



Image File Formats: Past, Present, and Future¹

*Richard H. Wiggins III, MD • H. Christian Davidson, MD • H. Ric
Harnsberger, MD • Jason R. Lauman, BS • Patricia A. Goede, BS*

Despite the rapid growth of the Internet for storage and display of World Wide Web-based teaching files, the available image file formats have remained relatively limited. The recently developed portable networks graphics (PNG) format is versatile and offers several advantages over the older Internet standard image file formats that make it an attractive option for digital teaching files. With the PNG format, it is possible to repeatedly open, edit, and save files with lossless compression along with gamma and chromicity correction. The two-dimensional interlacing capabilities of PNG allow an image to fill in from top to bottom and from right to left, making retrieval faster than with other formats. In addition, images can be viewed closer to the original settings, and metadata (ie, information about data) can be incorporated into files. The PNG format provides a network-friendly, patent-free, lossless compression scheme that is truly cross-platform and has many new features that are useful for multimedia and Web-based radiologic teaching. The widespread acceptance of PNG by the World Wide Web Consortium and by the most popular Web browsers and graphic manipulation software companies suggests an expanding role in the future of multimedia teaching file development.

Abbreviations: CRC = cyclical redundancy check, DICOM = Digital Imaging and Communications in Medicine, GIF = graphic interchange format, JPEG = Joint Photographic Experts Group, LZW = Lempel-Ziv-Welch, PACS = picture archiving and communication system, PNG = portable networks graphics, RGB = red-green-blue, TIFF = tagged image file format, 2D = two-dimensional

Index terms: Data compression • Digital imaging and communications in medicine (DICOM) • Education • Images, digitization • Images, display Images, quality • Images, storage and retrieval • Images, transmission • Internet • Picture archiving and communication system (PACS)

RadioGraphics 2001; 21:789-798

¹From the Department of Diagnostic Radiology, University of Utah School of Medicine, 50 N Medical Dr, Salt Lake City, UT 84132 (R.H.W., H.R.H.); the Electronic Medical Education Resource Group, Center for Advanced Medical Technologies, University of Utah School of Medicine, Salt Lake City (R.H.W., H.C.D., H.R.H., J.R.L., P.A.G.); and the Department of Diagnostic Radiology, Salt Lake City VA Medical Center, Salt Lake City, Utah (H.C.D.). Received July 17, 2000; revision requested September 27 and final revision received February 2, 2001; accepted February 20. **Address correspondence to R.H.W.** (e-mail: richard.wiggins@hsc.utah.edu).

Introduction

The introduction of picture archiving and communication systems (PACS) into academia has greatly assisted in the transition from hard-copy teaching files to the digital environment. As this transition progresses, an increasing number of radiologists are attempting to use the Internet for dissemination of teaching case material, usually with HyperText Markup Language (HTML), both throughout the department and around the world (1–3). Conversion of Digital Imaging and Communications in Medicine (DICOM) images from PACS to Joint Photographic Experts Group (JPEG [pronounced “jay-peg”]) or Tagged Image File Format (TIFF [pronounced “tiff”]) files for display (eg, over the Internet) is now the standard. However, no simple mechanism currently exists for transmitting labels, legends, or other image-specific data as part of the image file. A relatively new powerful and flexible image file format known as portable network graphics (PNG [pronounced “ping”]) (1–4) has some unique features that make it an attractive choice for multimedia projects and may help solve a number of problems associated with World Wide Web-based teaching file development.

In this article, we will define the three principal bit-mapped image file formats in widespread use today—graphic interchange format (GIF [pronounced “jiff,” although “giff” is more often used]), JPEG, and TIFF—and will discuss their history as well as their strengths and weaknesses. In addition, we will discuss DICOM with respect to PACS and as a possible image format in the electronic teaching environment. In addition, we will review the three major digital image compression techniques (JPEG method, fractal compression, wavelet compression) and discuss the novel features of the PNG file format.

Bit-mapped Images: Past and Present

Bit-mapped images (also known as raster images) make use of pixels, or picture elements, to define an image as a matrix made up of rows and columns of pixels. The advantage of using bit-mapped images in digital teaching files is that they are specifically designed to handle computed tomographic, magnetic resonance, and photographic images. The disadvantage of using pixel-based images is that they are resolution dependent, so that overall image quality is degraded if resolution is altered.

Bit-mapped images with higher resolution contain more pixels and more detail but are consequently large files that move slowly in the electronic environment. Compression algorithms help overcome these problems by decreasing the volume of data needed to reconstruct an image, thereby decreasing the storage space needed and increasing the speed of transmission over a network. With JPEG and GIF, these schemes can be used to maintain detail in a smaller file size. This gives these formats a theoretic advantage for use in the electronic teaching environment.

