Integrating the Healthcare Enterprise

IHE Radiation Oncology
Technical Framework Supplement

Multimodality Image Registration for Radiation Oncology (MMRO)

Final Text

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Foreword

This is a supplement to the IHE Radiation Oncology Technical Framework V1.7. Each supplement undergoes a process of public comment and trial implementation before being incorporated into the volumes of the Technical Frameworks.

This supplement describes changes to the existing technical framework documents and where indicated amends text by addition (bold underline) or removal (bold strikethrough), as well as addition of large new sections introduced by editor's instructions to "add new text" or similar, which for readability are not bolded or underlined.

NOTE: This supplement was originally developed prior to the release of the supplement template and installed directly into the IHE-RO Technical Frameworks. For compatibility purposes with current supplement and technical frameworks formatting, it has been extracted and re-formatted into a supplement prior to final review and conversion to Final Text status.

"Boxed" instructions like the sample below indicate to the Volume Editor how to integrate the relevant section(s) into the relevant Technical Framework volume:

Replace Section X.X by the following:

General information about IHE can be found at: www.ihe.net

Information about the IHE <Domain Name> domain can be found at: http://www.ihe.net/Domains/index.cfm

Information about the structure of IHE Technical Frameworks and Supplements can be found at: http://www.ihe.net/About/process.cfm and http://www.ihe.net/profiles/index.cfm

The current version of the IHE Technical Framework can be found at: http://www.ihe.net/Technical_Framework/index.cfm

Comments may be submitted regarding this TF Template Supplement document, itself, by going to the IHE Domain Coordination page wiki or directly at: https://docs.google.com/spreadsheet/ccc?key=0ArXo-8k7wNCYdHdTUnZBZDIwZ19STjJwaWFkTnBSOVE#gid=0 Please enter any comments/issues as soon as they are found. Do not wait until a future review cycle is announced. The intent is that this template itself is being tested in the Dec 2011 – June 2012 Technical Framework Profile development cycle.

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Introduction to this Supplement

This supplement defines the Multimodality Image Registration for Radiation Oncology Profile (MMRO). It adds information to Volumes 1 and 2 and of the IHE Radiation Oncology Technical Frameworks to describe the profile and define the actors and transactions that are present in the profile.

The Multimodality Image Registration for Radiation Oncology Profile specifies communications between systems creating and registering image sets. It defines how DICOM objects for spatial registration and the images themselves are created, stored, queried, retrieved, processed and displayed.

Open Issues and Questions

1. The RT Structure Set created on registered image sets in this profile is limited to reference only a single image set. In cases where multiple image sets have been registered to the referenced image set with different registrations, the Registered Display is not able to determine if the contours displayed to the user have been created on the image set combination currently displayed. This restriction was originally imposed to allow BRTO actors to use the objects created.
2. During trial implementation an inconsistency was found in the DICOM Spatial Registration Object (SRO). This inconsistency was fixed in DICOM 2011. A later version of this profile will update it to conform to that version.
3. A safety issue was noted by a vendor during implementation of an application using this profile. Images in the same Frame of Reference (FoR) as images used in creating a spatial registration, but potentially not the same patient position (due, for example, to patient movement between image set acquisitions) could incorrectly be assumed to be properly registered. As in 2 above, this will be addressed in a subsequent version of the profile and this profile retired from active testing.

Closed Issues

1. This supplement, as noted above, was extracted from its initial state in the draft version of the IHE-RO Technical Frameworks, version 2.2. As the profile had been inserted into that TF, all previous closed issues were removed with its insertion and, as such, do not appear here.

Volume 1 – Profiles

1.7 History of Annual Changes

Add the following to the IHE Technical Frameworks General Introduction section 1.7:

- Added the Multimodality Image Registration for Radiation Oncology Profile: In this profile a Registrator performs a rigid alignment of two image sets for the same patient and stores this information in an interoperable manner within a Spatial Registration IOD. The alignment information can then be used to render contours and dose distributions on the image set overlay or to contour additional structures.

1.9 Copyright Permission

Add the following to the IHE Technical Frameworks General Introduction Copyright section:

2.1 Dependencies among Integration Profiles

Add the following to Table 2-1

Integration Profile	Depends on	Dependency Type	Purpose
Multimodality Image Registration for Radiation Oncology	Scheduled Workflow	Acquisition Modality Image Storage (RAD-8)	Modality Images (CT, MR, PT…) will be stored in the archive in accordance with the referenced transaction
Multimodality Image Registration for Radiation Oncology	Scheduled Workflow	Creator Images Stored (RAD-18)	Created Images (CT, MR, PT…) will be stored in the archive in accordance with the referenced transaction
Multimodality Image Registration for Radiation Oncology	Basic Radiation Therapy Objects	Dose Storage [RO-5]	RT Dose will be stored in the archive in accordance with the referenced transaction

Add the following section to section 2.2

2.2.X Multimodality Image Registration for Radiation Oncology Integration Profile

The Multimodality Image Registration for Radiation Oncology Integration Profile involves the flow of multimodality image data to a Registrator to perform a rigid image alignment. The image sets in combination with the resulting Spatial Registration IOD can be consumed by Registered

Contourers to create new contours. Additionally, Registered Displays or Registered Dose Displays can use the registered image sets to visualize contours or dose.

3 Multimodality Image Registration for Radiation Oncology (MMRO) Profile

This Integration Profile specifies how images, RT Structure Sets, RT Doses, and associated spatial registration information can be exchanged, stored, processed and displayed. For a display workstation, it is essential that a workstation correctly identifies the corresponding image sets, matches data from single-slice and multi-slice datasets, matches coordinate systems, and performs spatial translations. The use of relevant DICOM objects (Spatial Registration) is clarified and constrained in order to avoid misinterpretation.

The Multimodality Image Registration for Radiation Oncology (MMRO) Profile focuses on content for image registration and does not define a registration workflow. Such workflow could be managed by using mechanisms described in the Post-Processing Workflow Integration Profile (see RAD TF-1:12).

The MMRO Profile currently only handles rigid registration. The intention is to add deformable registration as an extension to the Profile in the future.

The MMRO Profile does not specify the use of quantification methods for the image data that are created or displayed. In particular, interoperability for PET Standard Uptake Values (SUV) is considered a relevant future work item for IHE. Note that vendors may wish to provide SUV capability even though not required under this Profile.

