# JPEG 2000 in Practice: The Effect of Image Content and Imaging System Characteristics

*Ronald J. Murray*
*Library of Congress*
*Washington, D.C., USA*

## Abstract

Parties creating Digital Library resources adopt and reinvent preexisting image file formats and format management techniques to satisfy Digital Library system requirements. While it will take some time for JPEG 2000-based Digital Library practices to gain prominence, the result will partially supplant and exist in parallel with TIFF-based practices. Initial efforts at outlining a JPEG 2000 practice indicate that significant differences in image quality, post-processing, file management and network resource requirements may exist.

Our studies have indicated that not only must methods for determining digitizing device performance characteristics and image capture specifications based on TIFF practice must be revisited, clarified, and verified empirically; but that the concepts, terminology, and assumptions used to discuss or compare the two forms of practice must also be brought up to date; and that the specifications and techniques that constitute a JPEG 2000 practice are best developed by a multidisciplinary, mission-focused team of specialists from all Digital Library-relevant fields.

## Testing JPEG 2000 with Library and Archive-Relevant Images

This section will describe image capture and JPEG 2000 encoding studies using sets of images selected from a wide variety of collections at Library of Congress or acquired from elsewhere. The evaluation team processed and compared more than 140 GB of sample uncompressed TIFF image files – as single images and as batch-processed directories of images encoded in "lossless" and "lossy" mode.

### Choosing a More Appropriate Language for the Practical Evaluation of JPEG 2000

This discussion will be conducted using "Digital Library Creole" – a distinctive technological language that emerged when Desktop Publishing concepts, terminology, and techniques were adopted, adapted and utilized by those parties who designed, constructed, and who now operate Digital Libraries.[1] For reasons that will become clear, we find it necessary to supplement this venerable language with selected elements from the Imaging Science and Signal Processing Engineering fields. This is because only with an *updated* Digital Library Creole can concepts, terminology, and techniques appropriate for understanding and evaluating JPEG 2000 be discussed.

### Selecting Sample Images

Images from a number of Library of Congress (LC) collections and other sources were selected in order to explore their performance under JPEG 2000 encoding:

***Illustrated Book Study Resolution Samples***
http://www.library.cornell.edu/preservation/illbk/AdComm.htm

The samples represent major types of printing processes that are regularly digitized by library or archive personnel.

***Federal Theatre Project***
http://memory.loc.gov/ammem/fedtp/fthome.html

Images of deteriorating 4" x 5" B&W publicity photo negatives.

***Garden and Forest***
http://lcweb.loc.gov/preserv/prd/gardfor/

Page images containing halftone areas that may require descreening to improve on-screen readability and printing.

***NBC Radio Play Master Books***
http://www.loc.gov/rr/record/recnbc.html#masters

Digital images of a deteriorating 16mm microfilm service negative made from poor quality printed and handwritten materials.

***Wright Brothers***
http://lcweb2.loc.gov/pp/wriquery.html

1900's era images documenting a historically significant event.

***Civil War Glass Photographs***
http://lcweb2.loc.gov/pp/cwpquery.html

Images of 8" x 10" glass plate negatives made with 1860's-era lenses.

***Adams Manzanar Internment Camp Photographs***
http://lcweb2.loc.gov/pp/manzquery.html

4"x5" B&W negatives made with 1940's-era lenses.

***Washington Post***

Five pages from the September 2, 2003 edition of the Washington Post were digitized in 8-bit greyscale, with two of the same pages reimaged in 24-bit color at 435 DPI, representing halftone (some color) newspaper content capture with fine serifed text.

***ISO 16067 Synthetic and Analog Images***

We also had access to a digital image which conformed to the ISO 16067 standard, but which had not gone through any imaging system. This target would allow us to more cleanly explore phenomena that appear in the scanned images, but which may be ambiguously interpreted.

## Capture Device Characterization, Image Processing and Encoding, and Digital Image Inspection

***Devices***

Our JPEG 2000 study was specified so as to gain a measure of a digital system's performance at various critical points in the imaging/archiving/reproduction cycle. We also employed targets used for performing System Frequency Analyses (as specified by ISO 16067) that provided Modulation Transfer Function-like measures of imaging system performance for both reflective and transmissive materials.[2]

***Image Processing and Encoding***

Lacking access to many of the tools that Imaging Scientists and Signal Processing Engineers would use to characterize JPEG 2000 images (or any other kinds of images) we first sought to identify and use image-processing operations that are generally available to Digital Library workers who use commercially available image editors like Adobe Photoshop. The procedures executed could be readily duplicated and extended by interested parties, and are capable of being described in our updated Digital Library Creole as well as in more technical languages.

