (ToScA President),
Exponent International

Dr Jessie Maisano (ToScA North America Chair),
University of Texas

Dr Ana C. Bohórquez,
University of Florida

Mr Gary Scheiffele,
University of Florida

Dr Luisa Amelia Dempere,
University of Florida

Dr Edward Stanley (ToScA Local Chair),
University of Florida

Invited Speakers

Dr Bhart-Anjan Bhullar,
Yale University

Dr Doug Boyer,
Duke University

Professor Stephen Blackband,
National High Magnetic Field Laboratory, University of Florida

Dr Denton Ebel,
American Museum of Natural History

University of Florida, Gainsville, FL

With origins beginning with the East Florida Seminary in 1853, and the first buildings in Gainesville begun in 1905, the University of Florida has mirrored the growth and stature of its state. UF became a member of the Association of American Universities in 1985 and was first ranked in the top 10 of public universities in the United States in 2017. "With our finger on the pulse and an eye on the horizon, we've pursued the greatest heights of research and innovation, always together and always for the betterment of Florida and the world." As a land grant institution, the main campus has over 2000 acres housing 16 different colleges. An interesting fact: our school mascot, the alligator, does reside in the wild, on campus.

The College of Engineering

Dean Cammy Abernathy, the college's first female dean, currently leads the University of Florida's Herbert Wertheim College of Engineering (HWCOE). HWCOE is one of the largest and most dynamic engineering programs in the USA. The curriculum offered across nine departments and more than 20 centers and institutes is strongly oriented to leadership, interdisciplinary research and innovation, producing leaders and problem-solvers who take a multidisciplinary approach to reach advanced human-centered solutions. The Research Service Centers (RSC) in the HWCOE support and enhance the research, education, and public service missions, providing access to characterization and process instrumentation. Expert staff provides the assistance and guidance necessary so that students, faculty, and industry get the most effective and appropriate use of the center's facilities.

The Nanoscale Research Facility

The X-Ray Tomography (Nano CT) facilities at the RSC are extensively used by scientists at the Florida Museum of Natural History (FMNH) examining hundreds of samples taken from life on Earth from different locations around the world. The FMNH is a leading authority in biodiversity and cultural heritage, and an impactful hub for teaching and learning science. The Museum has been particularly successful at utilizing research collections and making them accessible to diverse audiences, inspiring people to value the biological richness and cultural heritage of our diverse world.

The Florida Museum of Natural History

The Florida Museum of Natural History is considered one of the top three university-based natural history museums in the United States. Originating as a teaching collection of the Florida Agricultural College, the Florida Museum was incorporated into the University of Florida in 1906, and became established as the State Museum in 1917. The museum and its scientific collections grew during the following 100 years and now house over 40 million biological, archeological and ethnographic specimens from across the world, with public exhibits that entertain and educate hundreds of thousands of visitors each year. The Florida Museum's researchers, educators and students utilize and grow these resources in their mission to understand, preserve and interpret biological diversity and cultural heritage to ensure their survival for future generations.

Things to do in Gainsville, FL

Gainesville serves as the cultural, educational and commercial center for the north central Florida region and is home the largest and oldest university in the state. In addition to the stimulating ToScA talks, workshops, and evening event, there is a lot to see and do around town and further afield during your stay!

Sweetwater Wetlands Park, 325 SW Williston Rd, Gainesville, FL 32601

Sweetwater Wetlands Park is filled with vast numbers of plants and animals, including birds, butterflies, alligators and Florida cracker horses. At the park, you can walk more than 3.5 miles of crushed gravel trails and boardwalks, experience the lush landscape from viewing platforms, and learn about the habitat through educational signs and tours.

Cade Museum for Creativity and Invention, 811 N Main St, Gainesville, FL 32601

Just south of downtown Gainesville on Main Street, The Cade Museum for Creativity & Invention is an interactive science center that serves to transform communities by inspiring and equipping future inventors, entrepreneurs, and visionaries.

Ichetucknee Springs State Park, 12087 SW Elim Church Rd, Fort White, FL 32038

Although well-known for its warm weather tubing, kayaking and paddle boarding, the 2,669-acre Ichetucknee Springs State Park is also a wildlife haven, where beaver, otter, gar, softshell turtle, wild turkey, wood duck and limpkin all find a home. The main draw is the park's eight major crystalline springs that join together to create the six-mile Ichetucknee River.

Kanapaha Botanical Gardens, 4700 SW 58th Dr, Gainesville, FL 32608

Twenty-five major collections make up Kanapaha Botanical Gardens, including the largest herb garden in the Southeast and Florida's largest display of bamboos. The name is derived from the Timucua Indian words for "palmetto leaf" and "house" referring to thatched dwellings of the village on the shore of nearby Lake Kanapaha.

Harn Museum of Art, 3259 Hull Rd, Gainesville, FL 32611

The University of Florida's Samuel P. Harn Museum of Art collaborates with university and community partners to inspire, educate and enrich people's lives through art. The Harn's collection totals more than 11,300 objects including African, Asian, modern and contemporary art, and photography with significant representations of Ancient American and oceanic art, as well as a growing collection of natural history works on paper.

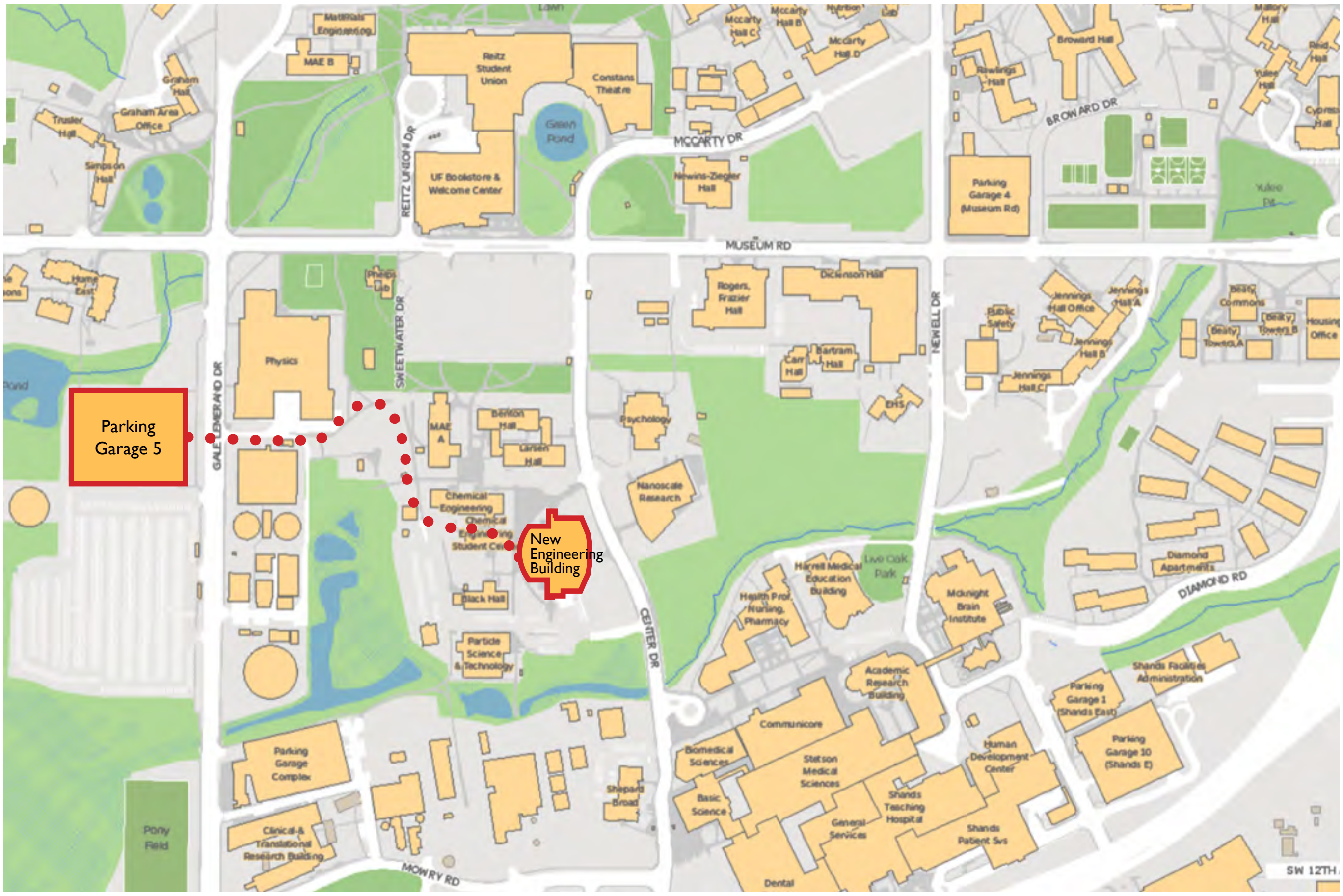
UF Bat Houses, Museum Rd, Gainesville, FL 32611

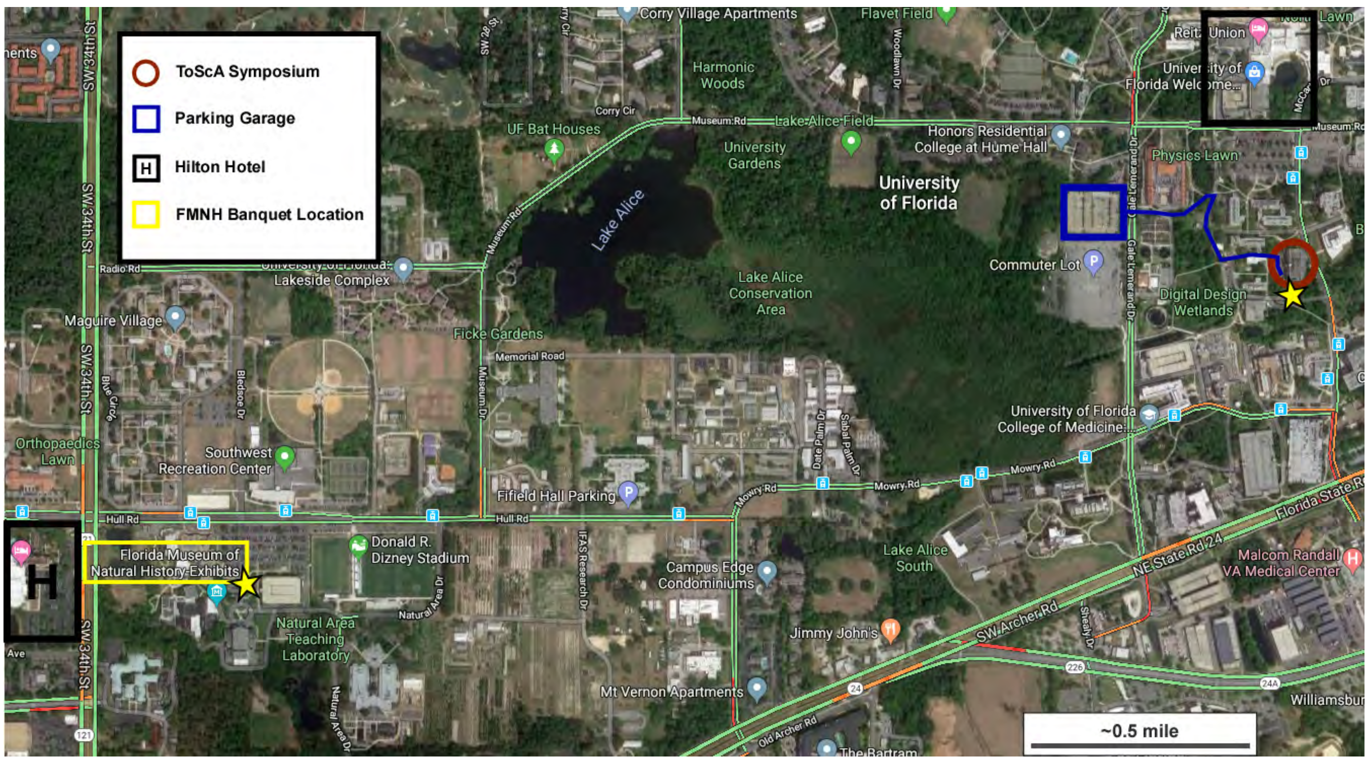
Every dusk, 500,000 Brazilian free-tailed bats, Southeastern bats and, Evening bats emerge from the world's largest occupied bat houses at the north side of Lake Alice on the UF campus. The spectacle lasts for 20 minutes and is well worth catching.

La Chua Trail in Paynes Prairie State Park

For a close encounter with alligators in the wild, there's no better place than the La Chua Trail at the north end of Paynes Prairie off the Gainesville-Hawthorne Trail. A 1/2 mile boardwalk takes you out to the upper ponds, offering spectacular views of a wide assortment of wildlife.

Campus Maps


Parking Garage 5
New Engineering Building


ToScA Symposium
Parking Garage
Hilton Hotel
FMNH Banquet Location
~0.5 mile

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North Star Imaging
www.4nsi.com

YXLON
www.yxlon.com

Workshop Information

Wednesday 6 March - Morning Workshops

Drishti, Drishti Prayog and Drishti VR

Drishti is a free volumetric data exploration and presentation tool developed at National Computational Infrastructure, Australia. Drishti Prayog is a free user-friendly presentation tool designed for users to visualise and explore the 3D datasets on a touch screen. Drishti VR is a free volume visualisation tool for virtual reality environments. The workshop will give an overview of all these three softwares.

VGSTUDIO MAX Introductory Workshop

This workshop will introduce you to CT data analysis and visualization using VGSTUDIO MAX. Volume Graphics will present typical workflows which are of special interest for the scientific community for the fast and precise analysis of voxel data: you will accomplish the first steps of quantitative analysis options, segmentation, and visualization techniques. Use VGSTUDIO MAX to easily get the information contained in your data sets, whether acquired by laboratory X-ray CT, a synchrotron, with neutrons, or with another source. Use this special opportunity to speak personally with Volume Graphics experts!

HeliScan micro CT Workflow – Acquisition/Reconstruction/Visualization & Analysis with Amira-Avizo Software

This workshop is an introductory course focusing on the capabilities of the combination HeliScan micro CT and the advanced 3D visualization and analysis capabilities of Amira-Avizo Software for exploring and understanding micro CT data. Participants will be offered a complete overview starting from sample mounting, acquisition strategy including trajectories and filtering, reconstruction methods to data visualization, image processing and segmentation, measurements and statistics, and other advanced set of functionalities.

Attendees will have the opportunity to see all steps of the workflow from data collection to the use the software through a hands-on session. Accessible to first-time users.

Wednesday 6 March - Lunchtime Workshop

A 'Best Practices in X-ray CT' working lunch will take place between the morning and afternoon workshops. Ed Stanley and Gary Scheiffele (University of Florida) and Jessie Maisano (University of Texas) will lead a Q&A discussion on topics such as:

- What criteria should I use when selecting a specimen for scanning?
- What is the best way to mount my specimen?
- What scanning parameters should I use?

Wednesday 6 March - Afternoon Workshops

VGSTUDIO MAX Segmentation & Analysis Workshop

This workshop will cover image segmentation and selected analyses available in VGSTUDIO MAX. Participants should be familiar with the basic operations of the software or have attended the VGSTUDIO MAX Introductory Workshop the same day. Volume Graphics will present typical segmentation tasks and solutions and give you tips and tricks for challenging multimaterial datasets. The second part of the workshop will be dedicated to selected quantitative analysis options. Take the chance to speak personally with Volume Graphics experts!

Amira-Avizo Software - Automation of Analysis Workflows

Building on a HeliScan dataset participants will be offered the chance to try some of the latest features of Amira-Avizo Software.

Amira and Avizo Software are well known software platforms for visualizing, inspecting, measuring and analyzing scientific and industrial data. All the powerful features provided by Amira and Avizo Software can be customized and automated to perfectly fit with your research needs and to increase your productivity.

The workshop will focus on automation of analysis workflows in Amira and Avizo Software.

Half-day Workshop on Dragonfly

In the workshop, students will learn the basics of image import, image segmentation, and movie making for tomographic datasets. Students will also learn how to train and apply neural networks for Dragonfly's Deep Learning image segmentation engine. The course will introduce students to the Macro recording and playback tools for batch-processing of datasets.

Program

Day 1: Thursday 7 March 2019

08:00 - 09:00	*Registration and Breakfast*
09:00 - 09:15	Opening Remarks ***Edward Stanley, Florida Museum of Natural History***
09:15 - 09:30	Welcome and Introductions ***Farah Ahmed, Exponent & Jessie Maisano, University of Texas***
Session 1: Earth and Space (Session Chair: Farah Ahmed)	
09:30 - 10:00	**Keynote Talk:** Meteorites in 3D: 2002 to 2022 ***Denton Ebel, American Museum of Natural History***
10:00 - 10:15	Using X-Ray Computed Tomography as a Tool for Preliminary Examination Tool of Current and Future Extraterrestrial Sample Return Missions ***Ryan Zeigler, NASA Johnson Space Center***
10:15 - 10:30	Accurate measurement of small features in X-ray CT data volumes: a golden example ***Richard Ketcham, University of Texas at Austin***
10:30 - 10:45	Advances in reconstruction and analysis of dynamic in situ microCT data in porous media ***Jan Dewanckele, Tescan XRE***
10:45 - 11:15	*Coffee Break, Exhibition, Posters and Image Competition*
Session 2: Medicine and Veterinary Sciences (Session Chair: Gary Scheiffele)	
11:15 - 11:45	**Keynote Talk:** Magnetic Resonance Imaging and Microscopy at the National High Magnetic Field Laboratory ***Steve Blackband, National High Magnetic Field Laboratory, University of Florida***
11:45 - 12:00	Investigating the effect of obesity in trabecular structure of the proximal tibia traditional and sliding semilandmark methods ***Devora Gleiber, Texas State University***
12:00 - 12:15	CT-analysis of a child mummy from Roman-era Egypt ***Michala Stock, High Point University***
12:15 - 12:30	*In situ* position-resolved x-ray diffraction of an intact Roman-era Egyptian mummy guided by Computed Tomography ***Stuart Stock, Northwestern University***
12:30 - 13:30	*Lunch, Exhibition, Posters and Image Competition*
Session 3: Earth and Space (Paleontology) (Session Chair: Jessie Maisano)	
13:30 - 13:45	Neutron micro-CT as a non-destructive tool for Palaeontology ***Joseph Bevitt, Australian Nuclear Science and Technology Organisation***
13:45 - 14:00	Olfaction written in bone: Using CT and imaging technology to establish a link between cribriform plate and olfactory gene repertoire size and to predict olfactory ability in saber-tooth cat (*Smilodon fatalis*) ***Deborah Bird, University of California Los Angeles***
14:00 - 14:15	Analyses of coprolites with computed tomography: a dearth of density differences in fossilized dung ***Karen Chin, University of Colorado Boulder***
14:15 - 14:30	289 Million year old terrestrial vertebrate community revealed ***Robert Reisz, University of Toronto Mississauga***
14:30 - 14:45	Utility of tomography in anatomical and taphonomic reconstructions of fragile skeletal remains from an Upper Cretaceous bonebed in Madagascar ***Joseph Groenke, Ohio University***
14:45 - 15:00	Locomotor functional morphology and ecology of an early pterosaur revealed by microCT scanning ***Adam Fitch, University of Wisconsin-Madison***
15:00 - 15:30	*Coffee Break, Exhibition, Posters and Image Competition*
Session 4: Data Solutions (Session Chair: Ana Bohórquez)	
15:30 - 16:00	**Keynote Talk:** Preserving 3D data of Physical Objects: Standards, Discoverability, Value, and Sustainability ***Doug Boyer, Duke University***
16:00 - 16:15	Blob3D 2.0 ***David Edey, University of Texas at Austin***
16:15 - 16:45	**Keynote Talk:** Deep Learning for Transformative Image Processing and Image Segmentation Solutions ***Mike Marsh, Object Research Systems***
16:45 - 17:00	*Lightning Talks from Posters*
17:00 - 17:15	Closing Summary ***Edward Stanley, Florida Museum of Natural History***
17:15 - 18:15	*Poster Reception and Awards Ceremony*
19:00 -	*Symposium Dinner* ***The Florida Museum of Natural History, University of Florida Cultural Plaza***