The MMRO profile has implicit limitations imposed by its dependency on the IHE-RO BRTO profile. The most significant of these are listed here:

- In order to allow MMRO-generated RT Structure Sets to be used by the BRTO *Contourer*, *Geometric Planner*, and *Dosimetric Planner* actors, the base image set shall be CT for this profile and the Registered Frame of Reference shall be associated with a CT image set.
- Similarly, the RT Dose shall be in the Registered Frame of Reference, e.g. in the same frame of reference as the base CT.
- Only the following patient orientations {HFS, HFP, FFS, FFP} shall be considered to be within the scope of this profile. Actors participating in this profile may be capable of handling additional orientations (decubitus), but such orientations will not be tested against this profile.

3.1 MMRO Actors, Transactions, and Content Modules

Figure 3.1-1 shows the actors directly involved in the MMRO Profile and the relevant transactions between them. If needed for context, other actors that may be indirectly involved due to their participation in other related profiles are shown in dotted lines. Actors which have a mandatory grouping are shown in conjoined boxes.

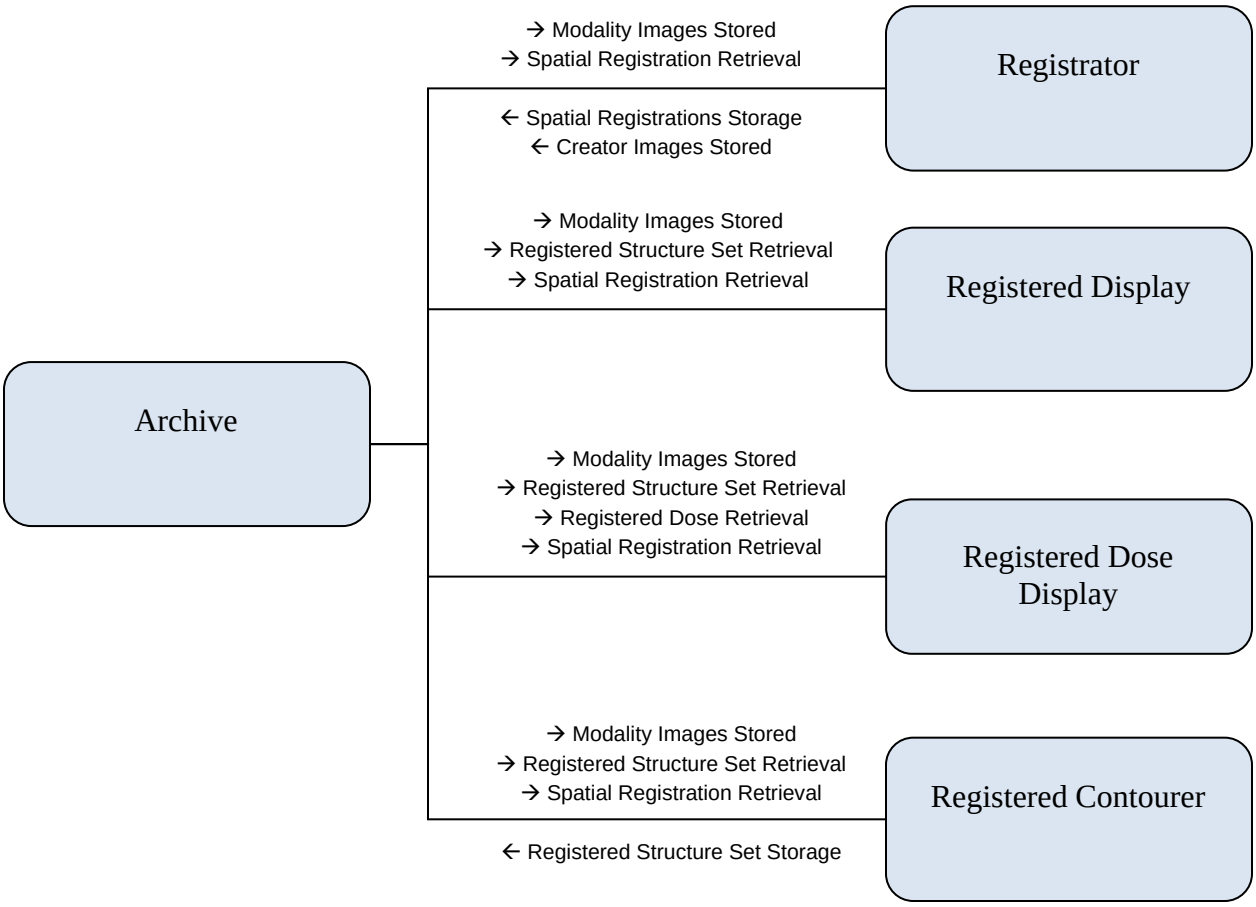


Figure 3.1-1. MMRO Actor Diagram

Table 3.1-1 lists the transactions for each actor directly involved in the MMRO Profile. In order to claim support of this Profile, an implementation of an actor must perform the required transactions (labeled "R") and may support the optional transactions (labeled "O"). Actor groupings are further described in Section 3.3.

Table 3.1-1. MMRO Profile - Actors and Transactions

Actors	Transactions	Optionality	Section in Vol. 2
Archive	Modality Images Stored	R	RAD 4.8
	Creator Images Stored	R	RAD 4.18
	Registered Structure Set Storage	R	MMRO-3
	Spatial Registration Storage	R	MMRO-1
	Spatial Registration Retrieval	R	MMRO-2
	Registered Dose Retrieval	R	MMRO-5

Actors	Transactions	Optionality	Section in Vol. 2
	Registered Structure Set Retrieval	R	MMRO-4
Registrator	Modality Images Stored	R	RAD 4.8
	Creator Images Stored	O	RAD 4.18
	Spatial Registration Retrieval	O	MMRO-2
	Spatial Registrations Storage	R	MMRO-1
Registered Contourer	Modality Images Stored	R	RAD 4.8
	Registered Structure Set Storage	R	MMRO-3
	Registered Structure Set Retrieval	R	MMRO-4
	Spatial Registration Retrieval	R	MMRO-2
Registered Display	Modality Images Stored	R	RAD 4.8
	Registered Structure Set Retrieval	R	MMRO-4
	Spatial Registration Retrieval	R	MMRO-2
Registered Dose Display	Modality Images Stored	R	RAD 4.8
	Registered Structure Set Retrieval	R	MMRO-4
	Registered Dose Retrieval	R	MMRO-5
	Spatial Registration Retrieval	R	MMRO-2

3.1.1 Actor Descriptions and Actor Profile Requirements

No special requirements

3.2 MMRO Actor Options

Options that may be selected for this Profile are listed in the table 3.2-1 along with the Actors to which they apply. Dependencies between options when applicable are specified in notes.