These operations included: scaling an image up or down in size using the **Image Size** … command; examining an image histogram using the **Histogram** … command; saving a file as a TIFF or JPEG 2000 (which for the moment requires a provided plug-in); finding differences between one image and another using the **Calculations** … command; stretching image levels using the **Autolevels** command;[3] blurring an image using the **Gaussian Blur** … command; adding noise to an image using the **Add Noise** … command; and using the venerable **Revert** and **Save As** commands to recover original images and save others.

## Our Results

***General File Size Phenomena***

We found that "lossless" JPEG 2000 encoding reduced file sizes in the range of 30% for color and grey scale materials in the sample corpus – as previously reported in the literature that tracked the standards-setting process.[4] With "minimally lossy" encoded files (i.e., with the highest compression short of "lossless" that could be specified with the encoding application), 83% file savings is achievable for digital images of the types currently found in LC collections. Images containing large expanses of color or tone were more efficiently encoded than ones containing contrasty, detailed content of any type.

***Image Noise***

We also noticed an interesting interaction between scanning device noise and minimally lossless encoding. Image noise that is introduced during the scanning process has a variable and significant effect on file size by reducing the efficiency of the encoding. This phenomenon is be observable visually by (a.) creating a Delta Image; (b.) checking the image's histogram for overall or select area means and standard deviations of the pixel difference; and then (c.) stretching the image contrast using the **Autolayers** … command.

With lossy encoding, the part of the image that could not be encoded (i.e., noise) is saved – resulting in a relatively large image file – but yields an entirely black Delta Image. No pixels have been changed. When an image is lossily encoded, the noise-laden layer is discarded, leaving only that part of the image that was more efficiently encoded using wavelet representation. Our Digital Library Creole interpretation of the resulting Delta Image's evenly distributed pattern of white pixels against a black background was: Image noise has been discarded, and the pixels that represented the that noise are now different, and are detectable. With regular JPEG, Delta Image detail is immediately visible.

To explore our interpretation of the minimally lossy results, we processed a synthetic ISO 16067 target and an AIIM#2 (draft) target. Using the Photoshop **Noise** … command, we added increasing amounts of RMS noise to the target, then encoded in the lossless and lossy mode. We also captured the ISO 16067 target on a number of scanners and compared the results. We noted that (a.) all scanners introduce noise into the images they produce; (b.) noise varies with brightness level; (c.) the noise level affects encoding efficiency; (d) noise can affect OCR accuracy; (e.) after JPEG 2000 encoding, noise tends to be concentrated in the last layer; (f.) the noise is separated out much more cleanly in the JPEG 2000 image than it is in regular JPEG encoded one; and (g.) that most Digital Library capture specifications do not provide for scanner noise measurements, nor do they follow-up with metadata annotation of noise levels and/or provide for noise removal from their archived images.

***Image Scaling Effects***

Often analog materials are digitized at less than their imaging system's optical resolution in order to reduce their resultant file sizes. To explore the effect that lossless and minimally lossy encoding has on identical images that are systematically reduced in scale, we began with a 10,000 pixel tall image (one that contained a layout of seven resolution samples from the Illustrated Book Study) and created a full-sized original and three smaller images, each one-half the *area* of the previous image. The images were then encoded in a lossless or minimally lossless mode, at which point each smaller image was scaled back to the original 10,000 pixel height to simulate the scaling up of an small image back ("Back" in filename) to the same dimensions (and approximate uncompressed file size) of a higher resolution original. The resultant file sizes were recorded and compared.

| Filename | Original Size | Lossless | Minimally Lossy |
|---|---|---|---|
| 0004a full size | 133,396 | 80,126 | **20,840** |
| 0004a ¾ | 66,672 | 39,241 | 10,417 |
| 0004a ½ | 33,337 | **19,856** | 5,209 |
| 0004a ¼ | 8,338 | 5,067 | 1,302 |
| 0004a ¾ Back | 133,382 | 70,165 | 13,612 |
| 0004a ½ Back | 133,367 | 64,366 | 9,664 |
| 0004a ¼ Back | 133,367 | 44,810 | 4,067 |

Of considerable interest to us is a comparison of the full sized, minimally lossy JPEG 2000 image against the ½-scale uncompressed image (table values in **bold**). Both images are comparable in terms of their file sizes, yet the JPEG 2000 encoded full-sized image will contain significantly more detail.[5] A TIFF practice-centered Digital Library Creole would not (by describing images solely in terms of its image sampling rate and uncompressed status) allow one to express accurately how the full-sized image could be about the same file size as the ½-scaled image – yet contain considerably greater detail.[6]

