DICOM℠
Digital Imaging and Communications in Medicine

Overview:

Supplement 208 Extension of DICOM Encapsulation of 3D Manufacturing Models

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Background

WG17 Original Mandate

- Allow store/query/retrieve 3D models, intended for 3D manufacturing (and virtual reality), as DICOM objects
- Addressed by Work Item 1
- Leverage
  a) Existing and growing ecosystem of DICOM-capable systems in use in healthcare institutions and
  b) Standards and conventions already in use in the 3D printing industry

WG17 Work Thus Far

- In 2018 WG17 focused on getting **DICOM Encapsulated STL** was added to the standard
  - This provides a lowest common denominator for use cases
  - It was recognized that while everyone can utilize STL, there are more advanced options

WG17 Extended Mandate

- Approached by members of medical **Virtual Reality** (VR), **Augmented Reality** (AR), and **Mixed Reality** (MR)
  - This community also uses non-medical 3D models and have **overlapping use cases** with 3D manufacturing
  - WG17 is now including **their input** into selection of formats for encapsulation and other needs
    - Primary format in current VR/AR/MR use is **OBJ**
    - Also concerned with multi-part assemblies and color

Direction & Current Challenges

Direction

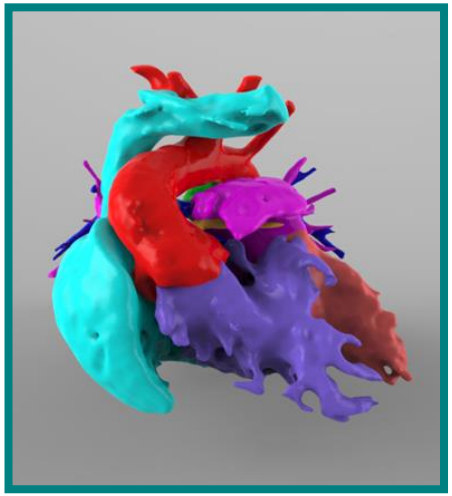
- Both the **3D printing** and **AR/VR/MR communities** have provided the following direction to WG17…
  - Address limitations of STL by allowing option for encapsulation of a more advanced format
    - Select based on **current** ubiquity of use in both communities
  - Address model management challenges related to…
    - Multi-part assemblies
    - Persistent component color

Challenge 1: Beyond STL

- Limitations of STL format
  - No ability to indicate color/texture individual polygons in model
    - Important for replicating real-world appearance of modeled anatomy/pathology
  - Poor adoption in virtual/augmented/mixed reality applications
- Many other 3D model file formats address these deficits (OBJ, X3D, AMF, 3MF)
- **OBJ format** has high **current** adoption among both 3D printing and VR/AR/MR applications & users

Challenge 2: Assemblies

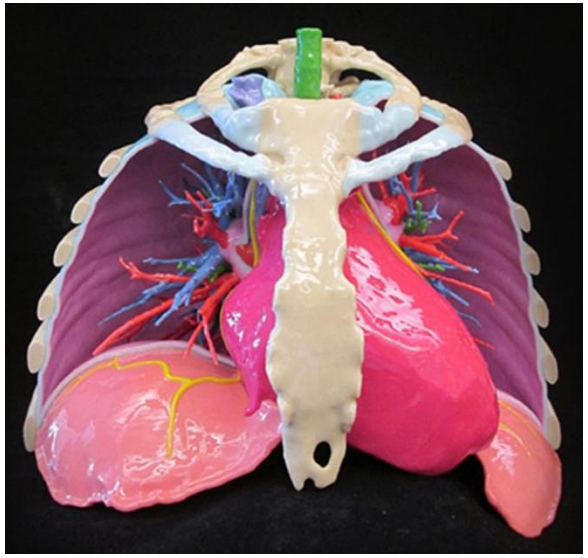
- Many 3D models are meant to be assembled together, example:
  - Multi-part implants
  - Training simulators requiring different materials
  - Explorable anatomic models
- May be multiple assemblies in the same DICOM study, example:
  - Left and right versions of multi-part implants



- Any convention using study and series can be ambiguous and inconsistent
- Desire to **explicitly** leverage DICOM identify which subset of models belong to the **same assembly**

Challenge 3: Persistent Color

- Many situations where **specific preferred color** should be used for a specific model
  - Example: Color-coded assemblies of multiple models (bone, venous, arterial, …)
- No good solution inside STL or OBJ models…
  - STLs **completely lacks** standard ability to indicate the **color** of the model
  - OBJ can indicate color, but it must be done on the **polygon-by-polygon** level (overkill)



- Desire to leverage DICOM to persistently indicate **desired color** for a specific model

Main Components of Supplement

This Supplement

- The second output of work item 1 is *Supplement 208: DICOM Encapsulation of Advanced 3D Manufacturing Models*
- Enable encapsulation of OBJ in a pathway similar to STL encapsulation
- Augment current encapsulation approach for assemblies and color

New IODs & Attributes

New Information Object Definition (IOD)s:

- **Encapsulated OBJ** (and supporting files) for Creation, Review, Update, and Printing (manufacturing)

New Attributes:

- Extend C.35 *Manufacturing 3D Model Modules* with new optional attributes
  - Model Group UID
  - Preferred Color