Day 2: Friday 8 March 2019

08:00 - 08:30	*Breakfast*
08:30 - 08:45	Opening Remarks ***Edward Stanley, Florida Museum of Natural History***
Session 5: Materials Science and Engineering (Session Chair: Andrew Ramsey)	
08:45 - 09:15	**Keynote Talk:** Recent advancements in 3D X-ray microscopes for Materials Research ***Hrishikesh Bale, Carl Zeiss X-ray Microscopy***
09:15 - 09:30	Investigation of imperfections and defects in automotive fibre-reinforced polymer composite by correlative tomography ***Bartlomiej Winiarski, Thermo Fisher Scientific***
09:30 - 09:45	Biomimetic Engineering Studies Using Lab-based X-ray Microscopy ***William Fadgen, Carl Zeiss X-ray Microscopy***
09:45 - 10:00	CO_2–Induced Structure Alteration of Oil Well Cement: a Micro CT Study ***Yan Wang, Chinese Academy of Sciences***
10:00 - 10:30	*Coffee Break, Exhibition, Posters and Image Competition*
Session 6: Organismal Biology (Session Chair: Edward Stanley)	
10:30 - 11:00	**Keynote Talk:** X-ray and synchrotron tomography and volumetric light microscopy as complementary tools for understanding the evolutionary and embryonic genesis of animal form ***Bhart-Anjan Bhullar, Yale University***
11:00 - 11:15	Using 3D X-ray microscopy to study plant cell biology and development ***Keith Duncan, Donald Danforth Plant Science Center***
11:15 - 11:30	Nano-CT scanning the light organs of fireflies (Coleoptera: Lampyridae) ***Kristin Dunn, University of Florida***
11:30 - 11:45	Morphological convergence revealed by cranium osteology across limb-reduced lizards from three continents: Australia, Asia, and Africa ***Supuni Dhameera Thennakoon Mudalige Silva, University of North Texas***
11:45 - 12:00	oVert: Lessons learned for High-Throughput Scanning across the Fishes Tree of Life ***Zachary Randall, oVert, Florida Museum of Natural History***
12:00 - 12:15	Digital Specimens and the Future of Natural History Collections ***David Blackburn, Florida Museum of Natural History***
12:15 - 13:15	*Lunch, Exhibition, Posters and Image Competition*
Session 7: Education and Outreach (Session Chair: Amelia Dempere)	
13:15 - 13:30	Design considerations for 3D-printed models targeting blind and visually impaired participants ***Alex Ball, Natural History Museum, London***
13:30 - 13:45	On the use of X-ray μ-CT for curation and conservation of cultural heritage artefacts ***Vincent Fernandez, Natural History Museum, London***
13:45 - 14:00	Spiders ***Ajay Limaye, Australian National University***
Session 8: Future Advances and Complementary Technologies (Session Chair: Stuart Stock)	
14:00 - 14:30	**Keynote Talk:** Opportunities for dynamic micro CT imaging in the laboratory ***Arno Merkle, Tescan XRE***
14:30 - 14:45	Digital Volume Correlation for Volumetric Characterization of Biomechanical Changes ***Alexander Hall, Thermo Fisher Scientific***
14:45 - 15:00	Enabling temporal CT in the lab through reprogramming existing machines ***Parmesh Gajjar, University of Manchester***
15:00 - 15:15	X-ray Imaging at the Advanced Photon Source ***Francesco De Carlo, Argonne National Laboratory***
15:15 - 15:45	*Coffee Break, Exhibition, Posters and Image Competition*
15:45 - 16:15	**Keynote Talk:** Advanced Image Acquisition and Analysis; Combining HeliScan MicroCT and Avizo Software ***Dirk Laeveren & Alexander Hall, Thermo Fisher Scientific***
16:15 - 16:30	Multi-Modal Volumetric Tomography and Surface Reconstruction on Elytra of a Florida Beetle ***Edward Principe, PanoScientific***
16:30 - 16:45	Using Convolutional Neural Networks to Study Phase-Change-Induced Flow in Polymer-Electrolyte Fuel Cells ***Andrew Shum, Tufts University***
16:45 - 17:00	Toward 4D neutron CT at the Australian Centre for Neutron Scattering ***Joseph Bevitt Australian Nuclear Science and Technology Organisation***
17:00 - 17:15	Closing Remarks ***Edward Stanley, Florida Museum of Natural History & Jessie Maisano, University of Texas***

Oral Abstracts

Earth and Space – Meteorites in 3D: 2002 to 2022

Denton S. Ebel[1,2], Jon M. Friedrich[1,3], Mark L. Rivers[4]

[1] Dept. of Earth and Planetary Sciences, American Museum of Natural History (AMNH), New York, USA
[2] Dept. of Earth and Environmental Sci., Columbia University, New York, USA
[3] Department of Chemistry, Fordham University, Bronx, NY 10458 USA
[4] Consortium for Advanced Radiation Sources, University of Chicago, Argonne, IL 60439 USA

Synchrotron computed tomography (S-CT) at the Advanced Photon Source (APS) allowed this curator of meteorites at AMNH to contemplate space rocks (petrography) in 3D starting in 2001 [1,2]. Rapid advances in hardware have decreased the time from acquisition to interpretable images by over 10x. New software applied to the same raw data yields image stacks with much less noise than a decade or two ago. S-CT has allowed quantification of 3D shapes, abundances and orientations of components in meteorites from 3D data [2-4]. This represents a fundamental shift from the previous 150 years of understanding based on 2D slices of rocks as thin sections. We can now cut surfaces for 2D chemical analysis with 3D precision. With the acquisition of a VtomeX-S dual-tube scanner at AMNH in 2010, CT of meteorites became routine, allowing application to many problems in solar system origins. Nevertheless, the synchrotron source remains the gold standard for data collection. Fresnel zone plates in S-CT at unprecedented resolution proved critical for studies of very small grains from comet Wild 2 combined with isotopic analysis [5,6]. Recent S-CT advances including 'pink beam' high-speed tomography allows study of dynamic geological processes that occur at the scale of minutes [7]. However, we have shown that CT x-radiation strongly disturbs the natural irradiation record contained in extraterrestrial materials [8].

Acknowledgments:
This work is supported by NASA Emerging Worlds grants NNX6AD37G (DSE). JMF recognizes the Camille and Henry Dreyfus Special Grant Program in the Chemical Sciences and a Theodore Dunham, Jr. Grant of the Fund for Astrophysical Research. This research has made use of NASA's Astrophysics Data System Bibliographic Services. Use of the APS was supported by the U.S. Department of Energy, Office of Science, under contract no. DE-AC02-06CH11357.

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[2] Ebel D.S. et al. (2008) Meteor. Planet. Sci. 43, 1725-1740

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[5] Nakamura T. et al. (2008a) Science 321: 1664-1667

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[8] Sears D.W.G. et al. (2019) Meteor. Planet. Sci., 53: 2624-2631.

Using x-ray computed tomography as a tool for preliminary examination tool of current and future extraterrestrial sample return missions

Ryan Zeigler

Astromaterials Acquisition and Curation Office, NASA Johnson Space Center, Houston, USA

The Astromaterials Acquisition and Curation Office at the Johnson Space Center is the past, present, and future home of all of NASA's astromaterials sample collections. The primary goals of the curation office are to maintain the long-term integrity of the samples and ensure that the samples are distributed for scientific study in a fair, timely, and responsible manner, thus maximizing the return on each sample. Part of the curation process is planning for the future. To this end, we perform fundamental research in advanced curation initiatives to better prepared for future sample return missions. Advanced Curation is tasked with developing procedures, technology, and data sets necessary for curating new sample collections, or getting new results from existing sample collections. As part of these advanced curation efforts, we have installed and are operating a Nikon XTH 320 X-ray Computed Tomography(XCT) system in the JSC curation office with four interchangeable X-ray sources, a large-area detector, and a heavy-duty stage. These instrument characteristics allow us exceptional flexibility to analyze a wide range of sample sizes, from sub-mm soil particles to rocks >10 cm in diameter. The penetrative nature of the XCT scans allows for astromaterials samples to be analyzed within sealed low-density containers (e.g., Teflon bags), preserving the pristinity of the samples. We have begun scanning of the Apollo and Antarctic Meteorite sample suites in order to non-destructively map out lithic clasts (and other features) within the samples. The data from these scans will be made available to scientists via the JSC curation website and the Astromaterials Curation Newsletter. We anticipate sample requests from these "new" lithic clasts identified in these "old" samples. We also anticipate that XCT analyses like these would be useful for future sample return missions, like the OSIRIS REx mission, as well as future sample return missions.

Accurate measurement of small features in X-ray CT data volumes: a golden example

Richard A. Ketcham, Alison S. Mote

Department of Geological Sciences, Jackson School of Geoscience, University of Texas at Austin, Austin, TX, USA

Keywords: X-ray microtomography, Partial volume effect, Segmentation, Volume data analysis, Mineral characterization

A good operating principle for measuring features in CT data is that results should be reproducible across different instruments and data resolutions. As resolution gets coarser, some small features may fall below the detection limit, but for those that remain above it, the answer returned by a measurement method should be consistent with results achieved at finer resolution. We present a method for accurately measuring small, discrete features near the resolution limit of X-ray computed tomography (CT) data volumes. The appearances of small features are greatly impacted by the partial volume effect and blurring due to the point-spread function (PSF) of the data, and we call our approach the PVE method. Features are segmented to encompass their total attenuation signal, which is then converted to a volume based on the end-member CT numbers of the feature and the surrounding matrix. For measuring shape and orientation, we use the brightest (or darkest, for negative features such as pores) voxels up to the PVE volume. We demonstrate the method on a series of gold grains, which present challenges due to their irregular shapes and severe attenuation leading to scanning artifacts, scanned with two instruments at a range of resolutions and with various surrounding media. We recover volume accurately and reproducibly over a factor of 27 range in grain volume and factor of five range in data resolution, successfully characterizing particles as small as 5.4 voxels in true volume. Shape metrics and orientations are affected variably by resolution effects. Calibrating the PVE method only requires knowledge of the end-member CT numbers for the features of interest. Altogether, the PVE method is an accurate, reproducible, resolution-invariant, and objective approach to measuring small features in CT data volumes, all important improvements over threshold-based methods.

Advances in reconstruction and analysis of dynamic in situ microCT data in porous media

Jan Dewanckele[1], Marijn Boone[1], Arno Merkle[1], Denis Van Loo[1], Bert Masschaele[1], Tom Bultreys[2], Veerle Cnudde[3]

[1] TESCAN XRE, Ghent, Belgium

[2] Department of Earth Science and Engineering, Imperial College London, London, UK

[3] Ghent University, UGCT, Ghent, Belgium

Over the past decade, laboratory based X-ray computed micro-tomography (micro-CT) has given unique insights in the internal structure of complex porous materials in a broad range of applications, improving the understanding of pore scale processes and providing vital information for pore scale modelling. The non-destructive nature of micro-CT imaging, combined with dedicated X-ray transparent in situ equipment (eg. flow cells, tensile stages, heating and cooling stages) make it possible to monitor a changing pore structure over time in 3D. Recent advances in lab-based microCT hardware have pushed the temporal resolution from the hours down to seconds, enabling the visualization of fast dynamic processes and real-time imaging (Bultreys et al., 2016). Dynamic acquisitions however generate a vast amount of raw projection data, which needs to be reconstructed and further post processed. It is therefore key to quickly identify the interesting moments in time prior to reconstruction to optimize the amount of data that is generated, but also incorporated the added time dimension in the 3D analysis workflow to improve image quality.

In this work we present challenges and possibilities in dynamic micro-CT imaging for fast real-time acquisitions, reconstruction and analysis. The methodology and dedicated workflow from acquisition to analysis is illustrated using different flow experiments performed in a custom made X-ray transparent flow cell on limestone, sandstone and sintered glass samples. The first experiment, described in Boone et al. (2016), is single phase solute transport, where during continuous acquisition a tracer salt is injected in the pore space of a limestone sample. The capabilities of dynamic reconstruction of this experimental data is shown and analysis of the resulting 3D images enable distribution mapping of solute in the pore space through time. Other studies to be shown consist of two multiphase flow experiments of drainage and imbibition. In the drainage experiment, described in Bultreys et al. (2015), oil is injected in a brine saturated sandstone and the pore filling process can be visualized. By incorporating the temporal information in the 3D analysis of the pore space, individual pore filling events can be automatically identified and the size of these events monitored. For imbibition, on the other hand, water as wetting phase is injected in a sintered glass sample and the growth of water films and speed of pore filling can be analysed by reconstructing images from different time intervals and merging the appropriate temporal and local information for analysis.

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Magnetic Resonance Imaging and Microscopy at the National High Magnetic Field Laboratory

Stephen J Blackband, Jeremey R Flint, John R Forder

Department of Neuroscience, University of Florida, Gainesville FL

Magnetic Resonance Imaging (MRI) has evolved rapidly since its invention in 1970's to arguably become the dominant human imaging modality. The most relevant driving force behind this continuing improvement has been the shift to higher and higher magnetic fields. Human scanners, initially at a fraction of a Tesla, have now been demonstrated at 10.5 Tesla at the University of Minnesota, and small animal scans have been collected at 17.6T at the National High Magnetic Field Laboratory (NHMFL), a collaborative facility at the Universities of Florida State and Florida, and the Los Alamos National Laboratory, where about 1,400 scientists do magnet related science yearly.

The field strength that can be achieved is intimately coupled to the bore size of the magnet, in that smaller diameter magnets can be made stronger, and thus higher field imaging is necessarily achieved on smaller samples. These increases in field strength allowed improvements in the spatial resolution of MRI, leading to what is now called MR microscopy. Practically, while spatial resolutions on large samples is limited to hundreds of microns, on small samples resolutions as low as a few microns can be achieved. This introductory presentation will discuss the state of the art in MR microscopy, resulting in the first images of single mammalian cells at the University of Florida. Ancillary hardware requirements and practical limitations will also be indicated. Further, we will discuss the future developments in MRI allowing imaging above 30 Tesla and beyond. The potential for MRI to contribute to the open Vertebrate (oVert) program, a collaborative effort lead by the Florida museum, will also be presented.

Investigating the effect of obesity in trabecular structure of the proximal tibia traditional and sliding semilandmark methods.

Devora S. Gleiber[1], C. Kinley Russell[2], Deborah L. Cunningham[1], Adam D. Sylvester[2], And Daniel J. Wescott[1]

[1] Forensic Anthropology Center at Texas State, Department of Anthropology, Texas State University

[2] Center for Functional Anatomy and Evolution, Johns Hopkins University School of Medicine

Keywords: Trabeculae, Tibia, Obesity, Semilandmark based VOIs

Obesity adds a biomechanical burden to the human knee joint that should be reflected in trabecular structures. We assess the differences in trabecular architecture of the proximal tibia in obese and non-obese individuals using cubic volumes of interest (VOIs) and 84 spherical VOIs positioned using sliding semilandmarks. Tibiae of ten obese and ten non-obese, age-matched females and males were scanned using high-resolution computed tomography. Cubic VOIs were extracted from below the centers of both condyles and bone volume fraction (BV/TV), connectivity density (ConnD), degree of anisotropy (DA), and trabecular thickness (Tb.Th) and separation (Tb.Sp) were calculated for each VOI. In addition, 3.5 mm VOIs based on sliding semilandmarks were used to create maps of Tb.Th and BV/TV across the medial condyle. Cubic VOIs demonstrate that males have thicker trabeculae than females, but two-tailed t-tests show that only female obese and non-obese individuals have significant differences in their trabecular architecture. Even so, males and females follow a similar trabecular pattern. Obese females have significantly lower Tb.Sp and greater ConnD in the medial condyle based on the cubic VOI. The trabecular maps show that obese individuals have greater Tb.Th and BV/TV in the central portion of the medial condyle, while in normal BMI individuals these properties are greater anteriorly. The results of this study suggest that the biomechanical burden of obesity is reflected in the architecture of the proximal tibia. The difference between obese and non-obese individuals is likely due to the inability of the anterior cruciate ligament to draw the femur anteriorly during extension in obese individuals. The signal strength of obesity may differ in males and females due to differences in body fat distribution. This study further contributes to our understanding of how obesity affects the skeleton, and more broadly, how bone reacts to mechanical loading.

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CT-analysis of a child mummy from Roman-era Egypt

M.K. Stock[1], S.R. Stock[2], J.D. Almer[3]

[1] Dept. of Exercise Science, High Point University, High Point, NC, USA
[2] Dept. of Cell and Molecular Biology, Feinberg School of Medicine, Northwestern University, Chicago, IL, USA
[3] The Advanced Photon Source, Argonne National Laboratory, Argonne, IL, USA

Keywords: skeletal biology, Egyptian mummy, non-invasive analysis, bioarchaeology, growth and development, museum exhibit

Hawara Portrait Mummy No. 4 (HPM4), "discovered" in Garrett-Evangelical Theological Seminary library, provided context in a recent Block Museum (Northwestern University) exhibit on mummy portraits from Roman-era Egypt. Multiple CT scans of HPM4 were performed in order to describe the human remains and other contents and to provide a "road map" for subsequent in situ x-ray diffraction studies of the mummy's contents. Analyses presented here focus on the human remains and other objects.

The data presented consist of voxels with 0.69mm in-plane and 1.00mm out-of-plane dimensions. Three-dimensional segmentation was performed in Amira. The following were separately segmented: skeleton, resin shards within the cranial vault, metal wires piercing the wrappings, inclusions within the wrappings, and wrappings with anomalously high absorption levels (Fig. 1).

The CT data show the complete skeleton is present, well-preserved and anatomically articulated. Dental development indicates that this individual was ~5 years old at death. This matches the observation the majority of the long bones remain as distinct diaphyseal and epiphyseal centers, prior to fusion. There is also a hole through the body of the sphenoid, consistent with postmortem removal of the brain. No other skeletal trauma was noted.

It is difficult to discern sex from the skeletal remains of juvenile humans; however, the mummified soft tissue is visible and well-preserved, but shrunken as expected from mummification. Internal genitalia could not be resolved and the absence of external, male genitalia supports what is seen in the portrait: the subject was a young girl.

Also discussed are the unusual morphology of the resin shards, which conform to a partial endocast of the cruciform eminence of the occipital; the dimensions and spatial distribution of the wires and other, dense inclusions within the wrappings; and a description of the higher-density layer of wrapping approximately midway between the body and the mummy's external surface.

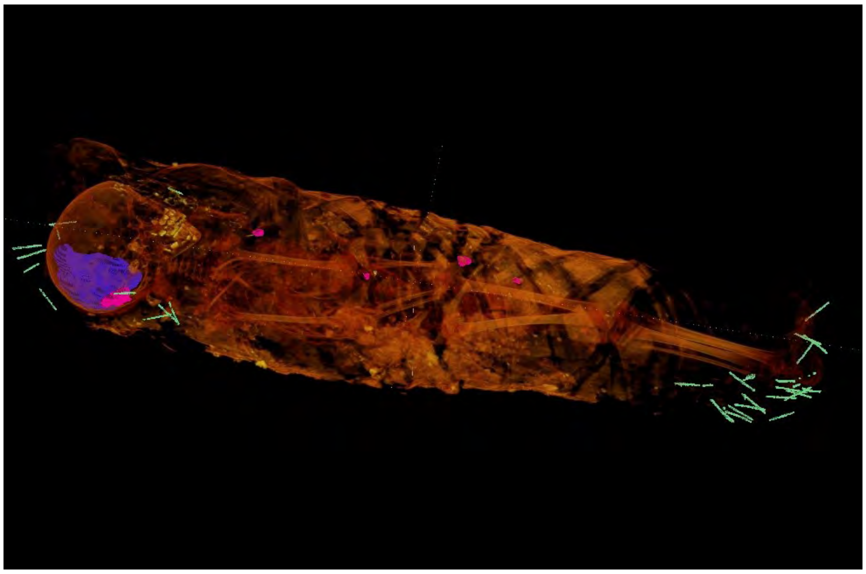

Figure 1. Volume rendering of the mummy and its segmented contents. Wrappings and skeleton in orange tones, resin shards in blue, wires in light green, inclusions in pink.

In situ position-resolved x-ray diffraction of an intact Roman-era Egyptian mummy guided by Computed Tomography

S.R. Stock[1], M.K. Stock[2], J.D. Almer[3]

[1] Dept. of Cell and Molecular Biology, Feinberg School of Medicine, Northwestern University, Chicago, IL, USA
[2] Dept. of Exercise Science, High Point University, High Point, NC, USA
[3] The Advanced Photon Source, Argonne National Laboratory, Argonne, IL, USA

Keywords: X-ray diffraction, Clinical CT, Egyptian mummy, Synchrotron x-radiation

Computed Tomography (CT) is most often performed with differences in x-ray absorption providing the contrast in the reconstructions. The absorptivity of each reconstructed volume element (voxel) is determined but not the identity of the material(s) producing the contrast. This talk described the first use of *in situ* position-resolved x-ray diffraction to identify different contents within an intact mummy.

Prior to the high-energy transmission x-ray diffraction studies, Hawara Portrait Mummy No. 4 (HPM4) was imaged with a clinical CT scanner, and these scans were used as 3D "roadmap" for the diffraction studies performed at beamline 1-ID of the Advanced Photon Source (APS). Only one day of beam time was available at 1-ID, and the CT data were essential to limiting data collection to volumes containing features of interest. The large beam path through the mummy was a major complication, and the solution was to collect each diffraction pattern at two well-defined detector-mummy separations. Diffracting volume origins could be localized to within 1-2 mm along the beam direction, providing enough precision for identification of the materials present.

