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A Context Metadata Collection and Management Tool for Computational Photography Projects

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Abstract

This paper will present the first module of an advanced set of metadata and knowledge management tools to record a "Digital Lab Notebook" (DLN), the equivalent of the traditional scientist's lab notebook. The DLN:Capture Context (DLN:CC) tool describes the means and context of photographic data capture. The tool is designed for broad use across computational photography technologies. The DLN:CC has already been implemented for Reflectance Transformation Imaging (RTI) and implementation for photogrammetry is underway. The collection and organization of contextual metadata is highly automated, facilitating use during the time the image data is captured and processed, rather than afterward. This project adds ISO-standard compliant metadata, which establishes the provenance of the imaging subject's digital surrogate. The captured photographic sequences and the DLN metadata contain all the information needed to generate and/or regenerate advanced, image-based 2D and 3D digital surrogates, such as Reflectance Transformation Imaging or photogrammetry's 3D models with texture. The DLN also provides each digital surrogate a scientific account of their collection and generation.

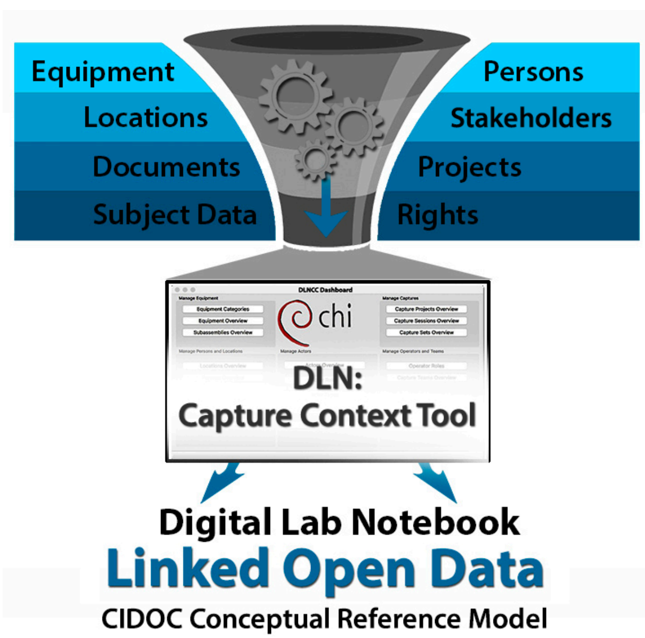

***Figure 1**: The Capture Context tool takes in information about imaging data collection and produces CRM Mapped Linked Open Data.*

Introduction

Today, humanity faces a great crisis: the magnitude of cultural heritage loss around the world. Today, there are three new, convergent opportunities, which, if used together, can mount at least a partial response. The three opportunities are: the creation of scientific digital surrogates; the development of computational photography technology; and the emerging semantic knowledge management infrastructure that can preserve the network of meaningful relationships between a "real world" subject and its digital surrogate. These relationships contain the context and procedures associated with the surrogate's creation. The next sections discuss these opportunities and why and how our new software module uses them.

Digital Surrogates

Humanity's legacy can be shared between people through digital representations. Many people are now at work acquiring and sharing digital representations of cultural heritage. The number and scale of these efforts is growing at an accelerating rate, despite the fact that digitization programs are costly, cultural heritage sector monetary resources are scarce, and appropriately trained human labor is relatively rare and precious.

One form of digital representation, the *digital surrogate*, offers great potential for the advancement and sharing of knowledge. The production of digital surrogates is a goal of museum, library, and other scholarly digitization campaigns. Digital surrogates can also serve as "lifeboats" for imperiled cultural knowledge if the original material carriers of that knowledge are damaged or lost.

The purpose of digital surrogates is to reliably represent the desired attributes of "real world" subjects in a digital form. Their objective is to enable scholarly and scientific study as well as personal enjoyment without the requirement of the direct physical experience of the subject or place. Their essential scientific nature distinguishes them from art and entertainment. They are built from verifiable empirical data and, like all scientifically acquired information, they require a provenance account of the means and circumstances of their creation. We call this provenance account the *Digital Lab Notebook (DLN)* [1].