Table X.2-1. MMRO - Actors and Options

Actor	Options	Volume & Section
Archive	*No options defined*	- -
Registrator	*Creator Images Stored*	RAD 4.18
	Spatial Registration Retrieval	MMRO-2
Registered Contourer	*No options defined*	- -
Registered Display	*No options defined*	- -
Registered Dose Display	*No options defined*	- -

3.3 MMRO Actor Required Groupings

Actor(s) which are required to be grouped with another Actor(s) are listed in this section. The grouped Actor may be from this profile or a different domain/profile. These mandatory required groupings, plus further descriptions if necessary, are given in the table below.

An Actor from this profile (Column 1) must implement all of the required transactions in this profile in addition to all of the required transactions for the grouped profile/actor listed (Column 2).

Table 3.3-1. MMRO - Actors Required Groups

MMRO Actor	Required Grouping Actor	Technical Framework Reference	Note
Archive	None	- -	
Registrator	None	- -	
Registered Contourer	None	- -	
Registered Display	None	- -	
Registered Dose Display	None	- -	

3.4 MMRO Document Content Module

3.5 MMRO Overview

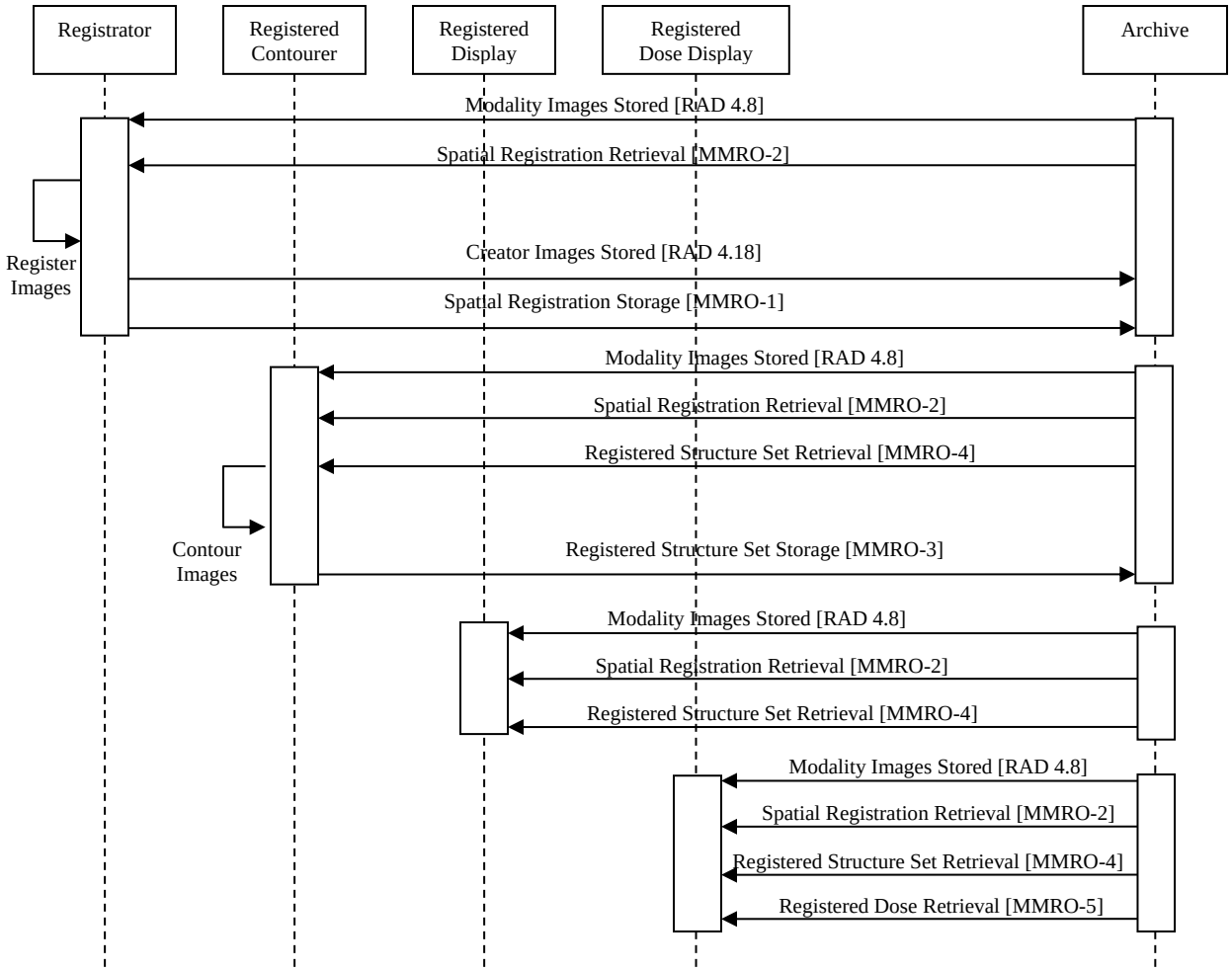


Figure 3.5.1-1 Overall Process Flow in MMRO Profile

3.5.1 Concepts

3.5.1.1 Creating Datasets

The MMRO Profile applies to many types of data. Although each type may need to be handled differently, fused display is possible with each type.

The image sets will usually be created by Acquisition Modality actors, however in some scenarios the image sets could be the result of post-processing by a Registrator actor.

This profile only addresses the registration of volumetric datasets, RT Structure Set and RT Dose objects.

Volumetric datasets refer to a collection of planar images which span a volume and each image has a defined location in space. Typical examples include a set of CT transverse slices, MR slice stacks and PET transaxial images. In the "easiest" situation, multiple volumetric datasets are created in the same Frame Of Reference. Datasets with the same Frame of Reference value are inherently registered and so a registration step is not strictly necessary.

A shared Frame of Reference may be the result of:

- A hybrid scanner such as a PET/CT being used to image the patient.
- A positioning system, such as a fixed head frame, being used to position the patient at the same location and orientation each time for imaging.
- A single scanner being used to image the patient at several closely spaced time intervals (e.g. gated cardiac or pulmonary imaging).
- A second image set being created by a post-processing step (e.g. tissue enhancement or tumor segmentation) and inheriting the Frame of Reference of the first image set.

Note that image sets with a shared Frame of Reference UID implies they are in the same reference coordinate system, but does not guarantee that they overlap. For example, a pelvis series and a head series from the same MR scan may share a Frame of Reference.

More typically, volumetric datasets are each created with a unique Frame Of Reference.

