Digital Imaging and Communications in Medicine (DICOM)

Supplement 205: DICOM Encapsulation of STL Models for 3D Manufacturing

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Scope and Field of Application

This supplement adds a new DICOM IOD to encapsulate Stereolithography (STL) 3D model file formats (see *StereoLithography Interface Specification, 3D Systems, Inc., October 1989*).

This allows 3D manufacturing models to be exchanged between various types of equipment using DICOM messages. This adds the ability to store, query and retrieve 3D models as DICOM objects. Updates are addressed by storing new instances, with reference back to earlier instances.

3D model files are a type of document that contains geometric instructions on how an object could be created by a 3D printer, milling machine, or other type of device capable of manufacturing a physical object.

To exchange these 3D models in an efficient manner in an imaging environment, especially as part of patient care planning and the patient's imaging record, it is useful to be able to "wrap" these model documents in a DICOM container.

Additionally, the identity of the patient (and any source image series) of the encapsulated 3D models can be ascertained through the attributes that the DICOM information model adds on top of the 3D model's general purpose geometric information.

Since its introduction, the STL file format has been used for a variety of applications, including 3D manufacturing. STL is the most prevalent file format in the 3D printing community and enjoys wide support by existing systems.

STL supports both an ASCII and binary encoding. In the interest of simplicity and minimizing SOP Instance size, **only the binary encoding of STL is supported** for DICOM encapsulation. The binary STL format is simple enough to be described here as the following IEEE little-endian byte sequence:

```
80 Character Header = Not interpreted
UINT32 = Number of triangles
For each triangle
      REAL32 x 3 = Normal vector coordinates
      REAL32 x 3 = Vertex 1 coordinates
      REAL32 x 3 = Vertex 2 coordinates
      REAL32 x 3 = Vertex 3 coordinates
      UINT16 = Reserved value. Always set to Zero in practice
end
```

OPEN ISSUES TABLE

#	Question	Comments
1	Is handling the preview image as an MIME-embedded JPEG the best option?	Other options include an external Secondary Capture option, embedded GIF (potentially animated). A single JPEG does not allow multiple views or animation of rotation. However, a single JPEG is already identically

#	Question	Comments
		handled by implementers in the case of Encapsulated CDA
2	Is the existing use of Frame-of-Reference adequate to handle registration in all cases?	Authors believe it does. Also, follows current conventions of 3D modeling software (model uses coordinate system of primary source series).
3	Does MIME byte stream lack order or does it follow the ordered described in List of MIME Types (0042,0014)?	If order is undefined, this would require implementers to skip through the byte stream to get to the JPEG preview and would be suboptimal. See question 1.

55 **CLOSED ISSUES TABLE**

#	Question	Comments
1	Should other formats (OBJ, X3D, 3MF) be referenced in this IOD also?	No, they will be added as separate IODs at a future date. Other 3D model file formats with additional capabilities beyond STL may be addressed in future supplements, but are beyond the scope of this document (other than that these are expected to make use of the new 3D Manufacturing Model introduced below).
2	Should ASCII STL be supported?	No, because it is verbose and inefficient. Essentially all systems that can accept STL can handle binary. There is no need to complicate the DICOM standard with an additional variant.
3	Should MIME elements be identified by name, in order to avoid future issues if additional elements of overlapping types are added later?	Yes. This has been incorporated (and should be considered for adoption by other encapsulated document types).

Changes to NEMA Standards Publication PS 3.2-2017b

Digital Imaging and Communications in Medicine

Part 2: Conformance

Item: Add to table A.1-2 categorizing SOP Classes:

The SOP Classes are categorized as follows:

Table A.1-2
UID VALUES

UID Value	UID NAME	Category
…	…	…
1.2.840.10008.5.1.4.1.1.xxx	**Encapsulated STL Storage SOP Class**	**Transfer**
…	…	…

Changes to NEMA Standards Publication PS 3.3-2017b

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions

Modify Section A.1.4 Overview of the Composite IOD Module Content – Insert Encapsulated STL