***Quality Settings: Composited Images***

To determine the effect that the JPEG 2000 encoder's numbered quality settings have on image size, the Illustrated Book Study sample was saved with a increasingly lower quality setting, and the file sizes/percentages compared. Naturally, the greatest savings for this sample occur when lossless encoding is selected:

| Filename | File Size (K) | % Of Orig.: Minimal Compression |
|---|---|---|
| 600.tif | 205,083 | 100.0% |
| 600.Lossless.jp2 | 14,732 | 7.2% |
| 600 Quality 099.jp2 | 15,402 | 7.5% |
| 600 Quality 090.jp2 | 4,022 | 2.0% |
| 600 Quality 075.jp2 | 1,628 | 0.8% |
| 600 Quality 050.jp2 | 818 | 0.4% |
| 600.Quality 025.jp2 | 546 | 0.3% |
| 600.Quality 001.jp2 | 414 | 0.2% |

The differences between any lossy settings are not as great as that those between lossless and minimally lossy settings.

***Blurring***

To explore the effects that diffident scanning technique (i.e., producing an out of focus image using an overhead capture device) might have on JPEG 2000 encoding, an image from the Illustrated Book Study was progressively blurred using the Photoshop **Blur** … Command. The Gaussian blurred images were then "resharpened" using the **Unsharp Masking** … command, the files JPEG 2000 encoded, and the results compared:

| Degree of Blur | TIFF Orig. & Sharp (K) | JP2 Lossless (K) | JP2 Lossless Sharp (K) | JP2 Lossy (K) | JP2 Lossy Sharp (K) |
|---|---|---|---|---|---|
| No Blur | 205 | 14.7 | 19.9 | 15.4 | 22.3 |
| Blur .1 | 205 | 14.7 | 19.3 | 15.4 | 21.7 |
| Blur .2 | 205 | 14.7 | 18.7 | 15.3 | 20.9 |
| Blur .3 | 205 | 13.6 | 17.1 | 13.7 | 18.8 |
| Blur .4 | 205 | 13.1 | 17.5 | 12.8 | 19.2 |
| Blur .5 | 205 | 12.9 | 20.5 | 12.5 | 22.9 |
| Blur 1.0 | 205 | 11.3 | 18.9 | 10.1 | 21.0 |
| Blur 1.5 | 205 | 9.9 | 16.1 | 8.2 | 17.7 |
| Blur 2.0 | 205 | 8.8 | 17.7 | 6.7 | 19.7 |

As there is less detail in increasingly blurry images, note the increasing efficiency of encoding in the lossless encoding case only. As Unsharp Masking creates more detail-like structure in an image, the efficiency of JPEG 2000 encoding for those images is correspondingly decreased.

***The JPEG 2000 Compound Document Format***

The Washington Post page images were encoded in the JP2 image encoding format and the JPM (Part 6) Compound Document format designed for materials of this type. The application performing JPM encoding decomposes the image into (a.) a "bitonal" layer containing sharp-edged, contrasty image content; (b) a "bitonal" mask layer that assigns to the first layer any coloration that might have been in the original; and (c.) a JPEG 2000 JP2 compressed (quality adjustable) background layer to capture the soft, textured content remaining in the document. The goal for the capture and encoding process is to retain the halftone content, esp. color, with some interest in reproducing paper texture, color, etc. for verisimilitude. (A "G" or a "C" next to a file name designates a color or greyscale version of the file.)

Of note are the very significant reductions in JPM file sizes, with retention of tonal quality and most color halftone detail. Uncompressed TIFFS were extracted from the JPM images, alternate image file formats (TIFF G4 & LZW via Photoshop) were secured, and their respective file sizes reported.

| Filename | Uncompressed TIFF | Lossless JP2 | Lossy JP2 | Compound JPM | Bitonal TIFF (LZW) |
|---|---|---|---|---|---|
| Casualties C | 176,580 | 113,207 | 29,430 | 1,300 | 3,651 |
| Casualties G | 17,055 | 9,622 | 2,842 | 219 | 576 |
| Front C | 173,542 | 110,862 | 28,923 | 1,357 | 593 |
| Front G | 17,047 | 10,030 | 2,841 | 296 | 593 |
| Inside A G | 169,401 | 107,563 | 28,233 | 2,013 | 1,957 |
| Kids C | 163,384 | 103,303 | 27,231 | 1,396 | 1,683 |
| Style | 171,386 | 107,700 | 28,564 | 1,148 | 1,546 |

| Filename | Bitonal TIFF (Group 4) | TIFF to JPM % Similarity | TIFF to JPM Filesize Reduction Ratio | Recovered TIFF Filesize | Old-New TIFF Filesize % Similarity |
|---|---|---|---|---|---|
| Casualties C | 58,860 | 99.26% | 136 | 176,575 | 99.997% |
| Casualties G | 527 | 98.71% | 78 | 17,051 | 99.977% |
| Front C | 1,061 | 99.22% | 128 | 173,539 | 99.998% |
| Front G | 384 | 98.26% | 58 | 17,043 | 99.977% |
| Inside A G | 1,842 | 98.81% | 84 | 169,397 | 99.998% |
| Kids C | 1,112 | 99.15% | 117 | 163,381 | 99.998% |
| Style | 1,065 | 99.33% | 149 | 171,386 | 100.000% |

