Image Formats: Five Years after the AAPM Standard for Digital Image Interchange

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ABSTRACT

The publication of AAPM Report No. 10 was the first attempt to standardize image formats in the medical imaging community. Since then, three other groups have formed (CART - the Scandinavian collaboration for Computer Assisted Radiation Therapy treatment planning; ACR-NEMA, a collaboration whose purpose is to formulate a standard digital interface to medical imaging equipment; and COST B2 Nuclear Medicine Project a European collaboration whose purpose is to define a format for digital image exchange in Nuclear Medicine). The AAPM format uses key-value pairs in plain text to keep track of all information associated with a particular image. The radiation oncology community in the U.S. has been defining key-value pairs for use with CT, nuclear medicine and MR images. The COST B2 Nuclear Medicine Project has also adopted this format and together with the Australian/New Zealand Society of Nuclear Medicine Technical Standards Sub-Committee which has also adopted this format has defined an initial set of key-value pairs for Nuclear Medicine images. Additionally, both ACR-NEMA and CART have been defining fields for use with the same types of images. The CART collaboration has introduced a database which is available electronically, but is maintained by a group of individuals. ACR-NEMA operates through committee meetings. The COST B2 group operates through electronic (and postal where necesary) mail. To insure a consistent set of field names in such a rapidly developing arena requires the use of a server rather than a committee. Via a server a person would inquire if a particular field had been defined. If so, the defined name would be returned. If not, the person would be given the opportunity to define the field. The next inquiry would return the previously defined field. As new modalities are added to the imaging repetoire, it would be easier and faster to ensure the consistency and adequacy of the database; e.g., in the present version of its standard, the ACR-NEMA fields are adequate for CT but there are very few fields suitable for describing the parameters associated with nuclear medicine and MR images.

Keywords:

Standardized Image Formats
Electronic Image Database
AAPM Image Format
ACR-NEMA Image Format
CART Image Database

1. INTRODUCTION

In any medical environment in which different types of images are produced, there are many common tasks which are required to handle these images. Following image production (either in analog or digital form), there may be a need to enhance (or otherwise process) the image, make it available for use (e.g., viewing), store it for later retrieval, and transmit it to different locations. In radiology, the conventional approaches to the performance of these tasks has led to workable but inefficient solutions. Most of these solutions revolve about the use of film.

However, film retrieval (for comparison or research use) is often hampered by film misplacement and the high personnel cost of filing, retrieving and transporting the film; radiologists and clinicians often have to physically travel to the image source locations; space requirements often dictate that older films be stored off-site, and sending films to other institutions involves reproduction, shipping cost and delays.

In the case of imaging modalities which are inherently digital, such as computer assisted tomography (CT), positron emission tomography (PET), single photon emission tomography (SPECT), nuclear magnetic resonance imaging (NMRI) and digital radiography (DR) in its various forms, the situation is worse: there is replication of hardware costs in having separate viewing systems for each modality, there is loss of image information when these images are archived on film, the image formats are all incompatible and once the machine producing the image is retired as obsolete, those images obtained on it are often (nearly always) no longer available in digital form.

The present authors started to grapple with these problems toward the end of the last decade. We realized that the problem existed on many levels. First, we needed a common image format to exchange images inter- and intramurally. We also needed a common image format to display and manipulate images from different modalities on the same viewing console, i.e., so one set of application programs would apply to any image, as well as so that further application programs could be developed as new information was obtained from the images. Furthermore, we needed to support different display systems, we needed to obtain the data and we needed a method of taking advantage of hardware upgrades without having to re-write all the software. Note that our solutions apply to any type of images and are not limited to the medical environment.