Graphic Interchange Format

GIF was created in 1987 (4). As one of the first solutions to the problem of electronic image storage, it is the oldest and most widely supported and used Web-based graphic file format (1,4,5). The primary strength of GIF is its lossless compression algorithm (4–6), known as the Lempel-Ziv-Welch (LZW) linear compression routine. This algorithm provides up to 4:1 lossless compression of images with similar compression and decompression times (5,6). GIF also offers an interlace option that allows a rough preliminary version of an image to be displayed before the entire image is transmitted (6).

However, GIF also has several weaknesses. First, it is limited to 256 colors or shades of gray in an image. GIF is a bit-mapped (raster) image format with pixel values stored in image files. It uses the classic red-green-blue (RGB) method for defining pixel values, in which values from 0 to 255 are defined for red, green, and blue. This allows several million color definitions. To limit the size of files, however, GIF allows only 256 different colors from a palette of several million possibilities and keeps these 256 color values indexed in a look-up table. Because of this limitation, complex images may lose some detail when reformatted into GIF. The practical implication of this weakness is the inability to display an image with its full color range (5,6).

Second, the initial GIF, known as GIF87a, had the small but real disadvantage of not allowing transparency creation. The newer GIF89a, released in 1989, does allow one level of transparency in an image, a partial solution to this limitation (5,6). However, for complex image annotation, one level of transparency may not be enough. Both versions of GIF have been supported in most Web browsers since 1990, including the two most widely used, Netscape Navigator (Netscape Communications, Mountain View, Calif) since version 2.0 and Internet Explorer (Microsoft, Redmond, Wash) since version 3.0 (5).

The third and greatest weakness of GIF is the proprietary nature of its compression technique. Unisys Corporation (Blue Bell, Pa) patented the LZW linear compression routine in 1995 (7,8). However, when the company attempted to collect royalties from users of this compression algorithm, GIF fell out of favor in the graphics and education community. Although this patent issue does not affect the ownership or transmission of a GIF file, the graphical application that compresses or decodes with use of the LZW routine may be affected. In response to the commercialization of this compression technique, a small group of graphics and compression users joined to create the PNG file format (4,8), which will be discussed later.

Joint Photographic Experts Group

JPEG was created in the early 1990s as the leader in the next generation of image file format compression schemes (9,10). JPEG is not actually a file format, but the name of the compression algorithm developed by the Independent JPEG Group. The JPEG file format is referred to as the JPEG file interchange format (JIFF) and was created specifically for the storage and transmission of photographic images (5). Like GIF, JPEG also uses bit-mapped information stored in pixel files; however, it does not use indexed color. The 24-bit color scheme of JPEG files displays each pixel on the screen with 24 bits of data encoding, allowing more color and contrast resolution than is possible with GIF (16.7 million colors as opposed to 256 with GIF) (5,9–11).

The strength of the JPEG format is its capacity to significantly compress larger image files, allowing faster movement in the electronic environment. As opposed to LZW compression, which is a type of linear or “file” compression, the more complicated JPEG algorithms allow genuine “image” compression. The JPEG discrete cosine transform compression scheme divides an image into 8×8 -pixel sections and compresses each section separately in three stages (10,11). The discrete cosine transform algorithm is used in many common image and video standards, including the Motion Picture Expert Group. With JPEG, the algorithm mathematically compares each pixel with adjacent pixels, allowing the user to adjust the compression level (9,10). Image compression to as little as 1/20 of the original file size can be achieved (5,10). Such compressed images can obviously be moved considerably faster in the electronic environment and require significantly less storage space per image. The basic format of JPEG is not patented (9,10).

Another useful feature of JPEG is progressive display, although it is only available with newer Web browsers (being first implemented in Netscape Navigator 3.0 and Internet Explorer 4.0) and requires more memory. Progressive display allows the user to see a preliminary albeit low-quality version of an image before the full image is transmitted (5,9).

The primary weakness of JPEG is that it is a lossy compression technique that results in a loss of data with each compression, which may translate into image degradation. This decoding process also requires more time before the image can be viewed (5). An additional weakness of JPEG is the possibility of distortion created by the compression technique. This can affect image files that are composed of only a few colors or those with large areas of the same color, such as a radiologic image background. Another possible distortion is Gibbs’ phenomenon, which can be seen on high-resolution images as well as high-bandwidth images (eg, line art) (5,12).

Tagged Image File Format

TIFF was developed by Microsoft and Aldus in 1986 (13). TIFF is a trademark that was originally registered to Aldus, which subsequently merged with Adobe Systems (San Jose, Calif). Adobe now controls the TIFF specifications copyright. TIFF was created primarily by imaging developers of input and output devices such as printers, monitors, and scanners; as a result, it is specifically designed to be compatible with different image processing devices (13).

The word “Tagged” in “TIFF” refers to this format’s complicated file structure. The initial header of the file data is followed by “chunks” of data called “tags,” which convey the image information to the program displaying the file. The actual TIFF specifications define over 70 different tag types. This level of complexity allows great flexibility between viewers; however, programs that interpret TIFF images must contain all the different data for the tags. Although many programs simplify this by implementing only certain tags, skipping some tags could theoretically affect image quality, and private tags may limit the use of TIFF files for some applications.