The DLN enables qualitative and quantitative evaluation of the associated digital surrogate's reliability. In turn, this leads to informed decisions by new potential users regarding whether or not to reuse the digital surrogate for their purposes. In the digital age, both the imaging subject and the scientific digital imaging product, which purports to represent it, require a provenance account. This was the key to the success of the Human Genome Project, which enabled the work from dozens of laboratories to be evaluated for reliability and included, or not, in the final published results [2].

While widespread generation of digital representations of cultural heritage materials is well underway, much remains to be done to ensure the preservation of this data's digital provenance for scholarly evaluation and subsequent reuse. Such information is absolutely crucial for current and future reuse of both the source photographic image set and the advanced digital representations derived from them – but it is also the information that is least likely to be collected today. This means that much of the new data being generated through computational photography may be or become of little scientific value in the not-too-distant future.

The digital surrogate's metadata and knowledge management methodology, the focus of this project, is designed to provide just such digital provenance management. Much of the digital photographic capture and image pre-processing is essentially the same across computational photography technologies. The Capture Context software offers a blueprint to extend this methodology broadly throughout the computational photography field.

Computational Photography

The digital photography revolution fostered the invention of a family of robust photography-based digitization technologies called *computational photography*. The field encompasses many areas of dynamic research activity based on the convergence of computer graphics, machine vision, and camera/illumination system design. Computational photography uses sequences of images to extract information about the imaging subject that is not present in any one of the constituent images. Computational photography overcomes the limitations of traditional photography by using computational techniques to produce more robust, information-rich representations of our world. Computational photography techniques are undergoing worldwide and accelerating adoption in many domains in the humanities and natural sciences.

Examples of computational photography tools include Reflectance Transformation Imaging (RTI), photogrammetry, multispectral/hyperspectral imaging, High Dynamic Range (HDR) imaging, and the various forms of mosaic photo-stitching. The common element in these technologies is the presence of an automatic algorithmic process that generates the resulting digital representation from a specially photographed sequence of digital images.

The transparent acquisition of computational photography's photographic sequences and their near-automatic processing into finished digital surrogates has metadata management advantages for the creation of these surrogates for science and scholarship. The photographic parameters and source image processing in computational photography are easy to track and log automatically. If 3D digital surrogates are the goal, photogrammetry should be used. This is not only because the processing is easier to track and tie back to the original images, but also because anyone with access to the original images can do their own processing and see the results directly from the image set. Also, with a proper workflow, the images carry their own metadata about camera settings and how they were individually processed (e.g., sharpening, white balance, tone curve, etc.)

Computational photography's exclusive use of digital photographic data also aids in long-term digital surrogate preservation. Whether a digital surrogate is a RTI or a photogrammetric, textured 3D model, all of the information used to generate the surrogate is contained in the original sequence of digital photographs. A well-captured photogrammetry photo sequence will generate essentially the same textured 3D digital representation every time a knowledgeable person using any sufficiently capable photogrammetric software processes the image sequence. The same is true of other computational photography technologies. The preservation of digital photographs is well understood. If the original photographic data sequence and its associated metadata are preserved, over time the ability to generate the robust digital surrogate generated from these assets will also endure.

Semantic Knowledge Management

Around the world, many are building the semantic knowledge management tools and information infrastructures necessary for global digitization and associated knowledge sharing efforts to succeed.

Over two decades of work by many of the world's top library and museum informatics and knowledge management professionals have led to a new, broadly integrated, and semantically organized system for knowledge representation. Semantically managed knowledge not only facilitates finding aids and search engine results for requested information, but also retains a record of the far more extensive and complex relationships existing between and among the individual elements of information. Knowledge of these information relationships permits reasoning across these relationships to discover new knowledge [4]. Semantic relationships are both recorded and revealed by mapping the information to a semantic *ontology*. An ontology is a way to describe the things that exist or happen in our world, as well as the relationships between them, in an abstracted and generic way. When two related individual pieces of information are mapped to their corresponding concepts in an ontology, the relationships existing between the concepts within the ontology serve to preserve the relationships between the two mapped individual pieces of information. In this way, photographic lenses with specific wavelength filters, oil paintings with their provenance, individual photographers, project funders, locations and a host of other information can be brought together in an organized, meaningful manner. In a DLN, all this information can be tied to a captured sequence of photographs. In combination, the DLN and the sequence of photographs contain all the information necessary to build a scientific digital surrogate. When the photo sequence, the DLN, and the generated digital surrogate are archived together, this structured digital provenance information will be available for all to see and evaluate.