The first step toward resolving the image format problem was the publication of the American Association of Physicists in Medicine (AAPM) report, "A Standard Format for Digital Image Exchange".[1] At the first meeting sponsored by the Society of Photo-Optical Instrumentation Engineers (SPIE) on Picture Archiving and Communication Systems (PACS) in medical imaging,[2] the present authors[3] along with many others proposed that the acquisition and storage problems be solved by implementing a network to interconnect imaging facilities and by encouraging broad cooperation which would lead to industry-wide standards. Since that time the ACR-NEMA Digital Imaging and Communications Standard 300 had been published.[4] The networking aspects of the problem have been discussed in many papers and is described in some detail in the review paper[5]. Additionally, a generic approach to frame buffers by use of a small set of easily programmed primitive functions has also been described.[6] A description of the mature formulation of the image format and its use in application programs has also been published.[7] This work is similar to what the Utah Raster Toolkit[8] has provided for eight bit gray scale and twenty-four bit real color raster images, but applies to a much broader range of images. Furthermore, the image format described in this paper can be easily adapted to any standard format which is adopted in the future. We took advantage of the UNIX* operating system (which has been ported to many different CPU's) to give us hardware independence and chose to program in a high level language (in our case C) so as to easily go from one hardware environment to another. (Presently our routines support UNIX System V and UNIX BSD 4.x as well as EUNICE.)

2. STANDARDS AND MODIFICATIONS

The standards described below have been defined by different organizations. Additionally, some groups or organizations which have adopted and extended one of these standards, or have proposed a modification to them.

2.1 AAPM Report No.10

The standard file format described in this report is meant for digital image exchange between heterogeneous computer systems. It provides a header file as text in the form of sets of standard key-value pairs for the non-pixel data and a second

* UNIX is a Trademark of Bell Laboratories

(separate) file composed of the N-dimensional array of numeric values (image data) which comprise the actual pixel values.

Examples of the non-image data might include:

1. date of image creation
2. type of instrument which produced this data
3. all the parameters (necessary) to convert the N-dimensional array of values to the representation required for interpretation (which may include viewing).

This non-numeric data is referred to as header information and is in the form of key-value pairs as ASCII character strings, with a key beginning a line, possibly with leading spaces or tabs, followed by a colon equal (:=), followed by the value and terminated by a newline character. Table 1 illustrates the type of non-image or header information that can be stored, and Table 2 shows those key value pairs which are essential for reading the image. A two's complement integer or positive integer format is recommended for the numeric data.

```
Image number := 1
Bytes per pixel := 2
Number of dimensions := 2
Size of dimension 1 := 128
Size of dimension 2 := 128

Institution := NYU Medical Center
Department := Radiology
Division := Nuclear Medicine
Date created := 17.10.1980

Date written := 20.10.1980
Patient name := Sam Jones
Exam Type := Liver spleen study
```

Table 1. AAPM Header Example 1

The following key-value pairs are required to access the image data:

```
Image Number :=
Bytes per pixel :=
Number of dimensions := N
Size of dimension 1 :=
Size of dimension 2 :=
.
.
.
Size of dimension N :=
```

Table 2. AAPM Header: Required Keys

Suppose a simple image consists of a three dimensional array of small (in the range -128 $\cdots$ 127) integers. The array happens to be a 3 by 4 by 5 array. Consequently, the header information when placed into the directory, could be used by a program to put the sequential bytes of image data into a 3 by 4 by 5 array. The header information for the image data would thus be stored as illustrated in Table 3.

Image Number := 1
Bytes per pixel := 1
Number of dimensions := 3
Size of dimension 1 := 3
Size of dimension 2 := 4
Size of dimension 3 := 5

Table 3. Example 2: Header Information

The information associated with an image thus always includes the dimensions of the image where, for a three dimensional image dimension 1 and 2 are the rows and columns and dimension 3 is the number of slices (views, frames).

The numeric data is stored in a separate binary file in order. A single datum is stored in one or more bytes (most significant byte first). The AAPM standard recommends using two's complement integer or positive integer format. The AAPM Standard recommends no compression algorithm, as the purpose of the standard was image interchange and compression would simply make this harder.

2.2 U.S. Radiation Oncology Collaboration

The radiation oncology community in the U.S. has adopted the AAPM format for digital image exchange and has been defining key-value pairs for use with CT, nuclear medicine and MR images.[9] Section 5.11 of their report describes the format for exchange of images and treatment plans, which conforms exactly to the AAPM document. In an appendix, the list of key-value pairs defined in the original AAPM report is considerably expanded. An additional appendix provides models of utility programs which can be used for reading and writing magnetic tapes.