Diffraction patterns were collected from the human mineralized tissues within HPM4, specifically the skull, cervical vertebrae, femora and teeth. Patterns from the femora's lateral and medial sides (and the skull's left and right sides) could be separated and analyzed separately. The lattice parameters and crystallite sizes of the mineral phase within bone were comparable with values from dried modern human bone. Within the wrappings, wires were located by diffraction and identified as a modern dual phase steel, and highly absorbing, millimeter-sized inclusions were identified as calcite. The position of these and other features were found at positions indicated by the CT scans.

Neutron micro-CT as a non-destructive tool for Palaeontology

Joseph. J. Bevitt[1], Bryan M. Gee[2], Ulf Garbe[1], Robert R. Reisz[2,3], Matt A. White[4]

[1] Australian Centre for Neutron Scattering, Australian Nuclear Science and Technology Organisation, Lucas Heights, New South Wales, Australia

[2] Department of Biology, University of Toronto Mississauga, Ontario, Canada

[3] International Centre of Future Science, Jilin University, Changchun, Jilin Province, China

[4] School of Environmental and Rural Science, University of New England, Armidale, New South Wales, Australia

The physical extraction of fossilised remains from rocks enables quantitative physiological investigation of bone-dimensions, volume, and porosity, however leads to the destruction of valuable contextual information and soft-tissue remains within the matrix.

Conventional and synchrotron-based X-ray computed tomography (XCT) have been utilised for many years as critical tools in uncovering valuable 3-D internal and surface renderings of scientifically important fossils, however poor contrast and X-ray penetration often prevents thorough tomographic analysis. DINGO, Australia's neutron micro-computed tomography (nCT) instrument, located at the OPAL nuclear research reactor, is being used to obtain unpreceded renderings of extraordinary fossilised anatomical features not visible with conventional imaging techniques. Drawing upon specimens scanned from across Australia, North America, New Zealand, and China, this presentation will demonstrate DINGO's capabilities and the complementarity of nCT to classic XCT methods for certain geological formations and fossil localities.

A selection of nCT case studies to be presented:

- nCT studies conducted on a Jurassic cynodont, one of the earliest and most primitive ancestors to all living mammals, has revealed exceptional conservation of internal bone structure of the cranium, teeth and internal soft tissues; features that are not visibly rendered by XCT, nor phase-propagation synchrotron XCT methods.
- The illumination of "corrective procedures" in paleontological specimens
- Uncovering the morphology and internal anatomy of fire-adapted mid-Cretaceous south polar conifers
- Applicability of nCT to the Richards Spur locality, Oklahoma, USA.
- Stomach contents of herbivorous and carnivorous dinosaurs.

Olfaction written in bone: Using CT and imaging technology to establish a link between cribriform plate and olfactory gene repertoire size and to predict olfactory ability in saber-tooth cat (*Smilodon fatalis*)

Deborah Bird, Lester Fox-Rosales, Iman Hamid, Blaire Van Valkenburgh

University of California Los Angeles

The mammalian olfactory system has undergone losses and gains throughout its evolutionary history, resulting in a wide diversity of olfactory morphologies and olfactory receptor (OR) gene repertoires. One clue to this diversity lies deep within the skull in a small, cryptic, perforated bone that separates snout from brain, called the cribriform plate (CP). The CP is the only passageway for axons from sensory neurons as they cross from snout to olfactory bulb and for this reason offers an osteological record of the relative olfactory innervation an animal invests in smelling. Axons crossing the CP are projections from multiple neuron subpopulations within the olfactory epithelium, each of which expresses a single OR gene. Because each functional OR gene is represented by a subpopulation of some thousands of neurons, all of which leave their imprint in the CP bone early in development, we hypothesized that losses and expansions in OR gene repertoires are reflected in smaller and larger CP morphology, respectively. To test this, we used CT scans and 3D imaging to analyze relative CP size of 27 species with known OR gene repertoires. Results showed that across mammalian superorders, from dolphin to elephant, CP size correlates closely with the number of functional OR genes in a species' genome. The regression equation from this correlation allowed us to predict a likely OR gene repertoire of an extinct mammal, the saber-tooth cat (*Smilodon fatalis*). Using the surface area of Smilodon's well-preserved CP, as measured from a CT scan, we estimated its OR gene repertoire to have been comparable to, but slightly smaller than, that of the extant domestic cat. The link found between CP morphology and OR gene number points to an underlying developmental intersection of genes, neuroanatomy and skull morphology along the peripheral olfactory pathway from nose to brain. These results reinforce relative CP size as a stand-alone metric of olfactory function that can be applied to extinct species for which molecular data no longer exists.

Analyses of coprolites with computed tomography: a dearth of density differences in fossilized dung

Karen Chin[1], Matthew Colbert[2], Jeffrey Rifkin[3]

[1] Department of Geological Sciences and Museum of Natural History, University of Colorado Boulder, 265 UCB, Boulder

[2] Department of Geological Sciences, Jackson School of Geosciences, 2275 Speedway Stop C9000, The University of Texas, Austin

[3] University of Colorado Boulder, Boulder

Keywords: Fossils, Coprolites, Paleontology

Many informative features of mineralized coprolites (fossilized feces) are hidden within the interior of these trace fossils. Thin sections offer internal views of coprolite contents, but random, two-dimensional sections may not show identifiable inclusions. Moreover, this approach requires damaging fossil specimens. Coprolites are thus good candidates for non-destructive, three-dimensional X-ray analysis. Analyses are challenged, however, by the often limited X-ray contrast between coprolite inclusions and the encasing coprolite ground mass. Such subtle differences in density likely reflect the taphonomic (fossilization) history of a coprolite; how the fecal mass became mineralized and the extent of subsequent diagenetic recrystallization. For example, fossilization of dung by permineralization of a porous fecal mass with allochthonous minerals can minimize the original density and compositional differences of labile inclusions.

The use of phase contrast techniques with synchrotron radiation has been effective in analyzing some coprolite specimens, but obtaining access to synchrotron facilities is not trivial. Fortunately, improvements in the resolution and sensitivity of computed tomography scanners using conventional X-ray sources allow detection of subtle material differences within coprolites. Perhaps the major challenge to scanning mineralized coprolites relates to their relatively high X-ray attenuation, especially with larger specimens. Such coprolites may require long acquisition times, and necessitate the use of high-energy X-rays, which can diminish X-ray contrast between materials. This can complicate subsequent visualizations. We have found, however, that phosphatic bone fragments can be discerned within a phosphatized coprolite ground mass, and outlines of soft-bodied worms are perceptible in coprolites wholly permineralized with calcium carbonate. The density and textural differences of such coprolite inclusions are so subtle that segmenting requires manually tracing faint outlines on each CT slice before rendering the segments using three-dimensional visualization software.

289 Million year old terrestrial vertebrate community revealed

Robert R. Reisz[1,2], Bryan M. Gee[2], Joseph. J. Bevitt[3]

[1] International Centre of Future Science, Jilin University, Changchun, Jilin Province, China

[2] Department of Biology, University of Toronto Mississauga, Ontario, Canada

[3] Australian Centre for Neutron Scattering, Australian Nuclear Science and Technology Organisation, Lucas Heights, New South Wales, Australia

The Dolese Brothers Limestone Quarry, near Richards Spur, Oklahoma, USA, preserves an Early Permian (298 million years old) infill in a series of Ordovician limestone and dolostone karst fissures. Speleothems intimately associated with the site indicate that Richards Spur is a cave system, suggesting a unique preservational environment for vertebrates, one that is distinct from those of more typical Early Permian lowland deltaic/fluvial localities. The locality is unique in the preservation of exclusively terrestrial vertebrates, with the vast majority of fossil material found at this site during the last 8 decades of excavations being completely disarticulated. Recent collecting activities have yielded articulated material, indicating that many of these animals were likely washed in before being disarticulated or probably fell into the caves during monsoonal rains. The fossil materials have been impregnated with hydrocarbons derived from the underlying Woodford oils of Oklahoma. Fossilization has resulted in dark coloured skeletal elements preserved in grey clays and limestones, making them easily recognizable, but the process likely occurred under conditions that facilitated the formation of abundant pyrite around and inside the bones. This unique combination makes the fossils from this vast cave system difficult to image using x-ray, but ideally suited for imaging using the quasi-parallel collimated bean of neutrons, as provided by the OPAL reactor at ANSTO, Australia. The superior image quality provided by this method has provided unprecedented access to the detailed anatomy and structure of both unprepared fossil materials, and to the internal anatomy of numerous new or little-known taxa from this locality, the richest and taxonomically most diverse assemblage of terrestrial vertebrates for the Paleozoic Era. The fossil materials examined using the DINGO facility include several small and medium sized amphibians, a stem amniote, several eureptiles and parareptiles, and a synapsid. The anatomical details of the skulls of these terrestrial vertebrates provided by neutron computed tomography have opened up new avenues for the study of the conquest of land by vertebrates.

Utility of tomography in anatomical and taphonomic reconstructions of fragile skeletal remains from an Upper Cretaceous bonebed in Madagascar

Joseph R. Groenke and Patrick M. O'Connor

Department of Biomedical Sciences, Ohio University Heritage College of Osteopathic Medicine, Ohio University, Athens, U.S.A

Keywords: Tomography; Organismal Biology; Taphonomy; Fossil

We demonstrate an integrated methodology for using CT in both mechanical and digital preparation of field jackets collected at the MAD05-42 locality in Upper Cretaceous deposits from the Mahajanga Basin of Madagascar. Following detailed in-quarry mapping, intact field jackets were documented in a medical CT scanner to identify contents and spatial relationships of vertebrate remains. Initial scanning assisted in both prioritizing and performing mechanical preparation. Using a single individual of a small, fragile, bird-like theropod skeleton as an example, we show how subsequent study of hospital scans, in-situ prepared materials, and locality mapping efforts in the field determined which materials underwent micro-CT scanning. Micro-CT data were digitally prepared (segmented), providing high-resolution information on the spatial and anatomical arrangements of materials too fragile to be exposed or removed from matrix. Associations of element fragments to a single individual were demonstrable taphonomically (e.g., by connecting fragments of sternum prepared digitally and prototyped for confirmation of fits along pre-depositional breaks) and anatomically (by close physical association of non-overlapping elements). Materials collected in separate field jackets and disassociated/reduced for micro-CT scanning, through a combination of field mapping records and medical and micro-CT datasets, were found to have a specific connection otherwise unrecognized from field collection or mechanical preparation. This link allowed for a taphonomic digital reconstruction and assignment of two collections of hind limb materials across largely unprepared blocks of matrix. Efforts allowed for prototype outputs of key morphology, and a digital reconstruction of existing skeletal materials including a sternum, sacrum, tail, and limb elements. Finally, digital reconstruction and positioning of dissociated/disarticulated elements provided critical spatial information related to whole organism structure, resulting in the production of research-ready 3D models for primary research, comparative work, and dissemination activities.

Locomotor functional morphology and ecology of an early pterosaur revealed by microCT scanning

Adam J. Fitch[1], Adam C. Pritchard[2], Bhart-Anjan S. Bhullar[3]

[1] University of Wisconsin-Madison
[2] Smithsonian National Museum of Natural History
[3] Yale University

Keywords: Pterosaurs, morphology, ecology, flight, evolution, reptiles

As one of three clades of flying vertebrates, pterosaurs provide important insights into the evolution of vertebrate flight. This utility is hindered by poor, two-dimensional preservation of many of the earliest pterosaur fossils from the Triassic. A notable exception is the minute, three-dimensionally-preserved holotype of *Arcticodactylus*

('Eudimorphodon') cromptonellus from the Upper Triassic of Greenland. Micro-CT scanning at the University of Texas at Austin, Texas, and at Yale University, Connecticut, has allowed the study of the three-dimensional skeletal locomotor anatomy of *Arcticodactylus*. Large, strongly recurved unguals and prominent phalangeal flexor tubercles suggest strong adaptations for grasping and climbing. Well-developed hindlimbs with elongate distal elements and a subperpendicular femoral head indicate upright, well-developed hindlimbs. Long forelimbs, inflexible interphalangeal wing joints, elongate wing phalanges, and a well developed humeral deltopectoral crest support well-developed flight despite the early-diverging nature of the taxa. Humeral/femoral section modulus ratios were calculated from these scans to determine comparative structure strength of these elements, particularly with respect to that of derived pterosaurs and other saurians. These demonstrate that *Arcticodactylus* possessed an intermediate condition between hindlimb-driven ancestral archosaurs and derived forelimb-driven pterosaurs. The combination of climbing adaptations and subequal hind- and forelimb contributions to locomotion reveal considerable arboreal and scansorial ability in this early pterosaur. The presence of powerful, subcursorial hindlimbs suggest a capability for saltatory hindlimb movement and imply a greater importance to the hindlimbs in early pterosaur flight takeoff and terrestrial locomotion than in later taxa. Arboreality and hindlimb prominence in *Arcticodactylus* support previous hypotheses suggesting arboreal leaping as the precursor to pterosaur flight.

Preserving 3D data of Physical Objects: Standards, Discoverability, Value, and Sustainability

Doug Boyer[1], Julia Winchester[1], Will Sexton[2], Tim Mcgeary[2]

[1] Duke University, Dept of Evolutionary Anthropology
[2] Duke University Library

MorphoSource is an online repository that researchers, subject experts and institutions can use to archive and share 3D data representing physical objects. It currently emphasizes biological specimens, principally those from museum collections. The site has been enthusiastically adopted by research communities and public educators, and there is growing interest from museum collections. MorphoSource was launched mid-2013. At the time of writing, it has almost 1,000 credentialed data contributors who have shared and/or archived approximately 58,000 data objects on the site. These 3D data objects represent 17,000 specimens across 6,100 species. About 4,000 different users download data per annual quarter. MorphoSource data has been cited in over 250 publications.

The initial success of this data platform is due to at least two features: 1) powerful discoverability and verifiability deriving from a specimen-centered data model, which also leverages authoritative specimen records by linking to online museum databases; and 2) tools allowing efficient management, documentation, and reporting of third-party data use.

Moving forward, MorphoSource is being redesigned to allow description and discovery of non-biological and/or non-museum objects. In this scope-broadening work, we are utilizing Dublin Core, Europeana, and CARARE 2.0 metadata vocabularies to promote interoperability. Furthermore, with direction and inspiration from imaging experts and community working groups focused on 3D data standards, we are overhauling aspects of the data model and metadata schemas to characterize a greater diversity of imaging technologies and workflows. An improved data model and metadata will amplify the potential for data to be reused in diverse ways. Finally, we are assembling a network of institutions interested in utilizing MorphoSource as an interface for ingestion, integrated discovery, and management of objects in institutional repositories, as well as gathering infrastructural requirements from these potential partners.

Ultimately, repositories and communities of data producers are required to justify costs of long term preservation and storage. Ideally, citation of data in a publication would be enough. But realistically, access to a given dataset will eventually be limited or extended by its value. Value should be measured by usage rate. While intrinsic qualities should drive value and usage rate, at least until now, extrinsic factors such as discoverability and accessibility have often been much stronger determinants of usage rate. MorphoSource aims to build sustainability by maximizing demonstrable data value through further improving discoverability and accessibility. Eventually we aim to minimize cost by optimizing distribution of governance and infrastructure among institutions with pre-existing mandates for data preservation.

Blob3D 2.0

R.A. Ketcham, R.D. Hanna, and D.R. Edey

The University of Texas, High Resolution X-Ray Computed Tomography Facility

Keywords: quantification, measurement, software, analysis

Measurement of discrete features in µCT datasets has long been a goal of geologists, material scientists, and others hoping to analyze their data in more comprehensive and quantitative ways. Blob3D was developed by The University of Texas High Resolution X-Ray Computed Tomography Facility (UTCT) for efficient measurement of thousands of discrete features (e.g. clasts, minerals, voids) within a single µCT scan. Blob3D remains unique because it gives the program operator primary control over data interpretation and measurement, especially in regard to customizing segmentation and separating objects from their neighbors, and all computations are carried out in 3D. It is freely available for academic users.

A "blob" is a contiguous set of voxels that meets some user-defined criteria. Three steps are involved in Blob3D data processing. In the first step, *Segment,* a set of criteria are defined by the user that defines which voxels belong to the material of interest. The second step, *Separate*, distinguishes contiguous sets of segmented blobs and allows the operator to divide interconnected or touching objects into individual objects. The third step, *Extract*, performs measurements on separated objects, such as size, shape, orientation, and contact relationships.

Since its first release in 2000, Blob3D has been under continuous development at UTCT, and new features have been added for µCT clients needing specific, specialized measurements for their research. It has also been used for internal research to implement and vet new measurement techniques. Major additions in the last couple of years include tools to: 1) measure the point spread function (PSF) of a µCT dataset, and use it to more accurately measure features like fracture and grains near the spatial resolution limit; 2) provide an expanded set of shape parameter measurements, such as 3D Feret (caliper) dimensions; 3) measure the F_T correction for long alpha particle stopping distances for (U-Th)/He thermochronology; 4) analyze shell-like structures around objects in 3D; and 5) define and measure objects that are difficult or impossible to segment using automated segmentation algorithms. In this talk we will present a brief overview of the Blob3D program and highlight some of these powerful, new features that have been utilized in recent studies.

Deep Learning for Transformative Image Processing and Image Segmentation Solutions

Mike Marsh

Object Research Systems

Quantitative analysis of computed tomography reconstructions is possible only when the image data are properly segmented. That successful image segmentation is often impeded by imaging artifacts such as noise and beam hardening or inadequate image resolution. We present here a general-use Deep Learning framework that we have applied for image enhancement techniques such as denoising and image sharpening, and more importantly, for comprehensive image segmentation.

Machine learning in general has proven useful in image processing in recent years. One subtype of machine learning, multi-layer convolutional neural networks--the Deep Learning approach--has shown remarkable success in problems that have been otherwise difficult or impossible to solve with traditional algorithm development and software engineering practices. The general purpose Deep Learning engine we describe here lets users deploy specific convolutional neural network architectures for image enhancement and segmentation. This engine includes a friendly interface and all of the features required to train and execute Deep Learning on reconstructed computed tomography image data.

We use our pre-existing imaging and visualization platform, Dragonfly, because it has the necessary tools that precede and follow the Deep Learning steps in our image processing workflows. After pairing a small set of unprocessed images with the corresponding segmented images, users can define training parameters and initiate training. After training, the fully trained neural network model can be used like any other image filter in the software to transform input unprocessed images into fully segmented output images. Similarly, users can train neural network models with low resolution and high resolution images for image sharpening, or high-noise and low-noise images for models that can perform denoising.

Great flexibility comes from the fact that users can import neural network models written in the popular Keras framework. Alternatively, users can design and refine new network models with graphical tools. For users that have no Deep Learning expertise, it is very easy to reuse others' neural network models that they can train on their own data for their specific needs. We provide a repository, the Dragonfly Infinite Toolbox, for users to share neural network models. We demonstrate the success of these tools on synchrotron x-ray tomography results of ceramic matrix composites and on laboratory x-ray tomography of iron ore pellets. These results showcase the diverse set of applications and the immediate value of this robust solution.

Biomimetic Engineering Studies Using Lab-based X-ray Microscopy

William Fadgen[2], Ria L. Mitchell[1], Peter Davies[1], Mark P. Coleman[1], Cameron Pleydell-Pearce[1], Laura North[1], Will Harris[2], and Richard E. Johnston[1]

[1] Advanced Imaging of Materials (AIM) Facility, College of Engineering, Swansea University, Swansea, UK
[2] Carl Zeiss X-ray Microscopy, Pleasanton, CA, USA

Keywords: Biomimetic engineering, X-ray microscopy, micro-CT

In engineering design, we can often benefit from drawing inspiration from the materials and structures we find in the natural world. There are frequent examples of organisms which, through years of evolution, have developed particular unique designs affording them some remarkable capability to tolerate, endure, or thrive in their environments. The ability to leverage such bio-inspired or biomimetic approaches hinges on our ability to properly observe and characterize these natural structures, ideally in their native or near-native states. By doing so, we can attempt to elucidate the connections between formation, structure, and function that give these materials and organisms their advantageous properties.

With X-ray imaging, we have unique opportunities to improve our understanding of such organisms. Since the emergence of X-ray microscopy (XRM) and tomographic imaging at synchrotron beamlines, continuous improvements in both spatial and temporal resolution have pushed the boundaries of non-destructive 3D characterization. Today's lab-based X-ray microscopes, offering sub-micron resolution and flexibly accommodating specimens of various sizes, geometry, and density, provide a powerful tool to interrogate internal 3D structures while being minimally invasive to the form-function relationships we wish to observe.

