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Reflections on the Digital Palimpsest: Data Modelling and Data Management

INTRODUCTION

The author began data management work on spectral imaging projects in 2005, with the Archimedes Palimpsest Project (APP). Since then, he has worked on several such projects, including the Syriac Galen Palimpsest (SGP, 2009–2010) and the Sinai Palimpsests Project (SPP, 2011–2015). The data management approaches the author employed beginning in 2005 with the Archimedes Palimpsest Project evolved and changed over the next 10 years. This paper will summarize that work from a data management point of view and give a detailed example of the relationship between data management, metadata, and data modelling that encapsulates this change in approach.

SUMMARY PROJECT HISTORY

The table below summarizes four of the projects the author worked on between 2005 and 2015, beginning with the Archimedes Palimpsests Project and ending with the Sinai Palimpsests Project. The Walters Art Museum's ongoing manuscript digitization is added here because of the role it played in the development of the methods used for the Sinai Palimpsests Project.

	Archimedes Palimpsest	**Syriac Galen Palimpsest**	**Walters Art Museum MSS**	**Sinai Palimpsests**
Image type	Spectral	Spectral	Colour archival	Spectral
Start date	1998	2009	2008	2011
Data publication	2008	2010	2010	2015
Number of MSS	1	1	475+	74
Capture images per folio side	16	23	1	31/33
Processed images per folio side	3	5+	N/A	ca. 30+
Data set size	1TB	0.37 TB	19TB	50TB
Image sequences	180	242	N/A	6,944
Distinct images	4,006	6,268	ca. 142,000	ca. 430,000
Data management methods	Stokes IWS; Spreadsheets; Ruby scripts; Unix shell scripts	MegaVision PhotoShoot; MSIMM; Ruby scripts; Unix shell scripts	Stokes IWS; WECT; Ruby scripts; Unix shell scripts; Bagger	MegaVision PhotoShoot; KatIkon; Spreadsheets; Ruby scripts; Unix shell scripts

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Explanatory Notes

Capture images

The *Archimedes* data set includes images captured apart from the spectral images in these data sets, including digital versions of Johan Ludwig Heiberg's 1906 photos of the manuscripts and X-Ray Fluorescence (XRF) images captured at the Stanford Linear Accelerator Center (SLAC).[1]

The *Galen* data set includes images of additional leaves of the manuscript not captured in 2009/2010. These are of leaves now at the Houghton Library at Harvard University, the Vatican, the Bibliothèque nationale de France, and St. Catherine's Monastery in the Sinai.[2]

Processed images per side

For each of the spectral imaging projects a fixed number of processed images were produced by Keith Knox using unsupervised batch processing methods. In addition to these images, special supervised statistical processing methods were applied to those images not amenable to the unsupervised processing. This work was done by William Christens-Barry, Roger Easton and students under his supervision, and David Kelbe.

Number of manuscripts

The Walters Art Museum has an ongoing operation to digitize and publish images of its medieval and rare manuscripts. 474 manuscripts with images are now online at the Digital Walters website.[3]