2.3 CART - The Scandinavian Collaboration For Computer *Assisted* Radiation Therapy *Treatment Planning*

This collaboration,[10] which was jointly sponsored by the respective nordic governments and by industry, had the mandate to define standards for radiation therapy treatment planning, the result of which would be the development of products adhering to these standards. One of the basic elements in such a design was the ability to exchange images and treatment planning information. One component of this was the development of a very large data base which could easily be used as a basis for defining key-value pairs.

The existing parameter sets in the CART Standard Database include image data set, treatment plan document data set, beam scanner data set, simulator data set, mould room data set and clinical register data set. The logical format drafts exist for image (Uppsala format), beam scanner - treatment planning, treatment planning - verification and treatment planning - mold room. These parameter sets include definitions for *Name, Units, Standard from which derived*, etc. The outstanding aspect of the CART standard database is that it exists as an electronic database (at UDAC - the Uppsala University Datacenter) which users can query electronically. Thus if a user needs to know about a particular parameter he/she can query the database and find (1) yes it is defined - in which case the person who entered the definition, along with the coordinate system, units, literature reference, etc. are provided, or (2) it is not defined and the person inquiring can provide a definition which will subsequently be available to anyone else who queries the database. However, the database is not publicly available outside the CART project members.

It is hoped that the database, which may be renamed to *CART Reference Database*, can be a resource for industrial development; i.e., that the definitions will be available and searches of the parameters will be able to be made. Future work with the CART Standard Database will concentrate on an integrated network approach including data transfer protocols. Planning is also going forward to transfer the maintenance responsibility of the database to a permanent organization.

2.4 ACR-NEMA Standard 300 - Digital Imaging and Communication

The ACR-NEMA Standard[4] approaches the problem of digital image exchange from two different aspects. It defines an electrical interface as well as specifying how images are formatted to cross this interface.

The ACR-NEMA data format is organized around data elements which are formed into groups which contain messages. There are 65,536 possible groups. Even-numbered groups are reserved for this standard, while odd-numbered groups are available for use by manufacturers or users. Groups numbered one greater than the number of a standard group are called shadow groups and are reserved for manufacturers and users to place information of the same category as that in the standard group that precedes them. So far, twenty-four groups, such as patient information and acquisition information, have been defined. These are found in Chapter 10 of the standard. Instead of using the element numbers to identify the meaning of the element as proposed by ACR-NEMA, these definitions could be used directly in the form of AAPM key-value pairs. This would simplify the implementation enormously as de-coding tables for the element numbers would be unnecessary. In the ACR-NEMA standard the element representation is not encoded, but must be derived from the group/element numbers. Thus an ACR-NEMA interface delivers bits with the paper document providing the semantic information of how to interpret these bits.

There exists now the X3H3..8 Task Group on the Application Programming Interface for Electronic Imaging within the ANSI X3H3 subcommittee which defines its scope as dealing with such items as conversion between image coordinate spaces, conversion between classes of images, operations on sets of images, color representation conversions, and other related issues, but not apparently, data representation.[1]

2.5 Standard Product Interconnect

While the ACR-NEMA standard includes both a hardware specification (down to the plug) and a software description, two companies, Siemens and Philips have collaborated on a software specification which is known as the Standard Product Interconnect. It is meant to allow the type of network image distribution proposed by the ACR-NEMA standard, without being limited to a single hardware interface. This interconnect was described by C.F.C. Greinacher at the CAR '87 meeting.[11]

2.6 COST B2 Nuclear Medicine Project and Australian/New Zealand Society of Nuclear Medicine Technical Standards Sub-Committee

Since the original writing of this report, we have found that a number of people using computers in nuclear medicine have been grappling with the problem of transferring files between different systems. Several have written programs to carry out very specific transfers (Gamma-11 to uDelta, or Technicare, for example).