### *JPEG 2000: Signal Data in the Digital Library*

As the results above indicate, the behavior of an image under JPEG 2000 encoding is very revealing of the basic characteristics of the *signal*[7]*-based* data produced by one-or two-dimensional optical scanning devices – data that we interpret as images. System Frequency Response, Noise levels, accuracy of focus, and image content all have notable effects on JPEG 2000 signal/image encoding efficiency.

### *TIFF from a JPEG 2000 Perspective*

The special status of TIFF practice in Digital Library operations (using different technology than that used for digital video and audio) leaves uncertain the ability to accurately specify and verify digital image quality. Just as early standards design decisions allowed TIFF to satisfy known Desktop Publishing needs and to provide opportunities for extension into other realms, JPEG 2000 was specified to do the same thing for images – but to do so in an environment where digital still images are not necessarily static data entities.

At this point the question of point of view taken for results analysis becomes very relevant: *From what point of view is JPEG 2000 to be evaluated?* At the beginning of this paper, we noted that updating the language used to describe Digital Library concepts, operations, etc., was required before an accurate, honest evaluation could be made. The following section expands on that statement.

## How We Got Here: A Selective History of Digital Library Innovation

In order to appreciate the implications of and suggest the practical applications of the JPEG 2000 digital image archive and delivery format, it is necessary first to describe how some existing technologies and terminologies used for Digital Library development came on the scene, how they become entangled in any subsequent effort to improve or supersede them, and what one will need to do in order to evaluate and implement an innovation like JPEG 2000 more fairly and effectively.

This somewhat backward & sideways looking approach is necessary because researchers studying the introduction and use of technological innovations in organizations[8] have made three highly relevant observations:

- Innovations are rarely adopted into a vacuum: having a preexisting related innovation in place strongly influences how potential adopters will perceive and evaluate a new innovation
- A critical point in the process of putting an adopted technological innovation into practice is when the technology is adapted and/or re-invented into a form compatible with that organization
- The proportions of information needed by potential and active adopters – Know- How; Know Why; and Know That[9] – will vary over the course of the adoption process, requiring proper access to the right knowledge combinations.

Parties developing Digital Library technologies and resources for the library, archival, and cultural heritage fields have followed that well-trod "Diffusion of Innovation[10]" path, adapting and reinventing preexisting image file formats to satisfy emerging Digital Library system requirements. These parties have greatly benefited from the technical characteristics and operational procedures of a *previous* technological innovation: Desktop Publishing.[11]

This innovation consisted of technologies, terminology, and practices that were adopted and adapted from a much broader Publishing field that hosts ancient and primitive analog printing techniques, as well as modern ones whose creation engages the knowledge, abilities and skills of Imaging Scientists and Signal Processing Engineers.

## The Origin of "TIFF Practice" in Desktop Publishing

The Tagged Image File Format (TIFF) was designed initially "with desktop publishing and related applications in mind, although it is conceivable that other sorts of imaging applications may find TIFF to be useful.[12]" TIFF's flexible structure proved useful for Desktop Publishing software developers and Desktop Publishers alike, and with a goal of encouraging some degree of interoperability, the technology users supported a rudimentary but proprietarily and private tag documentation & registry system. Various versions of TIFF also support specific Graphic Arts output requirements.

At some point, concerns about image file sizes – followed by a familiar set of image quality/file size tradeoffs –emerged when users wanted to (a.) acquire higher quality images and (b.) save those scanned images for later use.

### *TIFF and Desktop Publishing Pidgin Enter New Realms*

TIFF proved so successful at its original task that authors of the first widely used revision of the standard could advise developers that"[13]

*"The intent of TIFF is to organize, and codify existing practice with respect to the definition and usage of desktop digital data, not to blaze new paths or promote unproven techniques."*

while at the same time asserting that TIFF was sufficiently flexible to be used for a broader set of applications:

*"Yet a very high priority has been given to structuring the data in such a way as to minimize the pain of future additions. … The primary design goal was to provide a rich environment within which the exchange of image data between application programs can be accomplished."*

Ambitious parties, taking the authors of the Version 4.0 standard at their word, adapted or succeeded in adapting TIFF and TIFF-based practices (e.g., TIFF used with JPEG and GIF) in Web and Digital Library[14] applications.