Data management methods

- *Stokes IWS*.[4] The 2007 reimaging of the *Archimedes Palimpsest* used the database-driven, Stokes Imaging Workflow Solution (IWS) to manage file naming at capture time and record camera configuration and capture information. IWS accepts input spreadsheets containing filenames and metadata and records capture details, which can then be exported as Excel spreadsheets for use in other processes. These features were used in the Archimedes Project and the ongoing manuscript digitization efforts at the Walters Art Museum.
- *MegaVision PhotoShoot*.[5] In 2009, the MegaVision PhotoShoot software allowed users to enter the base names of capture files by hand. The 2011 version of the software accepted a formatted text file with the base name of each capture file and metadata to add to each image's header. Both of these systems were integrated with lighting systems developed by William Christens-Barry.
- *MSIMM*. The Multi-Spectral Image Manager ('Miss M.') was a first attempt at building a Ruby on Rails web application to manage the image metadata for a spectral imaging project.[6] It generated filenames, tracked capture images and processed images, and generated data files used to add metadata to image headers and assemble archival packages of data. The *Syriac Galen Palimpsest* metadata was managed by MSIMM.
- *WECT*. The Walters Electronic Cataloging Tool is used by the Walters Art Museum to manage manuscript imaging metadata and manuscript cataloguing and publication on its Digital Walters website (http://thedigitalwalters.org).
- *KatIkon*. The KatIkon built on the concepts of MSIMM and added a component for manuscript cataloguing and undertext identification. KatIkon was the data management heart of the Sinai Palimpsests Project.
- *Ruby and Unix shell scripts*. On all projects, custom scripts were used to collect, record, and manage metadata and to assemble data and metadata for delivery and archiving. The scripts were written in the Ruby programming language and the Bash shell script language, with heavy reliance on the utility ExifTool.[7]
- *Bagger*. The Walters Art Museum packages its image data using the BagIt protocol, which is used to create verifiable packages of digital data for delivery and archiving.[8] They use the Library of Congress Bagger application to create BagIt 'bags'.[9]

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1 Noel, Introduction; Bergmann, Imaging with X-Ray Fluorescence.
2 *The Syriac Galen Palimpsest.*
3 *The Digital Walters.*
4 *Stokes Imaging Inc: IWS.*
5 *MegaVision Archival Photography.*
6 *Ruby on Rails.*
7 *Ruby Programming Language*; *GNU Bash*; *ExifTool* by Phil Harvey.
8 Kunze *et al.*, *The BagIt File Packaging Format (V1.0).*
9 *The Bagger Application Packages Data Files According to the BagIt Specificatio*n.

As can be seen from the chart, the trend over time was an increase in the number of manuscripts that were imaged and the number of images produced per manuscript. While the data and metadata for the Archimedes and Galen Projects could be managed by one person, with the Walters project and the Sinai Palimpsests Project the duration and size of the projects moved beyond the management capability of one person, requiring personnel in multiple roles, working in a distributed fashion. While data and metadata collection could be managed with spreadsheets in the Archimedes Project, the Walters project demanded a different approach. For that project, a data and cataloguing management web application was developed, along with a small suite of scripts, to manage the Walters image data and metadata and detailed manuscript-level and page-level cataloguing information. This is Walters Electronic Cataloging Tool, or WECT, which was built in the Ruby on Rails web application framework. The WECT orchestrates data management for the project, collecting shoot list information to be uploaded to the camera software, Stokes IWS; managing post-capture technical metadata for all images and their derivates; and integrating detailed cataloguing with image data for publication as Text Encoding Initiative (TEI) compliant XML manuscript descriptions.[10] Distributed staff and project members use the WECT to manage image and cataloguing metadata and to publish that data on the Digital Walters website.

The ideas employed for the WECT were adapted for KatIkon, the tool used by the Sinai Palimpsests Project for data management, metadata management, manuscript cataloguing, and palimpsest undertext characterization. KatIkon offers these features:

- Collection of manuscript and folio metadata, with an emphasis on palimpsest description
- Creation of Shoot Lists used by the MegaVision PhotoShoot software to manage imaging workflow, filenames, and metadata
- Collection of metadata for capture and processed images for linking to manuscript folios
- The assignment of folios and images to scholars charged with identifying palimpsest undertexts
- The creation of image lists based on those assignments for packaging to be delivered to scholars
- Collection of undertext identifications made by the scholars and the grouping of undertexts belonging to the same source manuscript (e.g., all the undertext folios belonging to a single copy of the Gospel of St. Mark)
- The creation and export of files used to assemble archival packages of images and CSV and TEI manuscript descriptions for over- and undertext manuscripts

KatIkon was supported by two sets of scripts, spindle and sp-boxer. Spindle facilitated the delivery and receipt of data for the Sinai Palimpsests Project: validating and packaging images for delivery, unpacking and validating images upon receipt, and extracting metadata from received images for upload to KatIkon.[11] Sp-boxer (not publicly available) used metadata and package creation instructions downloaded from KatIkon to build packages for delivery to scholars and for long-term preservation.

