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Integrating Science and Art: the Scriptospatial Visualization Interface

Fenella G. France
Preservation Research and Testing Division, Library of Congress, Washington D.C, United States of America.
E-mail address: frfr@loc.gov

Michael B. Toth
R.B. Toth Associates, Oakton VA, United States of America.
E-mail address: mail@rbtoth.com

Abstract:

Advances in technology and digital access have improved utilization and interpretation of scientific analyses for cultural heritage and humanities studies. Integrating scientific and curatorial knowledge (STEM to STEAM) is a critical multidisciplinary approach. Researchers have exposed previously unknown contextual information within original materials, such as changing "subjects to citizens" on the Rough Draft of the Declaration of Independence. Using hyperspectral imaging, researchers provide new data layers by capturing images of documents in distinct wavebands of the visible and non-visible spectrum. Spectral imaging at the Library of Congress also allows integration of data from other non-invasive analytical techniques to map objects analytically.

Digital imaging capabilities allow researchers to characterize pigments and inks on the object, retrieve lost text, and illuminate creation methods. Captured data provides access to information from fragile historic documents, including the 1507 Waldseemüller World Map and 1513 Ptolemy Geographia. Investigations revealed links to the same printing location. "Scriptospatial" refers to a global information system approach for documents, creating an interactive interface for scholars and scientists to engage with object data. Viewing digital cultural materials in multiple dimensions applies an archaeological approach, uncovering and interconnecting information strata of unique documents. Utilizing an object-oriented approach in conjunction with the data layer allows mapping of spatial and temporal data with increasing complexity for direct sharing and visualization of data. This scriptospatial concept enhances the ability to support cross-disciplinary research collaborations and analyses. These relationships support valuable and innovative creative approaches to data integration, while strengthening effective art and scientific collaborations.

Keywords: Scriptospatial, spectral imaging, data visualization, cultural heritage.

Background

Recent advances in technology and digital access have paved the way for the improved utilization and interpretation of scientific analyses of Library source materials for digital cultural heritage and humanities studies. Integrating scientific analyses with curatorial knowledge (STEM to STEAM) is a critical multidisciplinary approach for expanding the full potential of scientific techniques and technological advances. Scientists and curators have exposed hidden and previously unknown contextual information within original source materials, such as changing "subjects to citizens" on the Rough Draft of the Declaration of Independence. Hyperspectral imaging provides additional data layers by capturing images of documents in distinct narrow waveband regions of the visible and non-visible spectrum – from ultraviolet through visible to infrared. The cube of captured digital data contains a wealth of information, but requires significant interpretation to process and analyse the collected data. Scientists, scholars and students in both disciplines have been collaborating to glean new information from historical manuscripts. The Library spectral imaging program includes development of a spectral reference database and integration of data from other non-invasive analytical techniques to create a full analytical mapping of objects for non-destructive analyses of collection materials.

Digital imaging capabilities allow researchers to characterize pigments and inks on the document, retrieve hidden and lost text, and illuminate production and creation methods. The range of data captured allows greater access to the information available from fragile historic documents, including the 1507 Waldseemüller World Map and the 1513 Ptolemy *Geographia*, where investigations revealed links to the same original printing location. Scriptospatial refers to applying a spatial information system approach to documents, creating an interactive interface for scholars and scientists to interact with the object and the data. Scriptospatial representations of digital data from documents utilize an accurate coordinate system that links scientific and scholarly analyses to the creation of a new digital cultural object (DCO), allowing inferences to be drawn to generate new knowledge. This approach to viewing digital cultural materials in multiple layers applies an archaeological approach toward uncovering and interconnecting information strata of historic and modern documents.

Scriptospatial mapping of data enables direct sharing and visualization of data to support analysis, with the capture of standardized instrumentation parameters and object metadata. The Library of Congress has used this approach to studies of some of the USA's top historic treasures. Processing of the data cube creates enhanced spectral features captured from the visible and non-visible regions of the spectrum. This scriptospatial concept greatly enhances the ability to share data to effectively support cross-disciplinary research collaborations and analysis. Examining and explaining the spectral, optical and chemical properties of original source materials with scriptospatial tools, from political cartoons to founding documents, while linking this with curatorial knowledge, permits scholars to relate these scientific analyses to the social context of how they were created and used. These relationships support valuable and innovative creative approaches to data integration, while strengthening effective art and scientific collaborations.