The ontology standard used in this project, the Conceptual Reference Model (CRM) [5], ISO standard 21127:2014, is not just the imaginative product of a committee. Rather it is grounded in over 20 years of bottom-up empirical analysis by the standards bodies of the International Council of Museums (ICOM) and the International Federation of Library Associations and Institutions (IFLA). This analysis examined the standards used by hundreds of different memory institutions to understand the conceptual distinctions they used to organize knowledge. From the collection of these conceptual distinctions of demonstrated usefulness, ICOM and IFLA abstracted generic representations in the form of two ontological conceptual models, the CRM and its now integrated subset, the Functional Requirements for Bibliographic References object oriented (FRBRoo). After more than a decade of working meetings, ICOM and IFLA unified the CRM and version 2.4 of FRBRoo [6]. Today, IFLA and ICOM jointly advocate adoption of the CRM and its extensions to bibliographic references, periodical publications, digital provenance, logical argument, the natural sciences, and archaeology. This is the first unified knowledge management recommendation from the museum and library world to international memory institutions.

People, by their nature, will never all agree to follow a single standards path. This is why the CRM is designed to encourage many diverse ways of managing knowledge. It does this by enabling different collections with dissimilar knowledge architectures to share and research across their combined information base. Here's how it works: The CRM employs an extensible group of defined classes and properties. This approach uses object-oriented, event-based modeling that can harmonize knowledge and different levels of detail from different data repositories in cases where each local repository uses incompatibly structured ways of organizing their data. In other words, two archives using completely different information architectures can share access between their collections, once both individual information architectures are mapped to the CRM ontology.

DLN:Capture Context

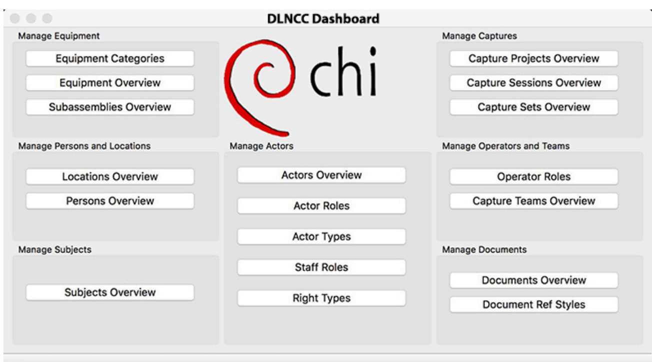

***Figure 2**: The dashboard screen of the DLN:Capture Context tool.*

This section describes the Beta release of the DLN:Capture Context (DLN:CC) software module, the first of a new suite of DLN software tools. The DLN:CC software is open source, licensed under the GNU General Public License v3, and it is available for free download from the Cultural Heritage Imaging website. [3].

DLN:CC captures the who, what, where, when, why, and how of the digital surrogate's original photographic information. This methodology is designed for digital surrogates intended for use and reuse in historic preservation, interdisciplinary science, and humanities scholarship. It is also designed for people exploring or enjoying their own cultural identities and those of their neighbors around the world.

Levels of Metadata

The DLN:Capture Context tool enables the collection of three levels of metadata: "Project" information, information pertaining to an imaging "Session" of multiple image set captures, and "Capture Set" information, pertaining to the capture of each image set that will be processed into a digital surrogate. Individual DLN files are exported for and associated with each complete set of captured images. For example, Project metadata could include the general information for a month-long rock art digitization campaign. The Session metadata could include information pertaining to the work of a single day or rock art cliff face. Each Capture Set of metadata inherits the metadata from the project and the capture session with which it is associated. The Capture Set metadata is exported as XML which is used by an X3ML transformer to produce an RDF representation that is based on the XML along with an X3ML file containing the CRM-compliant mapping information. This intermediate step has the advantage of allowing updates to the mapping without modifying or updating the software. The RDF file should be archived along with the images.