Both the WECT and KatIkon manage the complete life cycle of imaging and cataloguing, from the creation of lists of shots before capture to the final publication of images with complete technical and content descriptive metadata. To serve the complexities of spectral imaging and palimpsest description and text identification, KatIkon extended the WECT model in interesting ways.

PROCESS, DATA MODELLING, AND THE NAMES OF FILES

The following discussion looks at the practice of file naming, work processes, and data modelling. The case is made that good data management practice begins with the intended result and destination for that data. This practice also takes into account the scope of the project in terms of the quantity of data to be managed and the number of tasks and roles involved from the time of the data's creation to its final publication.

The question of file names in a spectral imaging project of the size of the Sinai Palimpsests Project is a critical one. Over 220,000 images were captured in the Sinai over a period of four years. They were brought to the United States in batches on hard drives and then distributed to project scientists for processing. The processed images were returned to the data operations manager to be added to the larger data set, and distributed to

[10] *10 Manuscript Description – The TEI Guidelines.*
[11] *Sinai Palimpsests Project Data Delivery and Receipt.*

scholars for undertext identification work. The scholars using those files entered undertext identifications into KatIkon. When the imaging, processing, and cataloguing for a manuscript was compete and the data ready for archiving and publication, all the correct files, capture and processed, had to be assembled in a directory with metadata files linked to those images. Some manuscripts had over 10,000 associated images, all of which had to be assembled and linked to the metadata. The final package of data is a fully-integrated, verifiable archive of a manuscript's palimpsest folio images and descriptive and technical metadata that is created often years after the leaves were first digitized. During that time the integrity of the data and its validity has to be assured and monitored.

A key component of the management of this data comes down to filenames, their consistent naming and handling. The currency of a spectral imaging project is the files, one for each exposure of a recto or verso side along with multiple processed images. In the case of the Sinai project, each folio side had thirty-three capture images and nearly the same number of processed images.[12] On the projects discussed here, capture images were distributed to project scientists in batches numbering thousands of images. Generated processed files were returned to the data administrator to be added to the larger data set. The files had to have unique names so that they could be distinguished from one another, by content, by mode of capture, by processing method.

A common approach for naming images is to use the folio number or numbers of the object imaged, the mode of capture or processing, and an image sequence serial number. Note the following filenames from the Archimedes Palimpsest Project:

103r-097v_Arch42r_Sinar_LED365_01_raw.tif
103r-097v_Arch42r_Sinar_LED445_01_raw.tif

The first file is an image of *Archimedes Palimpsest* overtext bifolio 103r+97v, with undertext folio side designated Archimedes 42r. It was captured using a Sinar camera and illuminated by 365 nanometer LED lights. It was the first such exposure captured (indicated by the '01'), was derived from a camera 'raw' file, and is in the TIFF image format. Each of these encoded values is, of course, shorthand for more complex data. The second file is identical, except that it was illuminated with 445 nm LED lights. Every image file in the Archimedes data is similarly named, with the name segments changed according to subject, capture, or processing method, and so on. This file naming convention was developed for a project that imaged one manuscript. To extend this approach to multiple manuscripts, one would need to add a call number or shelfmark at the beginning. Even more data can be added to filenames as a storage mechanism for persistent and transient information.

