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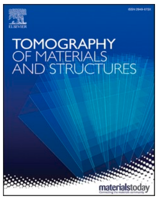

The role of networks to overcome large-scale challenges in tomography: The non-clinical tomography users research network

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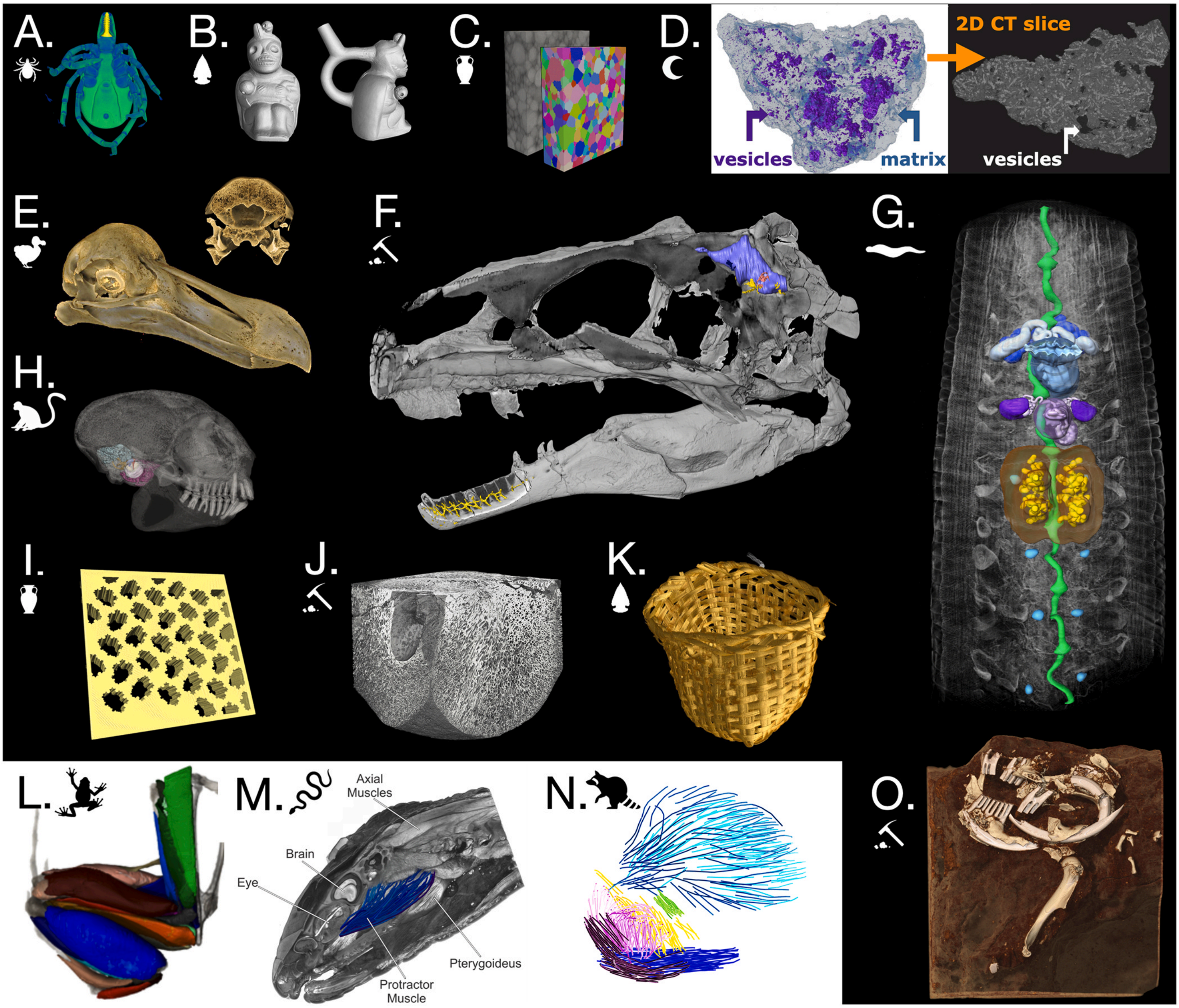