Data Collection Freedom

A key feature of the software's ease-of-use is that relevant metadata can be entered to any extent determined by the user, with the possibility of adding missing information afterwards, when it becomes available. If the user wishes to record everything possible or only a very minimal set of metadata, the software accepts that choice. Fundamentally, DLN:Capture Context expands the range of relevant metadata created while dramatically simplifying this task for the user.

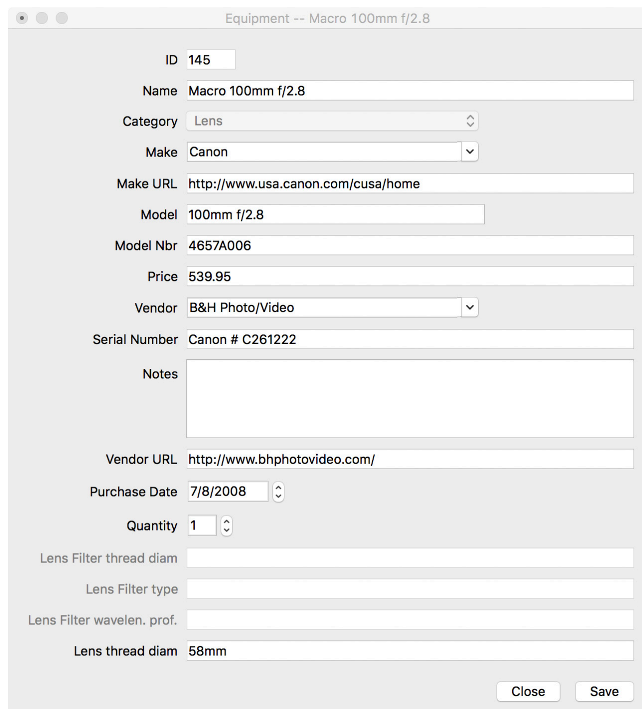

***Figure 3**: Equipment details for an item in the "Lens" category. Users can fill in as much or as little as they like.*

Dividends on Investments in Digitization

The DLN:CC software's use of metadata and knowledge management methodology produces metadata-rich, empirical digital data. This managed metadata will enhance the value of the investment made to digitally acquire the information. The DLN will generate these dividends through enhancing the digitized information's transparency and availability for qualitative evaluation and reuse. This will facilitate repurposing the information for novel use by others. In turn, this evaluation and reuse will pay dividends in the form of a higher likelihood of the digital data's long-term sustainability.

DLN:CC for Reflectance Transformation Imaging and Beyond

The current DLN:CC version 1.0 is coded for use with the computational photography technique known as Reflectance Transformation Imaging (RTI) [7] [8]. The development team selected RTI as the initial technology implementation because the CHI team was directly involved in developing the open source software and workflows for RTI, and has extensive experience with the technique. This expertise is critical for defining user requirements and creating use cases, as well as for testing the software and successfully exploiting user feedback. The tools were explicitly designed for adaptation to other computational photography imaging technologies. Currently, the DLN:CC team is modifying the software for use with photogrammetric 3D data capture. This work is generously supported by the U.S. National Park Service's National Center for Preservation Technology and Training (see the *Future Work* section below).

Design Principles

The development team based their design on a core principal: for the software to make a significant impact on the rate of cultural heritage loss, it, along with the associated computational photography capture methods, required wide-scale adoption by cultural heritage practitioners, local caretakers, and citizen scholars. For this to occur, the tools must be simple to use, as inexpensive as possible, and they must prepare the information for use in a semantic knowledge management memory institution environment. It is our belief that any requirement for direct user involvement in the semantic knowledge management of their data will discourage and even halt widespread adoption of the software.

Simple Use

The DLN:CC software requires only simple-to-understand, ordinary language communication with the user. Crucially, the DLN design keeps all the semantic knowledge management operations "under the hood," out of sight, behind the level of user interaction. This greatly simplifies collecting and validating computational photography metadata, making it possible for non-technical people to document their world.