Table A.1-3
COMPOSITE INFORMATION OBJECT MODULES OVERVIEW – MORE NON-IMAGES

IODs **Modules**	**…**	**Enc STL**	**…**
Patient		**M**	
Patient Summary			
Clinical Trial Subject		**U**	
General Study		**M**	
Patient Study		**U**	
Clinical Trial Study		**U**	
Study Content			
Encapsulated Document Series		**M**	
Clinical Trial Series		**U**	
…			
General Equip.		**M**	
Enhanced General Equip.		**M**	
…			
Encapsulated Document		**M**	
…			
SOP Common		**M**	
…			
3D Manufacturing		**M**	

Modify Annex A – Insert new section for Encapsulated STL IOD

A.X.3 Encapsulated STL Information Object Definition

A.X.3.1 Encapsulated STL IOD Description

The Encapsulated STL Information Object Definition (IOD) describes a 3D model in Stereolithography (STL) format that has been encapsulated within a DICOM information object.

A.X.3.2 Encapsulated STL Entity-Relationship Model

The E-R Model in Section A.1.2 of this Part applies to the Encapsulated STL IOD.

A.X.3.3 Encapsulated STL IOD Module Table

Table A.45.2-1 specifies the Encapsulated STL IOD Modules.

Table A.45.3-1
Encapsulated STL IOD MODULES

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Specimen Identification	C.7.1.2	U
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	Encapsulated Document Series	C.24.1	M
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Encapsulated Document	Encapsulated Document	C.24.2	M
	3D Manufacturing	C.24.Y	M
	SOP Common	C.12.1	M

A.X.3.4 Encapsulated STL IOD Content Constraints

The Encapsulated Document (0042,0011) attribute shall contain a binary [STL] byte stream. If inclusion of an optional JPEG preview image is indicated per List of MIME Types (0042,0014), then the STL byte stream shall be followed by a JPEG image byte stream.

The MIME Type of Encapsulated Document (0042,0012) value shall be '**application/stl**'.

The value of the Modality (0008,0060) shall be "3DM".

The instance shall use the same Frame of Reference as the primary source series from which the model was derived.

Note: Mapping to the frame of reference of secondary source series would be handled via registration objects.

Modify Annex C.24 – Clarifications for Encapsulated STL 3D Manufacturing Model

C.24.2 Encapsulated Document Module

Table C.24-2 defines the Encapsulated Document Attributes.

100 **Table C.24-2**
Encapsulated Document Module Attributes

Attribute Name	Tag	Type	Attribute Description
…			
Image Laterality	(0020,0062)	3	Laterality of the (possibly paired) body part that is the subject of the encapsulated document. Enumerated Values: **R right** **L left** **U unpaired** **B both left and right** **Note: If the document is a 3D model and the mirroring technique is used, then R or L values for the laterality attribute refers to the placement of the created object regardless of how it was generated (see also 3DM Creation Technique, C.24.3.1).**
Burned In Annotation	(0028,0301)	1	Indicates whether or not the encapsulated document contains sufficient burned in annotation to identify the patient and date the data was acquired. Enumerated Values: **YES** **NO** Identification of patient and date as text in an encapsulated document (e.g., in an XML attribute or element) is equivalent to "burned in annotation". A de-identified document may use the value NO. **If the document is a 3D model, then identification of patient or study as embossed or engraved text on any part of a 3D model shall be indicated by a value of YES.**
Recognizable Visual Features	(0028,0302)	3	Indicates whether or not the image **or 3D model** contains sufficiently recognizable visual features to ~~**allow the image or a reconstruction from a set of images to**~~ identify the patient. Enumerated Values: **YES** **NO** If this Attribute is absent, then the image **or 3D model** may or may not contain recognizable visual features.