Fig. 1. Exemplar 2D and 3D renderings, illustrating the broad application of tomographic research: A) Deer tick (*Ixodes*); B) Peruvian Moche effigy flute (The University of Arkansas Museum Collections 94–13-3); C) Microstructure of a ceramic monolith with grains color-coded according to their crystallographic orientation; D) 3D volume rendering (left) of Apollo 17 basaltic moon rock (matrix is transparent blue) with vesicles extracted (purple) and a 2D view (right) of vesicles within the rock, comprising a variety of phases; E) Dodo (*Raphus*) skull with inset showing a transverse section through the braincase (Oxford University Museum of Natural History ZC.11605); F) Partial skull with 3D-segmented endocast and cranial nerves of the dinosaur *Allosaurus;* G) Contrast-enhanced visualization of the internal organs of the hermaphroditic medicinal leech *Macrobdella,* featuring male reproductive structures (blue), female reproductive structures (purple), ventral nerve cord (green), and accessory organ (orange); H) Owl monkey (*Aotus*) skull showing the tympanic cavity (white), anterior epitympanic sinus (purple), posterior epitympanic sinus (light blue), malleus (red), incus (blue), and inner ear (yellow); I) Scattered-light filter, fabricated through Bosch etching of a silicon photonic chip; J) Trabecular bone in a *Tyrannosaurus* (Museum of the Rockies 1125) jaw joint; K) North American historical woven basket (The University of Arkansas Museum Collections 32–22-13); L–N) Contrast-enhanced digital dissection of skeletal muscles, progressing from whole muscle segmentation (L) to full isolation of individual muscle fascicles (N): L) the pelvis and hindlimb of the Guinea shovelnose frog *Hemisus* with each muscle segmented and colored separately, (M) the head of a copperhead snake *Agkistrodon* with major features labeled and an algorithmically reconstructed muscle fiber model of the protractor pterygoideus muscle (blue), and (N) isolated fiber arrangements of the masseter muscle layers (pink, purple), temporalis muscle layers (light blue, navy blue), digastric muscles (blue), medial pterygoideus muscle (yellow), and lateral pterygoideus muscle (green) of an adult male raccoon (*Procyon*); O) North American Late Pliocene-Early Pleistocene sediment block containing various bones and associated upper and lower dentitions of the arvicoline rodent *Ophiomys.* Silhouettes indicate the kind of specimen; sample images contributed by T.J.P., M.W. & C.E.T., A.K., Z.E.W. & J.J.B., J.M.W., E.J.L., F.E.G., K.P.F., E.M.-S., C.M.H., H.D.O., A.L., C.M.Z. & C.M.H, E.D., and C. B.W.

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ABSTRACT

Our ability to visualize and quantify the internal structures of objects via computed tomography (CT) has fundamentally transformed science. As tomographic tools have become more broadly accessible, researchers across diverse disciplines have embraced the ability to investigate the 3D structure-function relationships of an enormous array of items. Whether studying organismal biology, animal models for human health, iterative manufacturing techniques, experimental medical devices, engineering structures, geological and planetary samples, prehistoric artifacts, or fossilized organisms, computed tomography has led to extensive methodological and basic sciences advances and is now a core element in science, technology, engineering, and mathematics (STEM) research and outreach toolkits. Tomorrow's scientific progress is built upon today's innovations. In our data-rich world, this requires access not only to publications but also to supporting data. Reliance on proprietary technologies, combined with the varied objectives of diverse research groups, has resulted in a fragmented tomography-imaging landscape, one that is functional at the individual lab level yet lacks the standardization needed to support efficient and equitable exchange and reuse of data. Developing standards and pipelines for the creation of new and future data, which can also be applied to existing datasets is a challenge that becomes increasingly difficult as the amount and diversity of legacy data grows. Global networks of CT users have proved an effective approach to addressing this kind of multifaceted challenge across a range of fields. Here we describe ongoing efforts to address barriers to recently proposed FAIR (Findability, Accessibility, Interoperability, Reuse) and open science principles by assembling interested parties from research and education communities, industry, publishers, and data repositories to approach these issues jointly in a focused, efficient, and practical way. By outlining the benefits of networks, generally, and drawing on examples from efforts by the Non-Clinical Tomography Users Research Network (NoCTURN), specifically, we illustrate how standardization of data and metadata for reuse can foster interdisciplinary collaborations and create new opportunities for future-looking, large-scale data initiatives.