The greatest strength of TIFF is that it can support the full range of image sizes, resolutions, and color depths. Another strength is its use of different compression techniques. Lossless compression allows TIFF files to maintain image

resolution without loss of detail. TIFF 5.0 was released in 1988 and incorporated support for the LZW compression technique (13). Although the LZW technique is one of the most popular compression algorithms, its use may be restricted due to proprietary limitations as discussed earlier. Another useful feature of TIFF files is that each file can contain more than one image.

The primary weakness of TIFF is the large file size that results from the use of (a) lossless compression techniques and (b) tags for conveying image data. This larger file size limits the use of TIFF in the Internet educational environment and slows overall performance. The newest specification, TIFF 6.0 (released in 1992), incorporates the JPEG lossy method of compression, thereby allowing a decreased file size. This version has raised some issues concerning compatibility because images that make use of the new compression schemes cannot be successfully decoded by older software. However, this shortcoming is expected to be corrected in TIFF 7.0 (13).

Digital Imaging and Communications in Medicine

DICOM is the third and most comprehensive version of an imaging communications standard developed by the American College of Radiology in conjunction with the National Electrical Manufacturers Association. The purpose of DICOM is to provide platform-independent methods of interconnecting all types of digital medical imaging devices by means of standard computer networks. DICOM offers a wide variety of functions for use in PACS; these functions range from detailed technical and demographic data to methods for generating worklists and interacting with hospital information systems (14).

The strength of DICOM is its comprehensive set of specifications for medical images in PACS. These specifications allow detailed descriptions of bit-mapped digital images (including 12-bit grayscale images and color images), intensity mapping functions, annotations, and other elements that are used for digital medical images. In addition to complete image specifications, DICOM also prescribes multilayer communications and network protocols that are specific for use in PACS (14).

Unfortunately, the additional data in the DICOM specification that relate to communication protocols make this file format unwieldy for use in multimedia teaching tools outside PACS. Although it is now widely accepted in the radiology community, DICOM is not necessarily supported by medical computer systems outside the

field of radiology and is relatively obscure in the nonmedical digital imaging community.

Digital Image Compression Techniques

The performance of PACS has been greatly enhanced by the use of image compression algorithms. The ability to compress and decompress images without loss of diagnostic data has allowed PACS to become a reality by greatly decreasing transmission times and storage requirements and permitting shorter retrieval times. Whereas lossless compression maintains the full integrity of the original image file, the goal of lossy compression in PACS is to reach these objectives without compromising diagnostic image quality. This can be accomplished partly because the unaided human eye cannot perceive minimal changes in degradation; consequently, the data can be described as "diagnostically lossless" (15,16). The three most commonly used image compression techniques are the JPEG method, fractal compression, and wavelet compression.

The JPEG method described earlier can provide lossless compression at low compression ratios up to 4:1. Image data degradation can be minimized while still maintaining a significant amount of integrity if compression ratios below 30:1 are used. JPEG has been the most popular image file format on the Internet primarily because of its compression characteristics and the JPEG standards. These JPEG standards allow a Web browser or graphics program to compress and decompress any JPEG image with ease. The more complicated "tag" format of TIFF files prevents ready compression of TIFF images (5,10, 15-17).

Fractal image compression makes use of complex mathematics in analyzing patterns within an image, as opposed to the discrete cosine transform algorithms used in JPEG, which compare individual pixels with surrounding pixels. This is a patented lossy type of compression that permits rapid image decompression. The compression algorithm is complex and therefore slow compared with the JPEG algorithm. The ability to store a series of equations instead of pixel data allows compressed image files to be stored in a much smaller space while allowing some change in the size of the image displayed. Relatively little image degradation can be detected, even at compression ratios up to 100:1. Unlike the JPEG method, however, fractal image compression lacks strict standards (15-17).

Wavelet compression is the oldest of the three digital image compression techniques in common use. Wavelet concepts were first described almost 100 years ago (15-17). The original Fourier