This work will highlight some of the recent developments and uses of XRM for biomimetic materials. Examples will include applications in photonic crystals of butterfly wings, surface characteristics and adhesion of complex textured surfaces, and mechanical properties and structure through biomineralization in barnacles.

Recent advancements in 3D X-ray microscopes for Materials Research

Hrishikesh Bale[1], Will Harris[1], Ravi Sanapala[1], Sun Jun2, Erik Lauridsen[2]

[1] Carl Zeiss X-ray Microscopy, Pleasanton, CA, United States of America.
[2] Xnovo Technology ApS, Køge, Denmark

X-ray microscopy (XRM) is a powerful sub-surface imaging technique that reveals the three-dimensional microstructure from a range of materials, non-destructively. The non-destructive nature of X-rays has made the technique widely appealing, with the potential for characterizing sample changes in "4D," delivering 3D microstructural information on physically the same sample over time, as a function of sequential processing conditions or experimental treatments. This has led to a new generation of functional studies with applications and is in a state of rapid expansion [1]. Laboratory-based X-ray sources have been coupled with high resolution X-ray focusing and detection optics from synchrotron-based systems to acquire tomographic datasets with resolution down to 50 nm across a great span of sample dimensions [2]. More recently significant advances in lab sources that produce increased X-ray flux at improved source stability have enabled faster data acquisition, albeit quite slower in comparison to what the current state-of-the-art at synchrotrons is.

Additionally, newer contrast modalities such as laboratory based X-ray diffraction contrast tomography has recently become available; allowing the nondestructive routine characterization of 3D crystallographic information on polycrystalline materials in a commercial laboratory X-ray microscope (ZEISS Xradia 520/620 Versa). Known as laboratory diffraction contrast tomography (LabDCT), this imaging modality will open the way for routine, non-destructive studies of time-evolution of grain structure to complement destructive electron backscatter diffraction

(EBSD) end-point characterization. This talk will explore both the implementation of optics in nanoscale and sub-micron laboratory XRM architectures and review in detail several unique leading applications examples from a range of materials research use cases.

Investigation of imperfections and defects in automotive fibre-reinforced polymer composite by correlative tomography

Bartlomiej Winiarski, Grzegorz Pyka, Trond Varslot and Benjamin Young

Thermo Fisher Scientific (FEI Czech Republic s.r.o.), V. Pecha 12, Czech Republic

Fibre-reinforced polymer composites are a widely used material in the construction, automotive, marine and aerospace industries [1]. Automotive composites reinforced with glass fibres are used in various car components that requires weight savings, orthotropic mechanical properties, precision engineering. Increased component durability and operational safety are archived by careful selection polymer matrix and fibres and detailed orientation of fibres against specific stresses and fibre volume fractions [2]. Ultimate performance of components is achieved if the microstructural features of produced component comply with the design having negligible density of imperfections and defects.

This contribution investigates microstructural features, imperfections and defects in a slender specimen resected from a casing of car oil filter made of long glass-fibre reinforced PA66 composite. the sample is investigated using multi-scale and multi-modal correlative tomography/microscopy methodology [3-5], starting with micro X-ray helical computed tomography (µCT) particularly attractive for the imaging with low noise and wide contrast of high aspect ratio specimens [6]. Reconstructed volume and fibres from HeliScan µCT are next statistically analysed using XFiber Avizo software extension and defected regions of interest (ROI) are selected for further analyses using different imaging modality. Next the sample is transferred on a cross-platform holder into Multi Ion Species Plasma FIB – SEM (MIS PFIB-SEM) microscope for serial sectioning tomography (SST) study and material composition mapping at smaller scale with higher resolution. The sample and RoI coordinates from µCT data are tracked in the PFIB by Maps software where µCT information from Avizo and SEM images are coregistrated. Finally data from SST study is combined with µCT results using Avizo visualisation and quantification research platform.

The study found at different length scales a number of imperfections, i.e. fibre waviness and breakage, and defects in the matrix, i.e. various voids, cleavages and cavities. The correlative tomography solution used in this research allowed pin-pointing and detailed investigation of sparsely distributed ROIs and give a new insight into investigation of automotive composites.

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Biomimetic Engineering Studies Using Lab-based X-ray Microscopy

William Fadgen[2], Ria L. Mitchell[1], Peter Davies[1], Mark P. Coleman[1], Cameron Pleydell-Pearce[1], Laura North[1], Will Harris[2], And Richard E. Johnston[1]

[1] Advanced Imaging of Materials (AIM) Facility, College of Engineering, Swansea University, Swansea, UK
[2] Carl Zeiss X-ray Microscopy, Pleasanton, CA, USA

Keywords: Biomimetic engineering, X-ray microscopy, micro-CT

In engineering design, we can often benefit from drawing inspiration from the materials and structures we find in the natural world. There are frequent examples of organisms which, through years of evolution, have developed particular unique designs affording them some remarkable capability to tolerate, endure, or thrive in their environments. The ability to leverage such bio-inspired or biomimetic approaches hinges on our ability to properly observe and characterize these natural structures, ideally in their native or near-native states. By doing so, we can attempt to elucidate the connections between formation, structure, and function that give these materials and organisms their advantageous properties.

With X-ray imaging, we have unique opportunities to improve our understanding of such organisms. Since the emergence of X-ray microscopy (XRM) and tomographic imaging at synchrotron beamlines, continuous improvements in both spatial and temporal resolution have pushed the boundaries of non-destructive 3D characterization. Today's lab-based X-ray microscopes, offering sub-micron resolution and flexibly accommodating specimens of various sizes, geometry, and density, provide a powerful tool to interrogate internal 3D structures while being minimally invasive to the form-function relationships we wish to observe.

This work will highlight some of the recent developments and uses of XRM for biomimetic materials. Examples will include applications in photonic crystals of butterfly wings, surface characteristics and adhesion of complex textured surfaces, and mechanical properties and structure through biomineralization in barnacles.

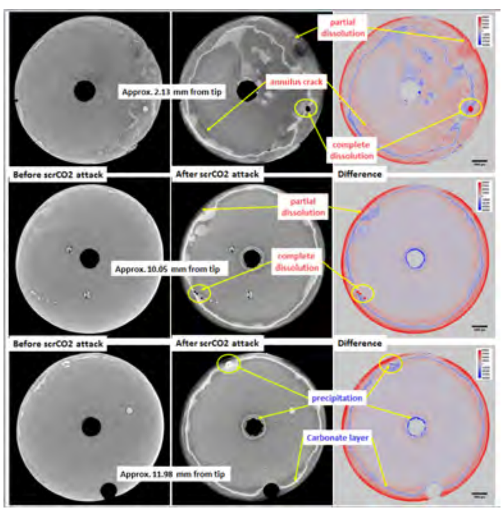
CO_2–Induced Structure Alteration of Oil Well Cement: a Micro CT Study

Wang Yan , Zhang Liwei , Miao Xiuxiu , Wei Ning , Li Xiaochun

State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, Hubei Province 430071, China

Wellbore cement integrity under CO_2 geologic storage (CGS) conditions is a key factor to assure safe and permanent storage of CO_2. Wellbore cement integrity may be impaired and the structure of cement may be altered as a result of CO_2 attack. To understand how CO_2-induced structure alteration in oil well cement under CGS conditions affects well integrity in CGS projects, this paper reports an experiment of reaction between CO_2 and oil well cement under CGS conditions. Samples were scanned by Micro CT before and after reaction. The Micro CT is capable of operating at 140KV and 10W, has a maximum resolution of 10μm. To simulate the reaction between CO_2 rich brine and oil well cement at CGS conditions, our team has developed a testing system which provides the storage temperature and pressure.

The samples were made by standard class G oil well cement used for CGS pilot projects. The cement was cured at CO_2 storage formation conditions: 62°C, 17MPa, and 1 wt% NaCl solution. The curing was maintained for 14 days. The diameter of the samples was 10 mm. Every sample contained a small borehole at center (around 1 mm diameter) that made the samples suitable for examining seepage through small leakage pathways within cement. During the reaction experiment, the samples were placed in the high-pressure, high-temperaure testing system for 14 days, given a temperature of 62°C and a CO_2 partial pressure of 17MPa. The goal of this experiment is to evaluate how the geochemical reactions between dissolved CO_2 and cement affect structure of the cement. Change of borehole geometry was not observed in the Micro CT images. However, a region with decreased porosity around the borehole due to $CaCO_3$ precipitation and a region with increased porosity around the borehole due to $Ca(OH)_2$ and C-S-H dissolution were observable. Initial distribution of cementitious materials and solution buffering governed the width of the high-porosity region and $CaCO_3$ precipitation region. This study demonstrates a 3-D sample characterization technique that can be used to investigate CO_2-induced structure alteration of oil well cement.



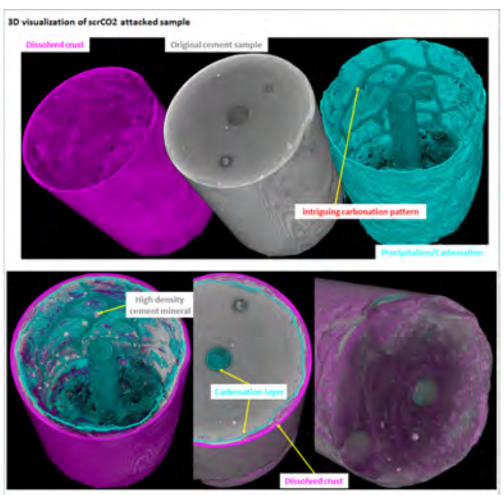


Figure 1 (Left): Micro-CT images at different locations of a cement sample before and after exposure to CO2-saturated brine.

Figure 2 (Right): 3-D view of dissolution and precipitation zones of the cement after exposure to CO2-saturated brine.

X-ray and synchrotron tomography and volumetric light microscopy as complementary tools for understanding the evolutionary and embryonic genesis of animal form

Bhart-Anjan Bhullar

Yale University

I will discuss the application of several 3D and 4D volumetric imaging technologies to a fundamental problem of evolutionary biology: how and why major anatomical transformations occur and new body plans emerge. Virtually every musculoskeletal region of the bird body is drastically modified from the ancestral reptilian condition; the history of avian anatomy can be traced back along the dinosaur, and then the archosaur, line. Because evolutionary transformations are the result of modifications to developmental programs, we have been examining the morphology of embryos and juveniles, extant and fossil, to determine when in early ontogeny dinosaur-specific and avian-specific features appear. Imaging of fossil taxa combines high-resolution CT imaging of the fossils themselves and of contrast-enhanced extant animals, whose "soft" structures serve as a guide for reconstructing their long-vanished antecedents in extinct forms. Imaging of development takes advantage of laser-scanning confocal microscopy combined with a modified CLARITY technique for making transparent entire immunostained embryos, and of subcellular-resolution synchrotron tomography. In the head, we have found that early proportional changes and repatterning at the phylotypic stage are responsible, respectively, for the unique architecture of the archosaur and the avian face. In several postcranial regions, in contrast, we have discovered late addition of bird-specific features to a more generalized skeletal form. This late addition stands in contrast to the way in which features specific to many other major terrestrial vertebrate clades are added and suggests that there is something unique, at the embryonic level, about the way in which dinosaurs became birds.

Using 3D X-ray microscopy to study plant cell biology and development

Keith E. Duncan

Donald Danforth Plant Science Center, St. Louis, MO

Keywords: X-ray microscope, plant cell biology, cell development

Plant anatomy and development are difficult to study if researchers are restricted to the examination of 2D images, regardless of the resolution of the imaging technology being used. Generating detailed 3D volumes of plant samples at cellular resolution, particularly the complicated floral and reproductive structures, would allow measurement and analysis of plant cell biology in unprecedented detail. In April 2018 we received a Zeiss Xradia 520 Versa 3D X-ray microscope (XRM) at the Donald Danforth Plant Science Center, as part of a collaborative agreement with Sumitomo Chemical and Valent BioSciences. Since that time we have been modifying sample preparation techniques from classical electron microscopy to optimize plant tissue fixation and contrast enhancement for imaging with the XRM. We have used these techniques to begin documenting floret and panicle development in a range of scientifically and economically important plant systems, and have used the resulting high resolution 3D volumes to study plant cell biology in ways not practical with light, fluorescence, laser, or electron microscopy techniques. We are studying maize vascular tissue at nodal regions, with the goal of mapping xylem and phloem in this complicated nexus of root and shoot vasculature, and we are documenting cell elongation and development in maize root tips. Further, we have been developing segmentation protocols to identify and measure specific cells within 3D volumes to identify potentially beneficial traits that may only manifest early in plant development. Using 3D XRM should significantly add to our ability to study and understand developmental plant cell biology.

Nano-CT scanning the light organs of fireflies (Coleoptera: Lampyridae)

Kristin N. Dunn[1], Seth Bybee[2], Kathrin Stanger-Hall[3], And Marc A. Branham[1]

[1] University of Florida
[2] Brigham Young University
[3] Univeristy of Georgia

Keywords: Lampyridae, Nano-CT, firefly, entomology, morphology

We investigate the use of nano-computed tomography (nano-CT) scanning as a means of viewing the internal structures of the light organs of fireflies (Coleoptera: Lampyridae). With nano-CT we are able to assess the internal structural networks of the light organ in 3D, which allows for quantification and analyses that have not been possible with traditional microscopy techniques. Using nano-CT scanning to view the internal structures of these light organs will provide insight into the morphological variation among taxa, as well as the evolution of bioluminescence in Lampyridae. We scanned specimens of *Photuris congener* and *Photinus pyralis* to test various staining methods and storage conditions in an effort to develop an optimal protocol for scanning members of Lampyridae. With this protocol, we have been able to visualize the two-layer morphology of the light organ tissue, as well as the larger network of the tracheal system. Further analyses will be necessary for the segmentation and visualization of finer features, and having this standard protocol in place is a crucial first step.

Morphological convergence revealed by cranium osteology across limb-reduced lizards from three continents: Australia, Asia, and Africa

Supuni D. G. Thennakoon Mudalige Silva[1, 2], Juan D. Daza[2], and Aaron M. Bauer[3]

[1] Department of Biological Sciences, University of North Texas, Denton, Texas, USA
[2] Department of Biological Sciences, Sam Houston State University, Huntsville, Texas USA
[3] Department of Biology, Villanova University, Villanova, Pennsylvania, USA

Keywords: Reptiles, Geckos, Skull, Ecology, Image analysis

Evolution of a serpentiform body where the body is elongated and the limbs are attenuated is a common process among squamates (lizards and snakes). Morphological convergence of this body shape might be linked to habitat preference and could be a response to their peculiar locomotion mode. Although evolution of body elongation has been studied extensively, its effects on the cranium anatomy remains largely unknown. Here, we quantify the cranium morphological convergence of limb-reduced lizards from three continents using geometric morphometrics. Twenty seven morphological landmarks associated with the cranium were studied in dorsal, lateral, and ventral views using high resolution CT scans of the heads of surface active, limb-reduced *Paradelma orientalis* (family Pygopodidae) endemic to the Australian mainland, New Guinea and the neighbouring islands; semi-fossorial *Acontias percivali* and *Acontias meleagris* (family Scincidae, subfamily Acontinae) endemic to Sub Saharan Africa; and semi-fossorial *Nessia burtonii* and *Nessia monodactyla* (family Scincidae, subfamily Scincinae) endemic to Sri Lanka. The level of similarity of the craniums of limb-reduced lizards was quantified using three-dimensional geometric morphometric analysis, including fully limbed and limb-reduced counterparts. PC1 versus PC2 reflected that the distribution of taxa follows a gradient that describes their nature of limbs (fully limbed, limb-reduced, limbless), which is correlated with their habitat preference (surface active, semi-fossorial and fossorial). PC1 versus PC3 also distinctly segregated the limbed and limb-reduced taxa with zero overlap. Semi-fossorial taxa *Acontias percivali* and *Acontias meleagris* clustered together in the PCA plot with semi-fossorial *Nessia burtonii* and *Nessia monodactyla. Paradelma orientalis* diverged from *Acontias* and *Nessia* species in morphological space. This supports the morphological convergence of *Acontias percivali* and *Acontias meleagris* of Sub Saharan African with *Nessia burtonii* and *Nessia monodactyla* of Sri Lanka.

oVert: Lessons learned for High-Throughput Scanning across the Fishes Tree of Life

Zachary S. Randall, Kevin Love, Edward Stanley, Larry M. Page, David Blackburn

Florida Museum of Natural History, University of Florida, Gainesville, USA

As part of the oVert (openVertebrate) Thematic Collection Network, > 1,000 scans of fishes have so far been produced at UF, representing > 150 families, and 530 genera across the fish tree of life. This presentation will discuss lessons learned at UF for high throughput scanning of fish taxa after the completed first year of the grant. Topics will include our process for creating a type species list for fishes, and identifying specimens of type species across collaborating institutions. It will also cover workflows for specimen selection and comparisons of different staging methods for scanning a variety of specimen shapes and sizes. Insights to workflows for data management and for making the data accessible through the online 3D repository Morphosource will also be discussed.

Digital Specimens and the Future of Natural History Collections

David Blackburn

Florida Museum of Natural History

The preserved specimens found in the scientific collections of natural history museums provide a unique trove of data on biodiversity, including for amphibians and reptiles. Digitization efforts over the past twenty years now enable us to access metadata for these specimens, facilitating both an increasingly global inventory of scientific collections as well as research on the distributions and historical records of species. Whereas it is increasingly easy to locate the collections where specimens of interest might be found, physically accessing those specimens remains largely unchanged. Researchers must visit those collections in person or obtain specimens on loan, which is increasingly difficult due to both regulations governing the movement of biodiversity and the shipment of preserved specimens. With advances in and lowering costs of sophisticated digital imaging, it is now possible to create three-dimensional digital surrogates of preserved specimens. These digital specimens facilitate both qualitative and quantitative analyses of external and internal phenotypes, including for rare specimens that could not be shipped or dissected. In addition, these digital specimens provide a new opportunity for using natural history collections in training and education through both on-line models and 3D-printed objects. Rather than replacing the physical objects, these digital specimens increase their impact and usher in a future of new possibilities for scientists, students, and the general public to make use of natural history collections.

Design considerations for 3D-printed models targeting blind and visually impaired participants

Kate T. Burton[1], Alexander D. Ball[1], Catherine Holloway[2] And Kenneth M.Y. Png[3]

[1] Imaging and Analysis Centre, The Natural History Museum, London
[2] UCLIC, University College London, 66 - 72 Gower Street, London
[3] Carl Zeiss Ltd. 509 Coldhams Lane, Cambridge

3D printing has opened huge opportunities for reproduction of replica objects. However, there are very few studies which have looked at the design considerations required for interaction with blind and visually impaired audiences. Robust and well-defined standards exist for print media, tactile diagrams and drawings and even signposting, but similar design guides for 3D objects do not appear to have been prepared.

Studies which have been carried out have typically focused on the reproduction of large-scale objects such as statuary or fossils. Frequent observations from study participants have asked why they cannot have access to the original objects. The lack of authenticity is thus cited as a negative part of the experience.

Our study takes objects which are too small to be handled and makes them accessible to participants through the medium of 3D scanning and 3D printing. The practice of accessibility is thus, in part, a shared experience made possible through the technology involved.

We aim to explore the role of colour, contrast, texture, and physical properties such as stiffness in the use of a variety of objects developed in conjunction with focus groups. Our long-term goals are to develop robust, tested standards which can be used as a basis for the design of 3D printed objects for education and outreach in the future.

On the use of X-ray μ-CT for curation and conservation of cultural heritage Artefacts

Vincent Fernandez[1], Brett Clark[1], Lu Allington-Jones[1], Natasha Almeida[1], Lucia Burgio[2], Konstantina Konstantinidou[1], Louise Tomsett[1]

[1] Natural History Museum, London, United Kingdom
[2] Science Section, Conservation Department, Victoria and Albert Museum, South Kensington, London, United Kingdom

X-ray micro Computed Tomography (μ-CT) systems have become quite common in natural history museums. Such equipment allow for museum items to be characterised in-house, limiting transportation and manipulation which can be of critical importance for rare and delicate artefacts. The Natural History Museum (NHM, London, UK) is equipped with two X-ray μ-CT instruments: a Nikon HMX ST 225 and a Zeiss Versa 520. These offer a wide scope for analysing the large diversity of items in the NHM collections, ranging from arthropod larvae to large fossils and meteorites. The ongoing development of this imaging and analysis centre in Central London, dedicated to cultural heritage and natural history, has seen an increase in collaborations with nearby institutes such as the Victoria and Albert Museum. Whilst these instruments are essentially used for research, they are increasingly used as a solution for curation and conservation problems. These data can also be used to gather information on the structure of the item itself and to help in taking decisions about the best conservation strategy. It also opens up avenues for experimental conservation, for example to understand better how the physical condition of pyritic fossils evolve over time when stored in barrier-film microenvironments, each with a known humidity and oxygen level. By repeatedly scanning these fossils, over intervals of several months, it should be possible to advise on the best conservation measures. One of the most important aspects of digitising collections using μ-CT is the creation of a virtual backup in case of damage to the real item, whether through accident or due to destructive analysis. In that respect Museums are also facing the incidental issue of curating data of virtual objects, and especially the challenge of linking the analytical information to the existing catalogues to avoid unnecessary duplicates of analyses.