Introduction

Since its inception in the early 1980's micro- and nano-scale computed tomography (CT) has fundamentally transformed the aerospace, archaeological, biological, biomedical, engineering, and geological sciences by allowing nondestructive imaging inside of complex, opaque objects (Fig. 1) (see also [11,41,20,44]). National and international funding agencies, such as the National Science Foundation (NSF), the National Institutes of Health (NIH), and the National Aeronautics and Space Administration (NASA) and their counterparts outside of the United States, have embraced CT for documentation of, and hypothesis testing about, the nature of 3D structure-function relationships in an enormous array of items. Institutional support has led to extensive methodological and basic science advances that have made imaging and 3D-digitization-based research and outreach core aspects of STEM toolkits. This includes studying the failure mechanics of engineered components, digitally unrolling friable ancient scrolls, analyzing meteorites for clues to the origins of the universe, documenting animal models for human health, optimizing iterative manufacturing techniques, investigating flow mechanisms in porous media, observing (longitudinally) processes such as crack dynamics during fatigue, or capturing the internal morphologies of modern and fossilized organisms using digital preparation (e.g., [1,2,3,4,5,7,9,10,13,15]; [17]; [23,26,28,29,30,35,36,40,43,45,47,50,51]).

The year 2022 marked the 50th anniversary of the invention of the first commercially successful CT scanner [19,42]. Across five decades investment in scanning systems and auxiliary equipment has generated a mainstream science, technology, engineering, and mathematics (STEM) industry adjacent to academia, focused on capturing the highest possible quality 3D image data, leveraging the resulting spatial accuracy and fine detail to create virtual objects, and digitally sharing the resulting data with colleagues, students, and the public. Within academia, this pipeline routinely incorporates student training (e.g., high school, undergraduate, graduate, medical, and veterinary students), collaboration across large and increasingly international research groups, 3D printing of internal features of micrometer-scale objects at macro-scales, and even repurposing research visualizations into scientific art [21,24,25,37,39].

In these joint efforts, members of industry typically design and build advanced imaging platforms or consult on academic instrumentation development, and teams of researchers and students utilize the resulting technologies. Manufacturers optimize CT data-collection workflows that incorporate proprietary metadata (e.g., information about data, such as acquisition and reconstruction parameters) and image volume file types. Notably, some communities (e.g., synchrotron tomography specialists) do rely heavily on custom-built systems and code. However, there have been relatively few successful attempts to standardize metadata content and outputs between functionally similar instruments for cross-platform use (e.g., OME BioFormats, DICOM). For example, even though the physics of scanning is fundamentally the same for X-ray CT platforms regardless of manufacturer, the resulting raw and metadata files are usually incompatible across scanners. Metadata fields describing essentially the same physical property are reported with disparate names, units, and even spatial axes across scanning hardware, making it difficult (or impossible) for even the most experienced tomographers to interpret metadata from instruments they have not personally used. In some cases, parameters are published without sufficient information for a user of any proficiency to interpret them.