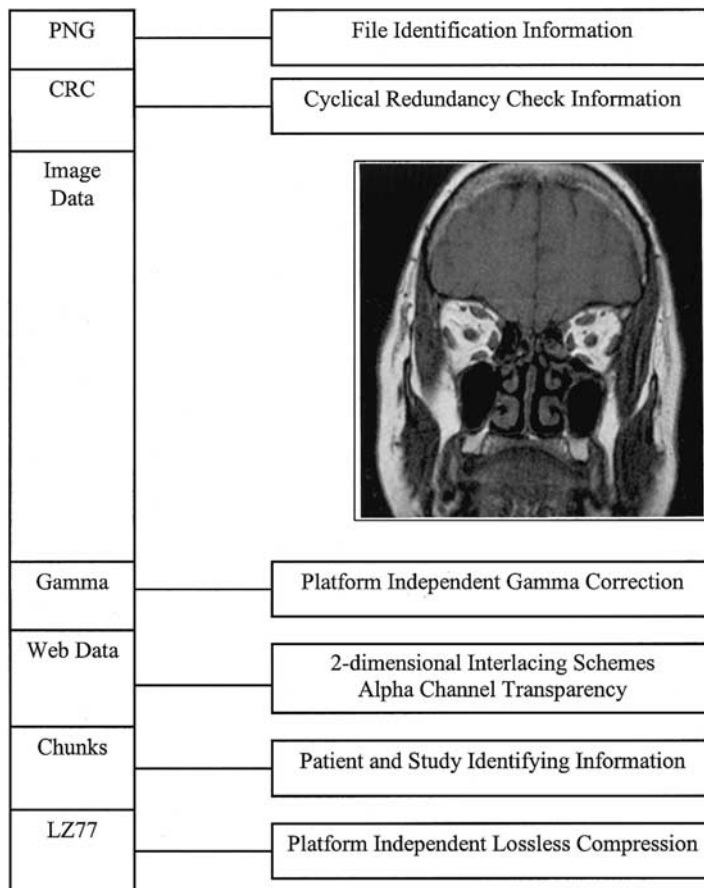


Figure 1. Schematic illustrates PNG attributes.

mathematical series theory has been adapted and modified, branching into several different versions that are not compatible with each other. No set standards for the wavelet compression technique have been adopted. Although lossless wavelet compression techniques usually do not exceed compression ratios of 4:1, commercialized lossy techniques have been reported to preserve diagnostic quality at ratios up to 150:1 (15). This multiresolution analysis usually involves filtering the data based on contrast and frequency, followed by removal of data that are unimportant to image quality before image compression encoding is completed. High-contrast data are preferentially retained, allowing preservation of image detail. Consequently, wavelet compression is an attractive method for use in medical imaging. The wavelet algorithms also allow image scalability, similar to fractal compression techniques (15–17).

Bit-mapped Images: The Future Is PNG

A relative newcomer on the scene, the PNG file format was created in 1995 in response to the GIF proprietary transition (4,8,10,12). In addition to their stated goal of remaining nonproprietary, the creators of PNG were looking to define

a flexible file format that would allow lossless data compression, gamma correction for cross-platform consistency in brightness, and variable transparency. They achieved their objectives, and since 1996, the HTML format used for the presentation of these files has shown great versatility and continues to increase in popularity. Consequently, the PNG file format has the potential to be the image file format of the future.

Chunk Architecture

A PNG file has a chunk architecture that allows flexible descriptions of each attribute (Fig 1) (12,18). It is this chunk architecture that gives the PNG file format its greatest theoretic advantage over other image file formats. A wide range of image information as well as supporting alphanumeric data may be housed within the same PNG file. A PNG image file consists of an initial “signature” (the initial eight bytes) identifying the file as a PNG image, followed by a series of chunks of data that encode the image information to the decoder program (eg, Web browser). The information for the image is stored in groups (chunks) marked with four-character names, each ending in a “cyclical redundancy check” (CRC) that verifies the integrity of the data. The initial signature

and CRC, together with the Adler-32 Checksum (an algorithm that is similar to the CRC for the uncompressed data), allow three types of integrity checks on a PNG file (12,18,19).

The chunk data can contain keywords and strings of information, sometimes referred to as "metadata" (ie, information about data), which are interpreted by certain decoder programs while being ignored by others (12,19,20). One of these chunks is designated as an alphanumeric text string such that information about an image (eg, annotations, patient data, image contributor) can be stored in this string. Consequently, data about an image can be stored in the same file as the image itself (12,19). Because there are Internet metadata image-capable search engines that can detect text strings, the image can be found faster on the basis of the image file name or the text material within the text string (21,22). The chunk architecture of a PNG file also allows private information to be read by certain applications while being ignored by others. This would allow the embedding of DICOM-specific chunks, which would aid in the transmission of the image between PACS and imaging software or database files. The ability to quickly input cases into databases in an easy-to-use graphical user interface would overcome a large barrier to most clinicians contributing to large-scale digital teaching file projects.

Pixel Support

The PNG chunk architecture supports three pixel types: palette-mapped, gray-scale, and true-color (RGB) (12,18,23). PNG supports true color with 48-bit color images, as opposed to the 24-bit color scheme of JPEG. PNG also supports 16-bit gray-scale images, which becomes important in detailed radiologic studies (8,10,12).