Spiders

Ajay Limaye

National Computational Infrastructure, Australian National University

Keywords: Drishti, Drishti Prayog

Computed Tomography allows us to look at structures that cannot be seen with the naked eye. Using the data generated from CT Lab scanners at Australian National University and using touch screen enabled Drishti Prayog software, visitors at the SPIDERS exhibition in Questacon, Canberra could explore the spiders from outside as well as inside. For the touch screen experience, three different aspects of the spiders were considered – venom glands, silk glands and reproduction. To show venom glands the Eastern mouse spider was chosen, for silk glands the Silver orb-weaver was chosen and to teach visitors about spider reproduction the Orange-legged swift spider was chosen. People who visited the exhibit and interacted with the display, could examine the CT scans of these spiders and they could digitally dissect and see the insides. Labelled images and movies were embedded in the display which allowed users to gain more information about the spiders.

Opportunities for dynamic micro CT imaging in the laboratory

Arno Merkle, Marijn Boone, and Jan Dewanckele

TESCAN XRE, Ghent, Belgium

Time-resolved 3D imaging with X-rays has rapidly emerged as an essential technique to understand materials evolution, facilitating in situ investigations ranging from mechanical deformation to fluid flow in porous materials and beyond. Imaging of dynamic processes is one of the key applications at synchrotron facilities, pushing the time resolution more and more down with quite some success. However, access to those facilities is often limited and operational cost are quite high.

In the laboratory, image quality and spatial resolution have been significantly improved, often at a cost of temporal resolution however. Recent developments at TESCAN XRE have made it possible to visualize and inspect dynamic process in the laboratory with a temporal resolution below 10 seconds. In this study we explore the challenges and innovations that have led to this capability.

Dynamic acquisitions however, generate vast amounts of raw projection data, which need to be reconstructed, further post processed and eventually quantified. It is therefore essential to devise workflow strategies to quickly identify the interesting moments prior to reconstruction to optimize the amount of data that is generated, but also incorporate the added time dimension in the 3D analysis workflow to improve image quality. Challenges and possibilities in dynamic micro CT imaging will be demonstrated here across materials, life science (figure 1) and geomaterial applications.

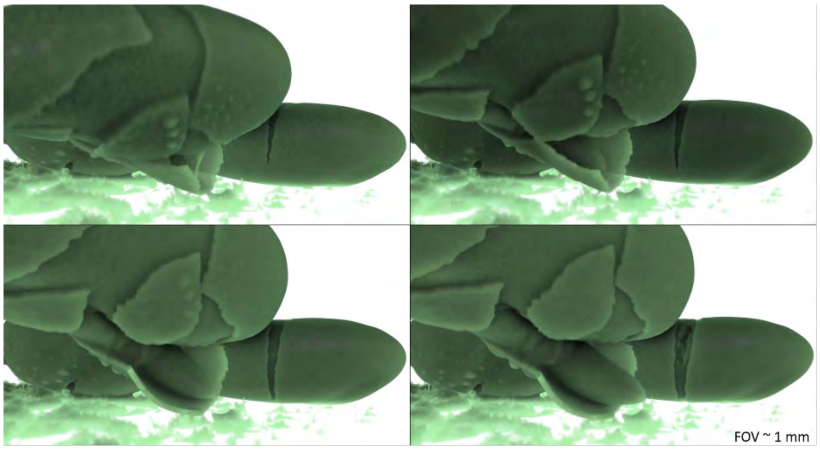


Figure 1: Four time frames from a dynamic experiment of growing seeds: continuous acquisition for 2 h with a selected reconstruction window of 4 minutes.

Digital Volume Correlation for Volumetric Characterization of Biomechanical Changes

Alexander S. Hall[1], Mason Dean[2], Hubert Taieb[2], Jan Giesebrecht[1,3], Kamel Madi[4]

[1] Thermo Fisher Scientific, Houston, USA
[2] Max Planck Institute of Colloids and Interfaces, Potsdam, Germany
[3] Zuse Institute Berlin, Berlin, Germany
[4] 3Dmagination, Didcot, UK

Keywords: DVC, 4DCT, FEA, Avizo

Digital Image Correlation (DIC) is customary when computing displacement and strains on materials. DIC works by calculating differences between rapidly acquired images of a speckle pattern on a surface. DIC is a non-contact replacement for strain gauges and extensometers, but can be misleading when an internal strain differs from an external strain. Digital Volume Correlation (DVC) is the logical improvement to DIC, as it uses internal textures to calculate strain in a 3D context. Typically, input data are before-after X-Ray Computed Tomography or synchrotron image stacks that must be carefully aligned, resampled, and compared. Amira-Avizo Software seamlessly implements all of these features, thus making it the program of choice for DVC experiments. This presentation covers the basics of DVC, how to set up a DVC experiment, and how Avizo's DVC implementation led to new understanding of in-situ volumetric strains for several of the program's users. We will highlight two time series CT experiments: a seed pod opening and ray (Order: Chondrichthyes) cartilage under mechanical loading. In each case, simply visualizing the surface would improperly characterize the complexity of changes happening inside the specimens. We hope to inspire future biomechanical and materials science researchers to consider DVC.

Enabling temporal CT in the lab through reprogramming existing machines

Parmesh Gajjar[1], Jakob S. Jørgensen[1,2], Jose R.A. Godinho[1,3], Chris G. Johnson[2,4], Andrew Ramsey[5], and Philip J. Withers[1,6]

[1] Henry Moseley X-ray Imaging Facility, School of Materials, The University of Manchester, Oxford Road, Manchester, UK
[2] School of Mathematics, The University of Manchester, Oxford Road, Manchester, UK
[3] Helmholtz-Zentrum Dresden-Rossendorf, Helmholtz Institute Freiberg for Resource Technology, Chemnitzer

Strasse 40, 09599 Freiberg, Germany
[4] Manchester Centre for Nonlinear Dynamics, The University of Manchester, Oxford Road, Manchester, UK
[5] Nikon Metrology Inc., 12701 Grand River Avenue, Brighton, USA
[6] Henry Royce Institute, The University of Manchester, Alan Turing Building, Oxford Road, Manchester, UK

Temporal micro computed tomography (CT) allows the non-destructive quantification of processes that are evolving over time in 3D. Despite the increasing popularity of temporal CT the practical implementation and optimisation can be difficult, especially in the laboratory where commercial black-box micro-CT instruments are normally used. In this presentation, we show how different flavours of temporal CT can be implemented in the laboratory by reprogramming existing machines. We demonstrate a new software extension for collecting a large number of tomograms automatically at regular intervals; this was used to provide a unique temporal insight into the germination of a mung bean. We highlight how a CT machine can be automatically synchronised with an in-situ rig, for example to examine granular segregation. Finally we enable a new flavour of temporal CT on laboratory systems through 'golden-ratio' projection sampling. A stream of projections is acquired as crystals precipitate in a porous media, with subsets of projections reconstructed ex post facto with an iterative scheme to form a time series. This overcomes the limitation of needing to know a priori what the best time window to acquire the optimal number of projections for each scan is, and allows the number of projections in a reconstruction to be varied as the sample evolves. The example of barite precipitation also reveals subtle differences in spatial and temporal resolution. This work has wide application across a number of fields, allowing temporal insight into for example mechanical testing, following battery degradation and chemical reactions.

X-ray Imaging at the Advanced Photon Source

Francesco De Carlo

Argonne National Laboratory

Full-field imaging is an extremely versatile technique that is broadly applicable to almost all scientific and engineering disciplines. Its versatility is reflected by the fact that every major synchrotron facility in the world has a dedicated full-field imaging facility. In many cases, full-field imaging is the keystone linking a sample to other X-ray techniques such as ptychography, μXRF, μXANES, and μXRD. The current Advanced Photon Source allows for hierarchical 3D imaging of dynamic systems and materials with spatial resolution up to 1 μm, without a major sacrifice in time resolution and 20 nm 3D imaging of static or slowly evolving systems.

In this talk we will present the latest nano and dynamic imaging results utilizing the current APS source together with their data analysis challenges and will describe the opportunities the new APS upgrade source will bring to this technique.

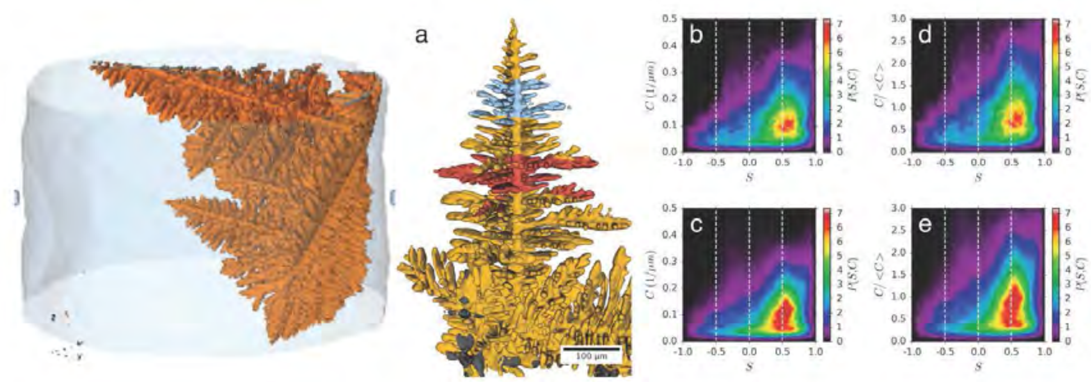


Figure 1. Left: animation at 1.6 3D-fps growth of Al-rich dendrite in Al-Cu alloy with a cooling rate 1 K/min from 550 K. Right: Interfacial shape distributions for two 75 μm thick slices normal to the growth direction of the nearly free-growing dendrite at 9.0 seconds after nucleation [1].

This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

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Advanced Image Acquisition and Analysis; Combining HeliScan MicroCT and Avizo Software

Grzegorz Pyka[1], Rémi Blanc[2]

[1] Thermo Fisher Scientific, Vlastimila Pecha 12, Brno, Czech Republic
[2] Thermo Fisher Scientific, 3 Impasse Rudolf Diesel, Merignac, France

Behind the huge successes that X-ray tomography experienced over the past decades, scientists and industrials appreciate that they can investigate their samples non-destructively, both visually and quantitatively. This ability to build knowledge from samples is fueled by evolutions of image acquisition hardware, reconstruction, and also of image visualization and analysis software.

Thermo Scientific™ HeliScan™ microCT is a tool which addresses the compromise between image resolution, scan time and imaging volume. It represents a technology change of the CT industry, as it is first commercially available high-resolution µCT instrument built on the principles of high-cone-angle acquisition and reconstruction. High image quality and low noise levels is made possible by a unique range of advanced scanning- and reconstruction techniques, even at low radiation dose and short scan times.

The versatility of the Heliscan micro-CT system enables researchers to examine high-aspect-ratio samples (1:10) in 3D, both sample sizes ranging from cm-scale to sub-millimeter scale, and resolution down to 400nm. Image acquisition performed in a guided workflow mode, allows the user to inspect multiple regions of interest within a sample, or image the entire volume.

Workflow mode enables scanning of multiple samples, where the vertical stage serves as a sample changer system, where scan settings and scan geometry is automatically adjusted for each sample. This allows effective experiment time management as well as for a direct multi-resolution object(s) examination, significantly extending the range of experiments that can be performed.

Thermo Scientific Amira-Avizo Software proposes a powerful and intuitive platform for visualization and analysis of 3D, but also multi-channel/spectral and/or time series data. It features abundant state-of-the-art image and data processing algorithms allowing researchers and industrials to develop and apply supervised or automated image analysis workflows. This allows to provide answers, within the same software interface, to either unique experiments or routine tasks.

Combining high fidelity imaging with advanced visualization and data processing software, allow for an optimal experience to generate knowledge from samples. This will be demonstrated through a variety of use cases from different fields including materials science, biomedical, life science and electronics applications, as well as an input for the optimization of the production processes in industry.

Multi-Modal Volumetric Tomography and Surface Reconstruction on Elytra of a Florida Beetle

E. L. Principe[1], Gary Scheiffele[2], Ana C. Bohórquez[2], And Luisa Amelia Dempere[2]

[1] PanoScientific, Inc, Melbourne Beach
[2] Herbert Wertheim College of Engineering's Research Service Centers (RSC), University of Florida, 1041 Center Drive, Gainesville

We explore multi-scale methods and generalized workflows to collect 3D surface and 3D volume reconstruction data. Scanning electron micro-photogrammetry, light optical photogrammetry, and x-ray computerized tomography (CT) is correlated in a combined dataset for 3D visualization. Initial studies are presented with application to characterizing the structural color exhibited by *Cotinis Nitida*, or more commonly, Green June Beetle. This species of the scarab family is distinguished by glossy iridescent colors in their elytra (wing case). The brilliant iridescence common to these beetles is due to complex selective geometric interferometric reflections from the multi-layer elytral cuticle structure. The scanning electron microscopy (SEM) micro-photogrammetric data provides nanoscale 3D surface detail and surface texture information. The CT yields micro-scale volumetric structural data, while the optical data allows correlation of the visible light coloration and elytra structure.

Future studies will use SEM surface reconstruction and CT data acquired over entire specimen to guide FIB-SEM nanotomography to capture photonic cell volumes from selected regions. 3D surface reconstruction data and volumetric structural data may then be segmented and extracted to define 3D mesh structures suitable for physics-based models which propagate an electric vector through the structure and simulate the color response. Through the combination of these workflows we aim to develop both general and efficient methods to capture 3D structures over multiple length scales and ultimately simulate mechanisms of 3D structural color over a broad range of natural systems.

Using Convolutional Neural Networks to Study Phase-Change-Induced Flow in Polymer-Electrolyte Fuel Cells

Andrew D. Shum[1], Dilworth Y. Parkinson[2], Iryna V. Zenyuk[1,3,4]

[1] Department of Mechanical Engineering, Tufts University, Medford, USA
[2] Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, USA
[3] Department of Chemical and Biomolecular Engineering, University of California – Irvine, Irvine, USA
[4] National Fuel Cell Research Center, University of California – Irvine, Irvine, USA

Keywords: Convolutional neural network, Image segmentation, Polymer-electrolyte fuel cell, Gas diffusion layer, Evaporation

As the abilities of X-ray computed tomography (CT) continue to expand, so does the quantity of data and the time required to process the data. In response, there is a push to further automate data processing and analysis through machine learning; in particular, convolutional neural networks (CNNs). CNNs can be applied to a multitude of image processing tasks such as finding centers of rotation for CT data [1], removal of reconstruction artifacts [1], and denoising of data sets [2]. However, CNNs are probably most known for their ability to perform segmentation/labeling. Examples span a broad range of research fields and physical scales including road scenes [2], biological samples [2], metal alloy phases [3], and soil/rock samples.

Although CNNs have proven to be widely applicable to image processing and analysis, it has also become apparent that individual pairings of architecture and application must be validated [1]. As such, we focus on the use of CNNs to segment synchrotron X-ray CT data sets of energy storage/conversion materials and devices. More specifically, we show successful use of CNNs to segment image stacks of polymer-electrolyte fuel cell (PEFC) gas diffusion layers (GDLs) containing liquid water. The water is tracked for an in-situ evaporation/condensation experiment. Knowledge of the water's location and shape as a function of time is necessary to understand the material's impact on PEFC performance. The challenge these samples present to more traditional segmentation methods is the low contrast between water and carbon fibers. Depending on the composition of a GDL, binder, polytetrafluoroethylene (PTFE), and a nanoporous material called the microporous layer (MPL) may also be present in the same narrow window of gray-scale values. Separating these phases is essential in evaluating the material's water transport properties.

We will present results from both our efforts with CNNs and the specific PEFC experiment that produced the data sets.

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Toward 4D neutron CT at the Australian Centre for Neutron Scattering

Joseph J. Bevitt[1], Ulf Garbe[1], Chris Wensrich[2]

[1] Australian Centre for Neutron Scattering, Australian Nuclear Science and Technology Organisation, Lucas Heights, NSW, Australia
[2] School of Engineering, University of Newcastle, NSW, Australia

Commercial and academic demand for time-resolved non-destructive 3D imagining of dynamic systems has resulted in the implementation of numerous acquisition strategies and software protocols for processing time-evolving tomographic data. These advancements have naturally been led by the medical and industrial X-ray user communities, resulting in the availability of bespoke 4D CT scanners.

Neutron tomography, 3D imaging based upon the attenuation of subatomic particles, is increasingly becoming available with neutron beam imaging capabilities located at fixed nuclear reactor and spallation sources, and more recently, with portable neutron source units. Relative to X-ray technologies, low neutron flux and long exposure times have inhibited the development of temporal neutron CT.

The DINGO neutron imaging facility at the OPAL nuclear research reactor operates with a high-flux ($\sim 1 \times 10^8$ n/cm^2/s), quasi-parallel thermal neutron beam (L/D = 500 or 1,000) and with a number of detectors enabling a range of true spatial resolution (7 – 200 micrometres). The recent implementation of CMOS detectors and other physical upgrades has enabled us to follow the lead of PSI and HZB to achieve "continuous streaming" or "on-the-fly" neutron tomography. Previous continuous streaming nCT have focussed on achieving ultra-fast CT with a reduction in number of projections and subsequent loss of spatial resolution, or the use of a golden-ratio sampling.

Here we present our efforts and outcomes in optimising the physical systems on DINGO to achieve a reduction in full CT scan times from ~24 h to just under 20 s, albeit with limited dynamic range, but maintaining spatial resolution to observe changes in a dynamic system - the ordering of granular materials with increasing applied load, and for the high-throughput scanning of geological samples. Also to be discussed are our next steps and plans for offering 4D neutron CT to the broader user community.

Poster List

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13. **Micro-computed tomography unveils Triassic stereospondyls encased within their burrows**
    Calvin So, *University of Wisconsin-Madison*
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Poster Abstracts

Recycled Blessings: A comparative study of X-ray and neutron micro-CT of a re-wrapped Egyptian votive mummy

Carla A. Raymond[1,2], Joseph J. Bevitt[3], Yann Tristant[1], Ronika K. Power[1], Anthony W. Lanati[2], Christopher J. Davey[4,5], John S. Magnussen[6] and Simon M. Clark[2,3]

[1] Department of Ancient History, Macquarie University, North Ryde, NSW, Australia
[2] Department of Earth and Planetary Sciences, Macquarie University, North Ryde, NSW, Australia
[3] Australian Centre for Neutron Scattering, Australian Nuclear Science and Technology Organisation, Lucas Heights, NSW, Australia
[4] Australian Institute of Archaeology, Macleod, VIC, Australia
[5] Centre for Classics and Archaeology, University of Melbourne, Parkville, VIC, Australia
[6] Australian School of Advanced Medicine, North Ryde, NSW, Australia.

This study involved investigation of an unusual Egyptian votive mummy (IA.2402) of unknown age and provenance, housed within the collection of the Australian Institute of Archaeology (AIA) in Melbourne, Australia. The AIA was interested to learn more about the authenticity and contents of the mummified bundle, while preserving the physical integrity of the object and causing as little damage as possible. The application of 3D imaging techniques was ideal to non-destructively study the object and still discover as much as possible about its contents. Using a combination of established and novel techniques: X-ray computed tomography (CT) and neutron CT provided valuable insight, both individually and collectively, revealing a partial animal skeleton, and several layers of textile and padding. Use of both techniques allowed for complementary study of bones, soft tissue, and textile components. Collaboration with a zooarchaeologist confirmed the animal remains to be a small, juvenile feline. Neutron CT, not yet routinely applied to archaeometric studies of mummified remains, provided insight into wrapping techniques used in the mummification process of votive animal offerings. In addition to these imaging studies, pigment analysis was also performed on the coloured markings on the wrappings. This was done using a scanning electron microscope (SEM) and Raman spectroscopy in order to determine their composition, and to verify their authenticity. Radiocarbon dates were acquired on samples taken from the external wrapping and the internal contents, revealing an age discrepancy between the two. This as a result is an example of recycling votive offerings, and sheds some light on the economic and religious climate in which the mummy was made and traded.