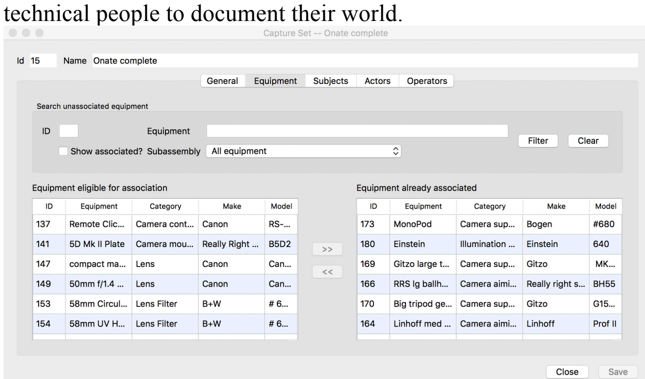

Figure 4*: The "Equipment" tab in the Capture Set screen. Users can search for equipment by name, or they can load pre-grouped sub-assemblies of equipment. It is easy to add or remove equipment from a Capture Set by selecting an item and using the arrows to move it to the right (used) or to the left (not used).*

In ordinary language and a simple interface, users can enter data describing equipment, operators, stakeholders, and other information. The tool provides convenient categories for users to organize their gear, such as cameras, lenses, filters, illumination equipment, and so on. The user can add new categories as desired. They can then create pre-built, easy-to-change metadata sub-assemblies, which are selected by a mouse-click just prior to photographic data capture. The user-entered data is stored in the open source Postgres database. To increase simplicity, the user has no need for direct interaction with the database.

For example, here is how to record the user's photo equipment metadata for a specific image set capture: once the information about the equipment has been entered into the system, the user can create groupings of commonly used equipment configurations, called "sub-assemblies." A camera can be grouped with a lens, filter, flash, and tripod. Once the user selects that sub-assembly, all its associated equipment can easily be added to the Capture Set record. Additional items can be easily added or removed (see Figure 4).

For the next capture in line, DLN:CC has an easy-to-use interface to duplicate the previously used Capture Set's metadata and select it again for use with the next imaging subject. Alternatively, the user can search the equipment, locations, subjects, and operators previously entered into the system and quickly group together a new set of information. The Capture Set screen is designed to bring the most commonly changed items to the user's attention. These items include the required Capture Set name and its location on the computer. The system uses flexible relative path names for the capture folder location, so that data can be moved to different systems.

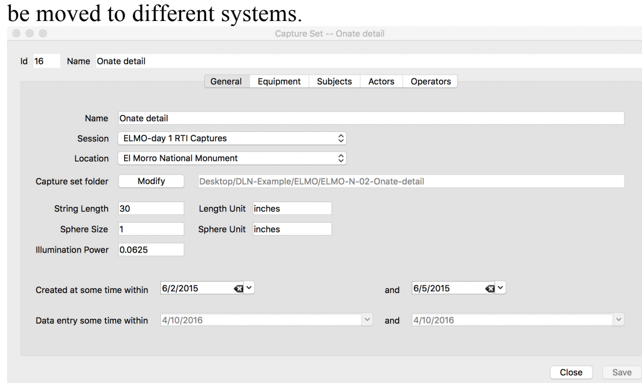

Figure 5*: The "General" tab on the Capture Set details screen. It is designed to surface the parameters specific for the Capture Set in the first tab, such as illumination power and string length, whereas the remaining tabs allow associating the Capture Set with equipment, subjects, etc. The only mandatory attributes in the first tab are the name of the Capture Set and its location on the hard drive; the other information is optional.*

The powerful technique of duplication is available throughout the system, making it easy to create new subjects, locations, equipment items, equipment sub-assemblies, etc. by duplicating an existing set of metadata that describes something and then modifying it as needed. For example, after duplicating the last configuration used, the user can remove a no longer needed element, such as a lens, select a new lens from the lens category, and group it with the remaining equipment (see Figure 4). The duplication of the previously used equipment combinations and then using it again, or making a quick swap to change a filter or a lens, is a powerful way to keep an accurate, running record of which equipment setup was used to acquire each photo set. At the time of the next photo set capture, the new equipment group can be selected with a mouse click, and all the associated metadata is then saved to the DLN for the new Capture Set.