The use of filenames to store information, especially content information, is problematic in projects of any size for which automated methods are used to associate complex metadata with images, and to manage and publish that data in bulk. Information like the identification of a folio side or a manuscript via its shelfmark can be incorrect (and at times indeed is incorrect), costing significant time and effort to fix. The *Archimedes Palimpsest* data set demonstrates an error of this type. The fourteen pages that make up the Aristotle commentary in the palimpsest are assigned undertext foliation with the code 'Alex' as a shorthand for Alexander of Aphrodisias, who was originally thought to be the author of the text:

143r-146v_Alex01r_Sinar_LED365_01_pack8.tif

This attribution is now disputed, and the project scholars prefer Porphyry as the likely author, making the filenames in the data set problematic at best.[13] Furthermore, human participation in the creation and management of meaningful file names and the temptation to manipulate, correct or 'improve' file names containing content information between the time of image capture and final publication can result in errors and inconsistencies that break the chain of information relied upon by automated workflows.

For the Sinai Palimpsests Project, the decision was made to base filenames on arbitrary numerical identifiers generated by the KatIkon application. These values were based on workflow units tied to an image's Shoot List and Shot Sequence, concepts developed to organize workflow and manage the relationship between images and manuscript and folio metadata (see Fig. 1). A 'Shoot List' is defined as a container for a number of Shot

[12] Early in the Sinai Palimpsests Project 31 capture exposures were made for each Shot Sequence.
[13] Chiaradonna *et al*., A Rediscovered Categories Commentary.

Sequences for a given manuscript and a given capture configuration. A 'Shot Sequence' is a named entity representing the subject of a single sequence of spectral images and typically corresponds to one folio side; however, in some instances a Shot Sequence can be assigned more than one folio side if needed. A Shot Sequence Number, or 'cube name', is composed of a Shoot List number and a Shot Sequence serial number; for example, Shoot List number *3* would have Shot Sequences 0003_000001, 0003_000002, 0003_000003, and so on. The cube name serves as the basis for the filename. For example, 0030_000076+MB625Rd_007_F.tif is an image from Shot Sequence 0030_000076 (in shorthand, 30-76), illuminated with 625 nm LEDs from the two main light panels (MB625Rd), the seventh in the series of shots in this sequence (007), and is a flattened (F) image in TIFF (.tif) format. Metadata stored in the folder with the images from this Shot Sequence informs us that the folder contains images of Sin. geo. NF 61, f. 38v. Note that each image is connected to a manuscript and one or more folios via its Shot Sequence.