Different Frames of Reference may be the result of:

- Different equipment being used to image the patient
- The same piece of equipment being used to image the patient at different times
- Different patients/subjects being imaged (as in a comparative study or when patient images are mapped to an atlas for display or analysis)

3.5.1.2 Registering Datasets

To perform registration when datasets do not share a Frame of Reference, it is necessary to define a relationship between them. Even if two datasets do share a Frame of Reference, for example on the basis of assuming no patient motion, or assuming two acquisition systems are perfectly calibrated, it is sometimes still useful to perform a registration based on fiducials, image content or something else.

Once the registration is complete, the resulting transformation is recorded in a Spatial Registration object which is typically stored in the study with the image data. The DICOM Spatial Registration object supports rigid registrations (translation, rotation and scaling).

Spatial Registration objects will usually be created by Registrator actors; however in some situations a registration object will not be strictly required (if the datasets share the same Frame of Reference).

There are many methods/algorithms for registration: matching fiducials that are visible in the datasets, using operator input to help align the data, correlating the information content in the datasets, etc. Specifying a method/algorithm to use to arrive at the transformation is outside the scope of this profile. The specific method/algorithm used may be of interest to the user (especially when several different registrations exist between the same datasets) so it is recommended that the name and description of the method be recorded in the resulting Spatial Registration Object.

If the application wishes to allow registration of more than 2 volumetric datasets it shall produce multiple Spatial Registration objects. The first Spatial Registration Object shall establish the Registered Frame of Reference for all of the Spatial Registration Objects. Subsequent objects shall transform a single volumetric dataset into the Registered Frame of Reference.

In some cases, it is conceivable that an Registrator may combine existing registration information without performing a registration process. For example if a registration exists to map dataset A into Frame of Reference C and another registration exists to map dataset B into Frame of Reference C, the Registrator could use those transforms to produce a new set of Spatial Registration Objects for dataset A and B which transform into a Registered Frame of Reference.

When registering volumetric datasets, the mapping describes the spatial transformation between Frames of Reference. Since the specific images exist in one of those Frames of Reference, they can be mapped to each other.

This profile does not address registering datasets which share a common Frame of Reference. If the application wishes to provide this functionality it should store one or both of the datasets with a new Frame of Reference UID and allow the user to perform the registration with those datasets. This avoids the ambiguity of defining a transform from one Frame of Reference to itself. This capability is not required to satisfy the profile.

Identifying and obtaining an appropriate matching pair of datasets to register is necessary but is not defined by this profile. IHE ensures that some useful query parameters are available, but in the end this task is left to the implementer.

3.5.1.3 Resampling Datasets

After a Spatial Registation has been applied, the data in the two datasets is in the same coordinate system, but may still have different pixel resolution, pixel spacing, slice thickness, number of slices, slice positions or even slice orientations. Before display is possible, it is necessary to resample the registered dataset into the Registered Frame of Reference. Also, the Image Orientation and Patient Position of the resampled dataset shall match that of the Base dataset.

Note that when resampling values, such as NM and PET counts, that are not normalized to the volume represented by the pixel, the resampled pixel value may be quite different from the original pixel value. For example, when creating a new image with twice the number of pixels in the X and Y directions, 1 pixel in the original data is now 4 pixels in the resampled data, and the value of each of the new pixels would be expected to be roughly ¼ of the value of the original

pixel. When resampling values that are not directly linked to the area/volume of the pixel (such as Hounsfield units), the new pixels will have values similar to the original pixel (partial volume effects notwithstanding).

The exact values produced by resampling also depends on the interpolation algorithm used. The specification of such algorithms is outside the scope of this profile.

In the Radiotherapy domain there will also be instances of RT Structure Set and RT Dose objects which exist in the same Frame of Reference as one of the datasets being registered. The structures described as contours in the RT Structure Sets will be subject to resampling prior to display. The resampling of the contours depends on the resampling algorithm used and is outside the scope of this profile.

Resampling of RT Dose objects is not supported within this profile.

The Registered Display actor is required to be able to perform any resampling needed for the display. Some Modalities or Registrators may choose to generate resampled datasets. The advantage is that such datasets might be useful to non-registration aware display stations, and even when provided to IHE Registered Display actors, might conceiievably provide improved display performance. In most cases, however, storing the resampled data will significantly increase bandwidth and storage costs. This capability is not required to satisfy this profile.

Note that the stepping interval when scrolling through slices may be of primary importance to users and care should be taken in that respect. Sometimes the user may wish to step in increments of the original slices of the underlying set, and sometimes in the increments of the original slice or pixel spacing of the superimposed data set.

3.5.1.4 Presenting Registered Datasets

Presentation of the Registered Datasets is performed by the Registered Display actor.

No DICOM Query transaction for Spatial Registration objects exists currently. For the purpose of this profile it will be assumed that the registered images and the required Spatial Registration objects will be made available to the Registered Display actor. The data will be transferred via C-STORE operations, but the initiation of the action is out of band for this profile.

The Registered Display transforms the datasets by applying the spatial registrations according to the DICOM specification, and resamples the datasets as necessary for display.

Simple registered display could involve presentation of a single frame at a time. For some clinical interpretation tasks, presentation of a registered MPR (Multi Planar Reconstructed) view is considered essential. Many users will also expect to be able to change the transparency of the fusion overlay (blending factor), the color map for the overlay, the Window Width/Level for each data set, and other display parameters. For PET data, controls for upper & lower Window Level are valuable.

3.5.2 Use Case #1: Multimodality Contouring

Two or more series of images, for example, CT, MR and PET, are acquired and stored to an archive system. The images, potentially with different Frames of Reference, are read in, registered, and then used for identifying volumes of interest (VOI) which are stored using an RT Structure Set object.

3.5.2.1 Multimodality Contouring Use Case Description

- Two or more series of images, for example a CT, MR and PET series, are acquired and reconstructed on multiple different Acquisition Modalities.
- The image sets, each with a different Frame of Reference, are stored to the Archive.
- A Registrator obtains the image sets and determines the transformation for mapping each secondary dataset from their respective Frame of Reference into the base Frame of Reference and records the transformations in Spatial Registration objects. For example: To describe the registration of 3 image sets, 2 Spatial Registration objects will be required. The first will register the MR to the CT, and the second will register the PET to the CT. The CT establishes the Registered Frame of Reference. More complex relationships may be described by the Spatial Registration objects, which do not subscribe to the above example yet do satisfy the DICOM standard. Support for those relationships is out of band for this profile. However, the Registrator may accept those Spatial Registration objects, and reorganize the registrations to satisfy this profile. This capability is not required to satisfy this profile.
- A Registered Contourer Actor receives the image sets and Spatial Registrations and creates an RT Structure Set in the same Frame of Reference as one of the datasets. Each dataset may have a RT Structure Set created in its Frame of Reference.
- The Registered Contourer will store the RT Structure Set(s) to the Archive.
- To render the display, the Registered Display uses the transformation in the Spatial Registration to translate the superimposed data into the same space as the underlying image data. Since each RT Structure Set shares a Frame of Reference UID with one of the datasets, the structures can be transformed by resampling using the same transformation for the volume of interest as defined for the underlying image set.
- The appearance of the fused display is out of band for this profile.

