Quality of DICOM header information for image categorization

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ABSTRACT

The widely used DICOM 3.0 imaging protocol specifies optional tags to store specific information on modality and body region within the header: *Body Part Examined* and *Anatomic Structure*. We investigate whether this information can be used for the automated categorization of medical images, as this is an important first step for medical image retrieval. Our survey examines the headers generated by four digital image modalities (2 CTs, 2 MRIs) in clinical routine at the Aachen University Hospital within a period of four months. The manufacturing dates of the modalities range from 1995 to 1999, with software revisions from 1999 and 2000. Only one modality sets the DICOM tag *Body Part Examined*. 90 out of 580 images (15.5%) contained false tag entries causing a wrong categorization. This result was verified during a second evaluation period of one month one year later (562 images, 15.3% error rate). The main reason is the dependency of the tag on the examination protocol of the modality, which controls all relevant parameters of the imaging process. In routine, the clinical personnel often applies an examination protocol outside its normal context to improve the imaging quality. This is, however, done without manually adjusting the categorization specific tag values. The values specified by DICOM for the tag *Body Part Examined* are insufficient to encode the anatomic region precisely. Thus, an automated categorization relying on DICOM tags alone is impossible.

Keywords: Content Based Image Retrieval, CBIR, DICOM, Image Categorization, PACS, Standardization, Validation

1. INTRODUCTION

Digital imaging and communication in medicine (DICOM) is widely used as a transfer protocol as well as a storage format for medical applications. DICOM 3.0 not only encapsulates the image data itself, but also stores and provides extensive information about e.g. the patient, the medical examination process, and the imaging modality setup. Due to its vendor- and hardware-independence, combined with the support for a network environment, DICOM plays a key role in the establishment of picture archiving and communications systems (PACS),[1,2] which themselves might offer interfaces to hospital information systems (HIS)[3,4] as well as content-based image retrieval (CBIR) systems.

Especially in the field of medical applications, image databases impose special demands for the retrieval process. Due to the textual limitations for the description of medical content and the constantly evolving underlying model for medical facts, TAGARE ET AL.[5] proposed a content-based access to the image material. Therefore, a medical image retrieval system has to incorporate a high level of image understanding, which should also be kept flexible in order to allow easy modification and refinement. The project of image retrieval in medical applications (IRMA)[6] aims to provide a theoretical framework according to these demands and defines several

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layers of image content abstraction corresponding to an increasing level of image understanding. Each level of abstraction is based on the information gathered during all previous processing steps. Thus, a first important step is the categorization of a medical image with respect to the imaging modality and its technical parameters as well as the body part and the functional system, which are subject to the examination. With the broad use of DICOM, it has to be evaluated whether this step can be assisted by using information automatically generated by the modality as part of the imaging process and manually determined by the clinical personnel.

After the imaging process, the CT images and MR images can be stored in a PACS utilizing DICOM as a transfer protocol between the modality and the archiving system. Note that this solution typically only supports image access via the patient's attributes (name etc.), whereas the IRMA-approach aims at providing content-based retrieval methods. Most other DICOM related publications focus on the image processing and interoperability aspects of PACS in a DICOM environment, e.g. the MRIPS/MARS system,[7] which serves as a platform for the implementation of image processing methods.

In this work, the conformance and the reliability of DICOM data generated by imaging modalities that are used in the clinical routine is examined. The paper is structured as follows: First, we give a short overview of the DICOM standard, the way it models the medical imaging process, and how the data is represented and stored. Further, the methodology of the survey is described, followed by the presentation of the results. The discussion part analyzes the results and their origins. It is followed by the conclusion, which summarizes our observations.

2. DICOM

Our survey is based on the present DICOM version 3.0.[8] The final draft of the standard is also available online.[9] The DICOM standard models real-world processes involving medical image data via a set of interdependent information entities. Each entity contains the data covering a certain aspect of the actual process (e.g. image acquisition, printing) and the real-life entities involved (e.g. patient, image modality).