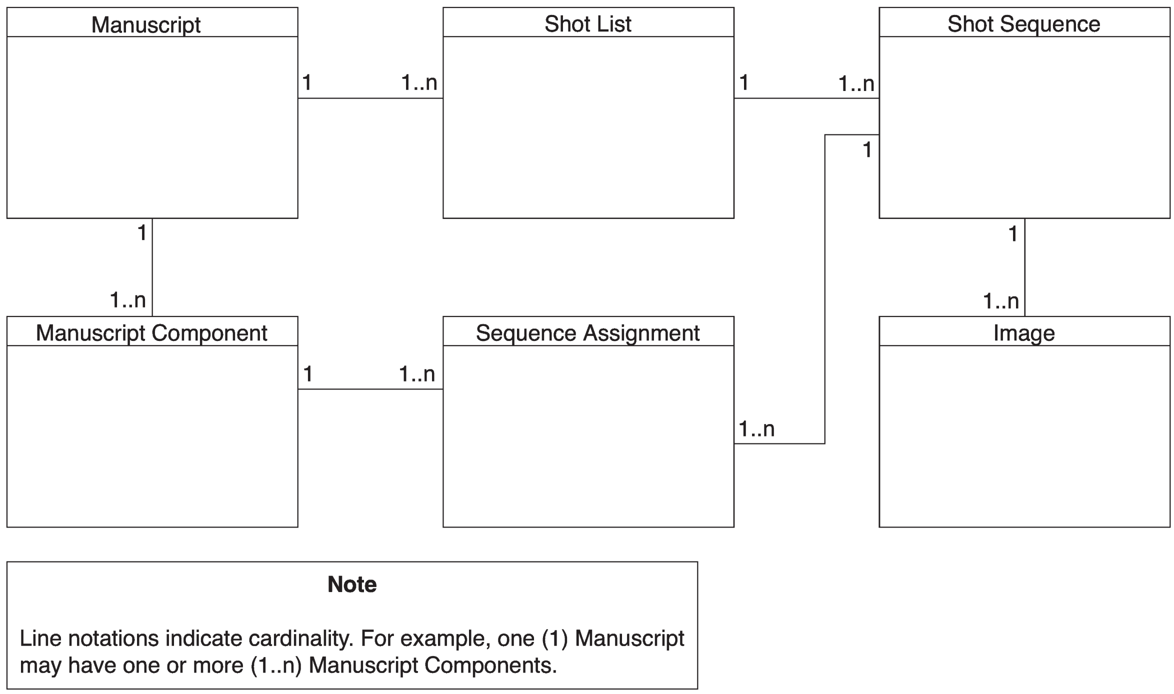

Fig. 1: KatIkon Shoot List and Shot Sequence

The use of the Shoot List and Shot Sequence has several benefits:

1. A Shoot List and all its child Shot Sequences belong to a single manuscript. Any number of Shoot Lists can be created for a manuscript. Thus, the Shoot List makes possible the creation of different groups of images for one manuscript.
2. Any number of folio sides from a single manuscript can be assigned to a Shoot List. Thus, the imaging of a manuscript's folio sides can be handled as discrete units of work. For example, a user can create separate Shoot Lists for folio sides to be shot on a book cradle and those to be shot on a copy stand.
3. Because each Shoot List will have its own identifying number, its Shot Sequences will have unique Shot Sequence Numbers and the files created with those numbers will have unique names. Thus, users can create multiple Shoot Lists for the same folio sides of a manuscript without risk of filename collision. This method was used by the Sinai Palimpsests Project to photograph the same manuscript using different capture configurations and retain both sets of images without ad hoc adjustment to file identifiers.
4. The use of the Shot Sequence number in the file name separates the file identifiers from image content information. If a Shot Sequence is assigned to the wrong folio sides, the error can be corrected in the metadata without requiring the renaming of files, files that may exist in several distributed copies.

5. Finally, the Shoot List-Shot Sequence model integrates a flexible workflow with the management and integration of images and metadata, both technical metadata and the descriptive metadata collected for the manuscript, its folio sides, and their undertext layers.

There are disadvantages to the use of Shot Sequence numbers as proxies for content information. The flexibility provided by filenames without content information comes at the cost of being able to quickly identify the subject of an image on the basis of the filename. The use of opaque filenames creates a need for tools and software to maintain the relationship between file and content metadata and to make content information discoverable by users. Image processors and other pre-publication users of the images had to rely on spreadsheets or other mappings to translate Shot Sequence numbers to shelfmarks and folio numbers. Further, these arbitrary names may be unsuitable for publication and archiving, thus placing an extra burden on the software that prepares and packages data for end user consumption. To send images to project scholars and prepare packages for delivery, Dr. Susan Marshall, the project's Data Operations Manager, used scripts that rewrite the filenames, adding shelfmark and folio information to their opaque working identifiers.

Nevertheless, the advantages of the Shot Sequence-based filename outweigh the disadvantages. One problem with content-based filenames is the need to handle unanticipated exceptional cases. Manuscripts often have duplicate folio numbers, accidentally skipped and unnumbered folios, or multiple, competing foliations. There may be the need to image the same folio side multiple times; for example, when a folio side has a fold-out that is imaged folded and unfolded. A folio side may be shot together with an opposing stub leaf bearing undertext writing. When unexpected complexities arise, reliance on content-based filenames creates the need to improvise ways of differentiating image content, often leading to inconsistent, cryptic, or cluttered filenames. Managing image labels, in metadata itself rather than in file identifiers, properly separates the roles of filenames and metadata. Moreover, as noted above, use of opaque filenames prevents their being incorrect or at variance with changing terminology or knowledge about the content of the image. The concepts of Shoot List and Shot Sequence provide a comprehensible and economical method for managing work and facilitating data integrity.