Revealing porosity in plant propagation substrates using X-ray Computed Tomography

Ana C. Bohórquez[1], Erin Yafuso[2], Gary Scheiffele[1] and Paul Fisher[2]

[1] Herbert Wertheim College of Engineering's Research Service Centers (RSC), University of Florida, Gainesville, Florida 32611, USA
[2] Environmental Horticulture Department, University of Florida, 2549 Fifield Hall, Gainesville FL 32611, USA

In horticultural plant propagation research, particle size, water holding capacity, cation exchange capacity, and nutrient content are often studied to determine a suitable growing substrate for horticultural crops. However, there is a lack of understanding on how porosity and pore size distribution can affect water holding capacity, so as to promote optimal water retention, drainage capacity, and aeration. With the advancement in root measurements using x-ray computed tomography (CT) scanning, we can now understand plant propagation substrate microstructure. In this work, we demonstrated CT methods to quantify and visualize the pore size distribution, and water relationships at both microscopic and whole container scale for a range of commercial propagation substrates. We also compare these results against alternative porosity measurement techniques. Overall, this study shows an innovative use of CT scanning technology in horticultural plant propagation research.

Interactive digital video animation promotes accessibility of complex insect anatomy to cytological and molecular audiences in pursuit of solving the citrus greening problem in Florida

Cicero, J.M.[1], Alba-Tercedor[2], J., Hunter[3], W.B., Cano, L.[4], Saha, S.[5], Mueller, L.A.[5], Brown, S.J.[6]

[1] University of Florida, Gainesville, FL
[2] University of Granada, Spain
[3] USDA-ARS, 2001 South Rock Road, Fort Pierce, FL 34945
[4] University of Florida, IRREC, Fort Pierce, FL
[5] Boyce Thompson Institute, NY
[6] Kansas State University, Manhattan, KS

Millions of dollars are lost annually in Florida due to citrus greening disease, vectored by the Asian citrus psyllid (ACP). We premier 2D interactive digital video animation of the ACP alimentary canal and stylet biogenesis at http://citrusgreening.org as a solution to the lack of synthesis between organ level and cell/molecular level studies. Prodigious data sets and analyses of proteomes, transcriptomes, metabolomes, biochemical pathways, and cell-pathogen interactomes have been generated in the collective efforts to solve the citrus greening problem. However, studies on their direct correlation to anatomy at the organ, tissue, and cell-field levels are relatively few. One reason for this is the difficulty in exposition by authors, and assimilation by readership, of ACP organ systems, owing to their 3-dimensionality, multifunctionality, ontogenetic differences, and in many cases their dynamic nature. Other reasons include the limitations of specimen processing techniques and interpretation of results, the static nature of cross-sectional micrographs, and their infinitesimal representation of the total organ from which they came.

Our platforms target broad audiences and are designed to be educational and to supplement, rather than replace, the traditional monographic style. They are novel in that their text flows with the frames, and micrographs appear when the animation calls for them. Viewers can page through the animation and hop to any micrograph in any direction by clicking buttons. Detailed study of organ components is simplified so that readers can assimilate organ complexity much more easily in association with their high-density monograph equivalents. Dynamics, such as the food stream, waste stream, seminal fluid stream, midgut transposition, and mobilization of the stylet biogenesis apparatus can be animated in lieu of available technology to visualize them *in vivo*. When combined with 3D computed tomography, this approach has the potential to revolutionize how anatomy is published.

Dynamic imaging using high-resolution X-ray CT at pore-scale to determine how wettability controls gravity-induced drainage imbibition in bead-pack porous media

Kuldeep Chaudhary[1] and D.r. Edey[2]

[1] Department of Geology, Kent State University, Kent, Ohio
[2] The University of Texas High Resolution X-Ray Computed Tomography Facility

High-resolution (µm-scale) 3D transient imaging of two-phase fluid transport at pore-scale through porous media allows detailed examination of mechanisms, controls, and topology of one fluid transport relative to the other. For example, one can investigate if and how pore network connectivity and pore surface wettability modify movement behavior of the 'front', i.e., piston type vs. fingering, and the nature of residual saturation or capillary trapping behavior. In this study, we present preliminary results from pore-scale gravity drainage experiments using hydrophilic, hydrophobic, and mixed hydrophilic and hydrophobic bead-pack (0.9 mm) porous media. During these experiments, the vertically-oriented bead-pack columns (10 mm x 50 mm) are subjected to atmospheric boundary at the top, and scanned at ~10 µm resolution every ~6 seconds for 2-3 minutes using the North Star Imaging, Inc. scanner at the University of Texas High-Resolution X-ray CT Facility. This approach allows the dynamic imaging of air-water transport by capturing the air-water interface as it moves across the static bead-pack porous media. Results of how saturation evolves with time and the processes of two-phase fluid topology evolution over time are presented.

Using Micro-CT for Quantitative Analysis of Polymeric Foams

Thomas Fitzgibbons

The Dow Chemical Company

Polymeric foams exhibit a complex 3-D cellular structure wherein numerous properties including the thermal conductivity and mechanical strength can be directly related to cell size present in the material. As is often the case then, it is important to be able to accurately measure the cellular dimensions within a foam. Herein we show how X-ray microtomography combined with image analysis procedures can directly measure the cellular morphology in 3-dimensions, alleviating issues with interpolating 2-dimensional imaging techniques to 3-dimensions. This work is being used to drive innovation in new foam technology with a clear eye to what formulation variables impact the cellular dimensions and internal morphology of the resulting foam.

Anomalous incisor morphology suggests tissue-specific roles for tfap2a/b in mouse dental development

Galaxy C. Gutierrez[1], Emily D. Woodruff[1], Eric Van Otterloo[2], Trevor Williams[2], Martin J. Cohn[1, 3]

[1] Department of Biology, University of Florida, Gainesville

[2] Department of Craniofacial Biology, University of Colorado Anschutz Medical Campus, Aurora

[3] Department of Molecular Genetics and Microbiology, University of Florida, Gainesville

Keywords: micro-CT, tooth, development

Mice have two types of differently-shaped teeth in their dentition, incisors, with a single cusp that are used for gnawing, and molars, with multiple cusps that are used for grinding food. Mammalian teeth develop from two types of tissues, the dental mesenchyme and the dental epithelium. Reciprocal signaling between epithelial and mesenchymal tissues is required to form properly shaped teeth, and the molecular basis of these interactions has received considerable attention. The transcription factors AP-2 alpha and beta (*Tfap2a* and *Tfap2b*) are important for craniofacial and dental development, but little is known about their roles in the regulation of tooth shape. In developing mouse teeth, *Tfap2a* is expressed in the epithelium and mesenchyme of incisors and molars whereas *Tfap2b* is restricted to the mesenchyme in the molars only.

To better understand the roles of *Tfap2a* and *Tfap2b* in dental development, we examined the shapes of incisors and molars in mice with conditional deletions of *Tfap2a* and *Tfap2b* in different tissue compartments. Tooth shape was analyzed using micro-CT and histology at embryonic day 18.5, when the tooth crown shapes are fully developed. We examined two different tissue-specific genetic mutants: one with *Tfap2a* and *Tfap2b* deleted from the epithelial tissue and one with *Tfap2a* and *Tfap2b* deleted from the mesenchymal tissue. Dental tissue was digitally isolated from other oral and craniofacial tissues from micro-CT data in VG Studio Max, and 3-dimensional volumetric models were constructed for each tooth. Results from the 3-D reconstruction and histology revealed that in mice with the epithelial-specific deletion of *Tfap2a* and *Tfap2b,* the upper and lower incisors are longer and are more curved than those of the control mice. Furthermore, some individuals have duplicated lower incisors. By contrast, the dental phenotype of mice with the mesenchyme-specific deletion of *Tfap2a* and *Tfap2b* did not differ from the control embryos. Overall, these results demonstrate that epithelial expression of *Tfap2a* and *Tfap2b* is important for controlling tooth number, length, and shape, whereas mesenchymal expression of *Tfap2a* and *Tfap2b* is not required for tooth development.

Digitally Unraveling Coiled Museum Specimens

Alexander S. Hall

Thermo Fisher Scientific, Houston, USA

Keywords: Volume Unfolding, Amira, ZIB, Museum Science

Museum specimens are often rolled, coiled, or flattened to fit storage containers. For formaldehyde-fixed specimens (e.g., most reptiles, amphibians, and fish), the storage geometry becomes rigid to the point of being irreversible. CT scanning may also impose unnatural orientations to accommodate a cylindrical scanning volume. One possible way to digitally restore a specimen's natural orientation is through volume unfolding. The best explored volume unfolding applications generally come from human medicine. Here, volume unfolding has been applied to colonoscopies, cortical tissues observed by MRI, and stomach lining as seen in barium contrasted medical CT. A recent development from the Zuse Institute Berlin permits virtual unfolding and flattening of folded and irregularly stretched papyrus scrolls considered too delicate to physically unravel (Baum et al. 2017). Borrowing from this innovation, I used this volume unfolding technique in Amira ZIB Edition (Stalling et al. 2005; https://amira.zib.de) to digitally unravel folded CT scanned museum specimens. This digital unraveling technique could be applied to any folded, wrapped, coiled, or otherwise deformed 3D specimen, such as from CT data. Some new applications were immediately apparent: direct visual comparisons between specimens, restored natural poses, more optimal posing for 3D animation, optimizing 3D printing geometry, and outreach through visual impact. Such a technique would not be restricted to any particular study organism. The added scientific value of an unfolded specimen is up to the creativity of the user, and I hope that this topic will spark further creativity in museum science.

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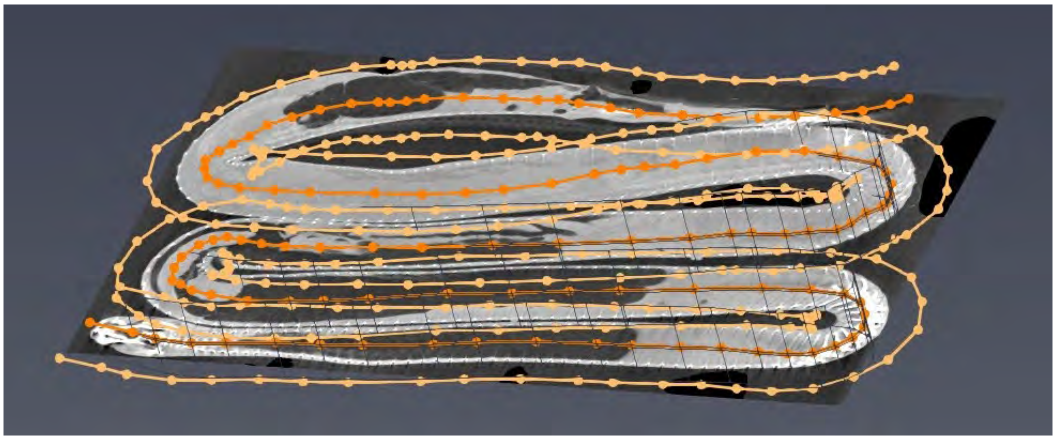

Development of armored skin in the genus Gekko (Squamata: Gekkonidae) using a CT-Scan approach

Cristian Hernández-Morales[1] Tony Gamble[2], Matthew Heinicke[3], Cameron D. Siler[4] and Juan D. Daza[1]

[1] Department of Biological Sciences, Sam Houston State University, 2000 Avenue I, Life Sciences Building, Room 105, Huntsville, TX, USA.
[2] Department of Biological Sciences, Marquette University, Milwaukee, USA
[3] Department of Natural Sciences, University of Michigan-Dearborn, 4901Evergreen Rd., Dearborn, MI, USA
[4] Department of Biology, University of Oklahoma, Norman, USA

Keywords: Morphology, Gekkota, Dermal ossifications

The development of osteoderms is widespread among reptiles, being present in crocodilians, turtles, and several squamates (skinks, cordylids, anguimorphs and geckos). There are three genera of geckos where osteoderms have been identified: *Tarentola, Geckolepis* and *Gekko*. Here, we studied 18 species of the genus *Gekko* using CT scans. We found osteoderms only in the species *G. gecko* and *G. reevesii* (formerly part of *G. gecko*). Osteoderms morphology changes ontogenetically; in *G. gecko*, osteoderms were not present in small specimens (64.72 mm SVL and below). These structures were registered in larger specimens (103.74 mm SVL and above). The osteoderms were distributed dorsally from the level of the anterior part of the frontal bone to the axis vertebra. In more mature specimens, the osteoderms are thicker and extend onto the anterior and the temporal areas of the skull. In one of the largest specimens (144.48 mm SVL), the osteoderms extended onto the jaw and the gular areas. The specimen of *G. reevesii* (133.23 mm SVL) also has osteoderms, but in smaller concentration to specimens G. gecko of comparable size. The morphology of individual osteoderms was also variable, presenting two different shapes. The more widespread type of osteoderms is rounded and flatter. In contrast, the second type is a conical tubercle distributed in a lateromedial row on the nape. The taxonomy of the genus *Gekko* needs to be revised, this unique feature would be of utility when differentiating from other members of the group.

Novel methodology for determining clinical wear in ceramic crowns and opposing enamel

Hsu SM[1], Ren F5, Chai J[2], Kim MJ[1], Abdulhameed N[1], Ana Bohorquez[3], Gary Sheffield[3], Clark AE[1], Neal D[4], Esquivel JF[1]*

[1] University of Florida College of Dentistry, Department of Restorative Dental Sciences, Gainesville, FL
[2] Northwestern University, Evanston, IL
[3] University of Florida Nanoparticle Research Facility, Gainesville, FL
[4] University of Florida College of Medicine, Department of Neurosurgery, Gainesville, FL
[5] University of Florida College of Engineering, Gainesville, FL

Keywords: intraoral scanner, wear, monolithic zirconia

A new method for measuring clinical wear of teeth was studied using a hand-held intraoral scanner equipped with metrology software. The accuracy of two quantitative data for wear measurement, depth and volume, of the intraoral scanner was evaluated by using a worn Dentoform® tooth, which was compared with X-ray computed microtomography (micro CT). A regression analysis demonstrated excellent correlation between the intraoral scanner and micro CT with 99.80% for depth and 99.84% for volume.

The hand-held intraoral scanner was further used to assess clinical wear. Thirty teeth in need of single crowns were prospectively randomized to receive either a monolithic zirconia (Lava Plus, 3M ESPE) or metal-ceramic crown veneered with a feldspathic porcelain (GC Initial™, GC America; Argedent 62, Argen, USA). In the same quadrants, two non-restored opposing teeth were used as enamel controls. The quadrants were scanned using the intraoral scanner at baseline, six-month and one-year after crown insertion. Monolithic zirconia and metal-ceramic crowns were compared at each time point. There was no significant difference in wear at any time point between both materials (six months $p = 1$; one-year $p = 0.165$); there was no significant difference in wear for antagonist enamel opposing each material wear at any time periods (six months $p = 0.152$; one-year $p = 0.235$). The antagonist enamel wear was also compared with control wear of opposing enamel. The wear of antagonist enamel from zirconia crown was greater than opposing enamel on metal ceramic, but the wear difference became insignificant after the first year (six months $p = 0.034$; one-year $p = 0.843$), suggesting a plateau in wear.

Hand-held intraoral scanner equipped with metrology software can be used to accurately quantify clinical wear data. The wear of monolithic zirconia was comparable with metal-ceramic crown and the opposing enamel after one year. This study demonstrates that monolithic zirconia is a promising restorative material.

Using micro-CT to investigate microanatomy of the giant Triassic ichthyosaur Shonisaurus popularis

Matthew R. Machado, Neil P. Kelley[†], Brandt T. Gibson

Department of Earth and Environmental Sciences, Vanderbilt University 5726 Stevenson Science Center, Nashville

Keywords: Paleontology; Marine Reptile; Fossils; Anatomy; Ichthyosaur; micro-CT

Ichthyosaurs are an extinct group of marine reptiles that occupied apex predator roles in Mesozoic marine ecosystems from the Triassic (~240 million years ago) until their extinction in the Late Cretaceous (~95 million years ago). Ichthyosaurs exhibit a number of anatomical novelties that distinguish them from other reptiles, and anatomical changes within the group track their evolutionary history and provide ecological and functional information regarding the lifestyles of these ancient marine predators. Historically, detailed studies of ichthyosaur microanatomy and histology relied on destructive serial sectioning of fossils, a technique that is undesirable for unique fossil specimens. X-ray microtomography (micro-CT or µCT) is a powerful, non-destructive alternative tool for investigating the microanatomy of fossils. Here we present high-resolution models of fossils belonging to the Triassic (~220 million-year-old) ichthyosaur *Shonisaurus popularis*. *Shonisaurus,* growing up to 15 meters in length, was among the first marine reptiles to attain gigantic proportions. *Shonisaurus* fossils are known primarily from a mass mortality assemblage where several adult specimens occur on a single bedding plane and are interpreted to have died over a short interval of time. Although the causes of this mass mortality remain unclear, the recent discovery of embryonic ichthyosaur fossils from this same site may help to clarify the paleobiological and paleoecological context of the assemblage. Our investigation confirms that these embryo fossils should be assigned to *Shonisaurus* based on shared anatomical characteristics and highlights important features including tooth morphology, tooth implantation within the jaw, and pattern of tooth replacement. These results will contribute to an eventual detailed redescription of this important fossil taxon and provide insight into the evolution and ecology of an extinct apex marine predator.

Digital Cranial Endocasts of Fossil and Modern Armadillos (Mammalia, Xenarthra, Cingulata)

Rachel E. Narducci[1, 2], Richard C. Hulbert Jr.[1], And Jonathan I. Bloch[1]

[1] Florida Museum of Natural History, University of Florida, Gainesville
[2] Department of Biology, University of Florida, Gainesville

Keywords: armadillo, cranial endocast, micro-CT, digital reconstruction

Cingulates (armadillos, pampatheres, and glyptodonts) vary in body mass from 85 g to about 1,000 kg and have had an impressive diversity in morphology and ecology since their first appearance in the early Eocene of South America. All are terrestrial with Chlamyphorini fully subterranean, Glyptodontidae and *Tolypeutes* ambulatory and/or graviportal, and the remaining taxa, Dasypodinae, Euphractinae, and Pampatheriidae, fossorial to some degree. Feeding strategies range from herbivory in the inferred grazing pampatheres and glyptodonts, omnivory in *Tolypeutes* and Euphractinae (except *Macroeuphractus* which is a proposed carnivore), myrmecophagy in Priodontini and Chlamyphorini, with Dasypodinae occupying a combination of myrmecophagous and generalist insectivore niches (Gaudin and Croft, 2015). The evolution of the brain in this diverse clade is not well known. In attempt to better understand how endocranial morphology correlates with differences in body size and ecology among cingulates, high-resolution x-ray computed tomography scans along with Volume Graphics Studio Max software were used to create digital endocranial models for 8 fossil and 7 modern genera of cingulates and 2 genera of modern anteater as outgroup representatives. Micron resolution of skulls scanned was between 34 to 115. Primary results highlight the diversity of endocranial morphologies among cingulates. In relation to other mammals, olfactory bulbs are large in all specimens, with relatively small cerebra and large cerebella (Fig. 1). Glyptodontidae have proportionally greater mass of the cerebellum than other cingulates and the modern fairy armadillos have greatest mass of the cerebrum. The extinct giant grazing forms, Glyptodontidae and Pampatheriidae, are the only cingulates that have pedunculate olfactory bulbs. The clade is mostly relying on sense of smell. Encephalization quotient (EQ) values (Jerison, 1973), based on digital endocranial cast volume and actual or estimated body mass from the literature (Bargo et al., 2000; McDonald, 2005; Tambusso and Fariña, 2015a, b; Vizcaíno et al., 2006), range from 0.16 to 0.75 in sampled fossil cingulates. EQ values of the modern armadillo sample range from 0.35 to 0.92 and 0.7 to 1.01 for the modern outgroup anteaters.

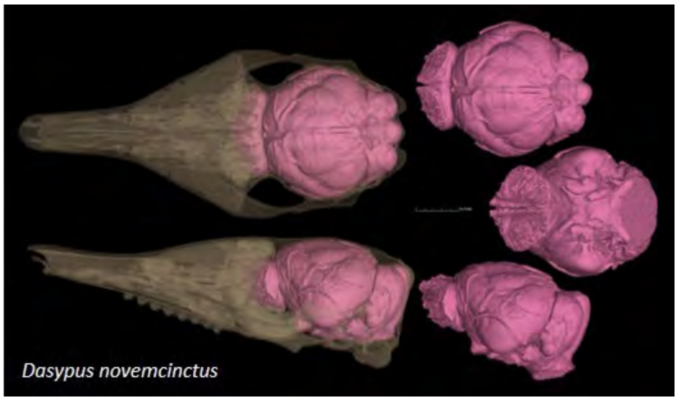

Figure 1: Digital endocranial cast and translucent skull model of the modern nine-banded armadillo, Dasypus novemcinctus.

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How does *Orcaella brevirostris* bony labyrinth morphology compare to other odontocetes (Cetacea: Odontoceti) and what are the implications for the evolution of high-frequency hearing in whales?