Expected Use

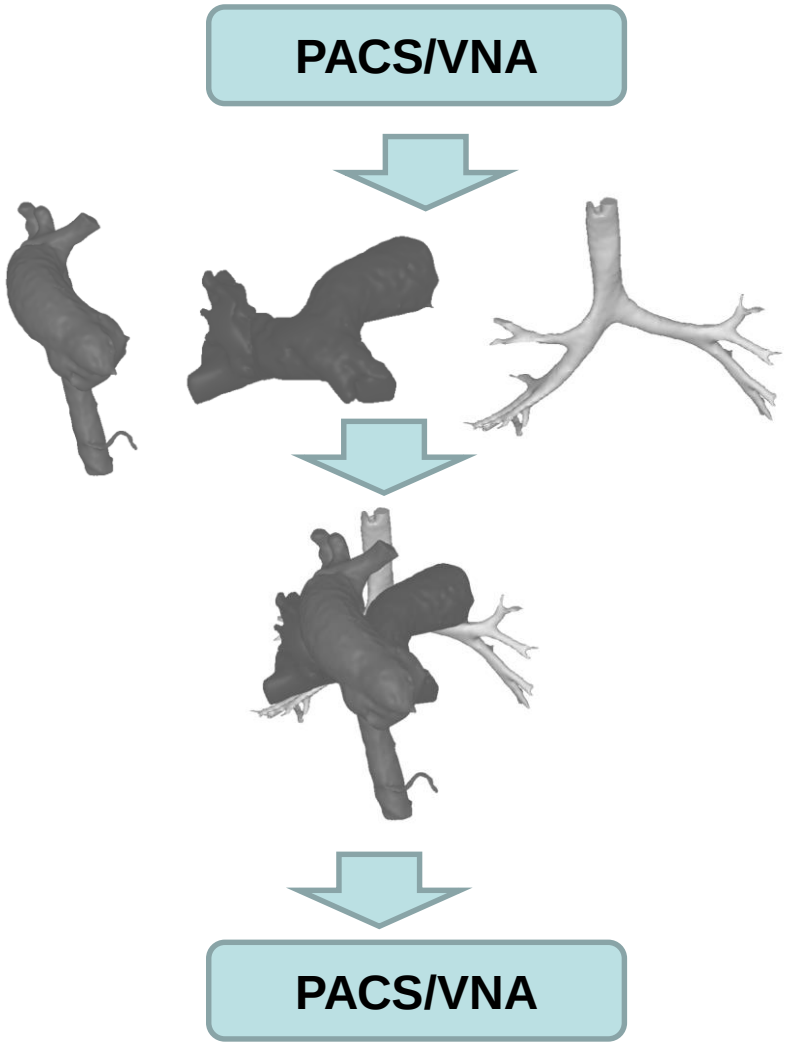
Model Augmentation

The new 3D Model encapsulation attributes is expected to address these real world use cases

- **Model Group**
- **Component Color**

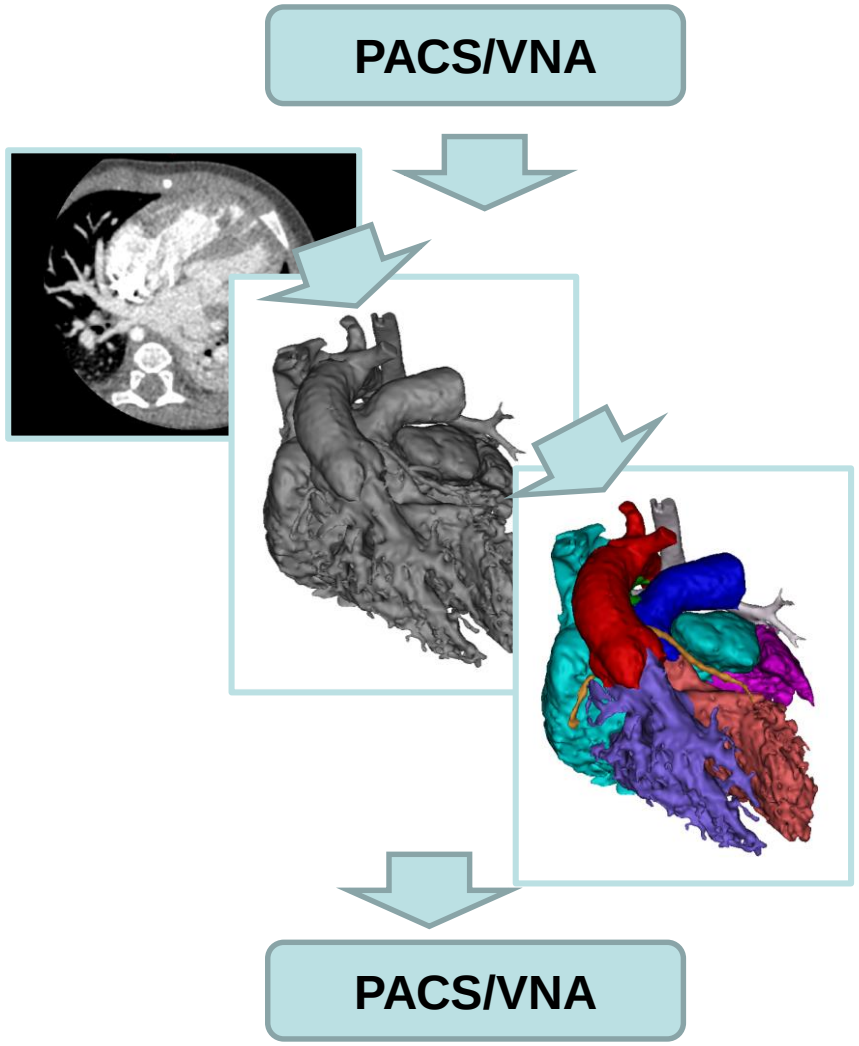
Expected Use: Model Group

- Medical reconstruction software queries Image manger system
- **User creates patient-specific 3D model** (reconstruction and modeling)
- User segments different regions into discrete manifolds (e.g., aorta, pulmonary artery, and airway)
- Modeler system creates 3 DICOM objects containing the 3D models
- Specifying **same Model Group UID in each object** enables modeler or subsequent DICOM-enabled software to identify group for joint printing / presentation
- **[see STL/OBJ encapsulation for remaining steps]**