Similarly, KatIkon's model for managing scholarly text identification takes into account the necessities of work process and conceptual clarity. The approach taken has been documented elsewhere, but a brief summary here is useful.[14] Several manuscripts had undertexts in more than one language. Scholars working on the Sinai Palimpsests Project were sent images of those folio sides from a manuscript with undertexts suited to their expertise. The concept of 'Text Layer Grouping' was used to organize a set of images of a manuscript's folios with Folio Undertext Layers in a particular language and script. From a Text Layer Grouping, KatIkon generated an exportable list of folio images as input for a script that assembled data for delivery to each scholar. The scholar would identify the content of Folio Undertext Layers and assign them to Undertext Objects. An 'Undertext Object' is defined as all Folio Undertext Layers in a single extant manuscript that likely belonged to same notional past manuscript; that is, those of the same text and in the same hand. When archival packages were generated for fully documented manuscripts—those deemed editorially complete—the Undertext Object and associated Folio Undertext Layers were used to create TEI manuscript descriptions of the notional manuscript linked to the appropriate images. Again, human processes and the requirements of the project were mapped onto the data model. Note, too, that the model employed is integrated with the handling of files associated with Shot Sequences (see Fig. 2). Thus, through the Shot Sequences linked to a Manuscript Component (i.e., folio side), an Undertext Object and its Folio Undertext Layers are linked to the correct images.

[14] Emery and Rapp, KatIkon: A Digital Catalogue as Multi-Purpose Tools.