One such group the Australian/New Zealand Society of Nuclear Medicine Technical Standards Sub-Committee, has adopted the AAPM Report #10 format and a technical sub-committee has already defined many key-value pairs for nuclear medicine based on this format. Another group consists of persons involved in nuclear medicine in Europe, the U.S. and Canada who began by working in conjunction with the Australian/New Zealand group. This later group has organized in Europe as the the COST B2 Nuclear Medicine Project. As a result of a meeting last summer (August 1988) in Vienna and in January (1989) in Bern, the COST B2 Nuclear Medicine Project has adopted the AAPM Report #10 standard and has proposed a preliminary set of key-value pairs relative to Nuclear Medicine images for adoption by the entire group.

2.7 QSH: A Minimal But Highly Portable Image Display and Handling Toolkit

The format of images is a very important consideration, because each device that needs to manipulate them needs to know the file format. Additionally, it would be convenient if the file format chosen could also act as a database for the data associated with the image. We describe here a body of software developed with both of these issues in mind.

An adaptation of the AAPM standard image format was used for the image file structure and the University of North Carolina (UNC) *vsh* (visual shell)[12] was used as a model for developing the image analysis software. The *vsh* names for the image access functions (*imopen, imcreat, imclose, imdim, imbounds, imgetpix, imputpix*) have been retained to facilitate the use of the new image format by existing programs written to use the UNC routines. Not all of the UNC routines are supplied; however, these (*imerror, imgetinfo, imputinfo, iminfoids*) can be written in terms of ImageGetValue and ImagePutValue. These two routines are the only routines necessary to use the key-value pairs. Given a key as a string, the ImageGetValue function returns either the value as a string or an error number. If the user wishes to interpret this string as a number, it can be converted to a number (integer, float, double, ...) by use of standard C library routines.

Thus key-value pairs behave just a LISP properties. The key-value pairs are unordered, they are created the first time ImagePutValue is given te key string, and a key retains the value given by last ImagePutValue for this key.

The ability to have arbitrary key-value pairs is so useful, that one user (Jonathan Stockley) has modified the image access routines to <u>only</u> deal with header files if the key "Number of dimensions := " is set equal to "0". He has constructed a server

1. More information on this task force can be obtained from Frank Drake Jr., Research Manager, Imaging Research Laboratory, University of Lowell, One University Avenue, Lowell, MA 01854, (617)452-5000 ext.2693, drake@ulowell.edu.

process which reads values from a header file, answers requests for values, updates values, adds new key-value pairs and when terminated, updates the header file. This provides the facilities of environment variables (which many operating systems provide) with the added power of being able to update these values and share them between separate processes. Typical values which users might want to update are ''Current color scale'', ''Background'', ''Saturation'', $\cdots$.

In *qsh*, the header information, following the AAPM standard, is in the form of key-value pairs as ASCII character strings. A key begins a line, possibly with leading spaces or tabs, followed by a colon equal (:=), followed by the value and terminated by a newline character. Table 4 illustrates the type of non-image or header information that can be stored, and Table 5 shows those key value pairs which are essential for reading the image. The date is written in ACR-NEMA format; two's complement integer format for the numeric data is indicated by the first line (Pixel Format := 8) of the header file.

Pixel Format := 8
Bytes per pixel := 2
Number of dimensions := 2
Size of dimension [0] := 128
Size of dimension [1] := 128

Institution := NYU Medical Center
Department := Radiology
Division := Nuclear Medicine
Date created := 1980.10.17

Date written := 1980.10.20
Patient name := Sam Jones
Exam Type := Liver spleen study

Table 4. QSH Header Example 1

The following key value pairs are required to access the image data:

Pixel Format :=
Bytes per pixel :=
Number of dimensions := N
Size of dimension [0] :=
Size of dimension [1] :=
.
.
.
Size of dimension [N-1] :=

Table 5. QSH Header: Required Keys

Note that the AAPM key "image number" is not needed as *qsh* stores only one image per file, while the AAPM format stores all the image headers for an entire tape in one file. In addition, the key "Size of dimension" is considered to be a vector, rather than the N different keys used in the AAPM format. These vectors follow from the C convention of being indexed from zero rather one.