Likewise, even though CT scanners produce processed datasets in the form of image stacks, files created during the virtual rendering of 3D objects (e.g.,.AM,.TXM,.VGL) often are fully or semi-proprietary and cannot be opened across multiple 3D-rendering software platforms. Instead, only finalized, sometimes highly derived, virtual products (e.g.,. JSON,.VTM,.STL) are standardized for cross-platform use. Researchers have embraced these lock-in systems out of necessity because meaningful alternatives are not yet available or else require enormous resources for *de novo* development. As a result, digital warehouses for publicly funded CT data (e.g., MorphoBank, MorphoSource, Phenome10K, Open Science Framework) tend only to host outputs from specific steps in the data generation pipeline that utilize nonproprietary file formats such as Unicode-8 plain text files (for metadata), Tagged Image File Formats (for image stacks and projections), and stereolithography and other mesh file formats (for surface geometry). Further, different scientific and industrial disciplines (e.g., from individual labs to separate fields) acquire CT scan data with a variety of intentions and metadata requirements. As a result, advancements made using these CT toolkits have come from an imaging landscape that is locally functional but highly fragmented, and especially discordant at the levels of peer review, interoperability, reproducibility, and democratization of access. This disharmony necessarily curtails methodological repeatability and data reuse, and it forestalls future advances in image processing (e.g., via machine learning; [16,22]) that could augment data already in hand.

The notable exception are synchrotron facilities, which rely on in-house development of tomography instruments for large numbers of users across multiple disciplines. For this class of instruments, data and metadata are generally well defined to guarantee experiment repeatability (e.g., Scientific Data Exchange, Nexus file formats), leverage open source reconstruction tools (e.g., The ASTRA Toolbox, TomoPy), and promote data-analysis repeatability [8]. Wider adoption of concerted efforts like these stand to make cross-disciplinary data--sharing easier and have the potential to accelerate scientific progress by ensuring opportunities to formally evaluate and replicate each step of the data capture and processing pipeline

Collectively, these issues speak directly to one of NSF's "10 Big Ideas" [32]: How can we harness the data revolution if we are not talking about the same data? Indeed, this splintering propagates down to the level of individual CT facilities, which make archival decisions based on hardware and software platform commitments, perceived future utility of intermediate file types, as well as available time, resources, and funds. Although tomography users have recognized these issues previously via formal working groups, conference workshops, and international symposia (e.g., International Congress of Vertebrate Morphology, SPIE—The International Society for Optical Engineering, U.S. National Evolutionary Synthesis Center; also see [6]), interoperability issues have, nonetheless, siloed research teams and datasets into user enclaves of highly similar hardware and software tools. Altogether, this limits communication, cooperation, and scientific advancement.

In the early 2000 s, the NSF began funding Research Coordination Networks (RCNs) with an aim to "advance a field or create new directions in research or education by supporting groups of investigators to communicate and coordinate their research, training and educational activities across disciplinary, organizational, geographic, and international boundaries" [33]. Research Coordination Network solicitations differ from most NSF awards in that they do not fund primary research. Instead, they facilitate information exchange, coordinate existing or planned research, encourage new collaborations, and establish community standards. Over the past twenty years, the kind of networks that RCNs embrace have proved an effective solution to address the multifaceted challenges faced by CT practicioners—facilitating better connectivity across communities, increasing research output of participating members, and engendering interdisciplinary approaches [38].

More recently, a worldwide conversation about global strategies for setting inclusive and open science standards has resulted in policy recommendations for the wide dissemination of publications and datasets. Endorsed by organizations like the G20 [12], United Nations [46], and European Commission [18], these goals have thus spurred broader policy adoption at national and state levels. In the United States, the White House Office of Science and Technology Policy Nelson Memorandum [34] furthered this conversation by articulating expectations for how U.S. federally funded research projects should conform with open science standards as a means to ensure that the scientific enterprise is resilient against abuse. Concordantly in 2022, the NSF announced a new initiative, the FAIR (Findability, Accessibility, Interoperability, and Reusability; [48]) and Open Science (FAIROS) Research Coordination Network program, which employs an RCN model to connect diverse scientific communities with the twin goals of developing industry standards and implementing FAIR guiding principles that reflect open science best practices. Selected by NSF as one of their inaugural awardees, NoCTURN, the Non-Clinical Tomography Users Research Network (www.NoCTURNetwork.org) seeks to advance FAIR practices in the domain of tomographic imaging. Although funded by the U.S. government, the network comprises an international community, with more than 75 representatives from diverse fields within research, education, and industry, including early career scholars as well as established practitioners at the forefront of CT science. Here we 1) outline the philosophy, goals, and organizational strategy behind the creation of this network, 2) summarize challenges that can be overcome through community action, and 3) provide a blueprint for others interested in developing (or expanding) an interoperable global network of tomography users.