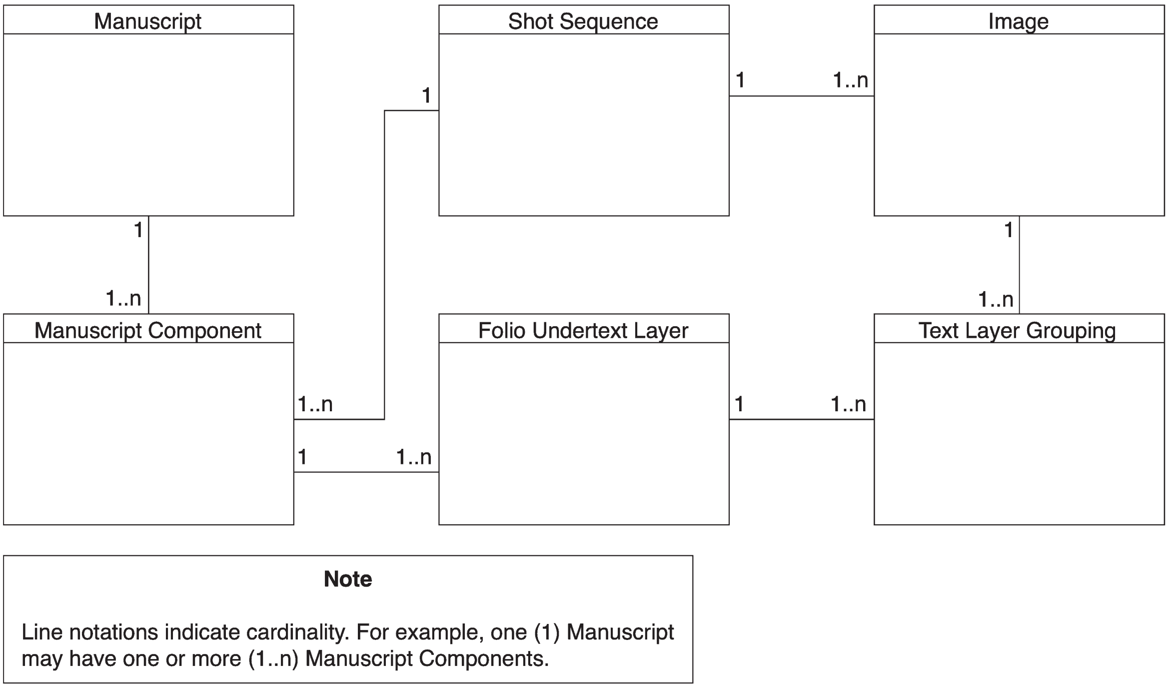

Fig. 2: KatIkon Undertext Identification model

CONCLUSION

This discussion is not intended merely as an argument for the virtue of one type of filename or data model. Rather it is intended to demonstrate the interrelationship between data modelling, work processes, and the management of data and metadata. The activity of cultural heritage digitization projects, particularly those that employ spectral imaging, involves many workflows and participants—curators, conservators, camera operators, image processors, scholars, digital archivists, and website developers. With large projects, the need for well-thought-out processes increases. The Sinai Palimpsests Project imaged palimpsest leaves from 74 manuscripts, and created a total of 6,944 sequences of images, 221,219 capture images, 217,834 processed images, all comprised in a data set of 50 TB. Imaging took place during several capture sessions spread over the period of the project. The image sets from each session travelled on hard drives from the Sinai to California, where they were logged and stored on the project's storage array by Susan Marshall, who then sent them to the four imaging scientists in New York, Maryland, and Hawaii. The scientists sent derived processed images back to Susan Marshall who logged and stored them. These processed images were packaged for delivery to scholars in Europe and the United States who did the work of identifying the palimpsest undertexts. Once all text identifications and codicological descriptions for a manuscript were complete, Susan Marshall generated an archival package of images, technical metadata, manuscript descriptions, and text identifications for delivery to the University of California at Los Angeles, for long-term preservation and publication on the project's research website. The scope and the operational complexity of the Sinai Palimpsests Project necessitated a robust, quality-focused process.

The processes designed for managing data, technical metadata, and cataloguing information for the Sinai Palimpsests Project are by no means the only approach that could have been taken. The tools created for the Sinai Palimpsests Project served a large and complex work process. The data model itself is a reflection of the objects and activities of the larger process. According to Matthew West, a data model 'defines the structure and meaning of data'.[15] Data models often define classes of objects that correspond to things in the real world, like 'manuscript'. These classes have attributes corresponding to their real-world counterparts, like 'shelfmark', 'title', 'language',

[15] West and Fowler, *Developing High Quality Data Models*.

'number of folios', and so forth. Often one class will have related classes. For example, a manuscript class can have many related objects of the class 'folio side'. The KatIkon model represents manuscripts, folios, and images, but also the activities of digitization and text characterization, as with the Shoot List and Text Layer Grouping.

Any work process, even one without a formalized model, has an underlying implicit data model. Designers of work processes, especially for large, distributed, or long-running projects that rely on data consistency and integrity over time, are well advised to be explicit about work products and activities, to think with rigour about the interrelationship between data and work activities. The concepts of the Shoot List and, especially, the Shot Sequence, recognize a critical fact of a spectral imaging project: the primacy of the *image cube*, the registered exposures of photographic subject captured in a sequential series, tied to a specific imaging system configuration. Previous imaging projects the author worked on implicitly treated multiple sets of images of the same folio side or sides as different versions of the same thing, using designations like '01', '02', '03' or 'A', 'B', 'C', 'D'. This is incorrect. However it is named, the sequence of exposures, called in the Sinai Palimpsests Project the Shot Sequence, is the unit of work, the unit of data, the unit of each folder of images. The use of the Shot Sequence concept, its concretization in the data model, workflow, and filenames adds clarity for project participants and consumers of the data alike, and reduces data conflicts and errors. It is one of a small number of developments in thinking and practice over the ten years of his work on spectral imaging projects that the author feels he got right.

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