Quantitative Evaluation of PACS Query/Retrieve capabilities

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ABSTRACT

The PACS (Picture Archiving and Communication System) market is heterogenous with dozens of PACS providers having deployed installations in healthcare facilities. The DICOM query and retrieve interfaces provided by PACS have multiple variations, related to the implemented SOP (Service Object Pair) Class UID (Unique Identifier), transfer syntaxes, extended negotiations, matching attributes and matching types. These variations make any integration of a new DICOM consumer with a PACS complex and time consuming. As there is no collective information describing the various PACS query and retrieve capabilities, application developers and healthcare facilities lack a method to evaluate the PACS capabilities and classify its functionalities. GE designed a method to evaluate the PACS capabilities in terms of query retrieve functionalities. Our aim is to analyze several PACS in test and production environments, using our method to provide the DICOM object consumers a macroscopic knowledge of query/retrieve capabilities of PACS functionalities and its different variations. Our evaluation can also be used by PACS and VNA (Vendor Neutral Archive) developers to evaluate their query/retrieve capabilities, for quality improvement purpose.

KEYWORDS

PACS, DICOM, Query, Retrieve, Quality.

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1. INTRODUCTION

Most of healthcare facilities have an archiving mechanism for patient images and exams. The most known and used archiving method is the Picture Archiving and Communication System (PACS) [1]. PACSs utilize the DICOM standard to store, to query and to retrieve DICOM objects, through DICOM C-STORE, C-FIND, C-GET and C-MOVE services [2]. We have developed an application to formally evaluate the query/retrieve capabilities of a PACS, in order to improve the interoperability of algorithms intended to automatically retrieve DICOM objects for analysis.

2. HYPOTHESIS

There are many variations in the marketplace in terms of PACS query and retrieve capabilities.

- The C-GET service is not always supported and may be prohibited by some PACS.
- The C-MOVE service could be performed through multiple SOP Classes, and vary through the supported extended negotiations.
- The C-FIND service possesses the greatest flexibility and variations related to SOP Classes, transfer syntaxes, matching attributes and types.

For each service, there are three different SOP Classes that can be implemented. However, PACS does not always implement all of them. Furthermore, for each SOP Class, several querying levels are defined. In C-FIND service, for each level, a multitude of matching attributes are possible. The possible matching attributes in each level are described within the DICOM standard; however, most of them are optional, and thus each PACS provider supports what it considers necessary for their system and for the facilities. Configuration varies from system to system. In fact, two installations of the same PACS version may have different matching attributes support capabilities, based on local configuration and based on the capacity of the PACS to activate or disactivate supported attributes. Nearly all PACS providers produce a DICOM Conformance Statement (DCS), where they provide a description of their matching attributes support for each level and for each supported C-FIND SOP Class. However, the DICOM Conformance Statement seldom describes configurability of the system, based on deployment context. The capacity of attributes matching has many flavors: universal matching, single value matching, range matching, list matching, and wildcard matching. PACSs do not provide the same capability for all the attributes they support; furthermore, this support is generally site specific. Thus, many PACS provide in their declarative DCS a high level description of their matching attributes support, without describing the supported matching types.

For a DICOM node wanting to consume DICOM objects across several PACS vendors and versions, the task is challenging. An in-depth site survey involving communication with IT and PACS administrators and on-site testing, is often required to fully understand PACS query/retrieve capabilities. From the development perspective, developers must assert suppositions regarding the matching attributes supported in PACS; incorrect suppositions will damage the product and reduce its usage.

Our aim is analyzing several PACS in test and production environments to provide the DICOM object consumers a macroscopic knowledge of PACS query/retrieve capabilities. Our method could also be used by PACS and VNA developers to evaluate query/retrieve capabilities, for quality improvement purpose.

3. BACKGROUND

3.1. Picture Archiving and Communication System (PACS)

PACS is used for storing and accessing exams and DICOM objects for multiple types of modalities, like computed tomography (CT), Ultrasound (US), magnetic resonance imaging (MRI), nuclear medicine exams (NM), as well as other known modalities [1][16]. Despite radiology, many healthcare application areas are supporting PACS integration, such as cardiology, oncology, dental domain, and ophthalmology. The storing and retrieval of images within PACS is mostly based on the DICOM standard, using the DIMSE-C services C-FIND, C-MOVE, C-GET and C-STORE service [2]. However, new technologies emerged recently and integrated with the most recent versions of PACS; such as DICOMweb® protocols for storing and retrieving images (STOW, QIDO and WADO) [3]. Despite the rapid adoption of web protocols over the last several years, the standard DICOM services are still widely used and are the reference implementation for any modality communicating with a PACS.

Dozens of PACS providers exist in the market. Many studies have attempted to collect PACS information for sale or for comparison purpose [4][5][6][18]. Based on our experience, there are a multitude and a variety of PACS deployed in hospitals and in healthcare facilities. The selection of a PACS provider depends on many factors, such as price, functionalities, and facility needs [16][18]. Large facilities do not target the same PACS providers as small facilities [11]. The following is a non-exhaustive list of known PACS providers, without order: General Electric, Sectra, INFINITT, Intelerad, Siemens, Agfa, Philips, Fujifilm, IBM, McKesson, Kodak, DR Systems, eMed, PaxeraHealth, Amicas, Cerner, IDX, Canon, and Carestream. Many other PACS providers exist including open source PACS [12], like the well-known DCM4CHEE, Conquest, Orthanc, and many others [5]. Some open source tools and methodologies exist allowing to test PACS capabilities [22] [23]; however, there are not enough to perform the needed analyses.

3.2. Query Retrieve PACSs variations

In general, PACS provides the possibility to perform query and retrieve of exams and DICOM objects through the C-FIND, C-MOVE and C-GET services [2]. There are variations from one implementation to another. Even for the same software version, two different installations may have different configurations, and thus, different query/retrieve capabilities. The variations between PACS can be divided into query variations and retrieve variations.