3.5.2.2 Multimodality Contouring Process Flow

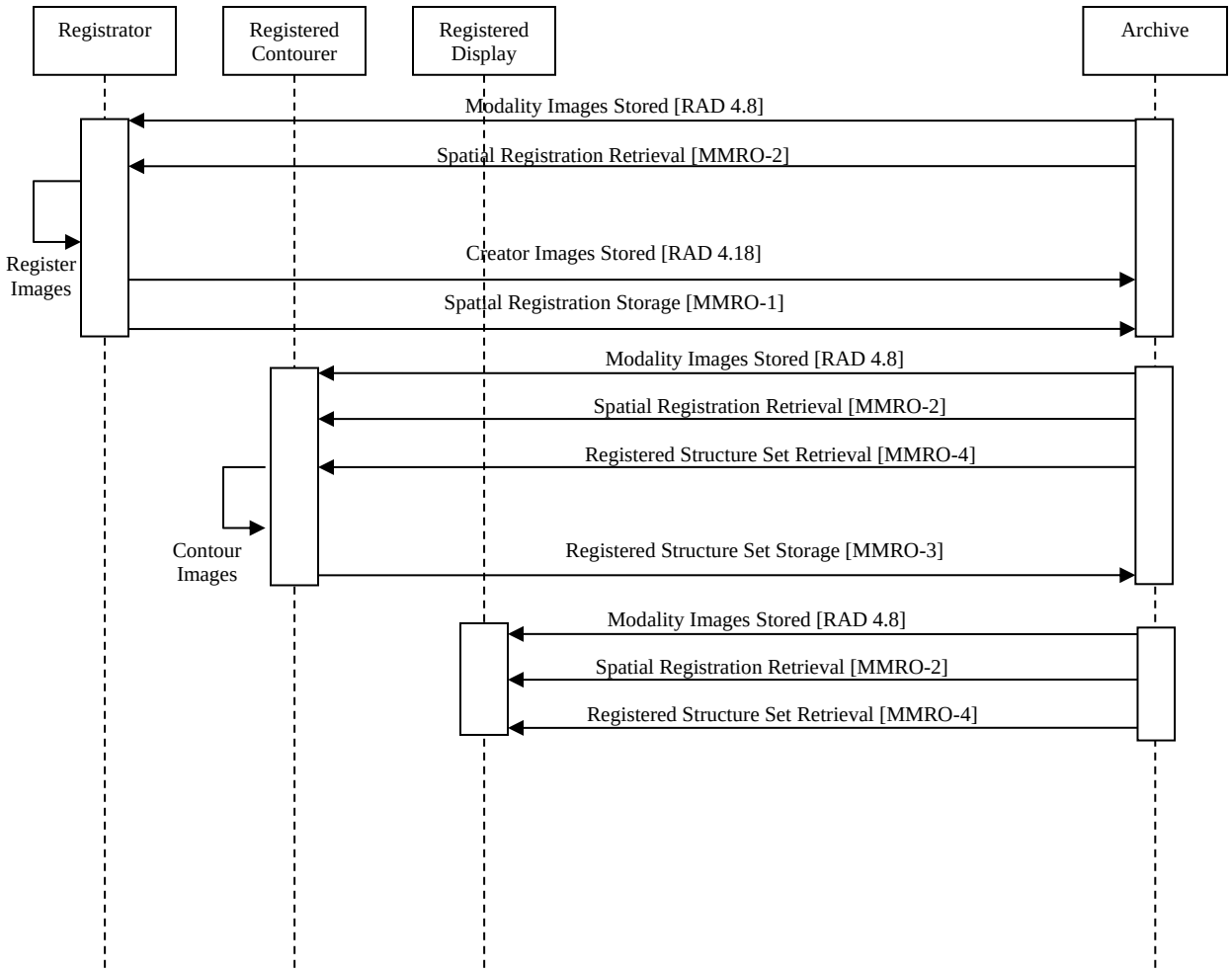


Figure 3.5.2.2-1. Process Flow for Multimodality Contouring Use Case

3.5.3 Use Case #2: Shared Frame of Reference

Hybrid Modalities, (e.g. PET/CT Scanner) combine two modalities into a single system. Typically they calibrate the couch motion and scan space and, assuming the patient does not move, store two image sets mapped into a common space (described by a single Frame of Reference). This also applies to RT objects, such as RT Structure Set and RT Dose objects, as they will share a common Frame of Reference with an image set.

3.5.3.1 Shared Frame of Reference Use Case Description

- Two series of images, for example a PET series and a CT series, are acquired and reconstructed on a single hybrid system.

- The image sets, each with the same Frame of Reference, are stored to the Archive. A common Frame of Reference implies that the two image sets are already in the same coordinate system and no transformation is required.
- A Registered Contourer Actor retrieves the image sets and creates RT Structure Sets in the same Frame of Reference as the image sets. Each RT Structure Set shall reference only a single image set. If structures are defined for both image sets, two RT Structure Set instances will be created.
- The Registered Contourer will store the RT Structure Set(s) to the Archive.
- A Registered Display is sent the image sets and RT Structure Set(s), and observes that no Spatial Registration object is referenced. It also observes that the two image sets and the RT Structure Set share the same Frame of Reference.
- The Registered Display re-samples the image sets, if necessary to match resolutions for display. No spatial registration transformation is required.
- The appearance of the fused display is out of band for this profile.