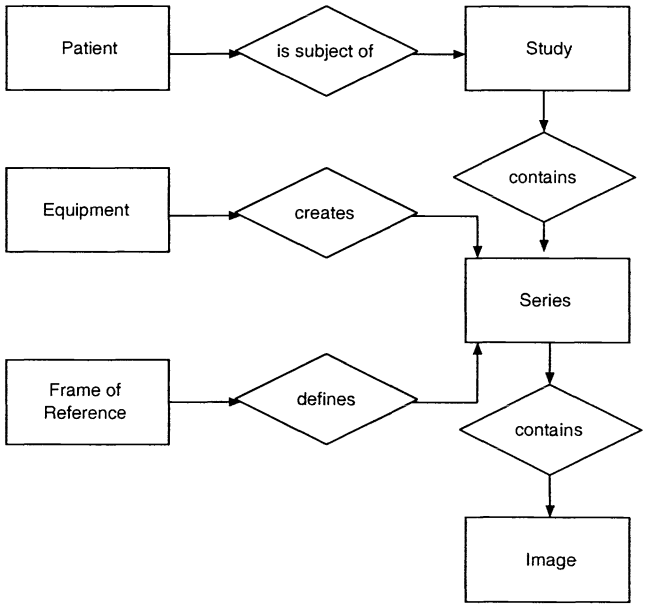

Figure 1: The DICOM composite instance IOD information model.

DICOM specifies an information object definition (IOD) to model all relevant information that is part of the imaging process, e.g. the CT image IOD for computed tomography and the MR image IOD for magnetic resonance imaging. These IODs encapsulate instances of several information entities: The *Patient* entity and

the *Study* entity are both modality independent and contain data about the patient (name, age, etc.) and the examination (e.g. physician's name, description). The *Series* entity, which forms a logical group containing e.g. a set of images, is logically defined and created by two information entities: the *Frame of Reference* entity, which insures the spatial relationship of images within the series, and the *Equipment* entity, which stores information about the imaging modality (e.g. manufacturer, software revision). Finally, the image data itself is stored within several image-related entities, which are partly modality dependent and partly modality independent. Figure 1 illustrates the entities and their relationships involved in the imaging process: information entities are displayed as boxes, their relationships are displayed as diamonds along with a text describing the interdependency.

In DICOM, an IOD contains the values for the IE attributes inside a corresponding module, e.g. Figure 2 illustrates the complete composition of the CT image IOD.

Information Entity	Module	Usage
Patient	Patient	mandatory
Study	General Study	mandatory
	Patient Study	optional
Series	General Series	mandatory
Frame of Reference	Frame of Reference	mandatory
Equipment	General Equipment	mandatory
Image	General Image	mandatory
	Image Plane	mandatory
	Image Pixel	mandatory
	Contrast/Bolus	required if contrast media is used
	CT Image	mandatory
	Overlay Plane	optional
	VOI LUT	optional
	SOP Common	mandatory

Figure 2: Modules used by the CT image IOD.

Categorization-relevant DICOM tags

In DICOM, attributes are accessed via their corresponding tag. Tag IDs consist of a pair of 16 bit integer numbers, called the *Group Number* and the *Element Number* within that group. For categorization purposes, DICOM provides several attributes:

- The attribute *Anatomic Structure*, which has the tag ID (0008, 2208). For this attribute, an anatomical region code defined by the systematized nomenclature of human and veterinary medicine (SNOMED) lexicon[10] is recommended by the DICOM standard, but this is not mandatory. The SNOMED DICOM Microglossary (SDM) aims to integrate the SNOMED nomenclature into the DICOM framework.[11] In DICOM 3.0, the *Anatomic Structure* attribute is obsolete.

- The attribute *Body Part Examined* is contained within the *General Series* module, which belongs to the *Series* entity. The attribute specifies the anatomical region that is subject to examination. Note that this attribute is optional, i.e. DICOM does not require this tag to be set by a modality to be compliant with the standard. The tag ID for the *Body Part Examined* attribute is (0018, 0015). The valid entries for this tag are displayed in Table 1. The spine is subdivided into four parts for a more precise categorization. Additionally, the DICOM 3.0 standard offers the value SPECIAL for this attribute.