Why Do Networks Matter?

Far-reaching coordination networks carry tangible benefits for scientific communities by catalyzing resource sharing, information exchange, training, and policy impacts [38]. Interoperable global networks cultivate these benefits from the experiences of their community members and promote them via collaborations within and beyond the network. NoCTURN, for example, seeks to be a timely and wide-reaching vehicle to ensure information sharing and debate necessary for the establishment of open community standards, new collaborations, and the clearheaded commitments needed to face future challenges to scientific openness that may impact the CT community.

An important aim for networks is to agree upon, and aggregate, community standards. The research communities that utilize CT are numerous and diverse, with thousands of researchers producing hundreds of thousands of tomographic datasets annually. For example, MorphoSource, a biology-focused digital repository established in 2013, by itself claims over 125,000 CT scans of biological and ethnographic material uploaded by more than 2000 contributors [49]. Regardless of subject matter, practitioners in these communities generally use stacks of 2D digital images to represent scanned volumes, which can be rendered, manipulated, and analyzed. Thus, although the research questions in these disciplines differ markedly, the form of the data and the information they convey are well-understood and highly congruent. This offers an advantage for recommending CT-specific community standards for data collection, publication, distribution, storage, and reuse (see, [31]). To ensure that the best practices are deployed in a timely manner, it is advantageous to recruit network members who operate CT facilities. This can enable the reciprocal improvement of standards over time as their success is re-evaluated, which is a key approach taken by NoCTURN teams. Further, networks that include representatives from manufacturers of CT scanners (e.g., General Electric/Baker Hughes/Waygate Technologies, Nikon, North Star Imaging, Comet Yxlon, ZEISS), individuals from the communities using custom-built scanners (including synchrotron radiation sources), as well as participants from commercial 3D-rendering software platforms (e.g., Avizo/Amira, Dragonfly, Horos, OsiriX, VGSTUDIO) and freeware platforms (e.g., 3D Slicer, Blob3D, SPIERS) are better positioned to identify cross-cutting opportunities for implementing standards at each step of the data collection and visualization/analysis pipeline. Often, it is small groups within a network that first recognize these opportunities, but they quickly come to benefit all members [38].

While much of the innovation that happens in networks is first undertaken by teams or committees, all-network meetings also present rich opportunities to support synthesis and new collaborations. Participants in interoperable global networks often have diverse research interests yet share broad areas of expertise across CT hardware, data management tools, visualization technologies, advanced analytical methods, education, and outreach. This broad expertise can and should be harnessed to develop and evaluate solutions to current image processing bottlenecks, data storage issues, sharing and repository standards, reproducibility, and reporting requirements so that commonalities across these activities enable new partnerships. Indeed, by leveraging FAIR goals networks can ensure that easily findable data diversifies the range of individuals and groups able to discover and utilize CT scans, thereby engaging a rich variety of perspectives. Likewise, promoting data accessibility through digital repositories and outreach enhances data equity by removing barriers to access. This can take the form of, for example, standardizing and simplifying terminology and centralizing resources to promote inclusivity, which is especially important for recruiting early-career CT users who are just starting to work in this space.