Expected Use: Component Color

- Medical reconstruction software queries Image manger system
- **User creates patient-specific 3D model** (reconstruction and modeling)
- User segments different regions into discrete manifolds (e.g., aorta, left ventricle, left atrium)
- Modeler system creates 3 DICOM objects containing the 3D models
- **Color each component (sRGB)**
- **Assign alpha/transparency**
- **[see STL encapsulation for remaining steps]**

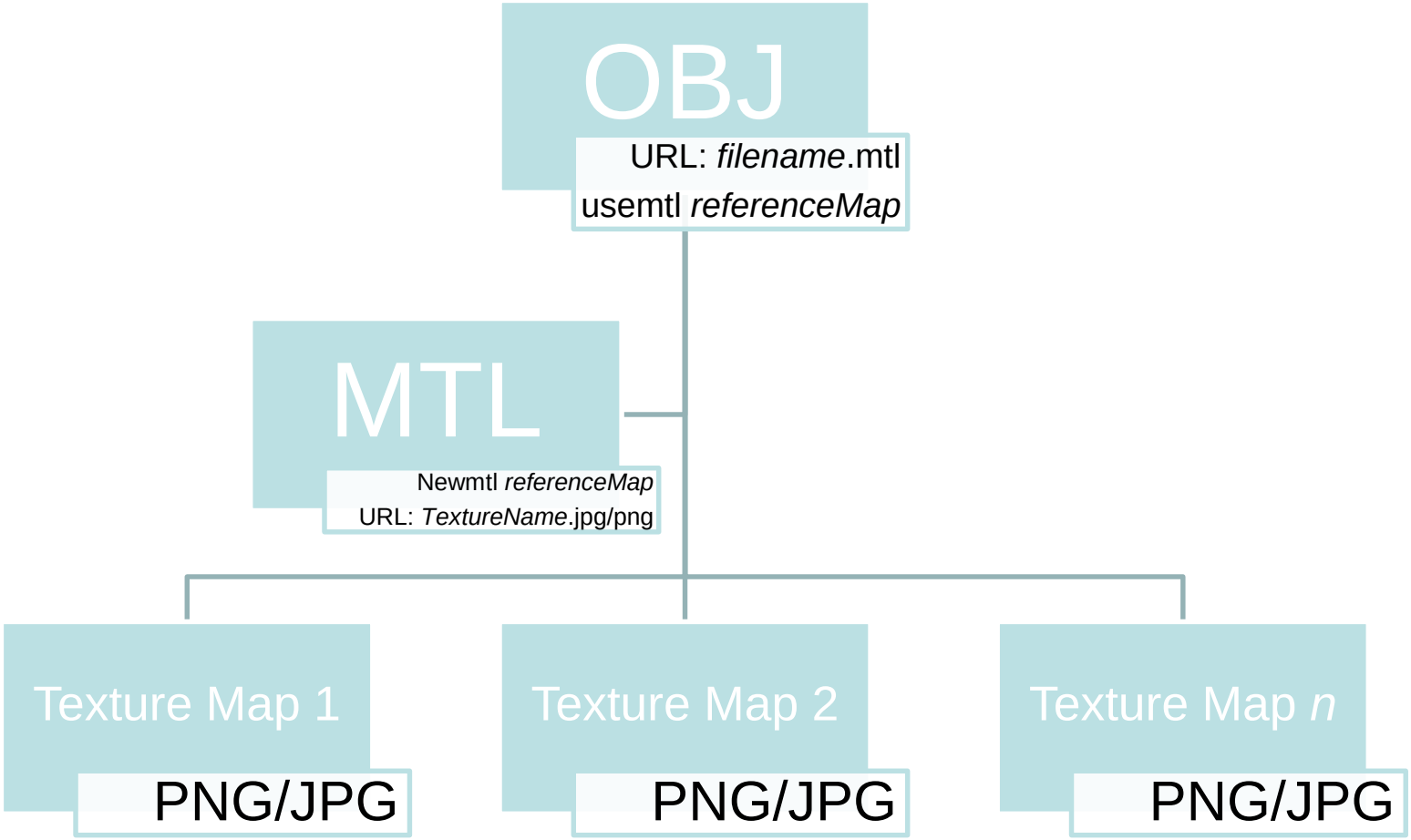


OBJ in DICOM

The proposed OBJ encapsulation necessitates multiple file encapsulation

1. **An OBJ object may actually be comprised of 2 or more files:**
   - 1 **OBJ** main file
   - 0-1 **MTL** supporting file
   - 0-*n* **Texture Map Image** supporting files
2. **These files refer to each other by name**