The launch of what became the first Landsat satellite a little over 40 years ago prompted a surge in both spectral imaging and large amounts of image data, with over 300,000 spectral images produced for civil applications (http://landsat.gsfc.nasa.gov/). With the advent of advanced spectral imaging in cultural heritage studies, the past decade has seen a similar surge in spectral image data. These need to be integrated with common standards to provide useful information to support scholarly research, preservation studies, and scientific analysis, and provide value-added data and information.

The Preservation Research and Testing Division (PRTD) of the Library of Congress has adapted data handling and management, data preservation, and methods and software for cultural heritage studies from those used to handle earth resource and geospatial data, but with the much more limited budget and infrastructure of a cultural heritage institution. This initiative has included customizing the imaging system and its hardware, software, metadata and processing with a standardized approach to enable rapid access to linked data by scholars and scientists.

Digital spectral imaging of cultural heritage objects at the Library of Congress has capitalized on over a decade of research and development into not only spectral imaging and processing, but also the development of standard spectral image products (France et. al, 2010). Advances over the past decade by an experienced team have led to an advanced capability to study cultural heritage objects with a robust spectral imaging system that provides large-format, high quality images and standardized data output using advanced commercial off-the-shelf components. (Christens-Barry et. al., 2009) The Library of Congress is building on pioneering research and development efforts in systems design, spectral illumination and imaging, and data management during spectral imaging studies of the Archimedes Palimpsest (Emery, et. al., 2011), David Livingstone Diaries (Wisnicki and Toth, 2012) and St. Catherine's Monastery Palimpsests (Father Justin Sinaites and Toth, 2012). Combined with continued research and development at the Library of Congress, an integrated spectral imaging system is now providing new insights into cultural heritage objects from the Library's extensive and rich collections (France and Toth, 2011). This capitalizes on best practices in government and industry in applying not only new technologies, but also work practices and personnel. The system includes integrated image collection, processing and data storage technologies and enhanced work processes, which trained and experienced personnel are transitioning from leading edge technology to a working tool.

The study, preservation, storage and display of historic parchment, paper and other artifacts requires the integration of large amounts of data to provide information of value to researchers, both nationally and internationally. Retrieving data and information about parchment, paper and other objects, preserving the data for current and future use, and contributing to the creation of knowledge from the retrieved information and digital data requires effective systems development that includes the technology, work processes and trained personnel. (Emery, et. al., 2009) There has been a shift over the past few decades from cultural heritage organizations as repositories of objects to repositories of knowledge (Reilly 2003) so there is a real need to understand the potential impact of these new imaging capabilities on libraries, archives and museums, including the value added for researchers as well as public outreach, and keeping all systems current with technology and standards

Scriptospatial Visualization

Developing an object-oriented approach to data access and sharing requires integration of spectral imaging with data from other sources in a variety of formats. This requires effective spatial metadata to allow linkages to specific locations within the images. This is necessary not only to register locations on the same section of a manuscript leaf in various spectral bands, but also to link other images and transcriptions with the spectral images. Based on geospatial mapping and layering of data used to identify points on satellite images, the same technologies, work processes and skills can be applied to spectral images of manuscripts: A camera collecting images over a manuscript is similar to a satellite collecting geospatial data over the Earth. Based on this analogy, in 2000, the managers of the Archimedes Palimpsest team used the Content Standard for Digital Geospatial Data (FGDC-STD-001-1998) as a basis for their spatial standard. Just as latitude and longitude are used to define points on the globe, they used a coordinate system to define points on each manuscript leaf. Using technologies developed for "geospatial" systems to link each point on the globe with images from earth resource satellites and data collected from other instruments with, spectral imaging can link the "scriptospatial data" from each point on a manuscript with images from various imaging and scientific devices. This provides a standardized method to support links between images and data from the same object location.

With multiple data entries for samples, precisely defining the specific point where the sample or scientific data collection takes place is critical in comparing data from different research types or objects. For samples taken from a larger, non-uniform, heterogeneous object such as a manuscript, textile or painting, the spatial location of the sample point on the object must be defined to be able to integrate the data from various research tools. Spatial metadata elements will allow linkages to specific locations on an object, potentially within images of the objects. Scriptospatial data can serve as an interface for scientific dialogue in "one shared layer," linking data from various sources for in-depth studies and analyses of a specific research topic or object.