### *From Imaging Science & Signal Processing Domains - JPEG 2000*

An examination of the JPEG 2000 standard document, or of the many papers published alongside it will indicate that the JPEG 2000 standard has returned digital still image capture, manipulation, and delivery to its parent domains of Imaging Science and Signal Processing. Several consequences follow from this positioning:

**First**, there is a long-standing and substantial body of theory and research in support of critical JPEG 2000 features. Fourier explored the notion that wave phenomena like luminous imagery could be represented by an appropriate number of sine waves in the early 19$^{th}$ Century.[15] Continued theoretical and applied research on this commonplace – to the Signal Processing community – notion led to the introduction and refinement of *wavelet analysis*, using a type of waveform that is more amenable to representing image and audio data, and one which allows very useful manipulations of wavelet-represented images. In practice, this means that the ability to comprehend and to construct/reconstruct algorithms that restore and manipulate images in their wavelet representations is widespread within the mathematical/engineering community – and could therefore be readily acquired by parties with the skills in mathematics, and image or signal processing.[16] The development and maintenance/migration of computer applications using JPEG 2000 image representation is supported a by broad and stable knowledge and skill base that extends beyond the well documented ISO specification.

**Second**, the techniques, tools, and points of view that are employed to reason about and manage other scalable, signal-based data – especially digital audio and video – can also apply to digital still imagery. Specifically, the JPEG 2000 file format was specified so as to be compatible with ISO 14496: MPEG-4, and with ISO 21000: MPEG-21. This means that any library/archive that develops or contracts for expertise in delivery of digital audio or video will be employing parties whose knowledge, abilities, and skills can be deployed to support still image delivery as well.

**Third**, personnel familiar with the current versions of Desktop Publishing or professional-level publishing may find the scaleable, image-oriented, "quality on demand" feature of JPEG 2000 overly complex and daunting. They may find it difficult to consider that – just as TIFF did for standardizing interapplication data transfer for Desktop Publishing – JPEG 2000 echoes TIFF's intent by making it possible to organize and codify digital still image *archiving and delivery* practices.

**Fourth**, the JPEG 2000 format shifts some of the complexity of still image management and delivery from the systems that house the images to the file format itself. By offering powerful and flexible image encoding, quality on demand via interactive or server-controlled delivery, standard and optional metadata embedding, security, authentication, and Intellectual Property Rights, the JPEG 2000 file format implements standardized interfaces for storage & delivery system features. In effect, the JPEG 2000 file format has been made *more complex* so that hosting and client systems can be made *less complex* – exhibiting a kind of "conservation of complexity in archival & delivery systems."

**Finally**, The wide range of options for image encoding, interactive delivery, metadata supplementation, and intellectual property management & protection will encourage adopters to coordinate their efforts so as to authoritatively and profitably engage in JPEG 2000 profile development. Fortuitously, this trend parallels library and archive initiatives for national-level digital information preservation infrastructures.

## Building a JPEG 2000 Practice

### Comparing JPEG 2000 with its Antecedents - Apples and Oranges?

Margaret Lepley's advice in the MITRE Information Technology Advisor cannot be stated more clearly:

*"One of the most radical differences between JPEG 2000 and other codecs will be its impact on the system as a whole. An image archive that previously stored images at many different quality levels, including lossless, could now store with JPEG 2000 just one compressed file and disseminate relevant portions to compatible client devices based upon user/application requirements.*

…

*JPEG 2000 has such a variety of options and myriad of uses, it is critical to consult someone knowledgeable of the many technical capabilities of JPEG 2000 during system design and requirements specification.*[17]*"*

The JPEG 2000 standard is now entering environments where system designers' and developers' assumptions, expectations, and practices have been strongly shaped by their experience with older, more limited image formats and related technologies. The fact that the "Digital Library Creole" currently in use is a doubly simplified derivation from the Imaging and Signal Processing fields (via Desktop and regular publishing) becomes problematic when JPEG 2000 is being considered for adoption or is being adapted and/or reinvented for Digital Library uses.

The effective implementation of JPEG 2000 assumes direct or indirect familiarity with and/or access to Imaging Science and Signal Processing knowledge, abilities, and skills. A technology evaluation or implementation process that assumes JPEG 2000 and its supporting practices is like those surrounding TIFF will not produce results that argue strongly for JPEG 2000 implementation. That or the implementation process will miss out on opportunities to implement genuinely "revolutionary" capabilities.