Background - OBJ Schema



Background: OBJ & MTL

```
1368658  vn -0.3449577391148 -0.6821315884590 -0.6447485089302
1368659  vn -0.2826717197895 0.0076980688609 -0.9591858386993
1368660  vn 0.6301043033600 0.7272020578384 0.2722969949245
1368661  vn 0.5974761843681 0.7891337871552 -0.1424432843924
1368662  vn -0.4890609681606 -0.7319647669792 0.4743911325932
1368663  vn -0.6451370120049 -0.6867179870605 -0.3349875509739
1368664  vn 0.9334340691566 -0.1631953120232 0.3194811046124
1368665  vn 0.0918825566769 -0.7192199826241 0.6886800527573
1368666  vn 0.0357546992600 0.8034136295319 0.5943468213081
1368667  vn 0.9314748644829 0.3603391945362 -0.0501018352807
1368668  vn -0.6770498156548 0.6993246078491 0.2292350381613
1368669  vn 0.6219043731689 0.7298039793968 0.2839385569096
1368670  mtllib reference.mtl
1368671  o Polygonal_Model_1 AO
1368672  usemtl _image
1368673  # Number of triangles: 58932
1368674  f 1161/1/25034 1172/2/25035 1149/3/25036
1368675  f 1174/4/25042 1175/5/25043 1176/6/25044
1368676  f 1175/5/25045 1174/4/25046 1177/7/25047
1368677  f 1175/5/25144 1177/7/25145 1194/8/25146
1368678  f 1176/6/25147 1184/9/25148 1174/4/25149
1368679  f 1229/10/25300 1194/8/25298 1230/11/25299
1368680  f 1229/10/25300 1230/11/25299 1231/12/25301
1368681  f 1231/12/25351 1230/11/25349 1243/13/25350
1368682  f 1231/12/25351 1243/13/25350 1244/14/25352
1368683  f 1393/15/25702 1175/5/27097 1394/16/299
1368684  f 1150/17/25880 1406/18/25881 1407/19/25882
1368685  f 1149/3/25036 1172/2/25035 1408/20/301
1368686  f 1149/3/25036 1408/20/301 1406/18/25037
1368687  f 1415/21/25283 1408/20/301 1172/2/25035
1368688  f 1419/22/25892 1415/21/25890 1172/2/25891
1368689  f 1229/10/25300 1423/23/303 1424/24/25906
```

Background: MTL & Images

```
 8  newmtl _image
 9      Kd 1.0 1.0 1.0
10      illum 1
11      d 1
12      Ns 0.125
13      sharpness 60
14      Ni 1
15      map_Kd_wrapU Clamp
16      map_Kd_wrapV Clamp
17      map_Kd_magfilter Linear
18      map_Kd reference_image.png
19
20  newmtl _image_2
```

Multiple Objects

The encapsulation strategy for OBJ will introduce 3 new DICOM IODs:

- **Encapsulated OBJ**
  - Stores the main OBJ byte stream
- **Encapsulated MTL**
  - Stores the MTL byte stream
- **Texture Map Image**
  - Stores the texture map image

Solution Part 2:

Preserve File Name

- The *Encapsulated MTL* and *Texture Map* IODs will contain a new string attribute:
  - **Referenced Name**
- Stores the file name under which the object may be referenced in encapsulated objects
  - From earlier examples
    - reference.mtl
    - reference_image.png
- When the encapsulated object is unwrapped and written to a file system, it uses the given file name so that linkages between files are preserved

Solution Part 3:
Link the Objects

- A new attribute is added to the Encapsulated OBJ object
  - **Supporting Objects Sequence**
- This is a sequence of UIDs for the:
  - **Encapsulated MTL**
  - **Texture Map Images**
- This allows a simple DICOM query to easily retrieve all of the supporting objects for a given Encapsulated OBJ

Use Cases for OBJ Encapsulation

Expected Use – OBJ

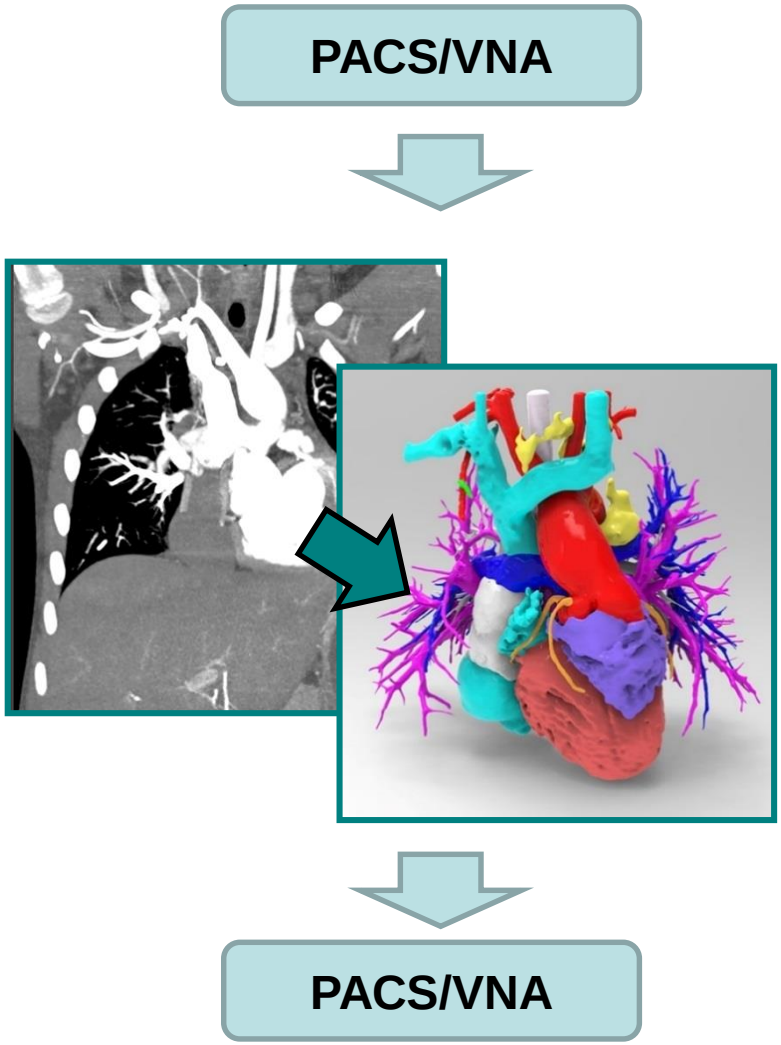
The new IOD/SOP is expected to address these real world use cases:

- **Creation**
- **Review**
- **Update**
- **Print**

Use Case 1 OBJ

Use Case 1: Creation

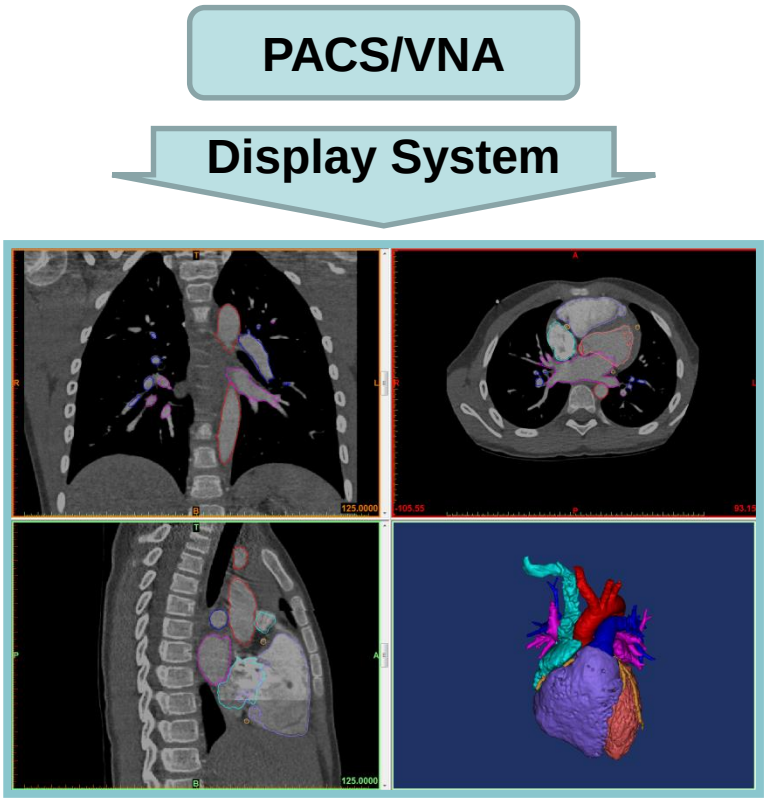
- Medical reconstruction software queries Image manger system
- **User creates patient-specific 3D model** (reconstruction and modeling)
- Modeler system creates the new type DICOM object containing the 3D model along with color information, populating all required metadata
- **User saves 3D model back to the patient's record in DICOM** format as either (a) an addition to an existing study or (b) a new study
- The **Modeler system stores the new DICOM** object in the Image Manager system



Expected Use (continued)

Use Case 2: Review

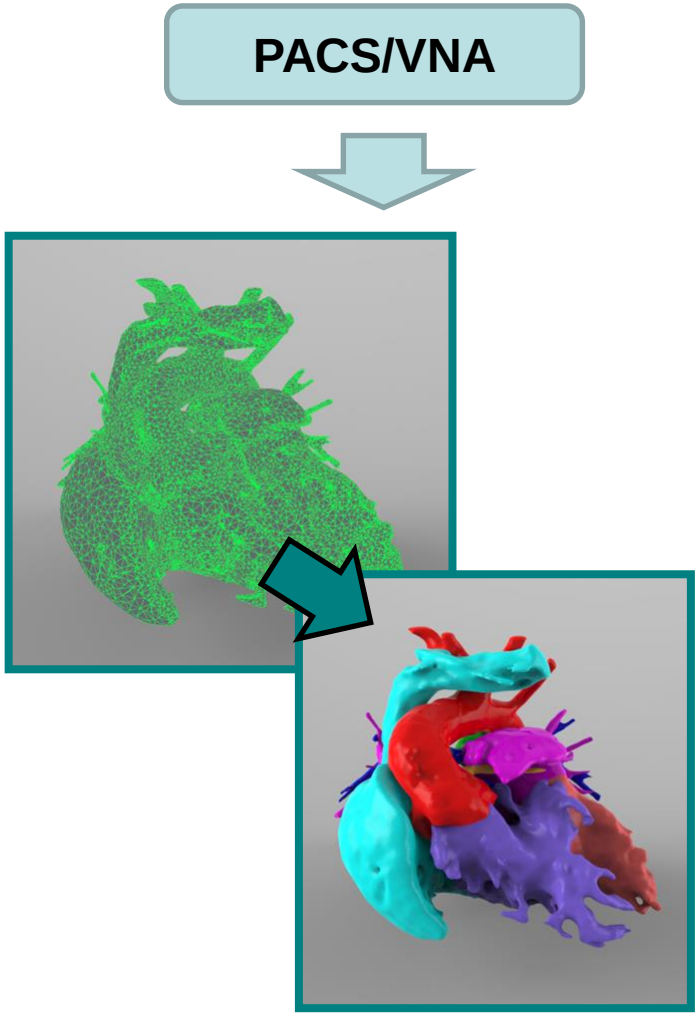
- At a later time to Use Case 1, a user indicates desire to **visually review a 3D model , prior to 3D printing**
- The Display system queries the Image Manager for the DICOM objects of new type
- The Display system retrieves the indicated object
- The **Display system extracts the 3D model** from the object and displays it to the user, potentially registered for simultaneous display with source images