3.2.1. DICOM Query variations

There are three SOP Class UIDs that enable DICOM query to a PACS, and each PACS may decide to implement one or multiple of the following SOP Class UID:

- Patient Root Query/Retrieve Information Model – FIND [1.2.840.10008.5.1.4.1.2.1.1]
- Study Root Query/Retrieve Information Model – FIND [1.2.840.10008.5.1.4.1.2.2.1]
- Patient/Study Only Query/Retrieve Information Model - FIND [1.2.840.10008.5.1.4.1.2.3.1]

For each SOP Class UID queries for exams are not performed in the same way. The main difference between the three methods is the query levels supported and the matching attributes supported at each level. The Patient Root Information Model has four query levels [2]: PATIENT, STUDY, SERIES and IMAGE. The Study Root Information Model has three query levels [2]: STUDY, SERIES and IMAGE. The Patient/Study Only Information Model has only two query levels: PATIENT and STUDY. For each level, a list of possible matching attributes can be queried. The Patient/Study Only Information Model is retired; however, many image managers continue to support it due to the large number of legacy consumer applications. Likewise, many healthcare facilities have legacy PACS, thus consumers may need to implement the Patient/Study Only Information Model method. The retained query method within the latest DICOM standard are the Patient Root Information Model and the Study Root Information Model [2]. The main difference being that the Study Root Information model has a query level STUDY, grouping the tags from the query levels PATIENT and STUDY, coming from the Patient Root Information Model. With this slight difference, there is a major difference in the implementation for DICOM objects consumers, as the STUDY level is not always directly 'query-able' for the PACS implementing only the Patient Root Information Model.

For each query level, a list of matching attributes can be used to perform queries to gather exams [20]. Each query level has a matching attribute as a unique identifier. For example, at the SERIES level it is the SeriesInstanceUID. Most other tags are optionally supported by the PACS; thus, it is difficult to construct algorithms to gather DICOM exams from PACS based on smart queries. For each tag, there are many ways to support it as a matching attribute. PACS may implement one of five matching types [14]:

- Universal matching: a zero-length key matches any value.
- Single value matching: an exact match on the value specified.
- Range value matching: applicable for date and time matching attributes, like StudyDate and StudyTime where either a start or an end or both may be specified.
- List value matching: applicable for some matching attributes like the ModalitiesInStudy.

- Wildcard matching: this is related to string matching and the capability to use '*' and '?'

Here, we note the complexity for DICOM consumers. Every PACS has the potential to implement any matching attribute from the optional tags for each level, and for each matching attribute, it can implement any matching capability from the previous described types; constructing an algorithm for collecting data from PACS is complex, and must take into consideration these variations.

Another variation of PACS DICOM queries is extended negotiations. C-FIND service can have multiple flavors from standardized options [2]:

- RELATIONAL: this is an important aspect that must be considered during DICOM queries. A query to a PACS can be relational or hierarchical. In relational PACS, you can perform C-FIND queries using any supported matching attribute from any related level; there is no need to provide the unique identifier of the upper levels. In hierarchical PACS you can only use tags from the targeted query level and must provide the unique identifiers of the upper levels.
- DATETIME: a variation to support combined date and time matching.
- FUZZY: a variation to support fuzzy semantic matching, used to query person names
- TIMEZONE: a variation to support timezone considerations.

Note: there is an additional extended negotiation defined by the DICOM standard that is not included in this analysis, which is Enhanced Multi-Frame Image Conversion.

In conclusion, we can identify three kinds of variations in PACS capabilities regarding DICOM queries support:

- Support of extended negotiations: RELATIONAL, DATETIME, FUZZY and TIMEZONE
- Support of Root Information models: Patient Root, Study Root, and Patient/Study Only Root.
- Support of tags as matching attributes: and for each matching attribute, the supported matching types: universal matching, single value matching, range matching, list matching, and wildcard matching.

Let's consider the following use case. An exam consumer application needs to gather all series performed last week. The easiest method is to perform a C-FIND query in the SERIES query level, using the matching attribute SeriesDate, and providing a range of date corresponding to the last week range. This method is targeting the PACS supporting:

- Patient Root or Study Root information model
- The RELATIONAL extended negotiation shall be supported
- The SeriesDate shall be supported as query matching attribute, with the type range matching.

Before this study, there was no quantitative analysis to confirm if these suppositions are enough to cover most of the PACS that a consumer application may encounter in hospitals or restrict its interoperability to only a few PACS providers.

3.2.2. DICOM Retrieve variations

To perform a retrieve of DICOM objects from PACS, there are two DIMSE-C services that can be used: C-MOVE and C-GET. Each of them has three related different SOP Class UID [20]:

- Patient Root Query/Retrieve Information Model – MOVE [1.2.840.10008.5.1.4.1.2.1.2]
- Study Root Query/Retrieve Information Model – MOVE [1.2.840.10008.5.1.4.1.2.2.2]
- Patient/Study Only Query/Retrieve Information Model - MOVE [1.2.840.10008.5.1.4.1.2.3.2]
- Patient Root Query/Retrieve Information Model – GET [1.2.840.10008.5.1.4.1.2.1.3]
- Study Root Query/Retrieve Information Model – GET [1.2.840.10008.5.1.4.1.2.2.3]
- Patient/Study Only Query/Retrieve Information Model - GET [1.2.840.10008.5.1.4.1.2.3.3]

The main difference between these SOP classes is in the creation of the retrieve query when the extended negotiation RELATIONAL is not supported [2]. We can conclude that there are two main variations in C-MOVE and C-GET services:

- Support of Root Information models: Patient Root, Study Root, and Patient/Study Only Root.

- Support of the extended negotiation: RELATIONAL.