#### *A Knowledge Gap?*

JPEG 2000, by returning the still image to its place with other signal-based data like digital video and audio, makes possible – on one hand – a much more capable and flexible approach to still image acquisition, archiving, and delivery, but – on the other hand – the knowledge, abilities, and skills required to do so might strain those found in typical Digital Libraries. Nonetheless, when one considers the magnitude of present prominent and planned Digital Library efforts, the need to proceed in that direction is also compelling. The Big Question: How to approach this issue? Our modest answer: Look to history.

### Big Projects Benefit From Multidisciplinary Teamwork

The Historian of Science Peter Galison argues that *Trading Zones*[18] – multidisciplinary, peer-oriented, mission-centered organizational and operational team environments – produced the most spectacular advances in theoretical and applied 20th Century Physics. These teams brought together theorists, experimenters, and engineers and assigned them specific missions, with specific, complexly structured deliverables. One of these missions required the utmost Theoretical and Experimental Physics interaction with engineering skills – The Manhattan Project.

We in the library/archival world should understand that designing and implementing a new National Digital Information Infrastructure to supplant the existing one is an information management mission of the same order of magnitude as the Manhattan Project. For us, then, the need to develop the same kinds of theory-experiment-practice teams is also paramount. That being the case, truly collaborative relationships between libraries/archives and universities, research laboratories, consultants, and commercial developers can – if operated as Digital Library technology development "Trading Zones"– manage the necessary tasks.

### Implementing JPEG 2000: A Multidisciplinary Team Approach

#### *Build a Team of "Native Speakers:"*

Assemble a multidisciplinary team of all specialties known to have a role in Digital Library design, construction, operation, and use. This would include not only library-centric specialists such as catalogers, system programmers, user interface designers, etc. but also Imaging Science and Signal Processing Engineers.

Few existing Digital Library design and development projects have JPEG 2000-knowledgeable Imaging Scientists or Signal Processing Engineers on their working teams. This has to change. Galison argues that team members must be in constant interaction with one another so as to develop an intimate understanding of mission requirements and how each contributes to it.

#### *Encourage Peer-Level Relationships Among Team Members*

Assume that team members will *not* be able to understand each other's theories, and concepts perfectly, nor that they will be able to deploy the intellectual, software, or physical tools that each brings to the team. Expect that each team member must be willing to subject their long-standing and deeply held assumptions, preferences, and beliefs to examination and critical test in the team environment.

***Set a Mission***

A mission of appropriate magnitude and complexity will motivate am interest in coordination of activities among Digital Library teams, responsibly executing team assignments, and delivering the result. One mission could be: Specify a range of JPEG 2000 profiles for everyday, widespread use in Digital Library, and develop a set of methods and tools for ensuring conformance to profiles by capture devices and existing or future displays.

***Coordinate Team Members' Actions and Beliefs***

Assigning a specific goal to team requires each team member to determine (a.) which aspects of their specialty – their knowledge, abilities, and skills – are relevant to achieving the mission, and (b.) how those aspects need to be shaped (simplified if need be), so as to communicate their mission-relevant features to the rest of the team.

This does not mean that Catalogers will be compelled to think in simplified terms about cataloging issues. It means that they will encourage all other team members to communicate their cataloging interests in the simplified, mission-relevant cataloging subset of their mutually constructed language – the team *pidgin* – so that when necessary, *the Catalogers* can then do the "heavy lifting:" reasoning about cataloging issues, and developing solutions using their full set of capabilities. On the other hand, it does mean that Catalogers will have to come to coordinative terms with the claims and experimental results of those Information Scientists who implement other systems of knowledge representation and access (ontologies, content-based indexing) for nontextual data.[19]

It does not mean that one or another aspect of the problem at hand that is of interest to one team member will be of equal interest to all. This is not achievable with a team whose members possess significantly different knowledge and skill sets.

***Assemble the Tools to Characterize Materials and Devices***

Establish JPEG 2000 profiles that provide specifiable quality levels, and develop procedures that execute the profiles and verify the results. Distribute profiles and verification tools. On the Theoretical and Applied Physics projects where this team approach was used, this coordination often required significant reworking of a team member's theoretical and applied knowledge – with benefits that extended far beyond the mission goals.[20]

**Getting to Work: A Microfilm Digitization Mission**

An example from a (partly fictional) research activity in LC's Digital Preservation Laboratory (DPL) will show how an extended multidisciplinary team operates.

DPL staff are trying to establish digitization parameters for microfilmed newspapers and maps, with the expectation that the Library's large collection of microfilm reels would be harvested for content that no longer exists or is not accessible in its hardcopy form.