Expected Use (continued)

Use Case 3: Update

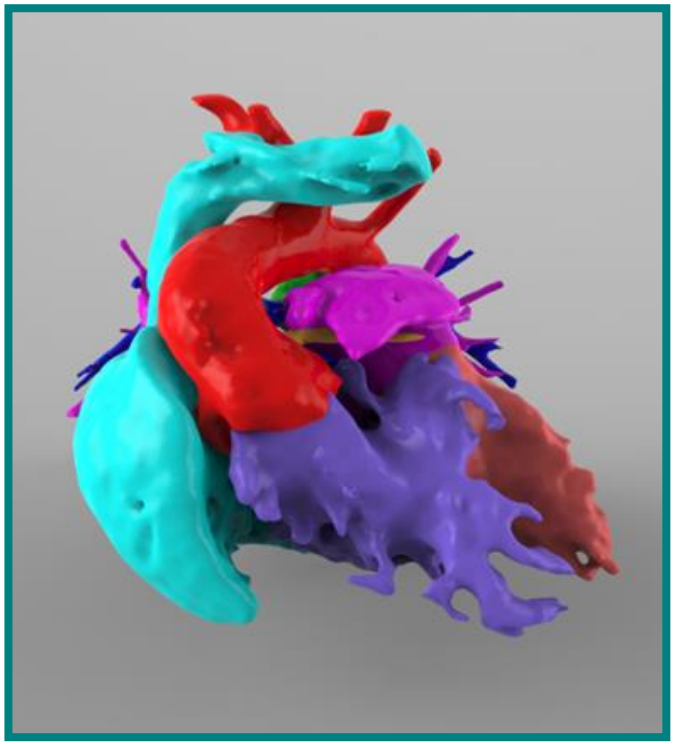
- At a later time to Use Case 1, a **user indicates desire to modify a 3D model** for a particular patient
- The Modeler system queries the Image Manager for the DICOM objects of new type
- If necessary, **the Modeler system retrieves any source images** (s1 to sN) required for this modification to occur
- User interacts with the Modeler system to adjust the 3D printable model as desired



Expected Use (continued)

Use Case 3: Update (cont'd)

- **User saves back to the patient's record in DICOM format** as either (a) an addition to an existing study, or (b) a new study
- The Modeler system creates the new type DICOM object containing the new version 3D model, populating all required metadata and including a unique identifier reference to the supplanted earlier 3D print model object
- The Modeler system stores the new DICOM object in the Image Manager system

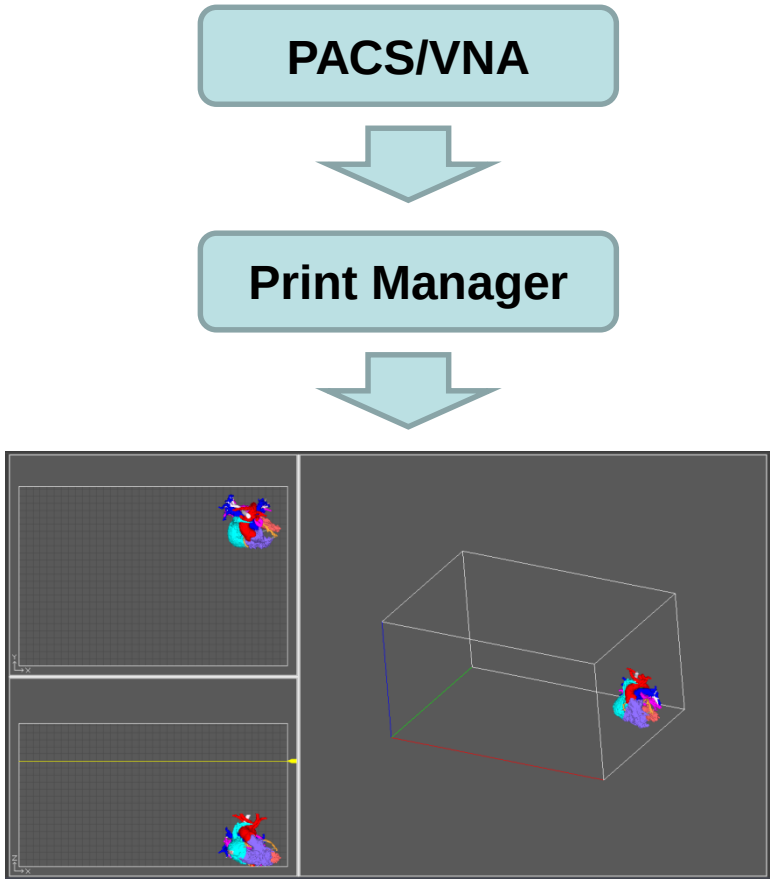


PACS/VNA

Expected Use (continued)