4. METHODS

4.1. Evaluation of Query and Retrieve capabilities

Query/Retrieve capabilities are described in the DICOM Conformance Statement, provided by the PACS vendors [7]. However, information in the DCS is not useful as 1) it is provided in a non-machine-readable format, and 2) query/retrieve capabilities are configurable per installation for most of the known PACS. Within the DoseWatch product [21], GE Healthcare developed an application to formally evaluate the query/retrieve capabilities of a PACS to improve the automation of algorithms designed to retrieve DICOM objects. The developed application identifies the following properties for each PACS:

- Supported Sop Class UID for query/retrieve services. For each Sop Class UID:
    - supported transfer syntaxes
    - supported extended negotiations
    - supported matching attributes for each query level. And for each matching attribute, the application identifies the supported matching types:
        - Universal matching
        - Single Value matching
        - Multiple Value matching
        - Range Value matching
        - Wildcard matching

The matching attributes are generally described in the DICOM Conformance Statement (DCS) of the PACS. However, the application does not take into consideration the content of the DCS; the identification of the matching parameters is algorithmically calculated through systematic query of the PACS with different parameters, to test real-world capabilities. For each matching attribute and for each matching type, positive and negative tests are performed with the PACS. The generated output from the discovery is then directly computed from the PACS installation, and not declarative from the PACS provider. This capabilities discovery simplifies the integration process with PACS.

The application also detects useful association information, such as the supported maximum PDU size, and the number of simultaneous associations per AE Title. The output is an XML file describing the listed properties. The Figure 1: PACS Q/R Capabilities Discovery Result is a partial presentation in HTML of the findings related to an evaluated PACS.

Level Name Attribute Name	Tag	VR	Types of Matching
PATIENT			
PatientName	(0010,0010)	PN	U S *
PatientID	(0010,0020)	LO	U S *
PatientSex	(0010,0040)	CS	U S *
STUDY			
StudyDate	(0008,0020)	DA	U S R
StudyTime	(0008,0030)	TM	U S R
AccessionNumber	(0008,0050)	SH	U S *
StudyID	(0020,0010)	SH	U S *
StudyInstanceUID	(0020,000D)	UI	U S *
ModalitiesInStudy	(0008,0061)	CS	U S * L
StudyDescription	(0008,1030)	LO	U S
ProcedureCodeSequence	(0008,1032)	SQ	U
ReferencedStudySequence	(0008,1110)	SQ	U
NumberOfStudyRelatedInstances	(0020,1208)	IS	U S
SERIES			
Modality	(0008,0060)	CS	U S *
SeriesNumber	(0020,0011)	IS	U S
SeriesInstanceUID	(0020,000E)	UI	U S *
SeriesDate	(0008,0021)	DA	U
InstitutionName			U S *
IMAGE			
InstanceNumber	(0020,0013)	IS	U S
SOPInstanceUID	(0008,0018)	UI	U S *

Figure 1: PACS Q/R Capabilities Discovery Result

This application was executed in several PACS installations from different vendors. We collected results in a database of PACS query/retrieve capabilities, to facilitate macroscopic analysis of PACS from the query/retrieve aspects.

4.2. Quantitative analysis methodology

In order to evaluate a PACS regarding its Q/R capabilities, we need to define comparison parameters based on the following information:

- The list of SOP Class supported
- The list of extended negotiations supported
- The list of matching attributes supported for each level and their different matching types.

To compare the different C-FIND matching attributes capabilities between PACS, we used three parameters:

- The global number of supported universal matching keys (N_u)
- The global number of supported single value matching keys (N_{si})
- The global number of strong value matching keys (N_{st})

46 different PACS installations were tested and analyzed in order to define a macroscopic understanding of the PACS query retrieve capabilities. The different selected PACS installations come from different environments, some are in production, and others from testing and beta testing environments. The evaluated PACS are coming from 26 different vendors, including most of the known providers.

The analysis included:

- Categorization of PACS through their Q/R capabilities
- Identification of a macroscopic view of matching keys capabilities

For each analysis of the results of PACS evaluation, two methods were performed:

- Blind analysis: all the PACS are analyzed as equivalent in terms of market share; there are no appreciation of one PACS over the others PACSs.
- Weighted analysis: the results are weighted based on market share [10]. For instance, if a PACS has a robust query capability, and small market share, the results will be lowly weighted with minimal impact, as the tested PACS does not describe the behavior that we may encounter in the marketplace from a macroscopic point of view.

Multiple Analyses were performed in order to provide a market share cartography of PACS [8][9][17]. The most recent study we found is an article on healthitanalytics.com [9], based on a HIMSS analysis report, following the installation base of 4605 hospitals. The weighted results in this paper are based on the values provided in the reference [9].

5. APPLICATION RESULTS

5.1. Macroscopic categorization of PACSs through Q/R capabilities

5.1.1. Extended negotiations analysis

Following the analysis of the selected PACS installations, Figure 2 describes the unweighted repartition of support for extended negotiations related to C-FIND service:

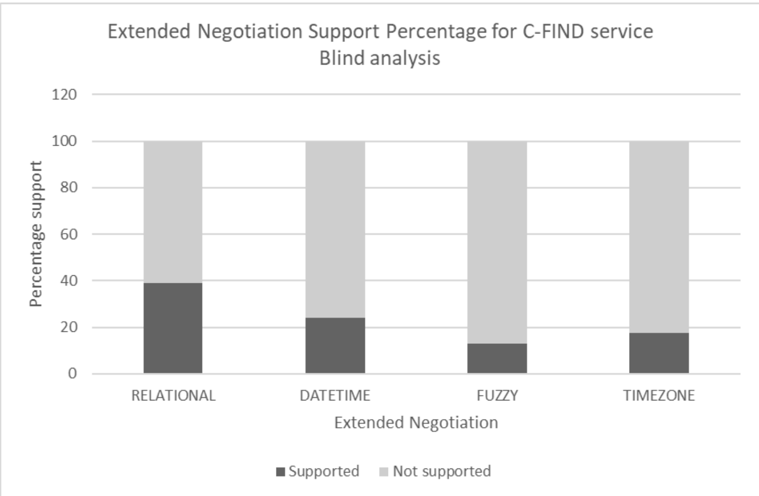

Figure 2: Extended Negotiation Support Percentage for C-FIND service – Blind analysis

This repartition is based on the PACSs analyzed during this study. However, it does not reflect marketplace. To have a market-based view of extended negotiations support, we need to include the percentage of PACS market share by PACS vendors [9]. The formula used for this weighted analysis is as follows [10]:

$$P_{opt}^{w} = \frac{\sum_{i=1}^{n} E_i \times S_i}{\sum_{i=1}^{n} S_i}$$

Where

n: is the number of PACS vendors found in our analysis and matching the study in the reference [9], related to PACS market share.