What is first needed is a means for determining the imaging capability of candidate microfilm scanners, so that images possessing the requisite detail are secured. Scanner manufacturers report their system performance in terms of MTF at specified lens apertures and in less informative DPI. Microfilm manufacturers and printer (e-beam film and tabloid-size laser) manufacturers also report *their* system performance in MTF form, so the ability to describe the total system needs both the Imaging Scientist's and the Signal Processing Engineer's expertise.

The Custodial Divisions' representatives on the team are not sure whether the quality of the digitized microfilm images will satisfy patrons who are used to working with the original hardcopy, nor are they happy with the contrast change that occurs when halftone images are microfilmed. (This latter sentiment is contrary to the real expectation that *no* halftone images are obtainable from digitized microfilm images that are usually bitonalized to reduce file size.)

The Imaging Scientist and the Signal Processing Engineer act on this issue differently. The Imaging Scientist can determine the extent of image contrast increase resulting from the filming step and develops a Photoshop plug-in that can reverse the effect. Meanwhile, the Signal Processing Engineer develops a plug-in that removes image noise (see above) from the scanned image, based on the scanner's System Frequency Response (MTF-like) measurements. A question arose whether measuring the detail characteristics of *actual newspapers* (as was informally done for the Illustrated Book Study) would be useful in filtering the spatial and tonal characteristics of the scanned images so as to further reduce file size – and was spun off as an experiment. Test images of microfilmed newspapers and test targets are acquired and stored in JPEG 2000 format in lossless mode with reduced bit-depth, and delivered.

Although the Signal Processing Engineer has produced a means for expressing the difference between the appearance of an original newspaper and a paper printout from a digitized microfilm frame of the same paper, it is not clear how patrons will react to the computer displayed or printed reproduction. The Custodial Division representatives are satisfied as to the quality of the printed newspaper reproductions from their point of view, so as a final check, the User-Interface Designer, privy to all of the prior activity through team discussions, conducts user studies to validate the Custodial Division representatives' impressions against the actual behavior of end users.

***Deliverables***

With all team members satisfied with the overall result, the procedures and tools for verifying minimum microfilm digitization and printer systems performance, and for post–processing the microfilm images with the plug-ins are released to the wider world, along with the Photoshop plug-ins, JPEG 2000 encoding parameters and other test materials.

***Beneficiaries***

Digital Library workers everywhere can acquire the released microfilm digitization mission deliverables and immediately apply them to their own situation, reviewing the samples and documentation, repeating measurement procedures, etc., as needed to satisfy their curiosity. For those other Digital libraries, all the foregoing R&D takes place safely away from their local Digital Library design activities such as metadata specification and collection, creating Quality Assurance methodologies, etc. JPEG 2000 profile and method distribution resulting from the mission-oriented R&D process will have spared all the other facilities the effort of attempting it on their own – and perhaps coming up with a solution that was less than optimal technically – while at the same time this effort provided a controlled method for producing useful Digital Library tools.

***Fact & Fiction***

The LC Digital Preservation Lab technology development scenario described above is partly fictional in that parties in other cities play the Image Scientist & Signal Processing Engineer roles. The lack of their presence "in the room" when large and small issues are raised, and general unavailability of their knowledge, abilities, and skills in dealing with ad-hoc mission-related issues and problems slows things down considerably. But the benefits of the extended team approach for effectively implementing new technologies in Digital Libraries is clear.

## Conclusion

The opportunities for creating and archiving high-quality Digital Library resources that can be flexibly delivered to end users have never been greater – but the creation of Digital Libraries from previous technological innovations has yielded practices and practice-dependent points of view that make it difficult to appreciate and exploit the innovative characteristics of newer technologies.

While the imperatives that follow from having to design systems that will archive and flexibly deliver tens to hundreds of millions of still images will eventually lead Digital Library workers in the direction of technologies like JPEG 2000, it is hoped that the above demonstrations of high image quality and great efficiencies in file size, combined with the discussion of how Digital Library design and implementation thinking has reached the current state of affairs will convince some to reconsider their approaches.

When they do reach that state of reconsideration, it is also hoped that the notion of extended multidisciplinary teams for Digital Library technology development presented here – one based on studies of previous, highly challenging scientific research and development efforts – will find favor.