3.5.3.2 Shared Frame of Reference Process Flow

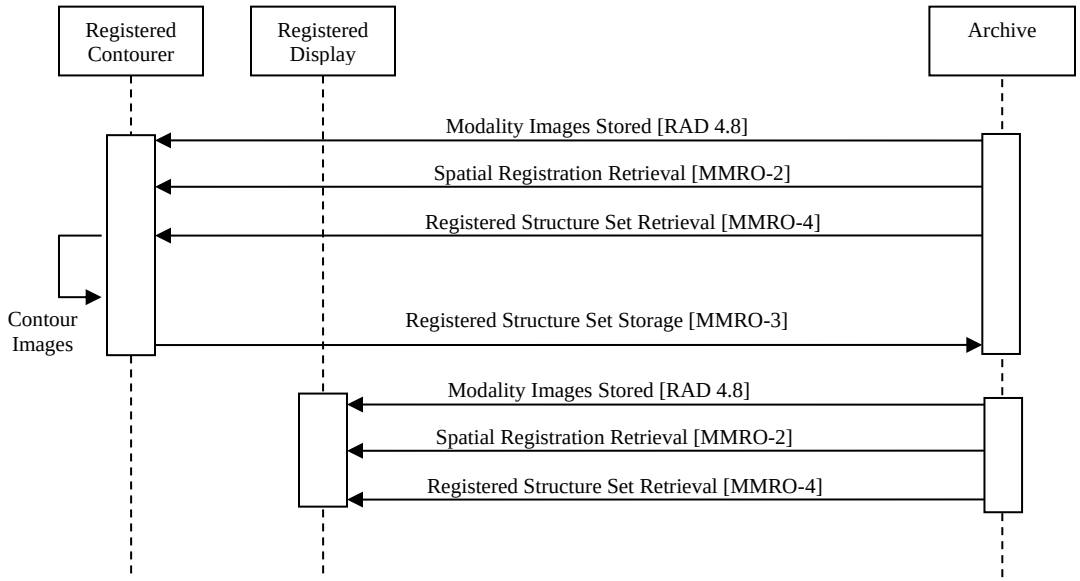


Figure 3.5.3.2-1. Process Flow for Shared Frame of Reference Use Case

3.5.4 Use Case #3: Multimodality Dose Display

Two or more series of images, for example, CT, MR and PET, are acquired and stored to an archive system. The images, potentially with different Frames of Reference, are read in,

registered, and then used for identifying volumes of interest (VOI) which are stored using an RT Structure Set object. An RT Dose object is created (out of band) utilizing the information and stored in the Frame of Reference of one of the image sets.

3.5.4.1 Multimodality Dose Display Use Case Description

- Two or more series of images, for example a CT, MR and PET series, are acquired and reconstructed on multiple different Acquisition Modalities.
- The image sets, each with a different Frame of Reference, are stored to the Archive.
- A treatment plan is created from the image sets, along with RT Structure Sets, an RT Dosimetric Plan, and an RT Dose object.
- A Registered Dose Display is sent the image sets, RT Structure Set(s)and RT Dose along with the required Spatial Registrations.
- The Registered Dose Display re-samples the image sets, RT Structure Sets, and RT Dose as needed for appropriate display.
- The appearance of the fused display is out of band for this profile.

3.5.4.2 Multimodality Dose Display Process Flow

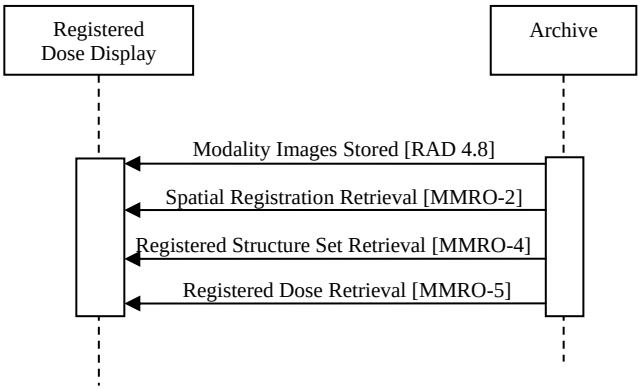


Figure 3.5.4.2-1. Process Flow for Multimodality Dose Display Use Case

3.6 MMRO Security Considerations

No specific considerations.

3.7 MMRO Cross Profile Considerations

No specific considerations.

Appendices

Actor Summary Definitions

Add the following terms to the IHE TF General Introduction Namespace list of Actors:

Registrator – A system that consumes multi-modality images and generates 1 or more Spatial Registration objects.

Registered Contourer – A system that consumes multi-modality images, RT Structure Set objects, and Spatial Registration objects and allows the user to contour images in a ***Registered Display***.

Registered Display – A system that consumes multi-modality images, RT Structure Set objects, and Spatial Registration objects and allows the user to display the registered information.

Registered Dose Display – A system that consumes multi-modality images, RT Structure Set objects, RT Dose objects and Spatial Registration objects and allows the user to display the registered information.

Transaction Summary Definitions

Add the following terms to the IHE TF General Introduction Namespace list of Transactions:

MMRO-1: Spatial Registration Storage

In the Spatial Registration Storage transaction, the ***Registrator*** stores one or more Spatial Registration instances to the ***Archive***. Spatial registration objects define how the pixel coordinates of one image data set are transformed to another coordinate system (for example to a coordinate system defined by another image data set thus allowing each dataset to be spatially aligned).

MMRO-2: Spatial Registration Retrieval

A ***Registered Display***, ***Registered Dose Display*** or ***Registered Contourer*** receives from an ***Archive*** one or more Spatial Registration objects carrying the transformation information to be applied to two image data sets intended for further processing or registered display.

MMRO-3: Registered Structure Set Storage

In the Registered Structure Set Storage Transaction, the ***Registered Contourer*** stores a Structure Set on an ***Archive*** to make it available.

MMRO-4: Registered Structure Set Retrieval

In the Registered Structure Set Retrieval Transaction, the ***Archive*** stores a Structure Set to a ***Registered Contourer***, ***Registered Display*** or ***Registered Dose Display***.

MMRO-5: Registered Dose Retrieval

In the Registered Dose Retrieval Transaction, the ***Archive*** stores the requested RT Dose to the ***Registered Dose Display*** actor.

Glossary

Add the following terms to the IHE Technical Frameworks General Introduction Glossary:

Data Set: A series of images or set of frames.

Frame of Reference (FoR): Identifies the coordinate system that conveys spatial and or temporal information of composite instances in a series. The identified Coordinate System typically includes an origin, orientation and dimension scaling. Data with the same Frame of Reference are inherently using coordinate systems with the same origin, orientation and dimension scaling.

Image Fusion: The process of superimposing (overlaying) data sets for display. This is typically done so that corresponding features of the data sets can be seen at once. Fusion typically requires that the datasets be registered. This would normally involve two data sets- one underlying and one superimposed.

Image Registration: Spatially aligning datasets. This is done by mapping the pixel spatial coordinates of the Original Data Sets to the Registered Space and may include translations or rotations between the coordinate systems. The primary purpose is to support display of correlated features in two images. Typically the Registered Space is defined by one of the datasets, and the other is aligned with it.

