The 2016 Advisory Committee Report
for
The University of Texas Computed Tomography Laboratory (UTCT)

Committee members:
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The committee visited UTCT facilities on 6-7 May 2016 and held discussions on site with the staff and students of the UTCT.

Summary

UTCT is a unique facility that both leads and serves the geosciences community in multiple ways. The directors and the staff, through their commitment and personal investment in UTCT achievements, their outreach across the geoscience community, and a cost-effective management, have created a high-quality and accessible center that has fostered the use of X-ray computed tomography across a broad swath of the earth and planetary sciences. UTCT continues to break new ground in CT imaging and provide a large and varied user base with quality service and is now entering into a new phase of operation. After 1.5 days of meeting and discussion the advisory committee has assembled a series of observations and recommendations that are designed to help UTCT evolve into its new, 2nd phase of operation:

The committee sees UTCT as the natural hub of a federation of 3D scanning facilities in North America because of its range of instruments and services, its excellence in data acquisition and derived imagery products, and its large user base around the country. Even though table-top X-ray tomography units are becoming widespread throughout the USA, because of its track record and expertise in serving the community UTCT should play a leading role in developing the 3D scanning community in North America and organize a federation of CT facilities to set standards, formalize best practices, and innovate X-ray tomographic data collection and analysis. UTCT should take a leadership role in developing the 3D scanning community in the geosciences, and form a Research Coordination Network (RCN) or similar federation of users.

The committee sees the clear need for UTCT to purchase a new X-ray tomography scanner with micron-scale resolution and enhanced abilities such as phase contrast imaging and the ability to perform in situ, 4D experiments. Such a new machine will complement the existing capabilities of the facility, allowing researchers to assemble data on multiple scales. Today's scientific frontiers include processes that operate on the micron scale; adding capability to the UTCT will open new avenues of research for the PI's and other users of the facility, but even more importantly will attract new users. A submicron-scale X-ray tomography scanner would also be a useful addition to UTCT and would also allow the PI's to perform some of their research discussed with the committee, but is of lower priority than a new, micron-scale scanner.

UTCT has been a leader in the archiving and browsing of CT data through its creation of the

Digimorph digital library. UTCT needs to continue its effort on this project and continue to help define the data standards for serving 3D data. The committee recommends that working in conjunction with computer scientists and a consortium of other 3D imaging laboratories, UTCT should expand the Digimorph website and make it a portal for all 3D imaging data available on the web in an interoperable format. Such a portal would be of immense aid to researchers by creating a readily accessible, easy to navigate, library of 3D images that would also serve educational purposes.

The committee recommends that UTCT increase outreach at both the scientific and K-12 levels. At the scientific level UTCT is well-known and respected by vertebrate paleontologists, but is less recognized more broadly. The committee recommends that UTCT—a federally funded facility—host booths at major geoscience meetings (e.g., GSA and AGU) to better inform the community of the UTCT capabilities and how they can be used in geoscience research. The user workshops offered by UTCT are extremely successful, but reach only a small number of scientists each year. To increase their reach, the committee recommends that UTCT, working in conjunction with other X-ray tomography experts, organize a MSA short course (with an associated volume in Reviews in Mineralogy) as well as at the Society of Vetebrate Paleontology meeting to teach the geoscience community. At the K-12 level, the committee thinks that the expertise and 3D reconstructions already developed at UTCT can be used in conjunction with help from other sources (e.g., iDigBio) to construct teaching modules on evolution.

Overview

UTCT is a leader in X-ray tomography applied to the geosciences. UTCT is one of the few labs where multi-scale X-tomography can be performed on a routine basis with resolutions from as high as approximately 1 mm down to under 10 microns. The laboratory is not only recognized for its leadership role in scanning, but also in developing some of the software tools that are routinely used at other laboratories around the world. The directors, R. Ketcham and T. Rowe, and the staff are world-renowned experts in their fields; they are dedicated and hardworking and are operating an important analytical resource for the entire geoscience community. UTCT continues to improve methods for data acquisition, reconstruction and segmentation as applied primarily to geological (*sensu lato*) samples. They also are uniquely equipped with the personnel to create the software needed for specialized, quantitative measurements of X-ray tomographic data. Furthermore, they play a valuable role in teaching the next generation of geoscientists to effectively use X-ray tomography to expand their horizons as they study samples varying from meteorites formed in the early solar system through fossils to the evolution and operation of mammalian brains. UTCT's development of the Digimorph digital library is an example of its leadership role in both the archiving of X-ray tomographic data and in outreach to both scientific researchers and the general public. Despite continuing IT challenges (such as the large size of many datasets, internet security threats, and rapidly changing technologies and sevices), UTCT is expanding Digimorph and considering new applications of the data contained within it. Digimorph is a model that can be used for the development of other digital data repositories for 3D data around the world. UTCT has been a leader in outreach to the scientific community by providing in-house workshops each year to students from around the country. In these workshops the students have been taught the tools and techniques they need to extract quantitative data from tomographic images that they need for their research.