## References

1. See Appendix A.
2. See Williams, Don. What is MTF … and Why Should You Care? RLG DigiNews, v. 21) Feb 15, 1998.
3. We dubbed images created by image differencing and autoleveling (i.e., histogram stretching) *Delta Images*.
4. Santa Cruz, Diego, et.al. An analytical study of JPEG 2000 functionalities. http://www.jpeg.org/public/wg1n1816.pdf
5. *If* the lens can resolve the object detail.
6. A 10,000px tall image of a 4"x 5" B&W negative will show film grain. A 2,500px tall image will not.
7. *def.* A modulation of an electric current, electromagnetic wave, or the like by means of which information is conveyed from one place to another. Oxford English Dictionary Online. Accessed 1/29/2004.
8. Rogers, Everett. Diffusion of Innovations. NewYork:Free Press. 2003.
9. Rogers, p. 172-173.
10. A sequence of information-seeking, evaluation, and action steps: Knowledge, Persuasion, Decision, Confirmation, Implementation, and Confirmation. Rogers, p. 169.
11. Using a desktop computer to produce high-quality printed output or camera-ready output for commercial printing. TechWeb Online Encyclopedia. Accessed 1/21/2004.
12. Davenport, Tim & Vellon, Manny Tag Image File Format Rev. 4.0. Seattle:Aldus Corporation. 1987.
13. TIFF 4.0. p.1.
14. A definition from the library world: Waters, Donald. *What are Digital Libraries?* CLIR Issues Jul/Aug 1998.
15. http://britannica.com/search?query=fourier&ct=&fuzzy=N
16. Signal Processing Image Communication. New York: Elsevier. 17(1) Jan. 2002.
17. Lepley, Margaret. Adopting the JPEG 2000 Standard. The MITRE Information Technology Advisor. v.1(6) March 12, 2001.
18. Galison, Peter. Image and Logic: A Material History of Microphysics. Chicago:The University of Chicago Press. 1997. p. 781.
19. Jorgensen, Corinne. Perspectives on Image Access: Bridging Multiple Needs and Multiple Perspectives -Introduction and Overview. JASIS 52(11) Sep 2001.
20. Galison, p.826.
21. *def.* A language as spoken in a simplified or altered form by non-natives, *spec.* as a means of communication between people not sharing a common language. Oxford English Dictionary Online. Accessed 1/23/2004 1:26pm
22. *def.* ***Creolized language***: A language which has developed from that of a dominant group, first being used as a second language, then becoming the usual language of a subject group, Oxford English Dictionary Online. Accessed 1/23/2004. See also Galison p. 831-832.

## Biography

**Ronald J. Murray** received a BA in Media and Cognition from Brown University in 1989, and a MLIS from the University of Hawai'i in 1991. A member of ASIS&T, and ACM, he is presently a Digital Conversion Specialist with the Library of Congress Preservation Directorate's Preservation Reformatting Division. He is also a doctoral candidate in Communications, focusing on libraries as elements of communications networks.

# Appendix A

**The Pidginization of Publishing: Desktop Publishing Technology and Terminology**

Along with the specialization and simplification of publishing technology also evolved specialized and simplified computer-assisted publishing concepts and terminology – a kind of Desktop Publishing language or *pidgin*[21]– which users created and used to describe their publishing activities to themselves, to each other, and to professional publishers. Terms such as "resolution," "pixel," "DPI," "compression," and "page numbering" were used to describe images, image & page layout files, and page layout application program use in terms useful enough to satisfy the needs of Desktop Publishing practitioners and their support personnel. Only later were the more sophisticated technologies of its parent publishing field incorporated into those applications initially created for the desktop market. Now, versions of those applications see heavy use in full-blown publishing environments.

In Digital Library environments, the original Desktop Publishing pidgin was extended with terms and concepts borrowed from analog libraries ("collection," "bib rec"), and has seen the invention of terms that are seem to be quite native to Web/Digital Libraries ("link," "thumbnail", "metadata"). In other words, the Desktop Publishing Pidgin has threatened to become a kind of *Digital Library Creole* "a pidgin extended and complexified to the point where it can serve as a reasonably stable native language,[22]" for those who "grow up" in the Digital Library world.

***Desktop Publishing Pidgin: A Domain Too Far?***

As can be seen above, the simplified concepts and terminology adopted from Desktop Publishing have persisted, and – in contrast to the limited scope accorded them when used with early page layout programs, etc., – are presently being used to inform Digital Library design and implementation decisions of increasing complexity and consequence. Imaging Science and Signal Processing concepts, language, and techniques that are actually used to design digital imaging devices and picture viewing/editing, etc., software are (in the absence of Imaging Scientists or Signal Processing Engineers) not readily available to inform Digital Library design and practice.

While a simplified perspective on imaging and digital image processing was of less important for Desktop Publishing's early days, Digital Library design and implementation decisions involving tens of millions (hundreds of millions?) of digital images – digital image "consumers," and hundreds (thousands?) of archive/delivery systems should be made via a process that includes access to the fully fleshed-out, conceptually scalable perspectives possessed by the parent disciplines.