Source Instance Sequence	(0042,0013)	1C	A sequence that identifies the set of Instances that were used to derive the encapsulated document. One or more Items shall be included in this Sequence. **Instances may be drawn from different studies**. Required if derived from one or more DICOM Instances (**e.g. 3D models derived from image series).** May be present otherwise.
MIME Type of Encapsulated Document	(0042,0012)	1	The type of the encapsulated document stream described using the MIME Media Type (see RFC 2046).
List of MIME Types	(0042,0014)	1C	MIME Types of subcomponents of the encapsulated document. Required if the encapsulated document incorporates subcomponents with MIME types different than the primary MIME Type of the encapsulated document. Note An Encapsulated CDA that includes an embedded JPEG image and an embedded PDF would list "image/jpeg\application/pdf". **An Encapsulated STL that includes a JPEG preview image would list "image/jpeg\application/stl".**
Encapsulated Document	(0042,0011)	1	Encapsulated document stream containing a document encoded … INSERT VERBATIM FROM STANDARD **The preview image of an Encapsulated STL shall have the MIME name "PREVIEW" and the 3D Model shall have the MIME name "3DMODEL"**
…			

Modify PS3.3 Annex C.24 to insert definition of a new 3D Manufacturing module and associated defined terms.

C.24.Y 3D Manufacturing IOD Module

Table C.24.Y-1 defines attributes of models used in medical 3D manufacturing (3DM).

Table C.24.Y-1
3D Manufacturing Module Attributes

Attribute Name	Tag	Type	Attribute Description
3DM Creation Technique	(aaa1,bbb1)	3	Technique used to create the 3D manufacturing model. See Section C.24.Y.1.
3DM Purpose	(aaa1,bbb2)	3	Purpose for which the 3D manufacturing model was created.

			See Section C.24.Y.2.
3DM Unit Scale	(aaa1,bbb3)	1	Conversion factor from model unit to millimeters. A value of 1 indicates 1 unit = 1 mm. A value of 25.4 indicates 1 unit = 1 inch. A value of 1000 indicates 1 unit = 1 m.

C.24.Y.1 3DM Creation Technique

3DM Creation Technique (aaa1,bbb1) specifies the approach that was used to create the 3D manufacturing model from the source patient imaging data.

Defined Terms:

As Observed Model is based on the observed shape of patient anatomy in source images

Modified Model simulates potential modification of observed patient anatomy (for example, anticipated post-surgical intervention appearance) using means other than mirroring

Mirror Left Mirror operation used to simulate normal left anatomy, using right anatomy as model

Mirror Right Mirror operation used to simulate normal right anatomy, using left anatomy as model

Mirror Left: Modified Mirror operation used to simulate a normal left anatomy (with modifications), using right anatomy as model

Mirror Right: Modified Mirror operation used to simulate a normal right anatomy (with modifications), using left anatomy as model

ALTERNATE PROPOSAL - MODIFIED AND MIRROR AS DISTINCT PROPERTIES

C.24.Y.1 3DM Modification

3DM Modified (aaa1,bbb1) specifies whether modification (beyond mirroring) was used to create the model, or whether the object represents the observed patient anatomy in the source data.

Defined Terms:

None Model is based on the observed shape of patient anatomy in source images, without alteration

Modified Model simulates potential modification of observed patient anatomy (for example, anticipated post-surgical intervention appearance) using means beyond mirroring (see 3DM Mirroring below)

C.24.Y.1 3DM Mirroring

None No mirroring has been performed

Mirrored Mirror operation used to simulate normal anatomy, using other side anatomy as model. Image Laterality (0020,0062) defines and target laterality.

C.24.3.2 3DM Purpose

3DM Purpose (aaa1,bbb2) specifies the purpose for which the 3D manufacturing model was created and thus for what uses it may be suitable. This allows for distinguishing potential similar appearing models by the intent of the designer.

Defined Terms:

Guide: Cutting	Modeled object is intended to be placed on specific bone or other patient anatomy to ensure proper location and angle of surgical incision.
Guide: Insertion	Modeled object is intended to be placed on specific patient anatomy to ensure proper location and angle of insertion of a needle.
Implant: Temporary	Modeled object is intended to be a temporary implant. This purpose includes absorbable scaffolds and hardware requiring later surgical removal.
Implant: Permanent	Modeled object is intended to be a permanent implant.
Surgical Planning	Modeled object is intended to be used for surgical planning
Surgical Simulation	Modeled object is intended to be used for surgical simulation

Changes to NEMA Standards Publication PS 3.4-2017b

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Part 4: Service Class Specifications

Modify Annex B.5 Standard SOP Classes – add new item.