JPEG supports only true-color and gray-scale images, whereas GIF supports only palette-based mapping (5,6,10,17,18). PNG's variable alpha-channel transparency support, similar to that of TIFF, allows the creation of an image with differing levels of transparency for each pixel such that multicolored images can be fully or only partially transparent (8,12,13,18,23). This creates true-color pixel data with four bytes for each pixel (red, green, blue, and alpha [RGBA]), predominantly used in transitions and drop shadow effects (18). JPEG does not support alpha-channel transparency or gamma correction, whereas GIF supports only a single layer of transparency (10-12).

Interlacing Scheme

The algorithm known as Adam7 is an interlacing method that displays PNG images in seven stages in less time than is required for the four-stage display of GIF. The GIF interlacing scheme remembers which lines of the file are even- or odd-numbered and progressively displays the file with the odd-numbered lines displayed first, so that the image appears to be displayed twice as fast. The PNG format makes use of a two-dimensional (2D) interlacing scheme that progressively displays the image, not only from top to bottom, but also from right to left, displaying the image even faster. However, this progressive display technique may increase the size of the image file (12,18,23).

The interlacing progressive display technique has been supported by GIF and TIFF essentially since 1989 and widely implemented by the JPEG file interchange format since 1996 (18). In a direct comparison of PNG and GIF interlacing schemes, only about the top one-eighth of the GIF image is visible by the time the PNG scheme has completed the first pass of the entire image, and four PNG passes have been completed by the time the first full pass of the GIF image has been completed. As a result, the PNG file image demonstrates better resolution in less time (12,18). Therefore, a PNG file can usually be recognized after approximately 25% of the file is transmitted, compared with the necessary transmission of 50% of a similar GIF file before it is recognized (10).

Gamma Correction

The inherent coding of gamma correction, which refers to the brightness reproduction curve of an image, allows the values displayed on any platform to be the same as those of the original. PNG's platform-independent gamma correction for independent brightness controls is a powerful tool for viewing radiologic images. This inherent feature allows PNG-formatted images to have standard colors and contrast settings without appearing too dark on Windows-based personal computers (Microsoft) or too light on Macintosh computers (Apple Computer, Cupertino, Calif) (10,12,18). This problem exists because Macintosh computers, Windows-based computers, and SGI workstations (Silicon Graphics, Mountain View, Calif) all have different gamma values, so there is no Internet gamma value standard. GIF and JPEG files have no inherent gamma correction (10,12,24). The PNG chromicity correction feature (for precise specification of color independent of brightness) allows similar standardization of RGB strength in the individual pixels of an

image (10,12,18). These gamma and chromicity controls allow more accurate depiction of pixel image levels in terms of color and gray-scale imaging. The PNG specifications even allow use of a complete color management system for increased color control (18).

Compression Options

Although the data chunks are capable of supporting multiple compression formats, the “deflate” compression method is the only one defined for PNG images (12,25). This algorithm, which is used with .zip files, is a version of LZ77 (so named because it was first published by Lempel and Ziv in 1977), a predecessor of the LZW technique (12). LZ77 is a platform-independent lossless compression technique that actually has 10%–30% better compression than the LZW technique used with GIF files (12,18). Unlike the LZW algorithm, however, LZ77 is not patented (4,7).

The PNG deflate compression method is essentially a combination of LZ77 and Huffman encoding algorithms. Lossless encoding with the PNG method was intended for use in applications such as medical imaging and detailed image editing in which strict preservation of all data is mandatory. Because of its chunk architecture, the PNG format is able to adapt and incorporate compression techniques common to PACS, allowing easier transition from DICOM to PNG for incorporation into digital teaching files and more complex multimedia projects (12,25).

The PNG specifications also define a compression filtering technique. There are five different options for this filter (including “None”), which significantly increases decoder efficiency. These options compare specific pixels with surrounding pixels to increase the degree of compression. As an extreme example, a 24-bit, 48-Mbyte image file can be losslessly compressed to 0.1 Mbytes but to only 36 Mbytes without the filtering option (12,18,25).

Browser Support

Perhaps the most significant limitation of the use of PNG in Internet digital teaching files is relatively limited support with earlier browser versions. The creation of PNG, with its complex interlacing scheme, alpha-channel support, and automatic gamma correction, was somewhat focused on Internet use. Although there are over 30 2D Web browsers with at least some PNG support, the two most commonly used browsers, Netscape Navigator and Internet Explorer, have had limited support with early versions and native support since versions 4.04 and 4.0, respectively

(23). Both JPEG and GIF have essentially been natively supported by Netscape Navigator and Internet Explorer since version 2.0 (24,26).

Netscape Navigator has limited support for PNG files since version 2.0 with multiple available plug-ins (helper applications such as QuickTime [Apple]) and support for progressive display since version 4.04. There is also full alpha-channel and gamma correction support in the latest version (6.0). This latest version is based on Mozilla, another browser developed with the support of Netscape, which has widely supported PNG (23,26,27).