Eve Preucil, R.A. Racicot

W.M. Keck Science Department, Claremont McKenna, Pitzer, and Scripps Colleges, Claremont CA

Keywords: Inner ear, Dolphin, Hearing sensitivity

Bony labyrinth morphology varies across marine mammals and contains key information regarding hearing sensitivity. Understanding the morphology provides insight into phylogenetic relationships as well as ecological preferences. Globacephaline (melon-headed dolphins) hearing ranges have been extensively studied using acoustic technologies, but the relationship between morphology and hearing is yet to be fully understood. We investigated the variation in hearing-relevant morphology within globacephaline dolphins using microCT close-up scans of isolated petrosals. Using VGStudioMax 2.2, ImageJ and Avizo software, the bony labyrinth of several globacephaline species were digitally isolated and then measured. Specimens included both extant and extinct species including the Irrawaddy Dolphin (*Orcaella brevirostris*). Principle components analysis (PCA) yielded taxa groupings consistent with phylogenetic relationships. Further, the hearing sensitivity of globacephaline dolphins visualized by the PCA indicates that the Irrawaddy dolphin seems to have hearing ranges near those of narwhals and beluga whales. By studying globicephalines, we are contributing to bridging the gaps of knowledge in the relationship between morphology and direct measurements of hearing ranges (such as audiograms). Our analysis adds to previous studies on bony labyrinth morphology, bolstering clade-wide data and deepening our understanding of the intersection between phylogenetic relationships and environmentally driven adaptations. More comprehensive understanding of these morphological adaptations is important for informing conservation decisions as well as advances in deep-sea technology.

Micro-computed tomography unveils Triassic stereospondyls encased within their burrows

Calvin So[1], Aaron M. Kufner[1], Adam K. Huttenlocker[2], Jason D. Pardo[3], David M. Lovelace[4]

[1] Department of Geosciences, University of Wisconsin-Madison, Madison, Wisconsin, United States of America
[2] Department of Integrative Anatomical Sciences, University of Southern California, Los Angeles, California, United States of America
[3] Department of Comparative Biology and Experimental Medicine, University of Calgary, Calgary, Alberta, Canada
[4] University of Wisconsin Geology Museum, Department of Geosciences, University of Wisconsin-Madison, Madison, Wisconsin, United States of America

Keywords: paleontology, amphibians, micro-computed tomography

Micro-computed tomography enables paleontologists to access parts of anatomy in fossils that were previously difficult to observe without damaging specimens. Attempts to use micro-CT have improved our understanding of modern amphibian origins, by scanning burrows of an extinct amphibian that belongs to the dominantly aquatic group of amphibians known as Stereospondyli. Physical preparation of the burrows has proved to be a difficult task--the sandstone matrix is well-cemented and competent, which contrasts with the delicate and diminutive skeletal remains of the burrowing stereospondyls. However, micro-computed tomography has unveiled internal features of the braincase and features otherwise obscured by the surrounding matrix, allowing for the observation,

comparison, and description of skeletal elements in several different individuals. Notably, the preservation of the columella in at least one individual is recorded, and the observation of a smaller, juvenile individual allows for comparison with adult individuals. Observations have led to the conclusion that these stereospondyls shift away from an entirely aquatic life and have several adaptations for fossoriality, such as a shovel-like head for burrowing, laterally-oriented eyes, and a smaller body size. From our robust collection of burrowing stereospondyls, the preliminary results of the phylogenetic analysis using a recently published dataset and Bayesian posterior probability finds that this new taxon resolves within a stem-caecilian lineage including *Rileymillerus* and *Chinlestegophis*. These findings reinforce a stepwise acquisition of caecilian characters and give insight into a new mode of life in Stereospondyli.

We would like to thank the David B. Jones Foundation for funding the excavation and preparation of these specimens.

Walking towards rapid phenotyping: A semiautomated workflow for the multimodal quantification, visualization, and statistical comparison of osteological variation using high resolution-CT data of the human calcaneus

Nicholas B. Stephens[1], Lily J. Doershuk[1], Jaap P.P. Saers[2], Tea Jashashvili[3,4], Kristian J. Carlson[5,6], Adam D. Gordon[7], Jay T. Stock[2,8], Timothy M. Ryan[1]

[1] Department of Anthropology, Pennsylvania State University, University Park, USA

[2] Department of Archaeology, Cambridge University, Cambridge, UK

[3] Molecular Imaging Center, Department of Radiology, Keck School of Medicine, University of Southern California, Los Angeles, USA

[4] Department of Geology and Paleontology, Georgian National Museum, Georgia

[5] Department of Integrative Anatomical Sciences, Keck School of Medicine, University of Southern California, Los Angeles, USA

[6] Evolutionary Studies Institute, University of the Witwatersrand, Wits2050 Johannesburg, South Africa

[7] Department of Anthropology, University at Albany, SUNY, Albany, USA

[8] Department of Anthropology, Western University, London, Canada

Keywords: bone structure, skeletal variation, osteological plasticity

The skeleton tends to be the only record of an animal's life following death and extended burial. For this reason, physical anthropologists and paleontologists alike focus on acquiring as much comparative skeletal data as possible, which has only increased with computational and methodological advances (e.g. x-ray, medical/micro CT). While these advances have allowed for more granular studies on bone shape and structure, there are few methods that compare multiple levels of variation on complete skeletal elements. Here we use a semiautomated workflow combining multiple software suites to quantify calcaneal shape variation, cortical thickness (Ct.Th), and trabecular bone volume fraction (BV/TV) from micro-CT scans (~35-50 μm) of human calcanei from two North American archaeological populations (Norris Farm, n = 17 and Black Earth, n = 14). To statistically compare our results, we generated a mean mesh based on the shape analysis, which was then registered to the Ct.Th dataset. For trabecular bone volume fraction, we generated point clouds of the volume and associated BV/TV values, which were registered using an implementation of the coherent point drift algorithm. Ct.Th and BV/TV values were statistically compared across the corresponding vertices and points, respectively. Primary shape differences (PC1-3 53%) were found for calcaneus in the talar articular angle, calcaneal length and width, as well as for the shape of the tuber (heel). Areas of increased Ct.Th were found to overlap with distributions of high BV/TV. In comparing the populations, Black Earth had significantly higher Ct.Th, with significantly higher BV/TV that extended farther into the central portions of the calcaneus. While preliminary, our results demonstrate the feasibility in creating a semiautomated workflow for multimodal comparisons of single skeletal elements, which is an important step towards developing rapid phenotyping for larger datasets containing multiple skeletal elements.

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Inside the head of the smallest lizards in the world, a gecko and a chameleon

Maria C. Vallejo-Pareja[1], Juan D. Daza[2], Mark D. Scherz[3], Frank Glaw[3], Benedikt Geier[4]

[1] Department of Biology, University of Florida, Gainesville, Florida, USA
[2] Department of Biological Sciences, Sam Houston State University, Huntsville, Texas, USA.
[3] Sektion Herpetologie, Zoologische Staatssammlung München (ZSM-SNSB), Munich, Germany
[4] Max Planck Institute for Marine Microbiology Celsiusstr, Germany.

Two record tiny extant lizards have been described in the last two decades. Both species are leaf-litter dwellers on tropical islands. On one hand, a small gecko from the Isla Beata in the Dominican Republic, *Sphaerodactylus ariasae* (14.1 to 17.9 mm Snout-Vent Length -SVL), while the other is the dwarf chameleon from Madagascar, *Brookesia micra* (15 and 19.9 mm of SVL). The metric used to establish small size is the standard measure of SVL, but this linear measurement is not ideal to address miniaturization of the head, a critical structure that poses some limitations due to the special senses organs. Here we used micro-CT scans to compared in detail specimens from these two species and report the extreme transformations hardly appreciable with other techniques. Both *B. micra* and *S. ariasae* have similar skull lengths (4.1 and 4.2 mm), but both present different skulls configurations. Miniaturization have different effects on lizard's groups which indicates phylogenetic contingency over determinism. *Sphaerodactylus ariasae* differs from *B. micra* in having a depressed skull with a relative long snout rather than having a tall narrow skull with a reduced rostrum.

A new look at aubrites: investigating 3d modal mineralogy with x-ray computed tomography

Zoë Wilbur[1,2], Arya Udry[1], Ryan Zeigler[3], Kathleen Vander Kaaden[2], Francis Mccubbin[3], Karen Ziegler[4], And Christopher Defelice[1]

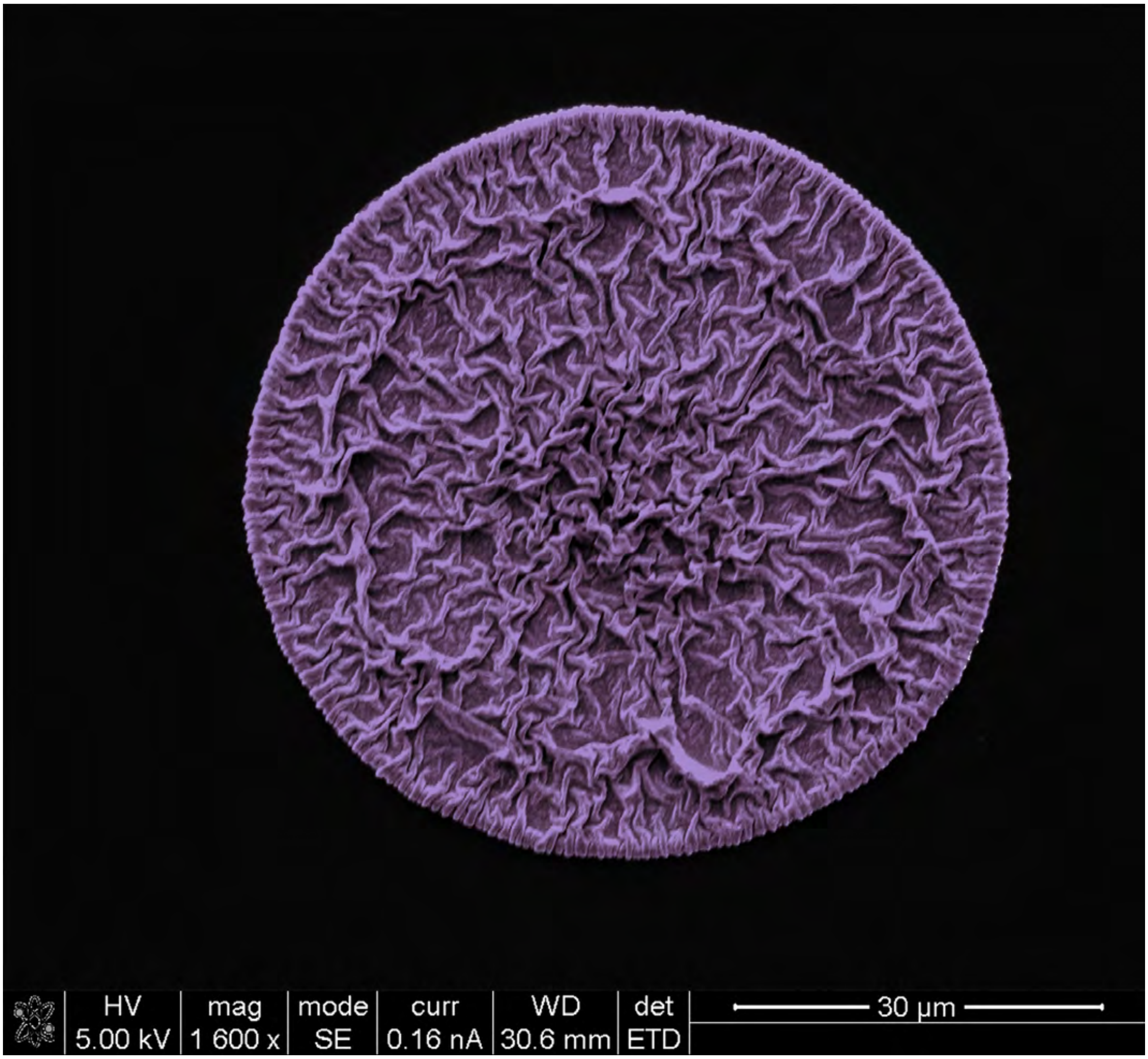
[1] Department of Geoscience, University of Nevada Las Vegas, Las Vegas, NV, USA
[2] Jacobs-JETS Contract, NASA Johnson Space Center, Houston, TX, USA
[3] NASA Johnson Space Center, Houston, TX 77058, USA
[4] Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, USA

The aubrites (~30 known meteorites) are a unique group of differentiated meteorites that formed on asteroids with oxygen fugacities (fO_2) ~2 to ~6 log units below the iron-wüstite buffer. At these highly reduced conditions, elements deviate from the geochemical behavior exhibited at terrestrial fO_2, forming FeO-poor silicates and exotic sulfides. While previous studies have described the petrology and 2D modal abundances of aubrites, this work investigates the 3D modal mineralogies of silicate, metal, and sulfide phases in aubrite samples, which are then compared to the available 2D data. In addition to 3D modal mineralogies, we have examined the geochemistry of fourteen aubrites, including mineral major-element compositions, bulk-rock compositions, and oxygen isotopic compositions to understand their formation and evolution at extreme fO_2 conditions. We utilize X-ray computed tomography (XCT) to non-destructively analyze the distribution and abundances of mineral phases in aubrites and locate composite clasts of sulfide grains for future analytical study. In order to better constrain elemental behavior under reduced conditions, we specifically target minerals phases that comprise moderately volatile elements (i.e. oldhamite [CaS], caswellsilverite [$NaCrS_2$] and djerfisherite [$K_6Na(Fe,Cu,Ni)_{25}S_{26}Cl$]) as it has been shown that their geochemical behavior changes as a function of fO_2.

Currently, we have produced 3D scans of the Norton County aubrite. The results of the XCT data have allowed for the determination of the abundances of silicate groundmass (i.e., enstatite, forsterite, albite, and diopside), light (based on electron density) sulfides (i.e. alabandite [MnS] and daubréelite [$FeCr_2S_4$]), heavy (based on electron density) sulfides (i.e., troilite [FeS]), and Fe,Ni metal by segmenting a density histogram in *Volume Graphics Studio* software. XCT scans of additional aubrites are underway. By combining the 3D representation of the exotic phases found in aubrites with existing 2D characterizations, we are able to better determine modal abundances. By integrating 3D and 2D modal abundances and geochemistry, we can ultimately better constrain aubrite petrogenesis and elemental partitioning under reduced conditions. Furthermore, application of this new 3D approach offers the opportunity to identify and select clasts for future study prior to cutting the sample, which will minimize sample loss of this precious material.

Imaging Competition

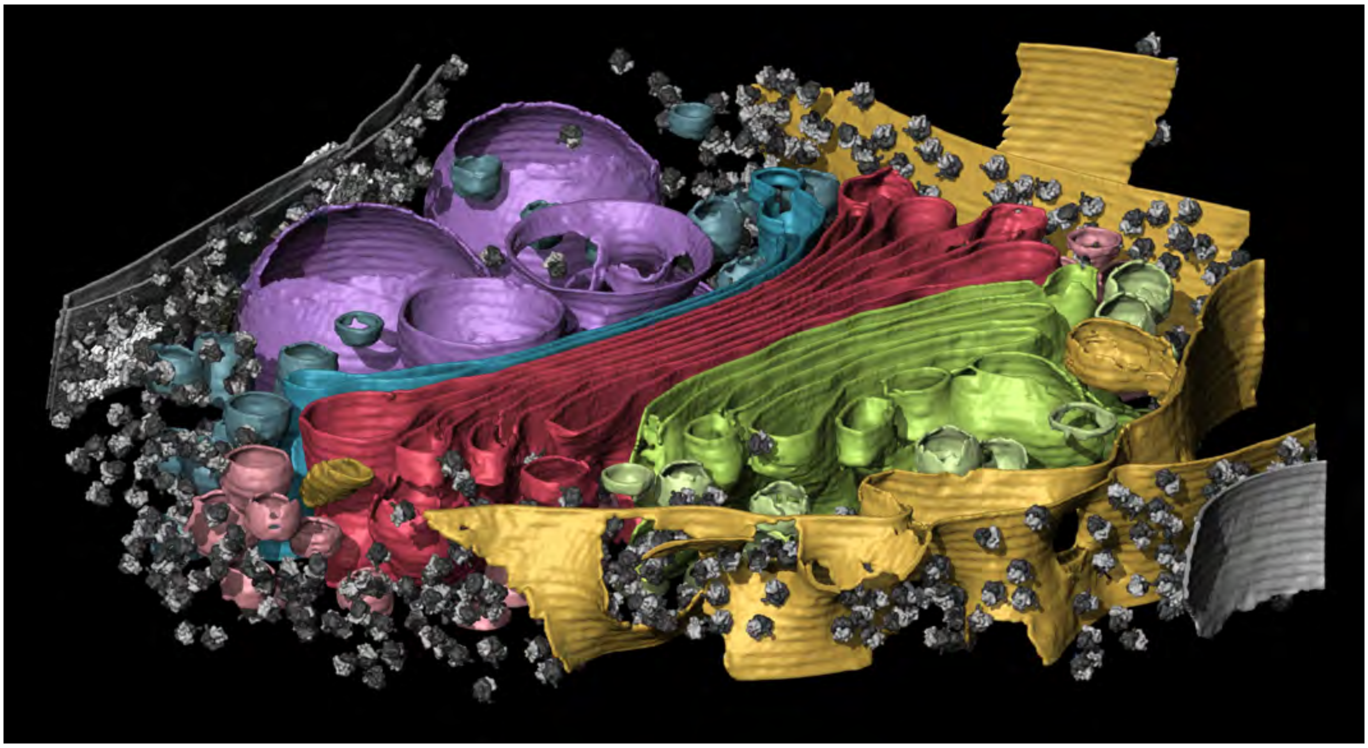
Thank you to those who entered the ToScA Imaging Competition. The images will be on display throughout the symposium and the winners will be announced at the symposium dinner.



Agglomerated ZnO seed nanostructures on ITO substrate

High aspect-ratio ZnO nanowire ar rays can be fabricated from ZnO seed layer by hydrothermal process. The above image was taken after coating the ITO substrate with ZnO seed layer. The samples were prepared in Ziegler's laboratory, Department of Chemical Engineering, University of Florida and I would like to thank Dr. Yang Zhao for preparing the samples.

Sarathy Kannan Gopalakrishnan, Department of Chemical Engineering, University of Florida



Golgi Apparatus Reconstructed from Cryo Electron Tomography

Thin lamella prepared using cryo-FIB on a flash-frozen green alga Chlamydomonas reinhardtii. A series of tilt-angle cryo-TEM images permitted 3D reconstruction of averaged subtomograms in Thermo Scientific™ Amira™ Software. Cryo-electron tomography reveals the in vivo spatial orientation of complex proteins at the resolution of a TEM.