S_i: is the percentage of market share, identified in the reference [9], related to vendor 'i'.

E_i: averages the number of extended negotiations found in the tested PACS from vendor '*i*'.

$\sum_{i=1}^{n} S_i$: a constant that describes the reliability of our analysis to represent the market segmentation. Note: this does not depend on the analyzed extended negotiations.

In our analysis this value is:

$$\sum_{i=1}^{n} S_i = 0.67$$

Figure 3 describes the result of weighting the Extended Negotiation support for C-FIND service by PACS Provider.

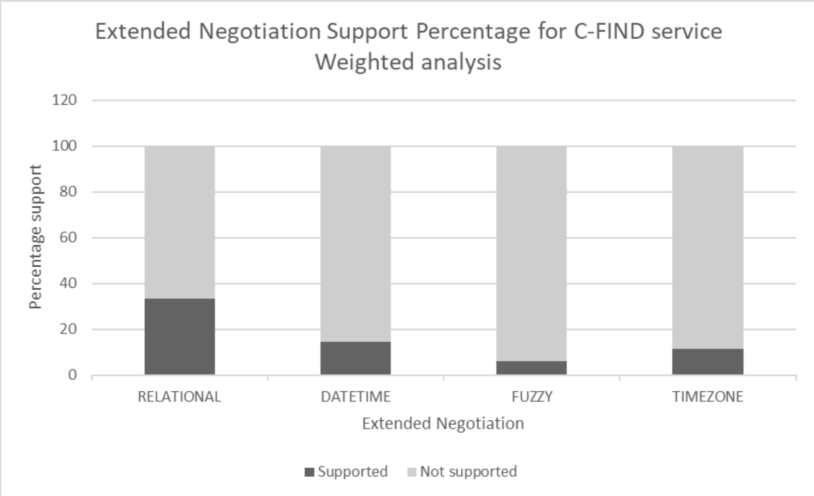

Figure 3: Extended Negotiation Support Percentage for C-FIND service

In both figures, we note that fewer than 50% of PACS support relational mode, which is considerable; this can be disadvantageous for DICOM object consumers utilizing relational mode only. This result mirrors findings in an article on the Medical Connection website [13]. The support of the other extended negotiations is also less than 50%.

Less than 20% support fuzzy semantic matching and time zone extended negotiation in the blind analysis, and less than 15% in the waited analysis. We noted that VNAs primarily support the time zone query adjustment option.

Even if the reliability indicator is far from 100%, the result of the blind analysis and the weighted analysis are not that different; the deviation between both analyses is less than 20% for the relational mode. However, the fuzzy semantic matching, the DATETIME and the TIMEZONE extended negotiations have higher negative deviation values. The deviation between the blind analysis and the weighted analysis is calculated using this formula:

$$D_{opt} = \frac{P_{opt}^{w} - P_{opt}}{P_{opt}^{w}}$$

Where

opt: is the tested extended negotiation option.

P_{opt}^{w}: is the weighted percentage of the support for the tested extended negotiation option.

P_{opt}: is the blind percentage of the support for the tested extended negotiation option.

The analysis of the RELATIONAL extended negotiation for C-MOVE and C-GET DICOM services are described in Figure 4 and Figure 5.

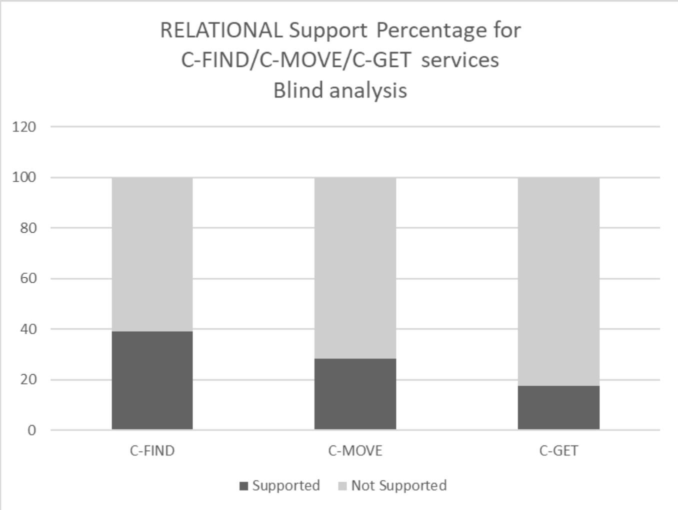

Figure 4: RELATIONAL Support Percentage for C-FIND/C-MOVE/C-GET services - Blind analysis

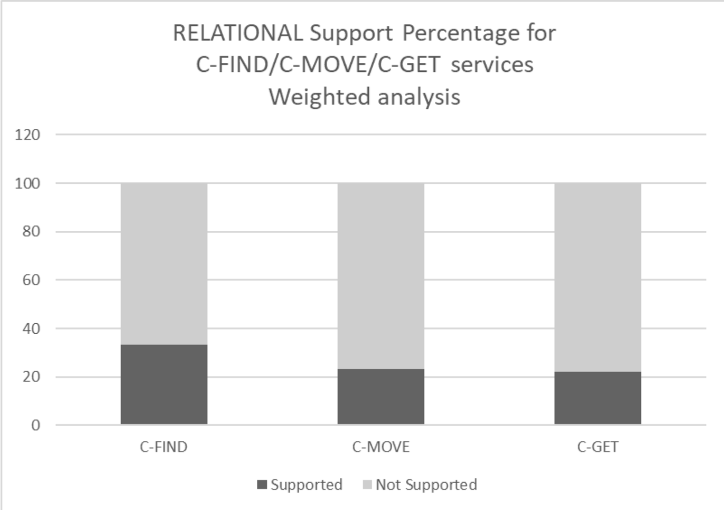

Figure 5: RELATIONAL Support Percentage for C-FIND/C-MOVE/C-GET services - Weighted analysis

We remark that less than 30% of the PACS supporting C-MOVE or C-GET are supporting the RELATIONAL extended negotiations. Not all PACS supporting a C-FIND service in relational mode support a C-MOVE system in a relational mode, forcing the DICOM consumer to check availability of a relational request before using a C-MOVE service, even if it is supported in the C-FIND service. The deviation between C-MOVE and C-GET percentage for supporting RELATIONAL extended negotiation, between weighted and blind analyses is less than 20% which rises the reliability of the findings.