- The attribute *Anatomic Region Sequence* is offered by the DICOM 3.0 specification as a more comprehensive mechanism to identify the body part being examined. The corresponding tag ID is (0008, 2218). However, this attribute is only supported by some IODs: It is contained within the nuclear medicine image

SKULL	CSPINE	TSPINE	LSPINE	SSPINE
COCCYX	CHEST	CLAVICLE	BREAST	ABDOMEN
PELVIS	HIP	SHOULDER	ELBOW	KNEE
ANKLE	HAND	FOOT	EXTREMITY	HEAD
HEART	NECK	LEG	ARM	JAW

Table 1: Valid entries for the tag *Body Part Examined.*

module, the ultrasound image module, the x-ray image module, the PET image module, the mammography image module, and the intra-oral image module. The tag is intended to "allow the specification of the information encoded by the *Body Part Examined* attribute (...) in a more robust, consistent way".[8] The suggested nomenclature for the attribute value is not specified by the DICOM standard.

3. METHODOLOGY

One goal was to examine the conformance of the devices to the DICOM 3.0 protocol and to check the presence of the optional categorization-relevant tags *Anatomic Structure* (used by DICOM versions prior to 3.0) and *Body Part Examined.* Note that the attribute *Body Region Sequence* is not used in combination with CT images and MR images.

We have evaluated images from the clinical routine at the Aachen University Hospital, taken by four digital imaging modalities: Two computer tomography imagers (CT) and two magnetic resonance imagers (MRI). The modalities have been manufactured between 1995 and 1999 (see Table 2). Via the tag *Recognition Code*, the modality can provide information about the protocol version that is supported by the device.

Imaging device	built in	software revision
Computer tomography imager (CT 1)	1996	1999
Computer tomography imager (CT 2)	1999	08/1999
Magnetic resonance imager (MRI 1)	1995	12/1999
Magnetic resonance imager (MRI 2)	1999	06/2000

Table 2: Imaging devices observed for this survey.

In order to evaluate the quality of the DICOM tags for image categorization, we observed all images taken by the modalities during an evaluation period of more than 500 images. This provides a continuous, representative sampling of the image data generated during clinical routine. It also ensures independence from the clinic personnel, who operates the modalities. The evaluation period began on August 1st, 2000 and ended on December 6th, 2000. In order to verify the results, a second evaluation was performed one year later. It started on October 11th, 2001 and ended on November 30th, 2001. Since there had been no software update in the time between the two surveys, we only evaluated the images by one CT, as it is the only one that provides the relevant tag data (see results below). The second evaluation was performed to ensure that the survey results are independent from the clinic personnel who operate the imaging modalities.

During the two periods, an experienced radiologist visually inspected and categorized all images to provide a reliable categorization reference. Since the attribute *Body Region Sequence* is not supported by the modalities, the categorization was done regarding the *Body Part Examined* attribute.

4. RESULTS

Computer tomography imager CT 1

The first computer tomography imager was manufactured in 1996 and its software version dates from 1999. During the first survey, 496 images were generated by this device. It identifies itself by the value "ACR-NEMA

1.0" (also referred as DICOM 1.0[12]) for the *Recognition Code* attribute. Thus, CT 1 offers neither support for the tag *Body Part Examined* nor the tag *Anatomic Structure* and therefore does not provide categorization relevant information. Even worse, images taken by this modality contained the tag *Repetition Time* and the tag *Inversion Time*. Normally, their use is only valid for magnetic resonance images. This is not conforming to the present DICOM 3.0 standard.

Computer tomography imager CT 2

The second CT dates from 1999 and uses a software version from August 2000. The images taken by this device provide values for the tag *Body Part Examined*, so their quality for categorization purposes can be evaluated. All relevant tags were compliant with the DICOM 3.0 standard. CT 2 generated 580 images during the first evaluation period in 2000 and 568 images during the second period in 2001.

Magnetic resonance imagers MRI 1, MRI 2

Since both devices act the same regarding the DICOM tags to be evaluated, they can be discussed at the same time here. MRI 1 and MRI 2 do not generate the tag *Body Part Examined* for images. Additionally, it is uncertain which standard is supported by these two devices since they do not provide the tag *Recognition Code* either.