In this way, the DLN tools let people easily collect metadata during documentation work. The system allows data to be edited or updated if needed at a later time. DLN:CC tool enables the near-automatic semantic knowledge management of the metadata describing the RTI data acquisition process. Such tools need to be nearly automatic in practice and employed as an integral part of, and used during, the capture process, or in most cases no metadata will be recorded. The DLN:CC workflow avoids "after the fact" metadata entry, which can result in a high percentage of user failure to record any metadata, or to record the metadata incorrectly.

The DLN:CC software can be used to collect information describing the entire photographic equipment configuration, the imaging operators involved, the project associated with the imaging, the stakeholders in the project, the location, the subject itself, and other related information. Documents can be associated with the elements in the project, such as subjects, Capture Sets, or projects. These can be referenced using links or incorporated into the DLN "in whole," such that the entire document file is included in the DLN. When documenting original data capture, these tools expand the range of relevant metadata capture while simplifying this task for the user.

Moving and Editing Existing Data

The system has features to support saving the database information and moving it to another computer. It is also flexible in that users can have different versions of the data stored and loaded separately. This allows entered data to be shared across computers and to better manage large sets of data. For example, an imaging team, traveling to work with collaborators, want to take with them information about their own equipment and staff to add to the DLN:CC data in use at the collaborating institution. The current implementation does this by supporting saving and loading the full set of data in the database, and storing multiple instances of the database. In a future version we anticipate supporting merging data from multiple sources, via an XML file, which would allow more fine-grained movement and sharing of data.

It is also important to allow users to edit data if a mistake was made, or information was not known at the time of capture. Take for example an object that is imaged and does not yet have a collections accession number. Later, when a number is assigned, the record for that Capture Set can be updated to include the newly available information.

DLN:CC Automatic Knowledge Management

The Capture Context tool is a new, practical application of the metadata and knowledge management standard ISO 21127-2014, the CRM. This makes it possible to entirely automate the mapping of the collected metadata to the CRM and the metadata's further transformation into Linked Open Data. The provenance model used is a CRM extension, "CRMDig," where all properties and classes are specializations of ISO 21127 and therefore completely accessible by querying with ISO 21127 concepts.

Here's how DLN:CC works. Ordinary language metadata information about the current capture is collected and stored in a database and then automatically mapped to CRMDig and exported as Extensible Markup Language (XML). In order to better support future changes or extensions of the CRM data model, the mapping between the data model internally used by DLN:CC is formally described in an X3ML mapping file, which provides the necessary information for producing CRM-compliant RDF output files. The machine-readable Resource Description Framework (RDF) statements are simple subject-predicate-object statements, such as "El Morro is a National Monument," sometimes called *triplets*. RDF is emerging as a key standard for encoding metadata and other knowledge on the Internet. RDF statements can also be represented as Linked Open Data (LOD) [9], containing Universal Resource Locators, URLs, and/or Universal Resource Identifiers, URIs. In addition, the DLN:CC creates universally unique identifiers (UUIDs) automatically where appropriate. It also allows the user to use URLs and URIs from controlled vocabularies, such as Getty Names for locations. All Getty-controlled vocabularies are now mapped to the CRM [10].

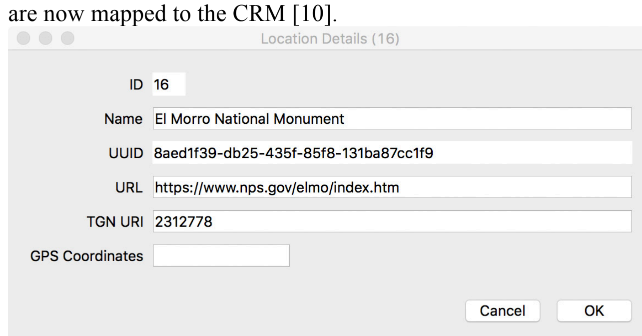

***Figure 6**: The "Location Details" screen. The software automatically creates a UUID. The user can enter a name, URL, TGN URI, and/or GPS coordinates.*

At the final stage, the DLN:CC creates new DLN files in both XML and RDF formats for each set of captured images that will be used later to generate a digital surrogate. The Postgres database is only used internally to collect, organize, and facilitate easy reuse of data within the DLN:CC. Once the DLN:CC exports the DLN files in XML and RDF, the information becomes usable by a much broader audience and by a wide variety of tools, because of its standard-compliant RDF-format.