B.5 STANDARD SOP CLASSES

Table B.5-1
STANDARD SOP CLASSES

SOP Class Name	SOP Class UID	IOD (See PS 3.3)
…		
Encapsulated STL Storage	**1.2.840.10008.5.1.4.1.1.xxx**	**Encapsulated STL IOD**
…		

Modify Annex I.4 Media Storage Standard SOP Classes – add new item.

I.4 MEDIA STANDARD STORAGE SOP CLASSES

Table I.4-1
Media Storage Standard SOP Classes

SOP Class Name	SOP Class UID	IOD Specification
…		
Encapsulated STL Storage	**1.2.840.10008.5.1.4.1.1.xxx**	**Encapsulated STL IOD**
…		

Changes to NEMA Standards Publication PS 3.6-2017b

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Part 6: Data Dictionary

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Modify PS3.6 Annex A Registry of DICOM unique identifiers (UID) – add new item.

Annex A Registry of DICOM unique identifiers (UID) (Normative)

Table A-1 lists the UID values that are registered and used throughout the Parts of the DICOM Standard.
185 This central registry ensures that when additional UIDs are assigned, non-duplicate values are assigned.

Table A-1
UID VALUES

UID Value	UID NAME	UID TYPE	Part
…			
1.2.840.10008.5.1.4.1.1.xxx	**Encapsulated STL Storage**	**SOP Class**	**PS 3.4**
…			

Changes to NEMA Standards Publication PS 3.10-2017b

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Part 10: Media Storage and File Format for Media Interchange

Addition to PS3.10 Annex C – clarify use of encapsulated STL Files on DICOM Media.

Annex C Encapsulated STL Document Files on DICOM Media

STL 3D Model Documents may be stored on DICOM Interchange Media, and may be referenced from within DICOM SOP Instances (including the DICOMDIR Media Storage Directory). To ensure there is no ambiguity as to associated patients, the objects shall only be encapsulated in DICOM SOP Instances. Storage as native STL objects (i.e. unencapsulated) is not conformant with the DICOM standard.

An Encapsulated STL is referenced from the Media Storage Directory like any other DICOM SOP Instance.

Changes to NEMA Standards Publication PS 3.17-2017b

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Part 17: Informative

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Addition to PS3.17 Append new Annex containing informative information on the creation of encapsulated STL objects

HHHH Encapsulated STL (Informative)

210 The goal of the encapsulating an StereoLithography (STL) 3D manufacturing model file inside a DICOM instance rather than transforming the data into a different representation is to facilitate preservation of the STL file in the exact form that it is used with extant manufacturing devices, while at the same time unambiguously associating it with the patient for whose care the model was created and the images from which the model was derived.

215 **HHHH.1 Example Encoding**

Below is are tables given example excerpts for encoding of a STL file and its associated preview JPEG image (the latter being optional) for a patient. In the example, the patient will shortly be undergoing a complex cardiac surgery. A 3D manufacturing model (encoded in binary STL) was created to manufacture a surgical planning aid representing the patient's unique anatomy. The model used as input data, a
220 series of CT images (CT1) and MR images (MR1) that were registered and fused. The STL file is actually a second version, a modification of an earlier STL model (also encapsulated as DICOM) was requested by the surgical team in order to include less of the heart's surrounding anatomy.