Suppose a simple image consists of a three dimensional array of small (in the range -128 $\cdots$ 127) integers. The array happens to be a 3 by 4 by 5 array. Consequently, the header information when placed into the directory, could be used by a program to put the sequential bytes of image data into a 3 by 4 by 5 array. The header information for the image data would thus be stored as illustrated in Table 6.

Pixel Format := 8
Bytes per pixel := 1
Number of dimensions := 3
Size of dimension [0] := 3
Size of dimension [1] := 4
Size of dimension [2] := 5

Table 6. QSH Header Information Example 2

Note that following the C array convention, the fastest varying index is last, whereas in FORTRAN it is first. Therefore, for a three-dimensional image, dimension 0 corresponds to the z direction (or the number of slices), while dimension 2 corresponds to the x direction.

3. DISCUSSION

One item that has not been dealt with clearly by any of the above standards is the size of each datum item. ACR-NEMA only deals with the size of the storage of a data element and only describes the internal bit arrangement for the image data. It is desirable that each datum item be kept at its original value, i.e., byte data is stored in bytes, sixteen bit data is stored in sixteen bit (short) integer, floating point data is stored in floats. (Since byte order and floating point representations are not standard between heterogeneous systems, we at present would recommend network byte order and IEEE floating point format where appropriate).

Another item of great concern is the need to interchange not only images, but information about images between different sites, or between different modalities. Figure 1 gives some representative sample header information for four different imaging modalities. This information was generated simply by using the data already provided by the image source manufacturer in the image header. While it was possible to identify a standard name/form for some entries, (e.g., the date, patient name, ...) such an identification for most entries was not available from any of the sources referred to in this article (i.e., AAPM, ACR-NEMA, CART or the U.S. Radiation Oncology Group). The entire header for each of the four types of images is not shown here, but each contained at least sixty-six entries. The fact that there are so many entries in each header shows the magnitude of the problem. If databases incorporating these information items were to be built with no previously agreed upon standard keys, there would be no way to exchange data meaningfully between institutions. Beyond the simple wasted effort required to exchange data there is increasingly a problem associated with the fact that this data is now being written to WORM (Write Once Read Many times) disk; thus once the data is written it can not easily be changed without making a completely new disk. An additional problem will occur as a result of the trend toward merging medical care facilities. In order to merge the databases either all of the previous patient data will have to be rewritten or the computer will have to remember which version of keys are applicable to a given patients file. However, there is, for example, no key in the ACR-NEMA format to indicate which local version of keys was used for this file.

Both the COST B2 and the Australia/New Zealand Nuclear Medicine groups recognize that in addition to deciding on an image exchange format and defining a common set of key-value pairs, one element remains to be resolved; namely, to establish some central *agency* that is prepared to be the central clearing house when decisions need to be made concerning inclusion of a particular item and what format that item should take. For the time being, Trevor Cradduck at the University of Ontario, Canada, (trevorc@uwovax.uwo.ca) has accepted the responsibility for the central repository and a distribution list by e-mail and where necessary, postal mail has been generated. Exactly how communal input into any decisions will be handled has yet to be decided.

4. Conclusions and Call for Action

There are two distinct problems to be faced with respect to the digital exchange of images; namely

- The image format itself, and
- The format of the information about the image.

The publication of AAPM Report No. 10 was the first attempt to standardize image formats and image information in the medical imaging community. Since then, three other groups have formed: CART, ACR-NEMA and COST B2. The AAPM format uses key-value pairs in plain text to keep track of all information associated with a particular image. The radiation oncology community in the U.S. has been defining key-value pairs for use with CT, nuclear medicine and MR images. The

COST B2 and Australian/New Zealand groups are doing the same thing for Nuclear Medicine images. Additionally, both ACR-NEMA and CART have been defining fields for use with these same types of images.