Microsoft Internet Explorer and the new America Online Internet Explorer (Dulles, Va) have had read-only support of PNG files since version 4.0 and full alpha-channel support since version 5.0 for the Macintosh community. Windows Internet Explorer version 4.0 is able to display PNG files with plug-ins, similar to the earlier Netscape browsers, but full gamma correction and interlacing capabilities are not fully supported in this version. The more recent Internet Explorer version 5.5 for Windows does fix some of these problems but has not addressed full alpha-channel support (26,27). The desire to display Web pages that can easily be viewed by a majority of Internet users may limit PNG’s use in digital teaching file creation, and issues concerning random access memory and storage space limit users to early versions of these browsers.

Acceptance

The PNG file format is by design free of the patent issues that have hindered further GIF development. In 1996, the World Wide Web Consortium issued PNG specification 1.0 as a Consortium recommendation, the first recommendation to be issued by the group. The adoption of PNG by the Virtual Reality Modeling Language (VRML) Architecture Group for VRML 2.0 and the formal approval of “image/png” as an official Internet media type by the Internet Assigned Numbers Authority will ensure widespread use of this complex yet flexible graphic file format in the future (4). Both of the leading Web browsers, Netscape Navigator and (Microsoft) Internet Explorer, now have some native PNG support (23,26,27). Adobe PhotoShop 5.5 and Macromedia Fireworks 2.0 (Macromedia, San Jose, Calif) also contain PNG support (8). Photoshop offers easy “save” options for PNG 8-bit and 24-bit images. PNG support already exists or is being planned in over 125 applications. Animation can

Comparison of Image File Formats with Respect to Selected Parameters

Parameter	GIF89a	JPEG	TIFF	PNG
Maximum color depth	8-bit (256 colors)	24-bit (millions of colors)	48-bit (trillions of colors)	48-bit (trillions of colors)
Compression technique	Lossless	Lossy	Lossless (lossy)	Lossless
Interlacing	Yes (one-dimensional)	No	No	Yes (2D)
Gamma correction	No	No	Yes	Yes
Patent issues	Yes	No (yes)	Yes	No

be achieved with a closely related format known as multiple-image networks graphics (28).

The gamma and color correction features inherent in PNG are important for developing digital teaching files, and the added alpha channels for variable transparency support and lossless compression make PNG an attractive alternative for multimedia projects. The 2D interlacing scheme works up to eight times faster than GIF one-dimensional interlacing schemes and makes PNG graphics an attractive alternative for Web-based teaching files. PNG images can have crisp detail on varied backgrounds for transparency work (if needed) and demonstrate better detail than GIF images while having a similar file size (10,12).

Conclusions

Although the full capabilities of PNG may not be used by most radiologists, the ability to repeatedly update and edit files with lossless compression along with gamma and chromicity correction makes PNG the optimal image format for Web-based teaching files (Table) (10,12,23,24). The bit-mapped PNG image files are usually 20%–30% smaller than similar GIF files but contain images with equal resolution (Fig 2). In addition, GIF files do not support true color or gamma correction, limitations that still hinder the image quality of many Web-based projects, leaving many images either too dark or too light on different computer platforms. Some monitors also tend to display highlights and shadows of graphic files that are too dark or too light relative to the original file settings. The alpha-channel variable transparency capabilities of PNG will not directly affect the teaching file images in radiology Web-based projects but will allow sharper supporting graphics in the database interface.

Although PNG is clearly superior to GIF, a comparison of PNG with JPEG is more problematic due to significant differences. Whereas the JPEG format may be preferable for color photo-

graphic images that are not to be altered, PNG is better suited to computer-generated graphics (eg, in digital radiographic studies). The ability to open, edit, and save files repeatedly with PNG without data loss makes this a preferable format in multimedia projects (12). Although there is a nearly lossless version of JPEG compression, it is inferior to the earlier LZ77 compression scheme of PNG and has problems with the storage of bit-mapped color graphic files. The lossless version of JPEG uses a completely different compression scheme that has not gathered significant support among image-editing applications. The 2D interlacing capabilities of PNG allow an image to fill in from top to bottom as well as from right to left, making PNG images identifiable faster than GIF or JPEG images, which can be loaded only from top to bottom. This increased speed can be important on slower networks (eg, in teleradiologic or off-site PACS applications) and with digital teaching file projects.

Although TIFF is a good choice for bit-mapped data file transfer for image input and output devices, it is not an option for Web-based teaching tools. Although it would theoretically be possible to encode a new fully-supported (private) tag for TIFF files for Internet use, this would merely complicate an already very complex format. The multiple compression schemes already in use and the countless number of existing tags would make the creation of a Web-based image editor for radiologic case input over the Internet nearly impossible. Moreover, TIFF files have no existing tags for the progressive display that is so popular with the other formats and are not designed for stream processing. As discussed earlier, certain legal issues also limit the use of TIFF for such projects.