UTCT is moving into its second phase of operation. Rather than becoming less relevant as scanners proliferate at other institutions (often run by transient graduate students or other non-dedicated staff), the need for UTCT to serve as expert stewards is actually escalating. All CT users will benefit by

supporting UTCT as it enhances its role as a leader in the 3D imaging community through its continued development of new techniques, its archiving of 3D imagery, and its outreach to geoscientists and the general public.

Topical issues

The advisory committee's purpose was to discuss the short and long term goals of the University of Texas Computed Tomography laboratory (UTCT) and help them develop the strategies to achieve those goals. Prior to the visit the committee what provided with a list of questions that the UTCT would like to discuss with the committee. Each of these questions is listed below followed by the response of the committee following extensive discussions.

1. As the number of alternative sources of CT data grows, what relative priority should UTCT place on its roles on behalf of NSF and the geological community as: a repository of specialized expertise and training; a provider of high-quality data and scientific research; a curator for voxel data and data products; a center of active research into experimental and data processing methods?

The committee thinks that UTCT will broaden its impact by leveraging its history of technological innovation and demonstrated leadership in the field of 3D imaging in the geosciences to foster and develop the computed tomography community. In order to continue its leadership the committee strongly endorses UTCT's plan to extend their multi-scale analytical capabilities to finer scales through the acquisiton on new instrumentation that will allow not only better resolution, but also allow in situ 4D experimentation. Combining this new instrumentation with the existing capabilities in the lab will allow UTCT to forge new linkages between 3D morphologies and micron-scale geochemical analyses of the samples analyzed. These capabilities are critical for pushing the field- developing new research questions and training the next generation of geoscientists in new-generation methodologies.

Importantly, The committee advises UTCT to lead and federate other CT groups around the country (and the world, for that matter) to define best practices for 3D data collection and analysis, as well as the sharing and archiving of data. This goal could be accomplished through the establishment of a Research Coordination Network (RCN).

The Digimorph data repository (http://digimorph.org/) developed by UTCT has been a great success and can be used as a model for repositories of other 3D imaging data. The requirements for serving digital data and complying with data management plans are growing and changing rapidly. The facility needs to maintain this resource to the community. The committee recommends that UTCT lead, in conjuction with the 3D imaging community (the federated CT RCN), the continued development of portals (e.g. Digimorph) for serving and requirements for archiving 3D imaging data and consider building or contributing to a portal to other data repositories (at UT and other sites) that allows researchers and other interested people easy access to the 3D imaging data available on the web. Working together with other CT laboratories, UTCT should begin to establish linkages to other geoscience data archives such as IEDA. Such an ambitious project must be developed in conjunction with other CT laboratories and computer scientists in order to make an efficient, scalable access point for all and can be associated with the EarthCube and iDigBio websites.

As an NSF facility, UTCT should continue to drive experimental methods forward and develop new methods to analyze CT data that are not available in commercial software and make these methods available to the entire community. UTCT is poised to play a significant role in defining the compliment of laboratory based CT with synchrotron based CT and can aid researchers in determining

the proper CT tool to answer their research questions.

2. What are the present needs/desires of UTCT's various internal and external research constituencies, and how are they likely to develop in both the short- and long-term?

UTCT has consistently repaired and upgraded its currently owned equipment to keep the laboratory at the forefront of X-ray tomography research. Indeed UTCT is one of the few places in the world where multi-scale X-ray tomography can be easily and routinely performed. However, the latest generation of X-ray tomography machines provide new imaging modalities (e.g., phase contrast imaging) and the ability to perform in situ experiments on machines with spatial resolutions less than 10 microns, which cannot be performed on the equipment at UTCT. The committee thinks that there is a clear need for the acquisition of the latest generation of state-of-the art scanners which hold the promise of better imaging of biological tissues that are characterized by only small differences in X-ray absorption, invertebrate fossils (currently difficult because of the low contrast between fossilized body parts composed of the same material, calcite) and of crystals in matrices of similar composition (e.g., feldspars in a glass of rhyolitic composition). It is also clear that for some of the scientific cases discussed at the meeting a X-ray tomography scanner with a resolution in the sub-micron range will be a necessity and should be considered a future acquisition when the science needs this tool. Acquisition of such an instrument would allow UTCT to scan from submicron to almost mm resolution and has the potential to revolutionize our understanding of evolutionary processes and the mechanisms of crystal nucleation and growth.

The committee also recommends that UTCT encourage the development of 4D experiments in its imaging facilities. Such experiments could be in situ experiments utilizing continuous scanning of rapid processes as they occur, or ex situ experiments where the sample is subjected to a specified set of conditions (e.g., high temperatures), removed from the experimental apparatus, then imaged and returned to the experimental apparatus to experience the specified set of conditions for a longer duration before re-imaging. Such experimentation is still extremely rare and holds the promise of a better understanding of processes such as crystal growth.