The collective specialties and experiences of members in far-reaching networks, like NoCTURN, make it possible to tackle these issues from diverse perspectives, sharing common goals oriented towards making scientific advancements through community development. NoCTURN leverages common digital communication tools such as email, video conferencing, group messaging services, and collaborative writing tools to encourage participation. We have organized the network around formal committee structures to ensure fluid and equitable sharing of information and ideas and timely progress on network objectives (see below). We hold semiannual all-network conferences, one fully online and the other hybrid, to balance maximal participation with the spontaneity that can arise from in-person meetings. NoCTURN members also meet at ongoing CT-focused community meetings [e.g., Tomography for Scientific Advancement UK/Europe and North America; International Conference on Tomography of Materials & Structures; The International Society for Optics and Photonics] to coordinate with and engage the wider community. In addition, members present at discipline-specific meetings (e.g., societies of biological, biomedical, engineering, geological, materials, and paleontological science) to encourage conversations focused on more targeted applications of CT.

Organization of a Network

Here we describe the internal organization of NoCTURN as a working example of how global interoperable networks can coordinate their membership to innovate and problem-solve. NoCTURN seeks to advance FAIROS goals in the domain of CT. Because tomographic specialists utilize a shared pipeline to create digital representations of real-world objects for research, education, and outreach, the community faces a common set of challenges and limitations imposed by the insulation of current workflows. NoCTURN seeks to overcome these challenges by providing a platform to 1) engage the international scientific CT community via participant recruitment from laboratory and synchrotron imaging facilities, academia, museums, and data repositories; 2) stimulate improvements for imaging datasets that focus on findability, accessibility, interoperability, and reusability; and 3) work directly with private companies that manufacture the hardware and software used by these cutting-edge imaging platforms to better reflect the open science standards championed by federal funding agencies across the globe through standardized data acquisition, handling, and sharing.

To address current and future issues, NoCTURN members assemble into Working Groups, Communities, and Committees. Each sub-group within the network follows individualized mission statements while also coordinating collaborations. Fig. 2 illustrates the flow of information between these organizational levels. Working Groups focus on addressing FAIR paradigms in the context of CT data, coordinating among themselves directly. Each Working Group includes at least one member of each Community to facilitate cross-talk and sharing of ideas. Communities represent the interests of shareholders of CT data, including educators, the public, private companies, and members of scientific disciplines. Communities coordinate within their membership on common goals and reconcile potentially divergent interests. Working Groups and Communities all interface with the Open Science Committee, which makes recommendations regarding open science standards. The Open Science Committee interfaces directly with the Conferences & Digital Coordination Committee, which is responsible for maintaining the vital underlying communications infrastructure for the network to function and ensures that within-network communications embody open science criteria.