The capacity of PNG to integrate private chunks of data should allow seamless conversion of DICOM images into the PNG format. The integration of alphanumeric text in metadata (eg, patient information) will assist in incorporating case material into a database. The acceptance of PNG by the World Wide Web Consortium and by the most popular Web browsers and graphic manipulation software companies ensures its fu-

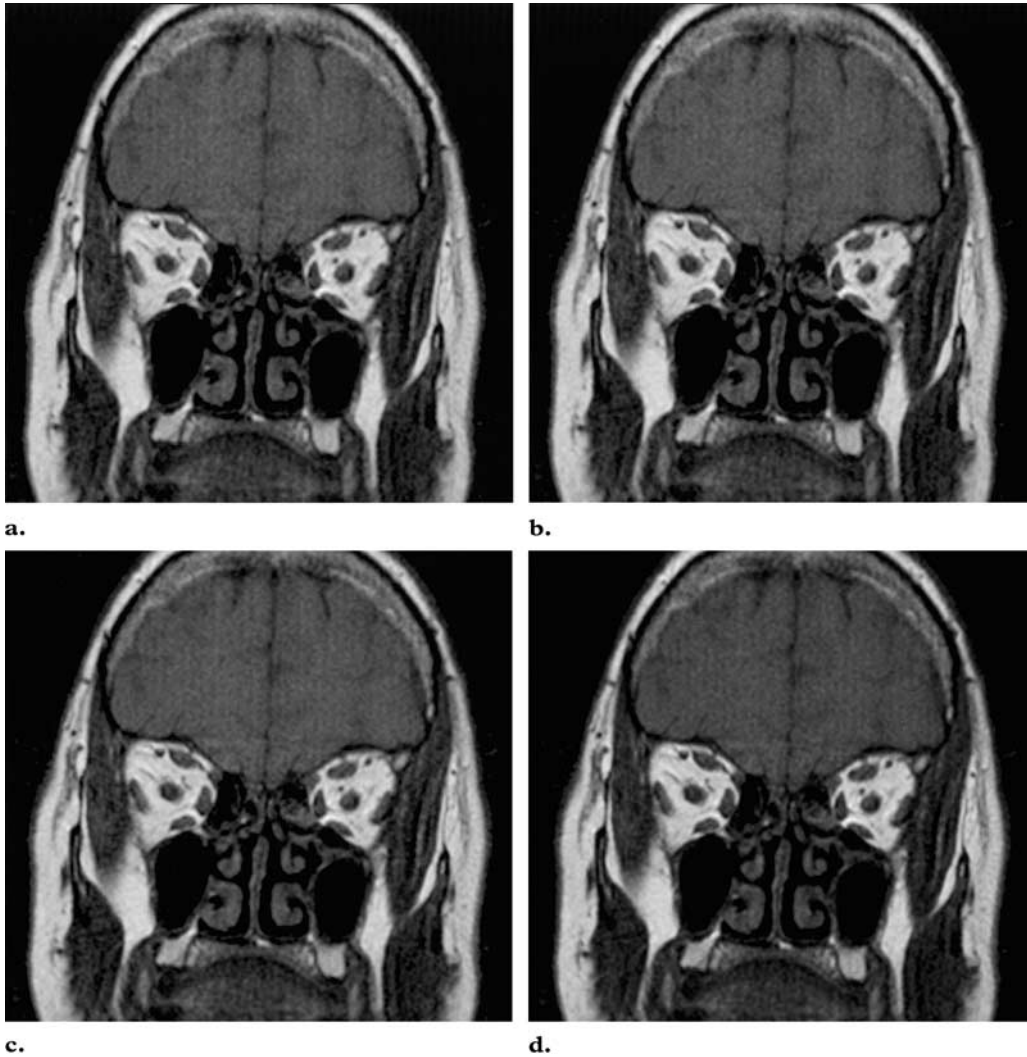


Figure 2. Comparison of image file formats. An original TIFF image was saved at 300 dots per inch in the following file formats: GIF file (687 Kbytes) (a), JPEG file interchange format file (250 Kbytes) (b), PNG file (549 Kbytes) (c), and TIFF file (959 Kbytes) (d). No interlacing was used to obtain the GIF image, and no interlacing or filtering was used for the PNG image. Maximum quality (minimum compression) was used for the JPEG (JFIF) image, and no compression was used for the TIFF image, which was obtained with Adobe Photoshop 5.5.

ture place in Web-based and imaging editing projects. In conclusion, the PNG file format provides a network-friendly, patent-free, lossless compression scheme that is truly cross-platform and has many new features that are useful for multimedia and Web-based radiologic teaching.

Acknowledgment: The authors thank Marconi Medical Systems (Cleveland, Ohio) for partially supporting this project by making academic research time available.