3. Is the present UTCT funding model, blending NSF and JSG support with user fees, the best one? How can we go about distributing facility support across other research constituencies, such as NASA and/or NIH?

The committee encourages UTCT to search for funding from multiple sources. NSF and JSG will most probably remain the primary funding sources, but UTCT should also approach NASA and if more biological research is performed using new techniques and instrumentation then NIH should also be approached. The UTCT directors noted that service to (and funding from) the petrochemical industry has not been a major constituent of UTCT activity by design, allowing a broad spectrum of research interests to fill out the UTCT portfolio.

4. In view of the needs of the larger scientific community, how should UTCT's outreach and training mission evolve? In addition to our in-house, hands-on short courses, should UTCT 'take the show on the road' to other scanning centers with concentrated user bases? Or, should we aim for larger-scale leveraging? What is the national and international need for coordination and leadership in the CT community, and what role should UTCT play in fulfilling it?

The hands-on workshops UTCT has been holding for a small group of students and researchers have been very successful, but at a very small scale. These workshops are valuable training experiences and must be continued. The committee discussed holding similar workshops associated with major

geoscience meetings (e.g., GSA and AGU), but the logistics of providing the necessary hardware and software for these workshops at locations other than UTCT are daunting. An alternative is for UTCT to organize an MSA short course (with an associated volume of Reviews in Mineralogy) that could be given in association with other CT groups and held in conjunction with one of the major geoscience meetings.

X-ray tomography (and the NSF facility at UT) remains little known to many geoscientists; UTCT should take an active role to advertise CT to all members of this large and diverse community, especially as CT is becoming an increasingly important technique across the geoscience fields. The committee recommends that UTCT begin hosting booths at major geoscience meetings to provide the community with a better understanding of the capabilities of CT imaging through informal discussions supported by a display that profiles the facility's capabilities and some of the exciting images and discoveries made using CT. A meeting booth to show how UTCT can aid geoscience research, profile projects, and engage researchers and students will help broadcast the message to new audiences.

UTCT also can play a role in K-12 education. For example, the committee suggests that UTCT investigate how it can use its data on vertebrate evolution to develop teaching modules in collaboration with other scientific organizations (e.g., iDigBio).

5. What is the optimal vector for continued development of the DigiMorph library? Can and should it serve as a working exemplar of an on-line data repository, in consideration of NSF policies regarding long-term data management? If so, how does it need to evolve in terms of personnel, hardware, and software, and what should its funding and sustainability model be? How should we participate in other data management efforts, such as at NASA and through EarthCube?

UTCT should be proud of the success of DigiMorph, and it should be used as a model for future repositories of CT data. UTCT is urged to collaborate with other groups working to archive data on the web for all to use (e.g. iDigBio, EarthCube, IEDA, NASA etc.). UTCT has the expertise and the recognition to provide a portal that could be used to search and access 3D tomographic geoscience data housed at various websites around the world. In order for UTCT to participate in such a grand undertaking they must work with other CT laboratories and computer scientists to build a robust interface, and for this are almost certain to need a grant specifically targeted to improve data archiving.

6. What are the most important recent developments in CT technology, and what is their potential impact upon both current geological research and the development of new applications? What is the optimal upgrade path for UTCT instrumentation? What role, if any, should UTCT play in 3D printing?

UTCT has led the way in multi-scale CT imaging and the latest technological advances have increased the resolution of laboratory X-tomographic machines well into the sub-micron range, which opens many new avenues of study, whose impact, although unknown at the present time, is certain to be great.

In addition to the increases in resolution, new imaging modes on laboratory machines have been developed that allow the visualization and distinction of phases with only small differences in X-ray absorptivity. In addition, new algorithms for the segmentation and separation of objects of interest in 3D images have been developed. This new instrumentation is needed at UTCT, particularly because their association with NASA continues to grow and NASA's potential need for the non-destructive analysis of precious and very small samples such as those from asteroids, comets, and cosmic dust, that has been collected by aircraft and interplanetary spacecraft over the past few decades.

Other Recommendations

A few miscellaneous recommendations emerged during the discussions between the committee and UTCT:

The committee recommends that UTCT create a short vision statement to better support their outreach and messaging. Such a vision statement could be used in their informational literature and at the booths the committee recommends be hosted at national geoscience meetings.

The committee recommends that UTCT build a 5-10 year business plan. This will align with the strategic planning efforts of UTCT and enable UTCT to present definitive planning and goals to NSF in their future proposals. Such a document will aid UTCT in answering questions such as "How much should UTCT grow in the next years?".

The committee recommends that the advisory committee hold a virtual meeting (via webconferencing) with the UTCT directors and staff in the Spring of 2017 in order for UTCT to keep the advisory committee updated on any changes that may have occurred since the May 2016 meeting.

Final Comments

The committee was extremely impressed by the instrumentation, personnel, and productivity of UTCT. UTCT is a great resource for the geoscience community and has a width and breath of research spans from the study of fossils to meteorites. The laboratory is a success and clearly deserves support from its department, its school, its university and state and federal governments.