5.1.2. Q/R SOP Class UID PACS variations

Here we performed another analysis related to the supported SOP Class UID for the C-FIND, C-MOVE and C-GET services, supported by PACS. The results are shown in Figure 6 and Figure 7: Percentage of SOP Class UIDs deployment - Weighted analysis.

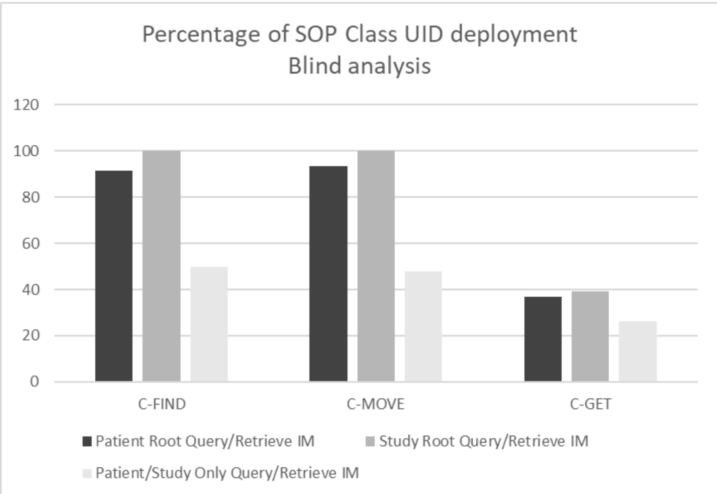

Figure 6: Percentage of SOP Class UIDs deployment - Blind analysis

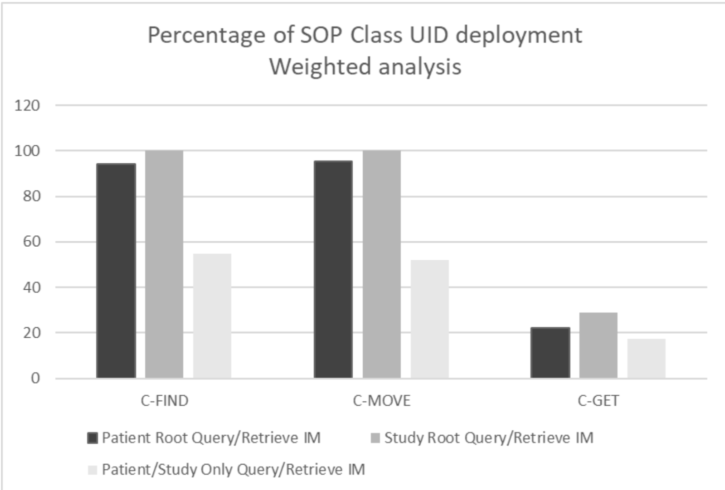

Figure 7: Percentage of SOP Class UIDs deployment - Weighted analysis

The weighted analysis follows the same pattern as the one for the extended negotiation support. We note three observations for the PACSs tested, 1) the C-FIND and C-MOVE services were always supported under the Study Root Query/Retrieve information model, 2) the Patient Root Information Model was almost always supported, and 3) the C-GET service was not always supported, with at most 40% support by the tested servers. Moreover, the C-GET support is lower (20%) if we consider only tested production environment. We can conclude that utilizing C-GET service as a source of information for a DICOM consumer covers few installations.

The Patient/Study Only Query/Retrieve Information Model is retired from the latest versions of DICOM standard; however, we note that nearly 40% of tested servers implement a SOP Class UID related to this information model.

The analysis confirms that most of the PACS vendors are implementing the Study Root Information Model as their primary method for C-FIND operations. The standard deviation between the weighted and blind analysis is still very low for the analyzed SOP Class UID implementations: less than 10% of deviation for C-FIND and C-MOVE related SOP Class UID, and nearly 35% for C-GET related SOP Class UID. This confirms that the analyzed PACS installations are describing the world wide installations distribution, and rises the reliability of the study.

5.1.3. C-FIND Matching Attributes PACS variations

In this analysis, we evaluate the number of supported matching attributes and their related matching types: universal matching, single value matching and strong matching. We consider a matching attribute to be strong if it supports at least the range matching, the list matching or the wildcard matching. From the samples of PACS selected, we calculated the normal distribution of supported matching attributes. The results of this analysis are summarized in the Table 1, and presented in the Figure 8 and Figure 9.