4.1. First survey (August 2000 – December 2000)

As stated above, only one modality (CT 2) set a categorization-relevant DICOM tag. 580 images were taken using this modality during the evaluation period.[13] In 90 images (15.5%), the data for the tag *Body Part Examined* was incorrect compared to the radiologist's reference categorization. Typical mislabelings were *ABDOMEN* instead of *CHEST* (30 of 169, 17.8%), *HEAD* instead of *CHEST* (20 of 169, 11.8%), and *EXTREMITY* instead of *ABDOMEN* (15 of 231, 6.5%). The complete results are shown in Table 3.

	DICOM tag entries											
correct body region	ABDOMEN	BREAST	CHEST	EXTREMITY	HEAD	NECK	PELVIS	SHOULDER	SPINE	SPECIAL	errors	total
ABDOMEN	216	-	-	15	-	-	-	-	-	-	15	231
BREAST	9	94	-	2	8	-	-	-	-	-	19	113
CHEST	30	1	118	-	20	-	-	-	-	-	51	169
EXTREMITY	-	-	-	4	-	-	-	-	-	-	0	4
HEAD	-	-	-	-	6	-	-	-	-	-	0	6
NECK	-	-	1	-	-	18	3	-	-	-	4	22
PELVIS	-	-	-	-	-	-	2	-	-	-	0	2
SHOULDER	-	-	-	-	-	-	-	4	-	-	0	4
SPINE	1	-	-	-	-	-	-	-	28	-	1	29
total	256	95	119	21	34	18	5	4	28	0	90	580

Table 3. Evaluation of the entries for the tag *Body Part Examined* for CT 2 during the first survey. Note that *SPINE* subsumes several values specified by the DICOM standard. The false categorizations result in an error rate of 15.5% (90 of 580 images).

4.2. Second survey (October 2001 – November 2001)

During the second evaluation period, 568 images were taken using CT 2. For this survey, typical mismatches were *CHEST* instead of *ABDOMEN* (20 of 148 images, 13.5%) and *CHEST* instead of *NECK* (30 of 255 images, 11.8%). In total, 87 of 568 images provided wrong information, which results in an error rate of 15.3%. Table 4 lists the results in detail.

correct body region	DICOM tag entries: ABDOMEN	CHEST	EXTREMITY	HEAD	HEART	NECK	PELVIS	SHOULDER	SPINE	SPECIAL	errors	total
ABDOMEN	127	20	-	-	-	-	-	1	-	-	21	148
CHEST	8	215	-	-	-	2	-	-	-	1	11	226
EXTREMITY	2	4	5	-	-	-	-	-	-	-	6	11
HEAD	1	3	-	64	-	-	-	-	1	-	5	69
HEART	-	-	-	-	0	-	-	-	-	1	1	1
NECK	2	34	-	-	-	23	-	-	-	-	36	59
PELVIS	-	-	-	-	-	-	6	-	-	-	0	6
SHOULDER	-	-	-	-	-	-	-	5	-	-	0	5
SPINE	2	2	-	3	-	-	-	-	36	-	7	43
total	142	278	5	67	0	25	6	6	37	2	87	568

Table 4. Evaluation of the entries for the tag *Body Part Examined* for CT 2 during the second survey period. Note that *SPINE* subsumes several values specified by the DICOM standard. In total, 87 of 568 images (15.3%) contained a wrong entry.

5. DISCUSSION

Our survey yields two results: Although all imaging modalities have new manufacturing dates and recent software revisions, not all imaging modalities support the use of the categorization-relevant DICOM tags. In fact, only one of the four modalities observed provided data for the tag *Body Part Examined*, while the other devices only support older versions of the DICOM protocol or it is even impossible to verify the DICOM conformance level, respectively. Although none of the imaging devices uses a software revision older than 2 years, the overall DICOM 3.0 conformance is rather poor. Only CT 2 can be effectively evaluated regarding the categorization-relevant DICOM tags. It is uncertain, whether future software updates will support the use of the categorization-relevant tags. OOSTERWIJK[14] points out that DICOM is a voluntary standard and therefore, no organization for conformance approval or validation exists. He also discusses general DICOM compatibility and interoperability issues.