It seems very timely to propose a way to unify the naming of these fields. The CART collaboration has introduced a data base which is available electronically, but is maintained by a group of individuals. ACR-NEMA operates through committee meetings. To insure a consistent set of field names in such a rapidly developing arena requires the use of a server rather than a committee. Via a server a person would inquire if a particular field had been defined. If so, the defined name would be returned. If not, the person would be given the opportunity to define the field. The next inquiry would return the previously defined field. A number of computerized services already operate in this manner, such as the set of archive servers based on the software developed by Brian Reid at DEC Western Research Laboratory.[13] Thus the next step is for a representative body such as for example, the National Cancer Institute, to set up a server and load the keys already defined by (or in the format of) AAPM, CART, and ACR-NEMA and to make this server available via Bitnet, Internet, and UUNET (the nonprofit corporation which provides connections between UUCP, the Internet and commercial networks). This would serve the purpose of

- Forming an initial database structure,
- Ensuring a universally understood and accepted meaning for any datum item regardless of whether it was pixel or non-pixel information and
- Allowing a migration to a formally specified file format using the Information Processing - Open Systems Interconnection - Specification of Abstract Syntax Notation One (ASN.1) published as final proposal International Standard ISO 8824.

CT Header	MRI Header
Manufacturer:=GE 9800	Manufacturer:=Philips Gyroscan
Modality:=CT	Modality:=NMR
Manufacturer Model:=10	Magnetic Field Strength:=1.5
Station ID:=1	Packages:=2
Exam Decimal Number:=9046	echo sequence:=2.se_mod.echo1
Patient ID:=00000	nucleus:="1H"
Patient Name:=John Doe	Patient Name:=John N.M.R. Doe
Referring Physician:=John S. Doe	imaging_sequence:="SE"
Institution ID:=FACULTY PRACTICE	preparation_phase:="M"
Radiologist:=John R. Doe	slices_MS:=30
Operator Identification:=JS	slice_factor:=1.000000e+00
Admitting Diagnosis:=COLON CA	Real image minimum[29]:=12.000000
Study Date:=1988.10.08	Real image maximum[29]:=91749.703125
Study Time:=12: 5:44	min_time_out:=60
Contrast-0=no,1=yes:=1	acceptable_nearness_SE:=1.100000e+00
Contrast Description:=C	scale_step_RF180:=0.000000e+00
Filter Type-1=body,2=head:=1	maximum_gradient:=3.000000e+01
First View Angle - Degrees:=0	send_coil:="head"
Defining Scout used:=1	DC_tuning_and_matching:="yes"
Axial Type:=1	profiles:=256
Preparation Delay:=1.200000	load_time:=1.000000e+02

SPECT Header	PET Header
Manufacturer:=Siemens Orbiter 75	Manufacturer:=PETT VI
Modality:=SPECT	Modality:=PET
Collimator/grid:=MED	Resolution - 0=low; 1=high:=0
Radionuclide:=IN-111	Isotope Code:=1
Radionuclide Total Dose:=5 MCI	Pharmaceutical form:=CDG
mode - 1=byte,2=word:=2	Number of Slices in file:=9
end condition 0 = time:=0	Total Counts in Slice:=948134
mode - 1=byte,2=word:=2	Scan time for normalization run:=300
raw data file extension:=0	INT:=101.399963
file type- 1=image file:=1	No of Rotations - 0/1:=0
image type- 4=64word,6=128word:=4	No of wobbles per second:=1
Images in Acquisition:=64	Random Corrections - each slice[0]:=0
Patient Name:=John S. Doe	Transmission Scan File Name:=D141T1
Patient ID:=ZCE018	Patient ID:=D2141B
organ:=vDI MOAB	Random Corrections - each slice[1]:=0
view:=Transverse	Slope:=23.000000
Study Date:=1988. 5.10	Study Date:=1986.10.24
Software Version:=8	PETT Number:=6
Patient Birthdate:=1930.12. 5	CE:=71.399963
Referring Physician:=John R. Doe	Manufacturer Model:=0

Figure 1: Sample header information available for different modalities

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