Use Case 4: Print

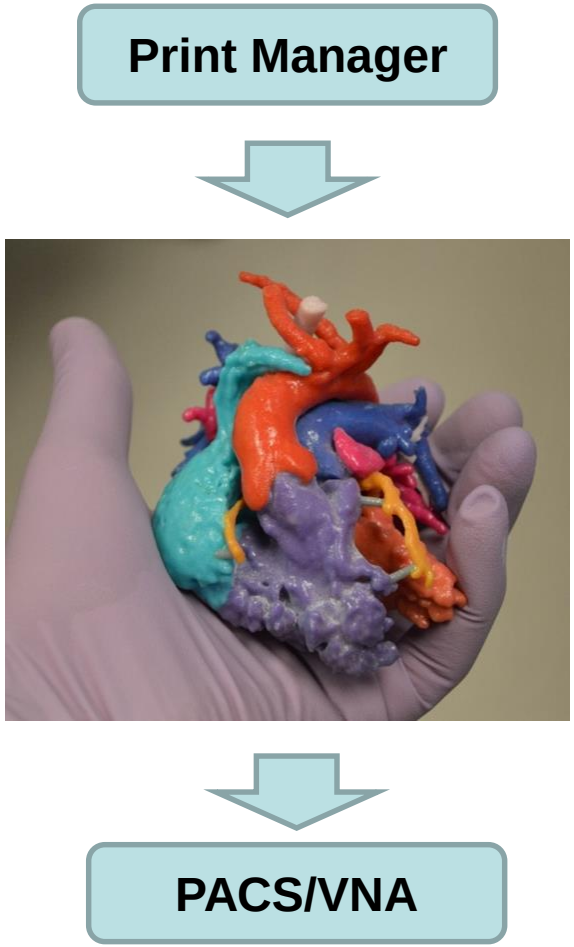
- At a later time to Use Case 1, a user indicates desire to print a 3D model for a particular patient
- The Print Manager system queries the Image Manager for the DICOM objects of new type belonging to the patient
- The Print Manager system retrieves the indicated 3D print model object
- The Print Manager access the 3D model information within the object, using this to create non-DICOM print instructions for a specific 3d printer (e.g. *.obj)



Expected Use (continued)

Use Case 4: Print (cont'd)

- The Print Manager prompts the user for any necessary additional print parameters (e.g. support, bed placement, material parameters, etc.)
- The Print Manager submits the print job to the printer
- Optionally, the Print Manager may save an updated 3d print object back to the Image Manager in order to preserve exact print parameters used (per Use Case 3, steps 7+).



Specific Changes to Standard

Assembly Group Information

ISSUE TO RESOLVE

- Encapsulated models that are part of same assembly have no inherent grouping
  - Relying on humans to guess grouping of numerous DICOM encapsulated models is problematic

ADDRESSED VIA

- Optional ***Model Group*** UID
- Explicitly allows model grouping if part of same assembly

Attribute Name	Tag	Type	Attribute Description
Model Group	(aaa1,bbb1)	3	UID shared by manufacturing models that are considered distinct parts within the same assembly.

Addition to C.35.1 Manufacturing 3D Model Module

Color Information

ISSUE TO RESOLVE

- Encapsulated models lack uniform inherent component color (and transparency)

ADDRESS VIA

- **New Attribute: *Preferred Color***
  - Specifies color for DICOM component
  - Includes optional transparency component
  - sRGBA format (W3C: https://www.w3.org/TR/css-color-3/)

Attribute Name	Tag	Type	Attribute Description
Preferred Color	(aaa1,bbb2)	3	Preferred sRGBA color recommended to be used for the model when visually representing and selecting material for manufacturing. This would typically be used to visually distinguish between models that are part of the same assembly and/or provide best analog to real world appearance. This may be ignored if individual colors have been specified inside the encapsulated model for individual polygons and/or vertices may be specified (when encapsulated format allows this).

Addition to C.35.1 Manufacturing 3D Model Module

Payload - OBJ

- **Builds on approach used for encapsulation of STL**
  - Encode OBJ and MTL files via *Encapsulated Document* (0042,0011) attribute
  - Store texture map Images as VL Photographic Instances
  - Registration of 2 new MIME types *model/obj* and *model/mtl* to be completed with IANA

DICOM Retrieval of Linked Instances

ISSUE TO RESOLVE

- How does someone locate & retrieve all of the DICOM objects that an OBJ model directly and indirection references?

ADDRESS VIA

- **Leverage Existing Attribute: *Referenced Instance Sequence***
  - Designation of UIDs of
    - OJB -> MTL
    - MTL -> Texture Images

Attribute Name	Tag	Type	Attribute Description
Referenced Instance Sequence	(0008,114A)	3	Sequence of UIDs corresponding to supporting instances referenced within the encapsulated model. In an Encapsulated OBJ, only a single item shall be permitted in this sequence and that item shall be the UID of a Encapsulated MTL instance. In an Encapsulated MTL, all items shall be UIDs of VL Photographic Image instances (representing texture map resources).

Addition to C.35.1 Manufacturing 3D Model Module

File Name References

ISSUE TO RESOLVE

- OBJ files refer to MTL files by file name
- MTL files refer to texture map images by file name
- This naming must be preserved when recreating the files or linkage broken

ADDRESS VIA

- **New Attribute: *Referenced Name***
  - Allows disambiguation and recreation of files when de-encapsulating
  - Stored in the Encapsulated MTL and the Texture Map Image objects

Attribute Name	Tag	Type	Attribute Description
Referenced Name	(aaa1,bbb3)	3	The file name under which the object is referred to within an encapsulated object. Preservation in this attribute allows the file name to be reconstituted when needed to preserve referential integrity from the encapsulated object.