References

1. Khorasani R, Lester JM, Davis SD, et al. Web-based digital radiology teaching file: facilitating case input at time of interpretation. *AJR Am J Roentgenol* 1998; 170:1165-1167.
2. Mehta A, Dreyer KJ, Montgomery M, Wittenberg J. A World Wide Web Internet engine for collaborative entry and peer review of radiologic teaching files. *AJR Am J Roentgenol* 1999; 172:893-896.
3. Wiggins RH. The production of multimedia educational tools using HTML. In: Kilcoyne RS, Lear JL, Rowberg AH, eds. *SCAR 96: computer applications to assist radiology*. Carlsbad, Calif: Symposia Foundation Press, 1996; 50-55.
4. Roelofs G. History of the portable networks graphics (PNG) format. Available at: <http://www.libpng.org/pub/png/pnghist.html>. Posted 1999.
5. Stanek WR. Bitmaps and vectors: web graphics evolve—the old standbys. Available at: <http://www.zdnet.com/pcmag/pctech/content/18/11/ib1811.002.html>. Posted 1999.
6. CompuServe Inc. GIF89a specifications. Available at: <ftp://ftp.ncsa.uiuc.edu/misc/file.formats/graphics.formats/gif89a.doc>. Posted 1990.

7. Unisys Corp. LZW patent and software information. Available at: <http://www.unisys.com/unisys/lzw/>. Posted 2000.
8. Gillespie J. PNG: The 'other' graphics file format. Available at: <http://www.wpdfd.com/editorial/wpd1099.htm>. Posted 1999.
9. Houldsworth A. Tuning your images for the Web: JPEGs. Available at: <http://www.zdnet.com/devhead/stories/articles/0,4413,1600556,00.html>. Posted 1998.
10. Webreference.com. Optimizing Web graphics: compression. Available at: <http://webreference.com/dev/graphics/compress.html>. Posted 1999.
11. Hamilton E. JPEG file interchange format, version 1.02. Available at: <http://www.w3.org/Graphics/JPEG/jif3.pdf>. Posted 1992.
12. Sabio V. Review of the portable networks graphics (PNG) specification version 1.2. Available at: <http://www.mdtf.org/png/png-review.txt>, from <http://www.smartbounce.com/png/png-review.txt>. Posted 1996.
13. Aldus Corporation. TIFF 6.0 specifications. Available at: <http://www.tnt.uni-hannover.de/ljs/soft/imgproc/fileformats/tiff.doc.6.0.pdf>. Posted 1992.
14. National Electrical Manufacturers Association. Digital Imaging and Communications in Medicine (DICOM). Rosslyn, Va: National Electrical Manufacturers Association, 1996; PS 3.1-1996-3.13-1996.
15. Schomer DF, Elkes AA, Hazle JD, et al. Introduction to wavelet-based compression of medical images. *RadioGraphics* 1998; 18:469-481.
16. Slone RM, Foos DH, Whiting BR, et al. Assessment of virtually lossless irreversible image compression: comparison of three methods by using an image-comparison workstation. *Radiology* 2000; 215:543-553.
17. Jordahl G. Color, color everywhere, but not a byte to spare. Available at: http://www.imagingmagazine.com/db_area/archs/1997/May/4_1118.htm. Posted 1997.
18. Roelofs G. A basic introduction to PNG features. Available at: <http://www.libpng.org/pub/png/pngintro.html>. Posted 1999.
19. Roelofs G. PNG (Portable Network Graphics) specification, version 1.2, chunk specifications. Available at: <http://www.libpng.org/pub/png/spec/PNG-Chunks.html>. Posted 1999.
20. Youngs K, Brickley D, Williams J. TASI: Meta-data. Available at: <http://www.tasi.ac.uk/framework/capture/metadate.html>. Posted 1998.
21. Beckett D. pngmeta home page. Available at: <http://www.libpng.org/pub/png/apps/pngmeta.html>. Posted 2000.
22. Hunter J, Zhan Z. An indexing and querying system for online images based on the PNG format and embedded metadata. Available at: <http://archive.dstc.edu.au/RDU/staff/jane-hunter/PNG/paper.html>. Posted 1999.
23. Roelofs G. Feature: the story of PNG. Available at: <http://slashdot.org/articles/99/03/18/0958203.shtml>. Posted 1999.
24. Stanek WR. Bitmaps and vectors: web graphics evolve. Available at: <http://www.zdnet.com/pcmag/pctech/content/18/11/ib1811.001.html>. Posted 1999.
25. Roelofs G. PNG (Portable Network Graphics) specification, version 1.2, deflate/inflate compression. Available at: <http://www.libpng.org/pub/png/spec/PNG-Compression.html>. Posted 1996.
26. Houldsworth A. Tuning your images for the Web: PNGs. Available at: <http://www.zdnet.com/devhead/stories/articles/0,4413,1600557,00.html>. Posted 1998.
27. Roelofs G. Browsers with PNG support. Available at: <http://www.libpng.org/pub/png/pngapbr.html>. Posted 2000.
28. Roelofs G. Multiple-image network graphics. Available at: <http://www.libpng.org/pub/mng/>. Posted 1999.