Table 1: Average and Standard Deviation of attributes supported by PACS

Matching Type	Blind Analysis		Weighted Analysis	
	Average	Standard Deviation	Average	Standard Deviation
Universal Matching	30.61	11.03	35.26	16.17
Single Value Matching	20.04	7.11	19.57	8.76
Strong Matching	17.06	6.07	16.70	5.04

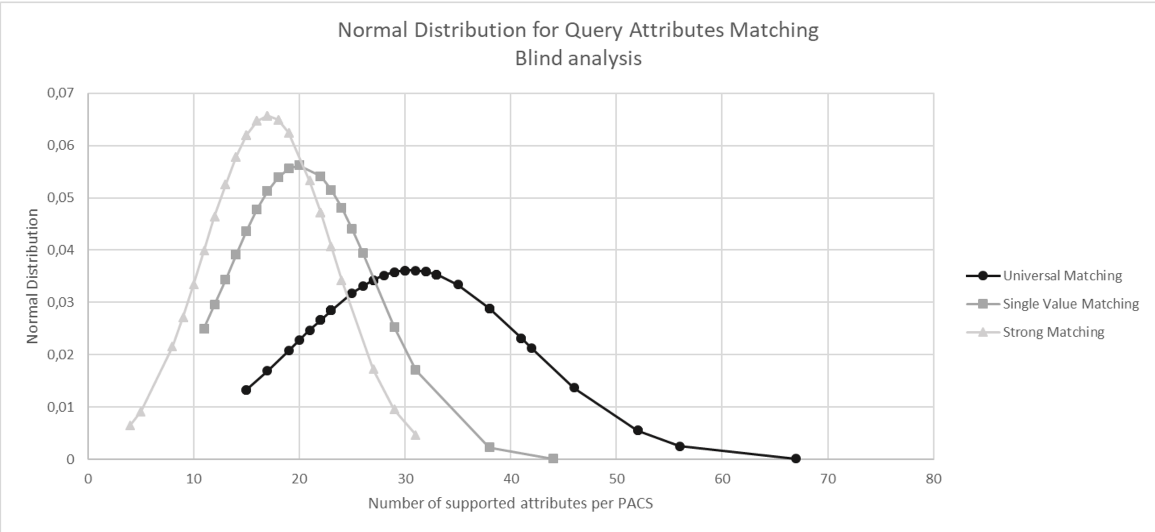

Figure 8: Normal Distribution for Query Attributes Matching - Blind analysis

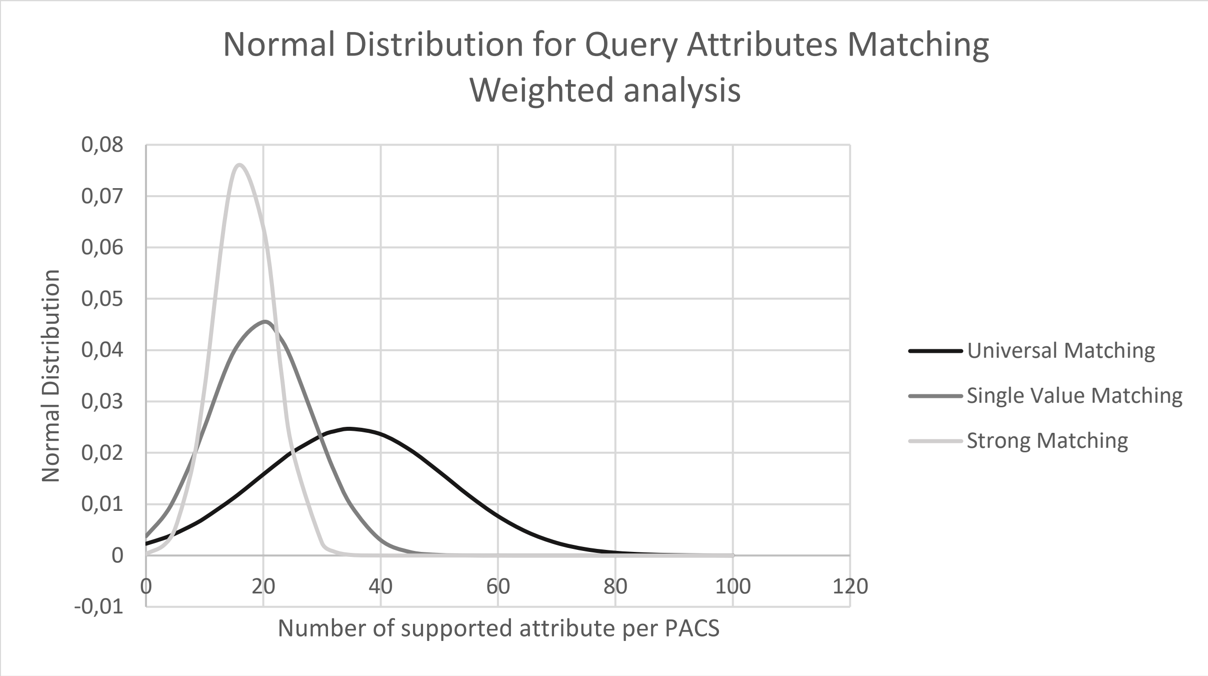

Figure 9: Normal Distribution for Query Attributes Matching - Weighted analysis

The average of implemented universal matching attributes is 35.26 in the weighted analysis, which is quite high when compared to single value and strong matching.

Figure 8 shows the disparity between PACS implementations. Some of the PACS are providing only few matching attributes, highly reducing the possibilities offered to the DICOM consumers. For example, in terms of universal matching, we observed PACS providing only few matching attributes (19 to 25 matching attributes), and others are providing more than 50 matching attributes.

This led us to develop a PACS classification that DICOM consumers and healthcare delivery organizations can use to compare vendor capabilities. Likewise, PACS vendors can also use this classification to understand their capabilities relative to the market.

Our classification is calculated as follows:

$$R_{find} = N_u \times N_{si} \times N_{st}$$

Where

R_{find}: is the rating for the C-FIND attributes matching

N_u: is the number of supported universal matching attributes

N_{si}: is the number of supported single value matching attributes

N_{st}: is the number of supported strong matching attributes

The Figure 10 and Figure 11 describe the Rating of C-FIND matching attributes for both blind and weighted analysis.