Addition to C.35.1 Manufacturing 3D Model Module

Addition to VL Photographic Image (for Texture Map Images)

Avoid Inappropriate Display of Textures

ISSUE TO RESOLVE

- Software may assume the texture map images in a study are intended to be displayed directly to the user as patient images

ADDRESS VIA

- **Re-Use of Existing Attribute: *Presentation Intent Type***
  - A value of “FOR PROCESSING” indicates that the image should not be displayed directly
  - Convention understood by software that also has to deal with DX and MG images

Attribute Name	Tag	Type	Attribute Description
Presentation Intent Type	(0008,0068)	3	Identifies whether the intent of the image is for processing (e.g. is a texture map) or presentation (e.g. is directly interpretable by humans). Enumerated Values: FOR PRESENTATION FOR PROCESSING

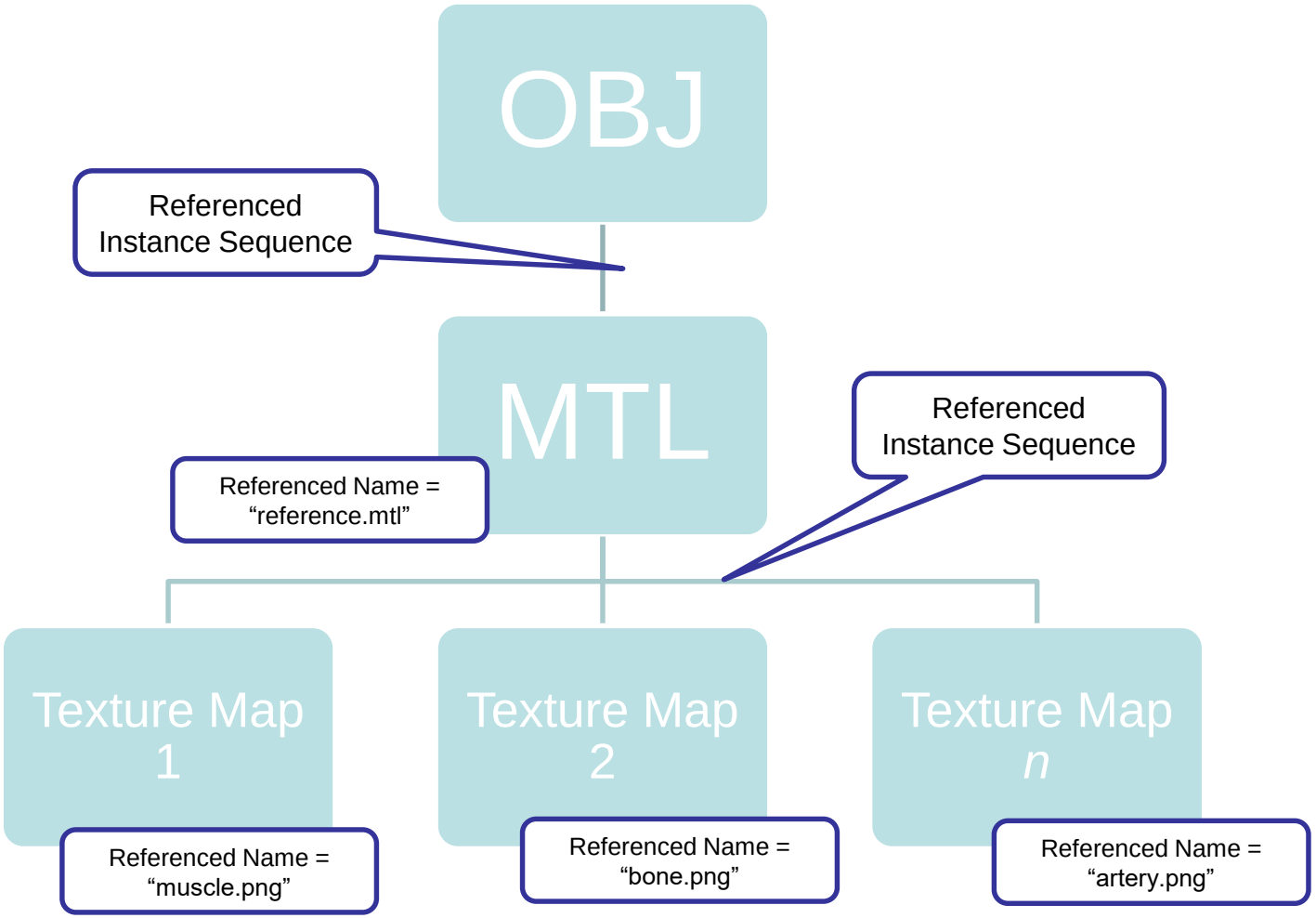
Addition to VL Photographic Image (for Texture Map Images)

Resulting DICOM Instance Relationship

Encapsulated OBJ

Encapsulated MTL

VL Photographic Images



Modality of Texture Maps

ISSUE TO RESOLVE

- Expect to be able to put all of the objects in the same DICOM Series
- But all objects in the same series must have the same study level information – including Modality

ADDRESS VIA

- Allowing Texture Map Images to have modality “M3D”
  - Same as the OBJ and MTL encapsulated objects
  - Should also help distinguish between “real” photographic images and texture maps

A.32.4.3.1 Modality

The value of Modality (0008,0060) shall be **M3D only if the image is a texture map of an Encapsulated 3D Manufacturing Model. In all other cases the value of Modality (0008,0060) shall be** XC.

Modification of VL Photographic Image constraints (for Texture Map Images only)

Thank You for your Attention

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END