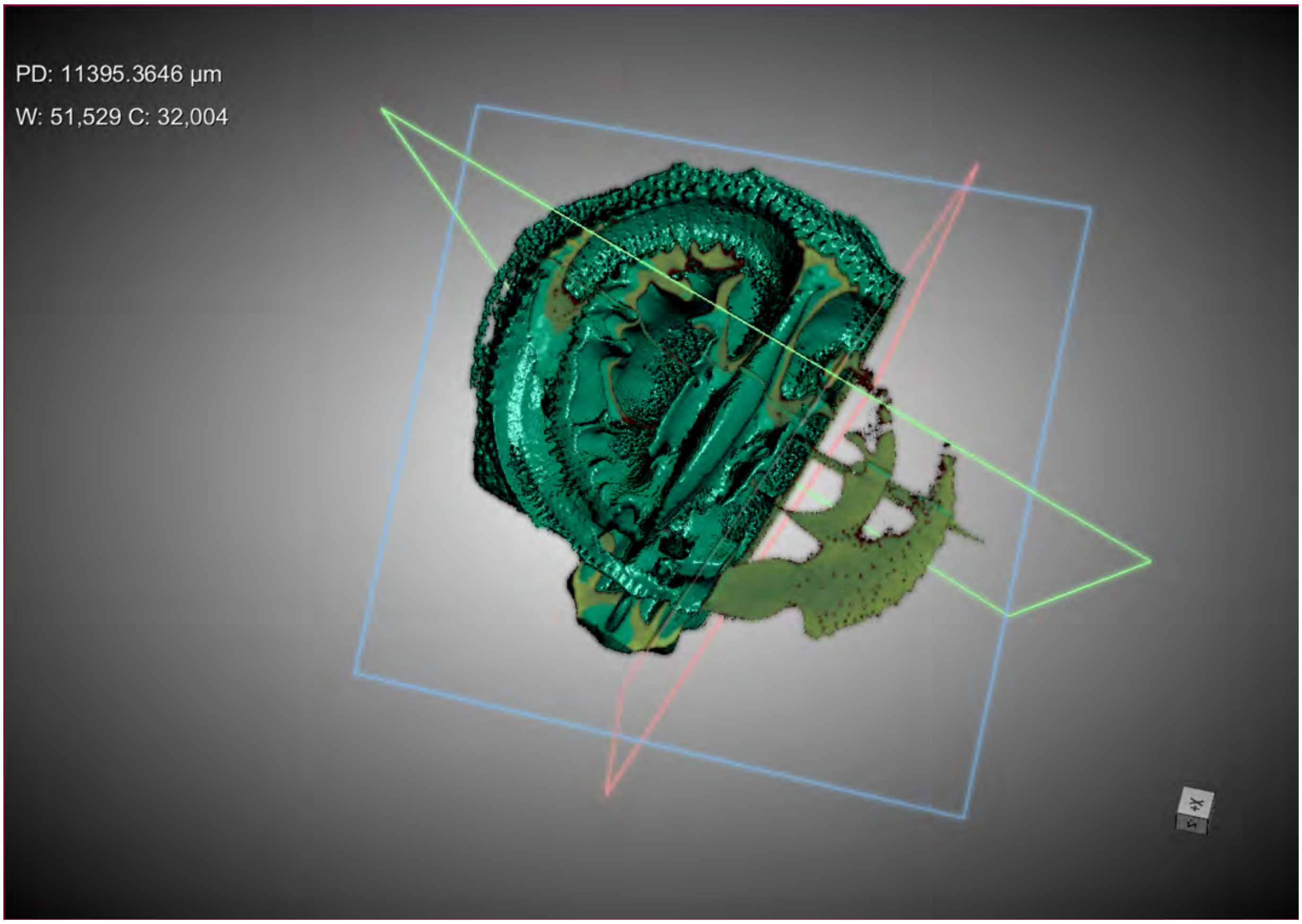
Data courtesy of Dr. Benjamin Engel at the Department of Molecular Structural Biology, Max Planck Institute for Biochemistry, Martinsried, Germany. First published in Bykov et al. 2017. The structure of the COPI coat determined within the cell. eLife, 6: e32493. doi:10.7554/eLife.32493

Alexander S. Hall, Thermo Fisher Scientific

Banded bellowsfish, Centriscops humerosus (SIO 05-134)

This image is a High-resolution computed tomography reconstruction of a Banded bellowsfish, Centriscops humerosus (SIO 05-134). The Banded bellowsfish is a deep water marine species found up to depths of 1,000 meters. Some of its close relatives include shrimpfishes, trumpetfishes, pipefishes, and seahorses. This reconstruction was colorized to show high and low density areas. This specimen was loaned from Scripps Institution of Oceanography in order to CT scan a representative species of every genus of vertebrate for the oVert Thematic Collection Network. Funded by NSF DBI-1701714.

Zachary Randall, Florida Museum of Natural History

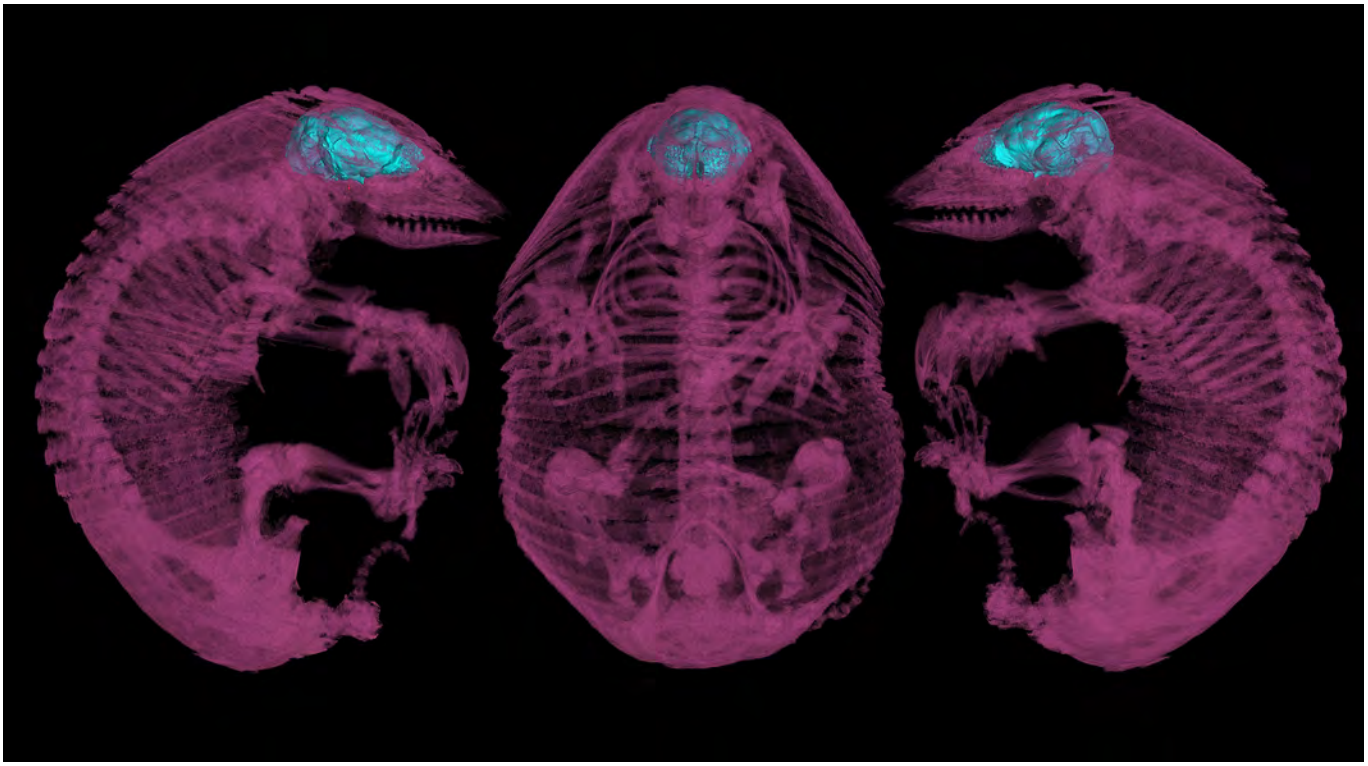


Modern Brachiopod Dorsal Valve Segmentation

Model of Thecidellina meyeri, featuring the dorsal valve including the skeletal structure that holds the brachidium (feeding tentacles) of this species. This specimen was collected by Dave Meyer in Curaçao, Netherland Antilles. Micro-CT data captured by James Hagadorn at the Denver Museum of Nature and Science, sample scanned unwedged at 40 keV and 200 uA for 4.1 s per projection; projections are at 0.26 degrees across 180 degrees. Threshold segmentation and modeling completed by Tasha Anderson at DMNS.

Acknowledgements: Dave Meyer; Ben Dattilo, Purdue Fort Wayne; James Hagadorn, DMNS; Patrick Sullivan, DMNS; Tasha Anderson, DMNS.

Lindsay Dougan, Denver Museum of Nature & Science, Digital Imaging Lab

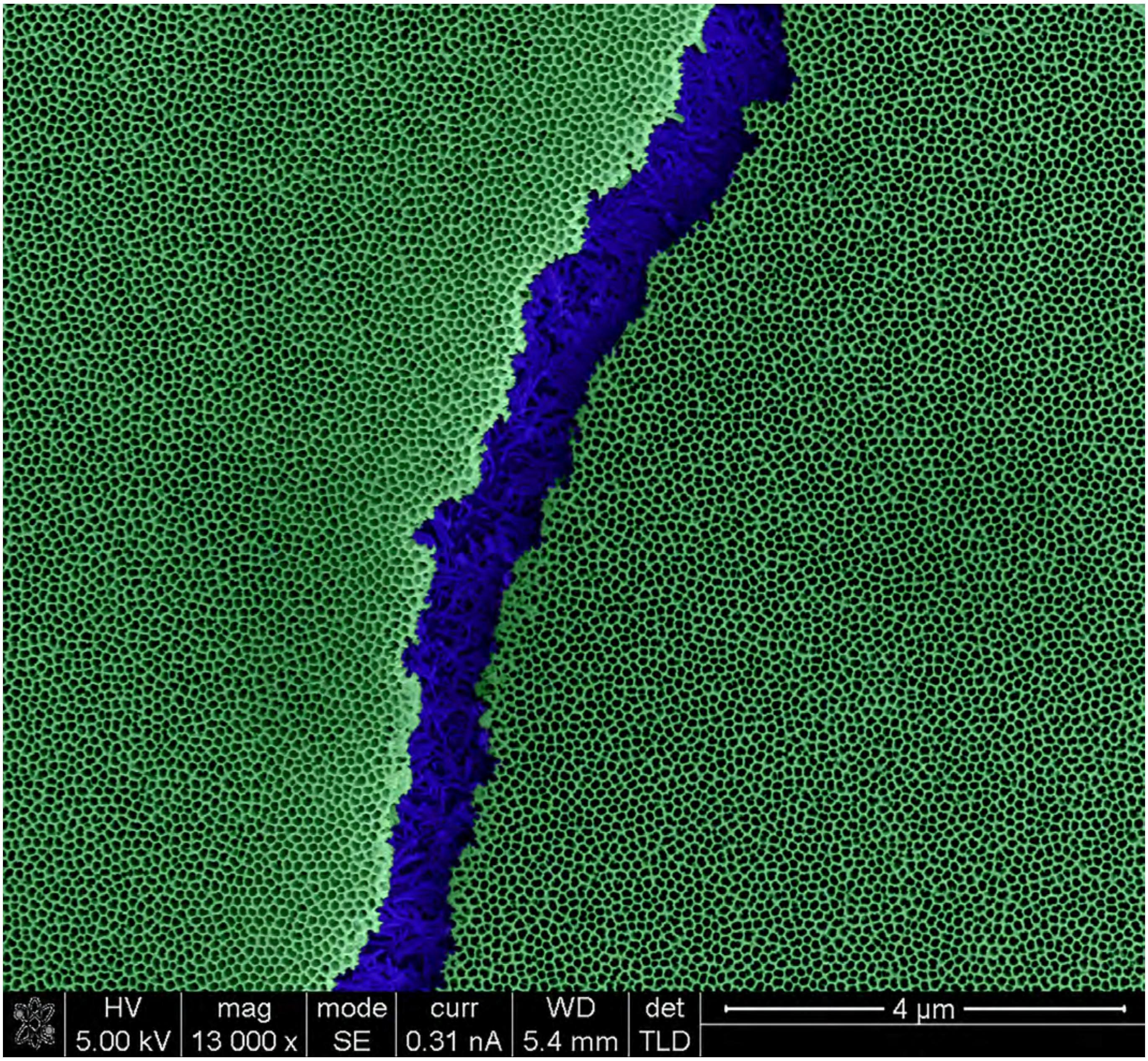


Armadillo Tea Party

Skeleton segmentation of a fluid preserved juvenile specimen of the Chocoan naked-tailed armadillo, Cabassous choacoensis (UF 20650), with digitally extracted cranial endocast in right and left lateral and ventral views.

Acknowledgements: This material is based upon work supported by the National Science Foundation (NSF) Graduate Research Fellowship under Grant No. DGE-1842473. The NSF funded initiative, oVert Thematic Collections Network, provided funding for CT scanning and access to the specimen via Morphosource.org. I thank Edward Stanley for scanning the specimen and training of the segmentation software and the Florida Museum Mammalogy Collection Manager, Verity Mathis, and Curator, David Reed, for providing access to the specimen.

Rachel E. Narducci, University of Florida



Polystyrene nanowires (blue) lurking underneath cracked anodized aluminum oxide template (green)

Anodized Aluminum Oxide (AAO) has high surface energy. When spin-coated with polystyrene (in toluene) solution, it is wicked into the AAO pores due to capillary action. Once the solvent dries, the wicking structures of polystyrene are retained inside the pores. The above image was probed into a cracked AAO, exposing the polystyrene nanowires. Anodized Aluminum Oxide (AAO) templates are widely used as an etch mask in plasma etching techniques. To aid the template transfer process, the brittle AAO templates are coated with polystyrene polymer to act as a mechanical support layer. The samples were prepared in Ziegler's laboratory, Department of Chemical Engineering, University of Florida.

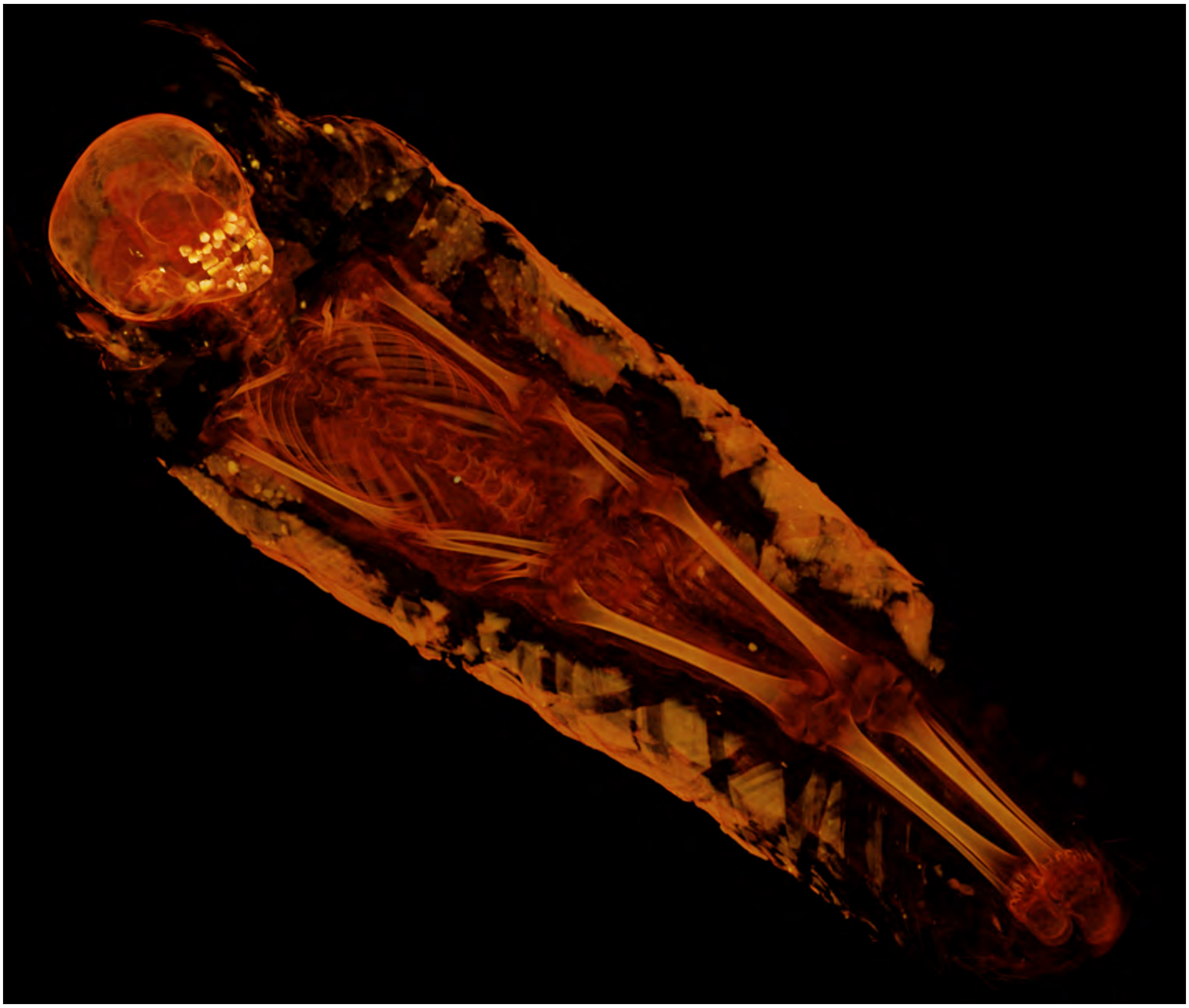
Sarathy Kannan Gopalakrishnan, Department of Chemical Engineering, University of Florida

Horned Desert Viper

This horned desert viper image was created from a spirit specimen belonging to the collections of the University Museum of Zoology, Cambridge. It was found in the Sinaitic Peninsula of Egypt in the early 20th Century. The CT scan shows the skeleton of this specimen, showing the skull and the hinged fangs used for injecting venom into prey.

Acknowledgements: Dr Andrew Gillis and Dr Jaap Saers, Chairs of Cambridge Biotomography Centre, Dr Jason Head, Curator of Vertebrate Palaeontology at University Museum of Zoology, Cambridge

Keturah Smithson, Cambridge Biotomography Centre, Department of Zoology, University of Cambridge



Unwrapping the life and death of a child in Roman-era Egypt

Volume rendered CT scan of a Roman-era Egyptian mummy, with particular focus on the skeletal remains of the child within. Thanks to Dr. Stuart Stock for collecting these data and providing the opportunity to collaborate, as well as to Drs. Paul Morse, Richard Kay, Blythe Williams, and James Pampush for assistance in the preparation of this image.

Michala K Stock, PhD, Department of Exercise Science, High Point University (current); Department of Anthropology, University of Florida (prior affiliation when image was produced, student)

Notes

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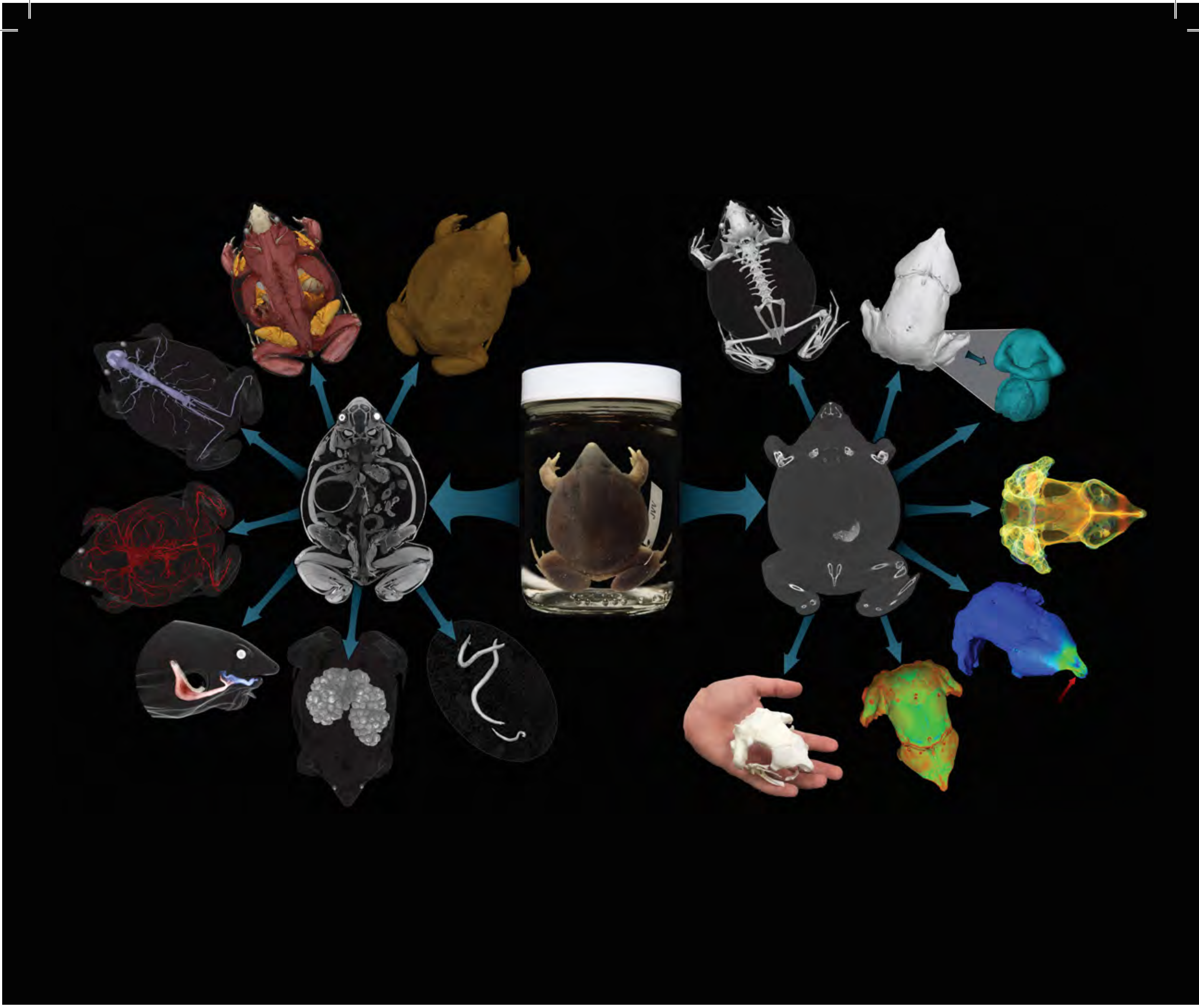

Thank you to the Florida Museum of Natural History and the University of Florida for supplying the images used throughout this booklet.

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