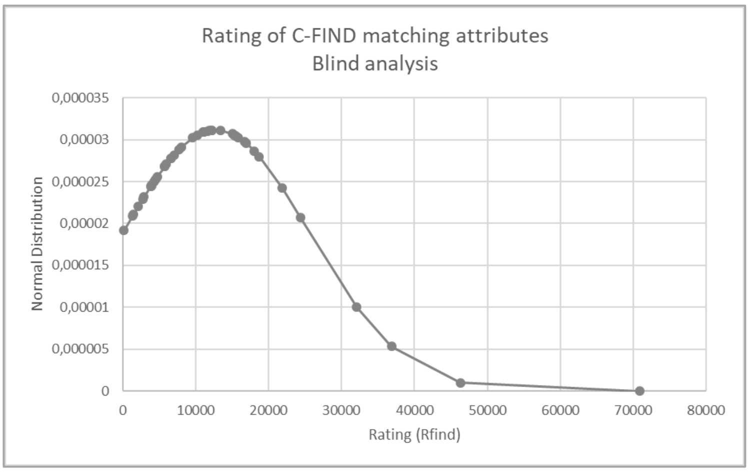

Figure 10: Rating of C-FIND matching attributes - Blind analysis

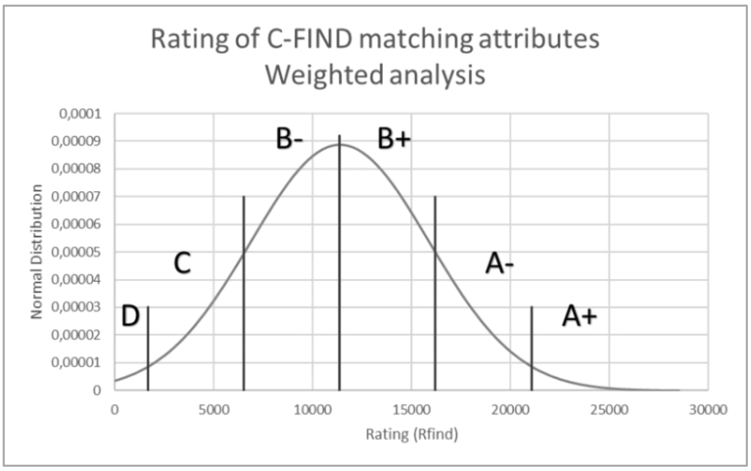

Figure 11: Rating of C-FIND matching attributes - Weighted analysis

Following the blind analysis, the average R_{find} is μ=12796.57. For the weighted analysis, the average R_{find} is μ=11365.41. The deviation between both averages is 12.6%; this helps confirm that our PACS sample is representative of the marketplace.

From the blind analysis, we note that some PACS are good in the three dimensions of R_{find}: the universal matching attributes, the single value matching and the strong matching ($R_{find} > 21000$), and others do not possess rich search capabilities ($R_{find} < 2000$).

As a PACS vendor, our method allows you to have a deterministic way to qualify your C-FIND matching capabilities. By calculating R_{find}, you can assign your system a grade. Grading medical systems capabilities is indeed a common method [19]. Below is the grading system that can be attributed to PACS based on our analysis:

- D: very poor search capabilities, $R_{find} < \mu - 2\alpha = 1673$
- C: poor search capabilities: $1673 < R_{find} < \mu - \alpha = 6519$
- B-: adequate search capabilities, but less than the average: $6519 < R_{find} < \mu = 11365$
- B+: adequate search capabilities, but better than the average: $11365 < R_{find} < \mu + \alpha = 16210$
- A-: good searching capabilities, $16210 < R_{find} < \mu + 2\alpha = 21056$
- A+: excellent searching capabilities: $R_{find} > \mu + 2\alpha = 21056$

Of the 26 vendors, only four PACS were classified as A+; three were classified as D. Some tested PACS were very good in the universal matching, but were poor in the single and strong value matching. This is not helpful when optimizing PACS queries, resulting in a poor grade following the R_{find} calculation method.

5.2. Macroscopic Matching Keys analysis

In this paragraph, we discuss matching attributes implementations, with a focus on attributes specificities, not attributes quantity. In the previous application, we evaluated the number of matching attributes implemented by PACS systems; this allowed to compare between PACS providers. As a DICOM consumer, we also need a detailed cartography of the frequency of matching attributes implementations, for a better understanding of the PACS, and for optimization of DICOM object identification and collection. The analysis of 46 PACS installations, weighting of market share for the 26 different PACS vendors, provided us the outputs in Table 2: Macroscopic matching attributes grading. For each matching attribute, a grade is provided. It describes the implementation percentage of the analyzed matching attribute based on the tested PACSs.

Table 2: Macroscopic matching attributes grading

Matching Attributes	Blind Analysis				Weighted Analysis		
	G_u	G_{si}	G_{str}		G_u	G_{si}	G_{str}
STUDY							
StudyDate	A	A	A		A	A	A
StudyTime	A	B	B		A	A	A
AccessionNumber	B	B	B		B	B	B
PatientName	A	A	B		A	A	B
PatientID	A	A	B		A	A	B
StudyID	A	B	B		A	A	A
StudyInstanceUID	A	A	A		A	A	A
ModalitiesInStudy	A	A	A		A	A	A
SOPClassesInStudy	E	F	F		E	F	F
ReferringPhysicianName	C	D	D		C	C	C
StudyDescription	B	C	C		B	D	D
StationName	D	E	E		D	E	E
PatientBirthDate	B	C	C		B	C	C
PatientSex	B	C	C		B	C	C
PatientAge	D	F	F		D	F	F
NumberOfStudyRelatedSeries	A	D	E		A	D	E
NumberOfStudyRelatedInstances	A	D	E		A	D	E
SERIES							
Modality	A	A	B		A	A	C
SeriesNumber	A	A	E		A	A	D
SeriesInstanceUID	A	A	A		A	A	B
StationName	D	D	D		C	D	D
NumberOfSeriesRelatedInstances	B	D	F		A	E	F
SeriesDate	D	E	E		C	E	E
SeriesTime	D	E	E		C	E	E
PerformingPhysicianName	E	F	F		D	F	F
ProtocolName	D	F	F		D	F	F
SeriesDescription	B	C	D		B	D	D
RequestAttributesSequence							
RequestedProcedureID	E	F	F		E	F	F
PerformedProcedureStepStartDate	D	D	D		C	D	D
PerformedProcedureStepStartTime	D	D	D		C	D	D
Manufacturer	E	F	F		E	F	F
ManufacturerModelName	E	F	F		E	F	F
InstitutionName	D	E	E		D	E	E
IMAGE							
InstanceNumber	A	C	F		A	C	F
SOPInstanceUID	A	A	A		A	A	A
SOPClassUID	A	B	B		B	C	C
ImageType	D	E	E		D	E	E

The matching attributes are divided to three levels: STUDY, SERIES and IMAGE. The attributes related to the PATIENT level are merged with the STUDY level, following the Study Root Information Model. We performed two analyses, as in our previous analyses: a blind analysis and a weighted analysis, following the PACS market share description [9]. For each analysis, we calculated for each tested matching attributes, the following values:

- G_u: the grade of the implementation of universal matching type
- G_{si}: the grade of the implementation of single value matching type
- G_{str}: the grade of implementation of a strong matching type (a range value matching, a multiple value matching or a wildcard matching type).