In addressing the preservation science challenges in sharing scientific data from diverse instruments, institutions and research goals, it is important to look at the challenges faced in another discipline three decades ago. In highlighting the importance of "Open Geospatial Information Systems (GIS)," ESRI's 2003 Spatial Data Standards and GIS Interoperability White Paper highlighted the progress made by the GIS community, which faced many of the same challenges:

> "In early years, the constraints of computational speed and cost limited our ability and caused us to focus on practical solutions such as direct file conversion. Data sharing between organizations with different GIS vendor systems was limited to data converters, transfer standards, and later open file formats. Sharing spatial data with other core business applications was rarely achieved. Today, most GIS products directly read and sometimes dynamically transform data with minimal time delay. The point here is that the GIS community has been pursuing open interoperability for many years, and the solutions to achieving this goal have changed with the development of new technologies.
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> "Another factor to be considered is the still evolving view of the role that GIS plays in an organization. In the early days of GIS, the focus, with rare exceptions, was on individual, isolated projects. Today the focus is on the integration of spatial data and analysis in the mission-critical business processes and work flows of the enterprise and on increasing the return on investment (ROI) in GIS technology and databases by improving interoperability, decision making, and service delivery.
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> "Finally, it is worthwhile to remember why we implement geographic information system technology in the first place. Even if we have specialized responsibility for gathering and managing geographic data, we need to remember that a GIS is not an end in itself. A GIS must produce useful information products that can be shared among multiple users, while at the same time provide a consistent infrastructure to ensure data integrity. It is important not to get caught up in the technology and forget this basic principle. Interoperability enables the integration of

> data between organizations and across applications and industries, resulting in the generation and sharing of more useful information."

The progress and successes of the GIS community over what is now three decades in establishing an open architecture in which diverse data types can be integrated are dependent on standard interchange formats and open file formats. One can look at progress made to date with metadata standards in the preservation science community as a similar foundation for development of an open scientific data sharing architecture. With the introduction of spatial metadata to common standards, the preservation science community can now piggyback on what is now 30 years of collaboration and standardization by the GIS community to rapidly develop an open "scriptospatial" architecture. The cultural heritage and preservation community can capitalize on the investment made by earth science, national security and defense organizations and contractors into common systems and standards for sharing spatial data.

In many current research databases, the metadata elements for spatial location are not provided to capture detailed data on where an instrument collects data, or a sample is taken. This is not an issue for uniform, homogeneous samples of paints, pigments, media or other samples, but is critical for samples taken from a heterogeneous object like a painting, manuscript or textile. By defining a Cartesian coordinate system on an object or image of an object, as well as the degree of precision required, specific sample points on an object can be defined. This allows integration with other images of the same object and scientific samples from the same point. The Content Standard for Digital Geospatial Data (FGDC-STD-001-1998) serves as a basis for defining metadata elements for cultural heritage and scientific research. Utilization of this standard will also allow use of geospatial software and systems to manage and integrate "scriptospatial data" from object samples. This will provide a standardized method to support links between various samples from the same sample point or object by a range of users.

In its Scriptospatial Visualization Initiative, the Library of Congress PRTD has capitalized on developments with geospatial systems to apply Thermopylae "i-spatial" support and Google Map tiling and data formatting to the integration of large and complex visual scriptospatial datasets populated with scientific data from various instruments, research topics or objects. This provides data access in "one shared layer" of scientific data. This is an important first step in capitalizing on the three decades of technology development by the GIS community to advance preservation science and cultural heritage data sharing and research. The additional unique component will be the layering of scholarly research interpretations and publications, enabling ease of access to a rich resource of data directly linked to the original object. This will reduce the challenges faced with searching through data that is not well catalogued, or yet searchable without this expanded document interpretation and linking of scholarly knowledge.

Figure 1. Scriptospatial Imaging of Manuscripts based on GIS Model

Data Management

Scriptospatial mapping of documents with an accurate coordinate system allows the layering of scientific and scholarly analyses to the DCO. This allows inferences to be drawn to generate new knowledge through analysis of the data linked to spatial points. This approach to viewing the DCO applies a GIS methodology toward uncovering and interconnecting information layers of cultural heritage artefacts, just as in the case of archaeological strata. Utilizing an object-oriented approach in conjunction with the spatial data layers allows the mapping of spatial and temporal data with increasing complexity. Examining and explaining the physical, spectral and chemical properties of these historic materials permit scientists and scholars to link these scientific analyses to other data about the creation of the object.