Image Re-sampling: Synthesizing a new image dataset where the number of pixels, resolution, number of slices, slice locations and slice orientations may differ from the original, but the frame of reference is preserved (i.e. the pixel value at a given spatial location in the new dataset corresponds to the value at the same spatial location in the old dataset).

MPR: Multi-Planar Reconstruction. Creating orthogonal images from a data set, e.g. creating coronal and sagittal images from a transverse data set.

Original Dataset: Either of the data sets that are to be transformed and blended.

Registered Frame of Reference: The Frame of Reference to which the datasets are being registered. Typically this will be the space of one of the Original Data Sets. The Registered Frame of Reference is identified by the Frame of Reference UID of the Spatial Registration object.

Resulting Dataset: The data set created by applying a Registration Transformation to an Original Dataset.

Volumetric Dataset: A collection of planar (cross-sectional) images which spans a volume and each image has a defined location in space. Typical examples include a set of CT transversal slices, MR slice stacks, reconstructed tomographic NM or PET volumes or volumes re-constructed from projection X-ray images

Volume 2 – Transactions

Add the following to section 3

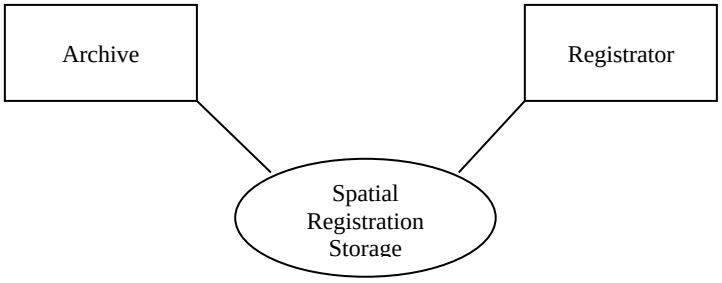
3.12 MMRO-1: Spatial Registration Storage

This section corresponds to the Spatial Registration Storage transaction of the IHE-RO Technical Framework. Transaction MMRO-1 is used by the ***Archive*** and ***Registrator*** actors.

3.12.1 Scope

In the Spatial Registrations Stored transaction, the ***Registrator*** sends one or more Spatial Registration instances to the ***Archive***. Spatial registration objects define how the pixel coordinates of one image data set are transformed to another coordinate system (for example to a coordinate system defined by another image data set thus allowing each dataset to be spatially aligned).

3.12.2 Use Case Roles



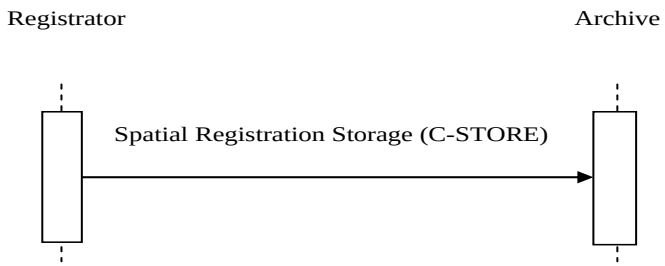
Actor:	Archive
Role:	Accept and store Spatial Registration instances from ***Registrator*** actors
Actor:	Registrator
Role:	Create and transmit Spatial Registration instances to an ***Archive***

3.12.3 Referenced Standards

DICOM 2007 PS 3.4: Storage Service Class

DICOM 2007 PS 3.4: Spatial Registration Storage

3.12.4 Interaction Diagram



3.12.4.1 Spatial Registration Storage

3.12.4.1.1 Trigger Events

A ***Registrator*** chooses to transfer one or more Spatial Registration objects to the ***Archive***. This may follow creation of the Spatial Registration object as part of a registration process.

3.12.4.1.2 Message Semantics

The ***Registrator*** uses the DICOM C-STORE message to transfer the Spatial Registration objects. The ***Registrator*** acts in the role of the DICOM Storage SCU and the ***Archive*** is the DICOM Storage SCP.

The ***Registrator*** is responsible for warning the user of mismatched patient demographics within registered series.

The Spatial Registration shall contain two Registration Sequences. Refer to DICOM 2007 PS 3.17 Figure O.4-1 for informative details on the structure of the Registration Sequences.

When registering volumetric datasets with different Frames of Reference, each Registration Sequence shall define the transformation of the corresponding Original Dataset into the Registered Frame of Reference. Typically, one of the Registration Sequences will contain an IDENTITY transform, indicating that the corresponding original dataset established the Registered Frame of Reference. In that case the Frame of Reference of the Spatial Registration object may be the same as the Frame of Reference of that Original Dataset.

When registering more than 2 Frames of Reference each Spatial Registration object shall include a reference to the Registered Frame of Reference UID with an IDENTITY transformation as one of the elements of the Registration Sequence. Each Spatial Registration object shall specify it's Frame of Reference UID attribute to be the same as the Registered Frame of Reference UID.

This profile shall not allow the re-registration of multiple series with the same Frame of Reference. The actor may re-write one or both of the series with new Frames of Reference and perform the registration on the new series. This capability is not required to satisfy this transaction.

A Registration Sequence item shall contain a Frame of Reference and optionally a list of images, indicating that the transformation is applicable to all images within that Frame of Reference. No meaning may be inferred by the actor from the presence of the image references.

The MMRO profile has implicit limitations imposed by its dependency on the IHE-RO BRTO profile. These limitations are described in the MMRO Profile description in Volume 1 of the IHE-RO Technical Frameworks.

Modifying an existing Spatial Registration Object shall result in a new instance with a new instance UID.

The Spatial Registration object shall be stored:

- in the Study to which the Registered Frame of Reference belongs. This Study is identified by the Study UID of the images which establish the Registered Frame of Reference in the Spatial Registration objects as described above.
- in a different series from images.

3.12.4.1.3 Expected Actions

The Archive will store the received Spatial Registration objects. The Spatial Registration objects shall be stored such that they can be later retrieved (See MMRO- Spatial Registrations) in a fashion meeting the requirements defined for a DICOM Level 2 Storage SCP (see DICOM PS 3.4 B.4.1).