Second, we observed that the data found in the DICOM tag *Body Part Examined* of the images generated by CT 2 is not a reliable information source regarding image categorization in clinical routine. An error rate of 15% was measured and verified during the second observation period. Since the evaluations were carried out over a long period and they are apart by almost a year, the results can be considered independent from the clinic personnel using the modality.

The main reason for the observed error rates originates from the user interfaces of the image modalities. The parameters controlling the image acquisition process are not adjusted individually in the clinical routine. Instead, the clinical personnel can choose an examination protocol from a predefined list. The list offers standard examination protocols defined by the manufacturer and is furthermore user expandable to allow the integration of new examination procedures. For instance, CT 2 offers ECG-triggered heart imaging functionality via a hardware add-on that required the definition of an additional protocol. Each examination protocol defines a parameter set for the imaging modality and reflects a medical context, which implies the application to a certain body part. Thus, the content of the tag *Body Part Examined* is also predetermined by the protocol. Due to the variability and differences among the patients' anatomies, an imaging protocol for a different body region may be used by the clinical personnel in order to obtain better image quality. Although each parameter of the protocol can still be adjusted individually, this option is not used during clinical routine due to time issues. This results in false entries of the automatically generated DICOM tag *Body Part Examined*. Note that the

PACS environment at the Aachen University Hospital does not evaluate the categorization-relevant tags, and therefore, this issue does not receive much attention.

The tag value SPECIAL for the *Body Part Examined* attribute bears a potential problem, because its occurrence (which is legal according to the DICOM standard) contains no useful information for the categorization. Fortunately, this value only appeared very rarely during our survey (2 images out of a total 1142 images).

Furthermore, the values offered by the DICOM standard for the *Body Part Examined* attribute have to be discussed. There are several principal problems: First, frequent categorization errors occurred between the categories *CHEST*, *ABDOMEN*, *NECK* and *HEAD*. In the clinical routine, *LEG*, *ANKLE*, and *FOOT* might throw a similar problem. Especially in combination with computed tomography imaging, an image might not fit into one category precisely (note that the classes above are connected inside the body). The suggested applicability in combination with any imaging method (since the *Body Part Examined* attribute is considered as modality independent by the DICOM standard) has to be questioned. Additionally, a CT or an MR image might cover multiple body regions on purpose (e.g. CT images of the full body), but there is no way to express this via the DICOM tag *Body Part Examined*. On the other hand, the 25 categories defined by DICOM are not strictly separable, for instance *ARM*, *FOOT*, and *EXTREMITY*. While the tag *Body Part Examined* with its very limited expression capability is seldomly used, none of the observed imaging modalities made use of the more advanced SNOMED anatomic nomenclature for other tags. Within the IRMA project, the definition of a detailed anatomic region code is in progress and currently submitted for publication. This region code encompasses body region specific information as well as modality specific and examination specific information, all integrated into a hierarchical definition.

Furthermore, several content-based categorization methods have been developed as part of the IRMA project. Using a corpus of radiographs derived from the clinical routine at the RWTH Aachen University Hospital, DAHMEN ET AL. achieved a categorization error rate of 8.6%.[15] Although the data sets are not directly comparable, since the radiographs are secondary digitized and the class definitions differ slightly from the one used in DICOM, this result suggests a significant improvement compared to a categorization method relying on the DICOM information alone.

6. CONCLUSION

Although this study is only based on one hospital, it is very likely that the results also apply for many other institutions, because the modalities evaluated are widespread standard equipment across hospitals.

To address the image categorization problem, the DICOM 3.0 header information generated routinely by the image modalities during the acquisition process is insufficient. Therefore, reliable algorithms for automated image categorization require content-based approaches regardless of the DICOM information.

To improve the quality of the DICOM tag values for image categorization, future work should focus on a better implementation of the DICOM 3.0 standard among the devices used in the clinical routine. This includes conformance issues as well as the support and use for optional tags, which provide valuable information for e.g. the categorization.

Additionally, the limitations of user interfaces of the devices and the internal dependencies of imaging parameters and DICOM attributes should be brought to the clinic personnel's attention more clearly. This could help to reduce the categorization error rates resulting from the improper use of the imaging device at the present. Also, improvements regarding the user interface should address this problem. These measures might be a way to improve the quality of the DICOM attribute information for categorization and retrieval purposes.

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