Table HHHH.1
Example IOD Module Contents (per Table A.45.3-1)

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IE	Module	Reference	Comments
Patient	Patient	C.7.1.1	Used to unambiguously identify the patient. All Encapsulated STLs are associated with a patient.
	Specimen Identification	C.7.1.2	Useful if the 3D model is of a specimen (e.g. a tumour)
	Clinical Trial Subject	C.7.1.3	Useful if the 3D model is a component in a clinical trial
Study	General Study	C.7.2.1	
	Patient Study	C.7.2.2	
	Clinical Trial Study	C.7.2.3	

Series	Encapsulated Document Series	C.24.1	See Table HHHH.2 below
	Clinical Trial Series	C.7.3.2	Useful if the 3D model is a component in a clinical trial
Frame of Reference	Frame of Reference	C.7.4.1	Frame of Reference in an encapsulated STL indicates the specific Frame of Reference through which the coordinates of the model should be interpreted. In this example, the creator of the model registered CT1 and MR1, using CT1's frame of reference as the base coordinate system. The resulting STL was intentionally defined to be the same as that of CT1, so that they could share the same frame of reference value.
Equipment	General Equipment	C.7.5.1	
	Enhanced General Equipment	C.7.5.2	
Encapsulated Document	Encapsulated Document	C.24.2	See Table HHHH.2 below
	3D Manufacturing	C.24.3	See Table HHHH.3 below
	SOP Common	C.12.1	

Table HHHH.2
Encapsulated STL Example (Encapsulated Document Series and Document Values)

Attribute Name	Tag	Example Value	Comments
Modality	(0008,0060)	CT	Since the CT series was considered by the creator to be the primary data source and the MR series secondary, the value of "CT" is used.
…			
Series Description	(0008,103E)	Cardiac Model 2	This is a free text name the creator assigned to model
Content Date	(0008,0023)	20170716	Date the STL was created
Content Time	(0008,0033)	13:00:34	The time of date the STL was created
…			
Image Laterality	(0020,0062)	U	Since the heart is a singular organ in the body (i.e. not part of a bilaterally symmetric pair), the value of U (unpaired) is used.
Burned In Annotation	(0028,0301)	YES	In this example, the creator of the model inscribed the patient's medical record number on a side of the

Attribute Name	Tag	Example Value	Comments
			model, in order to avoid a wrong patient error.
Recognizable Visual Features	(0028,0302)	NO	In this example, the patient's face is not part of the model
Source Instance Sequence	(0042,0013)	A sequence referencing by UID the CT1 series and the MR1 series	Two image series are included because they both provided source data.
Predecessor Documents Sequence	(0040,A360)	A sequence referencing the UID of the earlier encapsulated STL	The earlier encapsulated STL is included so that iterative refinement of successive is properly represented.
MIME Type of Encapsulated Document	(0040,0012)	application/stl	This clearly identifies the content expected in the byte stream.
List of MIME Types	(0042,0014)	image/jpeg\application/stl	Since, in this example, a preview image was included in the byte stream following the STL. So, this needs to be indicated. Including a preview image simplifies the downstream task of allowing a visual selection of a desired encapsulated STL (rather than relying on textual description alone). If no preview image had been included, this attribute would be omitted.
Encapsulated Document	(0042,0011)	Byte stream containing by the preview JPEG image followed by the binary STL file,	If no preview image had been included, this would just be the STL data itself. Note that ASCII STL files are not supported. This is done to ensure the most compact data representation and to simplify the effort to support this part of the DICOM standard.

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Table HHHH.3
Encapsulated STL Example (3DM Module Values)

Attribute Name	Tag	Example Value	Comments
3DM Creation Technique	(aaa1,bbb1)	As Observed	3DM Creation Technique indicates how the 3D manufacturing model was created. In this example, the goal is to represent the patient's current anatomy (rather than simulate some post intervention result). See Section C.24.3.1 for other Defined Terms.
3DM Purpose	(aaa1,bbb2)	Surgical Planning	3DM Purpose indicates for what purpose the 3D manufacturing model was created and thus what uses it may be suitable. In this example, the purpose of the modeled object is planning the upcoming surgery. See Section C.24.3.2 for Defined Terms.
3DM Unit Scale	(aaa1,bbb3)	1	3DM Unit Scale indicates how the coordinate dimensions within the 3D manufacturing model should be interpreted in terms of millimeters of scale. In this example (as in most medical scenarios) the model is in millimeters, and thus a unit value is used.