The Spatial Data section of the Archimedes Palimpsest Metatadata Standard (APMS, 2006) (Table 1) – initially developed for a pioneering spatial imaging effort – defines the spatial metadata elements that must be included to provide the links between locations on the cultural heritage object and on the image of the object, based on those cited in the *Content Standard for Digital Geospatial Data*. Each element then includes the specific coordinate system and measurements of the specific location on the image and original object. This is currently used just for two-dimensional objects, but elements for the z axis are available to capture metadata about cockling of the surface of manuscripts, as well as application to three-dimensional objects.

Mature spatial technologies at the micro level can be used to "scriptospatially" link a variety of scientific data from spatial points on the object, and at the macro level to link the object to the geographic area where it was developed, fabricated, stored and displayed. The goal is to integrate the spatial data into a GIS interface adapted to cultural heritage needs. At the object level, the GIS display could link the scientific data collected from specific spatial areas on the object with a spatial reference to each data collection point. On another global level, the GIS interface could link the object to the geographic location where it was used, displayed and/or manufactured in traditional mapping fashion.

Table 1: Spatial Data Section of Metadata Standard

2.1 Coordinate Units: unit type used in quantitative spatial metadata
CORE: YES TYPE: SINGLE
DOMAIN: "pixel", "centimeters", "millimeters", "micrometer"

2.2 X Resolution: number of resolution elements per coordinate unit in the x-direction
CORE: YES TYPE: SINGLE
DOMAIN: REAL NUMBER

2.3 Y Resolution: number of resolution elements per coordinate unit in the y-direction
CORE: YES TYPE: SINGLE
DOMAIN: REAL NUMBER

2.4 Upper Left XY Coordinates: upper left coordinate of the limit of imaging expressed in resolution units.
CORE: YES TYPE: COMPOUND
DOMAIN: x= n and y= n

2.5 Lower Right XY Coordinates: lower right coordinate of the limit of imaging expressed in resolution units.
CORE: YES TYPE: SINGLE
DOMAIN: x= n and y= n

2.6 Bounding Coordinates: the limits of coverage of the complete data set for the entire sample expressed by Cartesian coordinate values assigned by the x:y table software in the order upper left, lower right.
CORE: YES TYPE: COMPOUND
DOMAIN: REAL NUMBER

2.7 Grid Coordinate System: Orientation of and definition of Cartesian coordinate so that spatial positions can be readily transformed to and from plane coordinates.
CORE: YES TYPE: COMPOUND
DOMAIN: TEXT

2.8 Vertical Coordinate System Definition: the reference frame or system from which vertical distances (altitudes or depths) are measured.
CORE: NO TYPE: COMPOUND
DOMAIN: TEXT

2.9 X-Positional Accuracy: an estimate of accuracy of the horizontal positions of the spatial objects.
CORE: YES TYPE: SINGLE
DOMAIN: REAL NUMBER

2.10 Y-Positional Accuracy: an estimate of accuracy of the horizontal positions of the spatial objects.
CORE: YES TYPE: SINGLE
DOMAIN: REAL NUMBER

2.11 Vertical Positional Accuracy: an estimate of accuracy of the vertical positions in the data set.
CORE: NO TYPE: SINGLE
DOMAIN: REAL NUMBER

The spatial links between data allow analyses that provide meaningful scientific outcomes of the content: retrieval of obscured or faded text; characterization of inks and pigments that can be traced to specific geographical locations; analysis of the intensity of handwriting to understand the author’s original intent; and gleaning the provenance and source of paper through the capture and analysis of the watermark. A continued focus on collaboration between people, data and processes is a major factor in promoting access and integration of scientific research through a scriptospatial system of linking data for analysis and study.

Visualization User Interface

With the expansion of analogue and digital scholarly sources available, there is a need for researchers to be able to interact more effectively with diverse multidisciplinary sources and increased volumes of data. This requirement for better access to integrated source materials requires an assessment of the way that sources and datasets are presented, accessed and made searchable. Historically, there has been a division between the integration of scientific analytical data captured during investigations of documents and manuscripts, and the scholarly analysis. There is a clear need to expand and balance the access to this scientific and often preservation based data while retaining and preventing loss of contextual scholarly information inherent in a cultural heritage object. Too often original source materials are treated essentially as separate entities for preservation and scholarly purposes, leading to a segregation of any data collected, and a divisive perspective based upon the original purpose of the study.