The DLN software encodes the RDF statements and associated UUIDs and URIs as Linked Open Data, which communicates the relationships between entries in the Digital Lab Notebook and promotes access to its information.

Linked Open Data uses a standard model for data interchange on the web. It is machine-readable and can be accessible to search engines. The DLN, using Linked Open Data, will enable qualitative evaluation of scientific digital surrogates through simplified access to the lab notebook's information and advanced, semantically organized query of the stored information. In short, this approach can lead to a breakthrough for people looking for answers: the integration and interrogation of large amounts of separately stored, but related, information. The DLN will be easier to query and access than today's metadata records, making scientific evaluation of digital representations and their novel reuse practical and easier.

The DLN:CC tool includes a software installer that installs the open source Postgres database, optionally including a set of demo data, then configures the Capture Context tool for use on both Windows and Mac OS X operating systems [3].

Future Work

The DLN:CC software is the first in a chain of tools that simplify and manage the metadata workflow for computational photography. DLN:CC version 1.0 was designed with the broad range of computational photography needs in mind, but was first implemented to support RTI image sets. Work to add support for photogrammetry based image capture is already funded and underway.

The next tool in the chain, the soon to be released DLN:Inspector, has been implemented for RTI data sets and is now being adapted to photogrammetry. The Inspector checks the captured photo set's validity for use in the selected computational photography technology by applying a set of coded rules. These rules are used to compare the metadata found in the image sets. The rules evaluate the camera settings (EXIF data) and processing settings (found in the archival photographs' XMP data structure), such as sharpening, tone curves, white balance, etc., for compliance with the validity requirements of the selected computational photography technique.

The next tool envisioned creates Submission Information Packets (SIPs) [11] for archival submission. This aids the user in wrapping up the archival Capture Sets, DLN data, generated digital surrogates, and any other processing reports and outputs for archival submission.

Future work also includes making all the software fully internationalized, such that different character sets and languages are more easily supported, as well as translating the interface and guides to additional languages.

In addition, we envision adding support for other kinds of image sets, such as multispectral/hyperspectral imaging, as well as general documentary photography images. These image sets share many of the attributes of the technologies already covered by the existing tools. Image sets from different technologies could be grouped into the same project structure within DLN:CC. In this way information about general goals, funders, dates, and related items can be shared across the different imaging approaches. Modified rules for the validation by Inspector and for building associated SIPs need to be identified and implemented.

And finally, we have identified through case studies the need for generating additional common metadata formats from the produced XML Linked Open Data Files. This would allow more widespread use by people and institutions that are not currently using the CRM or Linked Open Data.

Conclusions

We believe the Digital Lab Notebook, and its first tool, Capture Context, along with inexpensive photography-based documentary skills, are the keys to democratize scientific documentary techniques and foster their worldwide adoption by scholars, cultural caretakers, and citizen scholars. This work has the potential to radically transform the scientific and historic value of digital representations made by people without the credentials conferred by academic or institutional authority. In the hands of anyone who is a steward of, or simply cares about, art, history or culture, the DLN's metadata collection and future archiving tools will give them a way for their work to be qualitatively evaluated by anyone, based solely on its merits. Such evaluation is the foundation for informed reuse of digital documentation. More importantly, the DLN separates documentary "authenticity" from "authority." When anyone with the skills to collect cultural documentation photographically can contribute their work to the world's store of knowledge and prove its worth, the human cultural legacy will emerge with a fresh diversity and richness.

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Author Biographies

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__Mark Mudge__ is President and co-founder of CHI. Mark has worked in 3D digital imaging for over 25 years. He is a co-inventor, with Tom Malzbender, of the computational photography technique, Highlight Reflectance Transformation Imaging. Mark is also an associate editor of the Journal of Computers and Cultural Heritage.

__Erich Leisch__ is a Senior Software Engineer at The Foundation for Research and Technology Hellas (FORTH) since 1995. He developed the DLN:Capture Context tool for RTI and is developing the DLN:Capture Context tool for photogrammetry.

__Martin Doerr__ has been Research Director at FORTH since 1990. He is head of the Centre for Cultural Informatics, an activity of FORTH's Information Systems Lab of the Institute for Computer Science. He is also Chairman of the CRM Special Interest Group.