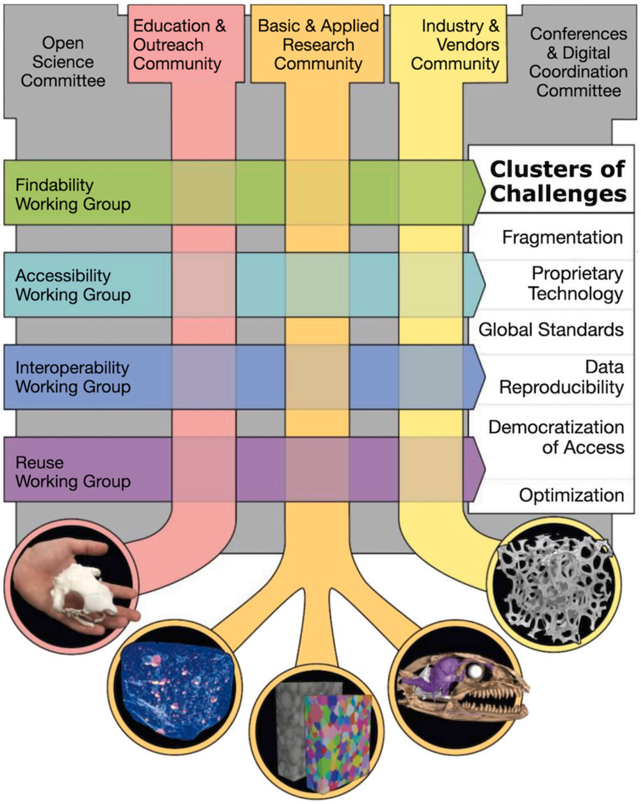

Fig. 2. Schematic of NoCTURN organization: Communities (top) each interface with Working Groups (left) via shared memberships and formal inter-team requests for information, feedback, and updates. The Open Science (upper left) and Conference & Digital Coordination Committees (upper right) serve all Community and Working Groups to facilitate their activities and ensure all teams uphold open science standards.

The activities within each Working Group, Community, and Committee reflect their mission statements and community interests:

Working Groups

1. **The Findability Working Group** - The mission of this Working Group is to: 1) establish formal guidelines for developing persistent, informative identifiers of tomography data; 2) determine repository minimum standards that can ensure short-term and long-term discovery; and 3) transform dataset findability by integrating the implementation of identifiers and repository guidelines for use by data archives. As part of its mission, the Working Group is also tasked with addressing questions about archiving and storage of the data and metadata, for which it will develop a scalable system of best

practices (i.e., "good, better, best"; [14]) that can be shared with labs around the world according to their available resources.

2. **The Accessibility Working Group** - The mission of this Working Group is to: 1) promote data sharing by developing standardized communications protocols (including authorization steps) that are platform agnostic, low cost, and readily available; and 2) design mechanisms to ensure that metadata access remains persistently independent of primary image data longevity. This Working Group also explores recommendations to develop scripts/automated tools for parameter extraction from metadata files produced by different scanners that will make interpretation of those metadata easier for audiences with diverse ranges of experience.
3. **The Interoperability Working Group** - The mission of this Working Group is to: 1) design unambiguous, informative, and accurate vocabularies for research CT, which will involve evaluating previous work for suitability in its current state, adherence to FAIROS principles, specifically referencing the American Standards for Testing and Materials (ASTM), Digital Imaging and Communications in Medicine (DICOM) standard, the industrial Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) standard (ASTM E2339–15), and International Organization for Standardization (ISO) technical specifications and reports; and 2) apply this language to data and metadata exemplars to ensure their operability with pre-existing and planned workflows, applications, and search mechanisms. This Working Group also facilitates the work of the other NoCTURN entities by proposing improvements to image processing bottlenecks created by existing, non-standard, and proprietary metadata. Finally, the Interoperability Working Group is creating a central resource for evaluating and sharing CT imaging phantoms (materials of known composition, which standardize attenuation across scans) and reference standards, such as the low-cost and easily reproducible volumetric phantom designed and published by NIST [27].
4. **The Reuse Working Group** - The mission of this Working Group is to: 1) represent the CT community through consensus building around accessible data usage licenses; 2) clearly define the scope of provenance for CT data and metadata; and 3) ensure that community standards recommended by other Working Groups promote data reuse and recombination. This Working Group also interfaces with Research- and Education-focused journal publishers to set minimal reporting attributes for peer-reviewed studies and establish a list of NoCTURN-recommended repositories, which are crucial steps towards widespread adoption of FAIROS standards and best practices. Working Group members include representatives of scientific collections, online repositories, data aggregators, and high-throughput digitization projects (e.g., iDigBio, Morphobank, MorphoSource, oVert TCN) who are actively involved in developing recommendations for reuse implementations that will be incorporated in those platforms as well.

Communities

1. **Education & Outreach Community** - The mission of this Community is to represent the interests of educators, technical trainers, and the general public. This includes accessibility and in-classroom use of digital models derived from CT data for STEM courses, guidance for students at primarily undergraduate institutions to take on research projects, asynchronous training resources for users of CT-related hardware and software (e.g., students, early-career researchers, established scientists new to CT), and promotion of CT as a vehicle for engaging with the scientific method in maker spaces and 3D-printing communities (e.g., public libraries).