Integrated access to associated source material scientific data adds contextual value, provenance information, and can reveal non-visible information hidden within the original document. The Scriptospatial approach allows layering of scientific and scholarly or curatorial research data within one location, enhancing the analysis and depth of knowledge off the original document, and creating a more effective interface for interaction with historic materials (France et. al, 2009). One of the challenges we face with the current data deluge, is how to effectively access, select and link appropriate data and information. Scriptospatial is a value-added data approach, creating cohesive structured management of multidisciplinary data.

The Digital Cultural Object

The integrated layers of data now create what is termed the "d*igital cultural object*" (DCO) – an object that cannot replace the original, but adds non-visible information contextually in both temporal and spatial layers. Historic documents do not readily lend themselves to context analysis, since documentation about the creation of the document may not be readily available. The additional contextual information is not apparent in conventional digitization techniques for these objects, so the integration of the spectral data assists in mining the layers of data stored within the objects. In this way the DCO provides a range of data and information. This allows a shift from the use of interpretive virtual heritage applications, which focus on the artistic, rather than the investigative and inferential, toward the development of interdisciplinary scientific data as part of cultural heritage scholarly studies. In this way, cultural heritage studies, science and technology are intertwined, advancing the capacity to mine and analyse historic data from multiple viewpoints. Coordinating the relationship between the original and the DCO entities enables greater access to scholarly information, since identification of materials enables access to provenance, geographical and temporal information to extend knowledge about the historic document.

Some institutions, including the Library of Congress, have taken a forensic type approach to assessing cultural heritage objects to uncover information about the history of the object including preservation treatments and evaluations. These treatments have changed significantly over the decades, often with little documentation that supports historic knowledge of how the artefact has been treated. At the Library of Congress, there has been a concerted effort to assess and analyse the impact of prior treatments before stabilizing an object, to ensure that any stabilization treatments do not remove scholarly contextual data. Technical studies are critical to this, but only with integration to standard work processes and cross-disciplinary analysis. Increasingly PRTD develops a team of curatorial, conservation and preservation scientific staff to coordinate the overall approach based on technical findings and make an informed decision about how preservation actions may impact contextual information, and ensure that this content remains with the object.

The application of this technology to a significant historic document can be seen in the example of the Waldseemüller 1507 World Map with captured data providing a number of insights for cartographic researchers. Johannes Schöner (1477-1547), a German astronomer and cartographer and pupil of Waldseemüller, drew red lines over the map from the Middle East north to the Black Sea, an area that must have been of interest (France 2011a). Over time, these inscribed red gridlines on Sheets 6 and 7 had faded significantly and become virtually imperceptible. These gridlines represented important added features in the cartographic history of this map, so it was important for curatorial collaborators to find a way to retrieve this lost information. With spectral imaging, these lines could be distinguished through their unique spectral response. The reconstruction allowed researchers to assess overlapping of the lines – including which lines were laid down first, where lines began and ended. This began to broaden the interpretation and understanding of Schöner's thought processes from the early 1500s. While the Waldseemüller 1507 World Map is famous for the first reference to 'America', it remains a source of intrigue since the cartographer is known, but not the precise time or location of printing (Hessler 2008).