The grade describes the percentage (P) of implementation of the tested attribute regarding the selected matching type; below is the definition of the grade values based on the percentage, P:

- A: P > 85%
- B: 70% < P < 85%
- C: 50% < P < 70%
- D: 30% < P < 50%
- E: 20% < P < 30%
- F: P < 20%

Note: Table 2 does not include attributes having 'F' grades for G_u, G_{si} and G_{str}.

We note that the weighted analysis and the blind analysis result in similar distribution of macroscopic attribute support, confirming the distribution of our sample. The most implemented attributes are in the STUDY level; always implemented are StudyDate, StudyTime, PatientName, PatientID, StudyID, StudyInstanceUID, ModalitiesInStudy, NumberOfStudyRelatedSeries and NumberOfStudyRelatedInstances. We were surprised that the StudyTime did not receive an 'A' grade for single and strong value matching. In order to query large archives, some consumers search based on both StudyDate and StudyTime. The absence of this tag from single and strong matching may be problematic for consumers and for some use cases. Also, the PatientBirthDate is not rated 'A', which is problematic; as many products utilize patient name and patient birth date to query patient-related clinical information. This method is typical in healthcare domain, as multiple patients may have the same name and differentiating by birth date provides a better combination to identify the desired patient, as in the IHE XCPD profile [15]. When PACS does not support PatientBirthDate queries, many consumers applications and functionalities are useless. ModalitiesInStudy is also well supported by all tested PACS systems, this finding simplifies exams collections by targeting only studies with the searched modality types.

Three attributes are strongly supported in the SERIES level: Modality, SeriesNumber and SeriesInstanceUID. Many other attributes are supported in universal matching, but few are supported in single and strong matching types. It is remarkable that the SeriesDate and SeriesTime are graded between C and F for their matching capabilities; this analysis allowed us to highlight the poor support of these matching attributes, and thus algorithms utilizing Series search through SeriesDate are limited to only few PACS systems. In the paragraph "DICOM Query variations", we described a use case using the SeriesDate and the relational mode as key concept for the objects gathering algorithm. We saw that the relational mode is supported by less than half of the deployed PACS systems, and the SeriesDate is graded with a 'E' for the single and the strong value matching types. This makes the defined algorithm ineffective in most of the encountered PACS systems.

At the IMAGE level, only the InstanceNumber, the SOPInstanceUID and SOPClassUID are strongly supported as matching attributes. Only the attribute ImageType was supported more than 20%of the time. We remark that the SopClassUID is graded B and C for some of the matching types, which was unexpected. Some algorithms filter on SopClassUID in order to avoid consuming unwanted objects. Without the support of SopClassUID and the ImageType, issues related to bandwidth and timeouts can be observed in DICOM consumer applications.

This analysis allowed a better macroscopic understanding of query/retrieve capabilities of PACS systems. For instance, GE DoseWatch product used it to improve gathering algorithms for radiation dose information, with a clear network bandwidth improvement. The analyses of the different PACS capabilities created a unique PACS Q/R capabilities database, which is helping during integration at new PACS based facilities.

6. CONCLUSION

This analysis provides a view of what to expect from different PACS Q/R within healthcare facilities, allowing us to understand the variability of PACS Q/R functionalities. Quantitative analysis enables comparison of Q/R functionalities and aids the DICOM consumer products in establishing optimized gathering and communication algorithms. Our analyses identified the macroscopic behavior of PACS from different perspectives: the support of Q/R SOP Class UID and information models, the support of extended negotiations, and the support of query matching attributes with their different supported matching types. The analyses confirmed that the Q/R PACS interfaces are quite variable and differ from one PACS to another. We also identified several consistent patterns and behaviors. All the tested PACS implement the Study Root Information Model, and most of them implement the Patient Root Information Model. The C-GET service is rarely supported in production environment. Less than the half of PACS are supporting the RELATIONAL extended negotiation, and fewer support the other extended negotiation options.

The comparison and the analysis between PACS C-FIND queries variations provides PACS providers, and healthcare facilities, a unique method for scoring their query capabilities, and to compare their functionality with competitors. The analysis of the matching attributes implementation regarding the supported matching types allowed to have a complete cartography of what can be expected in production environments regarding attribute matching. These results are valuable information for DICOM consumer products.

Using a grading system for attributes matching types allowed to have a visual interpretation of the results. Using two methods of analysis, the blind analysis and the weighted analysis, allowed to improve reliability of the found results. The results of this analysis are the direct output of the automatic query retrieve discovery method, developed within GE DoseWatch product.

Further research utilizing this analysis could include automatic validation of DICOM conformance statements.

7. ACKNOWLEDGMENT

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8. COMPLIANCE WITH ETHICAL STANDARDS

8.1. Disclosure of potential conflicts of interest

Mr. BOUFAHJA reports all the authors are employees of GE Healthcare, during the conduct of the study. In addition, Mr. BOUFAHJA has a patent Method for SYSTEMS AND METHODS FOR DEVICE QUERY/RETRIEVE CAPABILITY DISCOVERY pending.

8.2. Research involving Human Participants and/or Animals

This research did not involve protected health information from human participants; the methodology did not collect patient information, only system information.

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