5. **Industry & Vendors Community** - The mission of this Community is to represent the interests of hardware and software manufacturers during the proposal and implementation of FAIR guiding principles and open science initiatives. We recognize that the success of NoCTURN is based in part on the strength of interactions between industry, academic researchers, and educators, and we aim to ensure that these interests are given a voice by embracing them within our organizational structure (Fig. 2).
6. **Basic & Applied Research Community** - The mission of this Community is to represent the interests of researchers, especially regarding the equilibrium of data accessibility and reuse with the creation and dissemination of new knowledge. This Community seeks to balance material and perceived individual benefits of prolonged data latency with the widely acknowledged group benefits of large-scale data discoverability and reuse.

Committees

1. **The Open Science Committee** - The mission of this Committee is to: 1) promote opportunities for increased scientific collaboration and sharing; 2) make scientific knowledge openly and widely accessible; and 3) ensure the communication of the scientific method and its outcomes within society (including and beyond the scientific community). To achieve this, the Open Science Committee recommends strategies for developing and testing mechanisms to assess the value of Open Science practices (e.g., [6]), especially quantitative measures of the worth of openness. The Committee is developing standardized metrics for gauging how often available datasets are downloaded and how they are used and reused. This is being accomplished via partnerships with online data repositories, which foster open data access and are committed to measuring the success of these efforts. The Open Science Committee also addresses new ways to share the products of NoCTURN activities, promote FAIROS goals generally through publications and conference presentations, and support increased representation in STEM fields (e.g., by recruiting membership from minority-serving institutions).

7. **The Conferences & Digital Coordination Committee** - The mission of this Committee, which overarches the Working Group–Community–Committee structure of NoCTURN, is to: 1) ensure smooth digital and in-person communication within and among NoCTURN entities; and 2) plan the process by which NoCTURN will join ToScANA (Tomography for Scientific Advancement North America) as a series of permanent committees at the end of its NSF funding period.

ToScA was founded in the UK in 2013 and franchised in North America as ToScANA in 2017. Its existing membership and symposium structure has grown from a small, community-based conference to an international, world-recognized society with significant participation and support from industry. ToScA symposia take place annually in the UK/Europe and biennially in North America. Each symposium features a day of vendor-led workshops followed by two days of keynote speakers and contributed oral and poster presentations. There is substantial overlap between the membership and objectives of ToScANA and NoCTURN, providing a strong partnership that brings together the cross-disciplinary CT community to advance sharing of information and ideas, coordinate research activities, foster synthesis and new collaborations, develop community standards, and advance science and education through FAIROS strategies. ToScANA is also the vehicle by which these endeavors can continue beyond NoCTURN's FAIROS RCN funding period (2022–2025). There can be substantial hurdles in maintaining the long-term momentum of large-scale group efforts to improve the scientific enterprise, and merging with ToScA is NoCTURN's solution to this concern. A primary responsibility of the Conferences & Digital Coordination Committee is to oversee the transition of the RCN into ToScANA as a series of standing committees. Planning this process from the founding of NoCTURN with the input of ToScA UK/Europe and North America board members will ensure a successful handoff and sustained fidelity to FAIR and open science values.

Conclusion

We support broad community engagement as the primary means to address the shared, emergent challenges and benefits of FAIR and open science commitments. NoCTURN is just one approach for tackling these issues, and it works for us. We hope to continue growing our ranks by drawing on the enthusiasm of ToScA, industry partners, funding agencies, and CT users abroad. Indeed, we call on all members of the CT community—teachers, students, technicians, specialists, and engineers alike—to join us, share your experiences, and ensure that your voices are heard. We invite you to call NoCTURN (www.NoCTURNetwork.org) one of your intellectual homes. We also hope that the success of NoCTURN will serve as a template for users of other data-heavy analytical approaches so that the frameworks described herein can be updated and applied to forthcoming CT innovations or additional imaging modalities by future global interoperable networks.

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CRediT authorship contribution statement

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