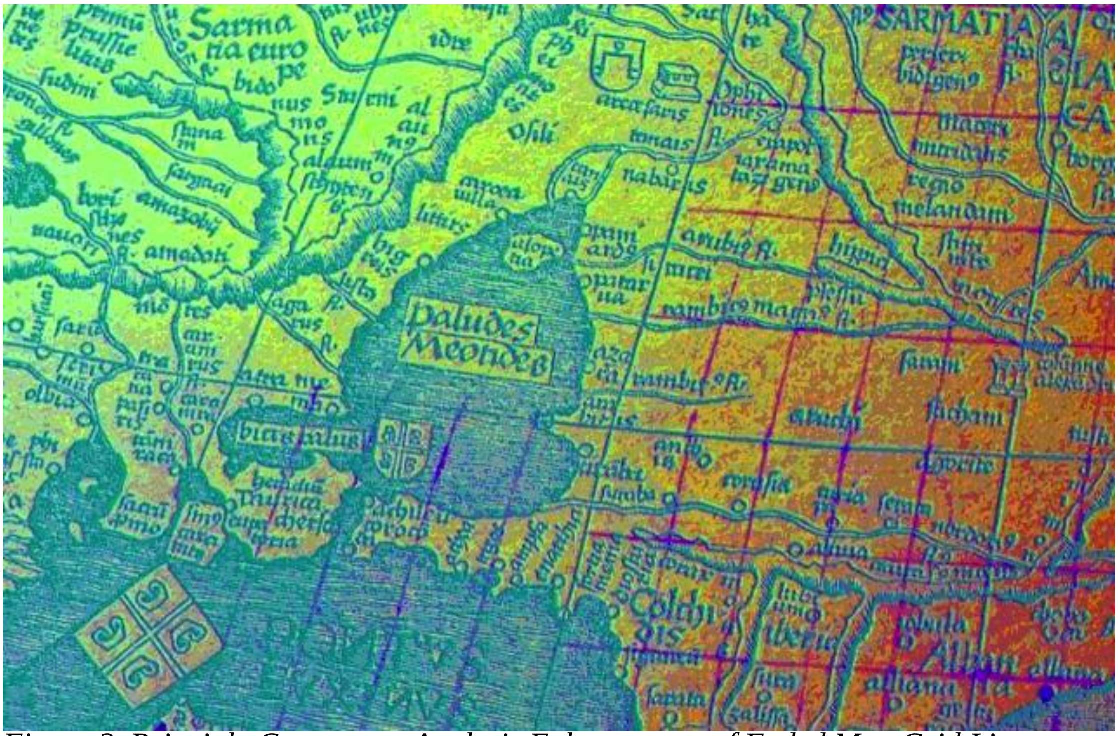

Figure 2. Principle Component Analysis Enhancement of Faded Map Grid Lines

The 1507 World Map was discovered in 1901 by Joseph Fisher, a Jesuit historian conducting research in the library collection of Wolfegg Castle, Wurttenberg, Germany. Fisher was convinced that the World Map sheets were printers' proof sheets, so the ability to gain greater understanding about how the woodcut was produced was of great interest to scholars, cartographers and historians. Specialized processing created a virtual 3-dimensional rendering of the map, giving a visual perspective of the original woodcut from which the sheets were printed. Since the original woodcut no longer exists, the processed images allow an analysis of possible techniques used in the early 1500s to inform scholars about creation techniques and gain a better understanding of the materials used in the process (France and Toth, 2013). These layers of data comprise the DCO, adding a rich resource of non-visible information that need to be stored and accessible as a critical data set to support expanded contextual knowledge of the document.

Conclusions

The challenges of linking data in cultural heritage databases stem from the large range of data that can be acquired and the volume and size of datasets that can be generated from spectral imaging and other scientific instrumentation reference sets. The development of a scriptospatial approach using advanced imaging techniques links scholarly and scientific data, information critical to collaboration for the preservation of the object and knowledge about it within library and cultural heritage collections. Expanding the utility of non-destructive scientific analyses for cultural heritage research enables both preservation and scholarly data to be linked and interpreted. It also provides greater access to lost and obscured data from collection objects that create insights into the author intent and provenance of documents. The object-oriented approach using a scriptospatial system based on geospatial standards allows representation of the original document, while supporting effective integration of standardized scientific and scholarly data, layered with spatial, temporal, cultural and historical data. While this approach develops layers of data that augment scholarly and curatorial research, the digital component and the cultural heritage object greatly enhance interdisciplinary access while preserving and protecting both the data and the original documents.

With collaborative input and leadership, the combination of advanced preservation spectral imaging and integrated data information management systems can make major contributions to artefact studies and the information needs of a range of cultural heritage organizations. The changing roles of staff and other professionals in libraries, archives, and museums demands significant attention to the multidisciplinary information needs of external users – public and researchers – as well as those benefitting internal staff requirements and the needs of collections. This can be attained through management and maintenance of quality data, while allowing access to an increasing volume of integrated images and data within a structured metadata scheme for increased collaboration.

By maintaining focus on the content of the original artefact or document, the new digital object created from advanced spectral images and data for scientific, scholarly and preservation knowledge will allow access to, interpretation and preservation of fragile items of significant cultural heritage. This will allow libraries, archives and museums to converge with information technology and data management in supporting their common role as effective stewards of these artefacts for generations to come. As noted above, the integration of scientific analytical data with curatorial knowledge (science, technology, engineering arts and mathematics - STEAM) is a critical multidisciplinary approach for expanding the full potential of scientific techniques and technological advances to enhance the understanding of original source materials and collaboration in our extensive global heritage institutions.

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