3.12.5 Security Considerations

3.12.5.1 Security Audit Considerations

3.12.5.1.(z) Actor Specific Security Considerations

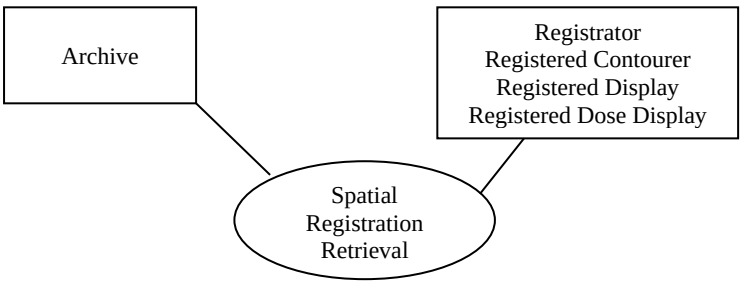
3.13 MMRO-2: Spatial Registration Retrieval

This section corresponds to Transaction MMRO-2 of the IHE-RO Technical Framework. Transaction MMRO-2 is used by the ***Registered Contourer***, ***Registered Display***, ***Registered Dose Display*** and ***Archive*** actors. It is optionally used by the Registrator actor.

3.13.1 Scope

A ***Registered Contourer***, ***Registered Display*** or ***Registered Dose Display*** receives from an ***Archive*** one or more Spatial Registration objects carrying the transformation information to be applied to two image data sets intended for further processing or fused display. A ***Registrator*** may (optional transaction) receive from an ***Archive*** one or more Spatial Registration objects.

3.13.2 Use Case Roles



Actor:	Archive
Role:	Send Spatial Registration instance(s) to the receiving actor
Actor:	Registered Contourer, Registered Display, Registered Dose Display
Role:	Receive Spatial Registration instances from the ***Archive***
Actor:	Registrator (optional)
Role:	Receive Spatial Registration instances from the ***Archive***

3.13.3 Referenced Standards

DICOM 2007 PS 3.4: Storage Service Class

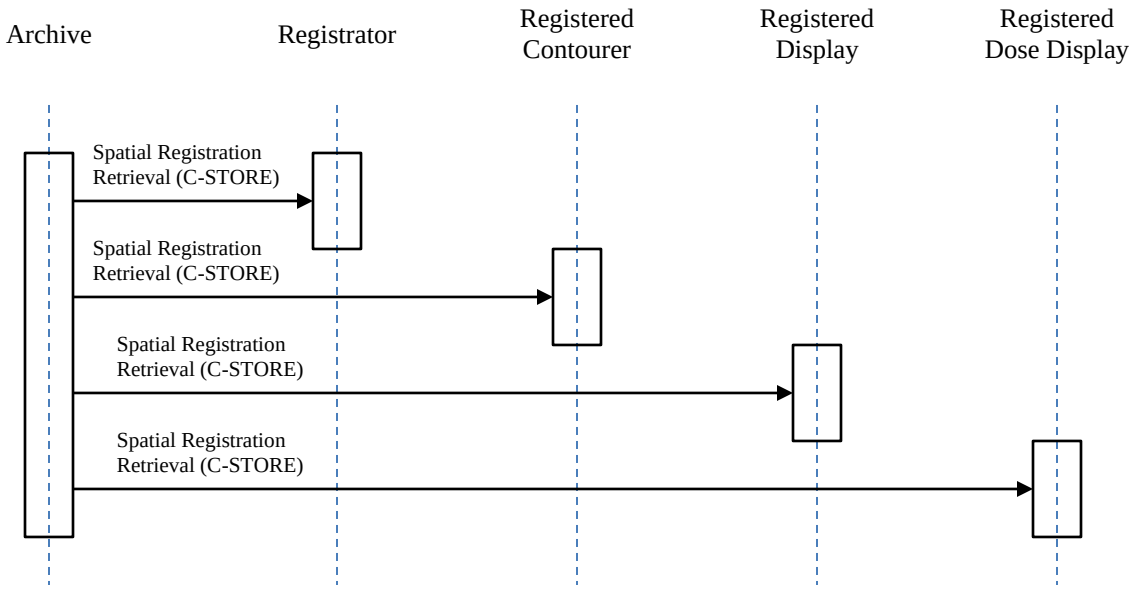
DICOM 2007 PS 3.4: CT Image Storage

DICOM 2007 PS 3.4: MR Image Storage

DICOM 2007 PS 3.4: Positron Emission Tomography Image Storage

DICOM 2007 PS 3.4: Spatial Registration Storage

3.13.4 Interaction Diagram



3.13.4.1 Spatial Registration Storage

3.13.4.1.1 Trigger Events

The ***Registered Contourer***, ***Registered Display***, ***Registered Dose Display*** or (optionally) ***Registrator*** receives one or more specific Spatial Registration objects from the ***Archive***.

3.13.4.1.2 Message Semantics

The Archive uses the DICOM C-STORE message to transfer the Spatial Registration objects. The Registered Contourer, Registered Display or Registered Dose Display is the DICOM Storage SCPU and the Archive is the DICOM Storage SCUP.

It is the responsibility of the Registered Contourer, Registered Display or Registered Dose Display Registered Display to apply the Spatial Registration as defined in DICOM. Refer to DICOM 2007 PS 3.4, Annex C, for detailed descriptive semantics.

A Registration Sequence item in the Spatial Registration will contain a Frame of Reference and no list of images, in which case the transformation shall be applied to all images within that Frame of Reference;

3.13.4.1.3 Expected Actions

The Archive establishes a DICOM association with the Registered Contourer, Registered Display or Registered Dose DisplayRegistered Display, and uses the DICOM Spatial Registration Storage SOP Class to transfer the requested Spatial Registration objects.

The Registered Contourer, Registered Display or Registered Dose Display Registered Display shall use the most recently received instances to ensure that the most recent patient data from the Archive is displayed.

3.13.5 Security Considerations

3.13.5.1 Security Audit Considerations

3.13.5.1.(z) Actor Specific Security Considerations

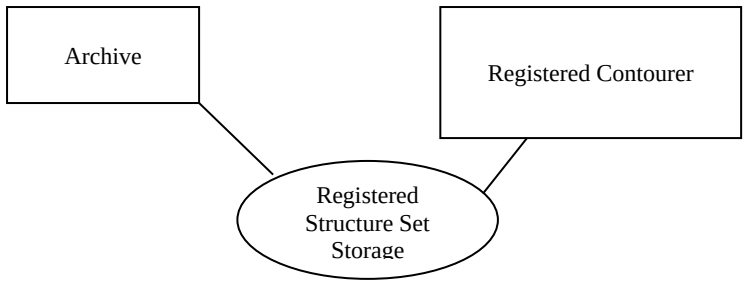
3.14 MMRO-3: Registered Structure Set Storage

This section corresponds to Transaction MMRO-3 of the IHE-RO Technical Framework. Transaction MMRO-3 is used by the ***Registered Contourer*** and ***Archive*** actors.

3.14.1 Scope

In the Registered Structure Set Storage Transaction, the Registered Contourer stores a Structure Set on an Archive to make it available.

3.14.2 Use Case Roles



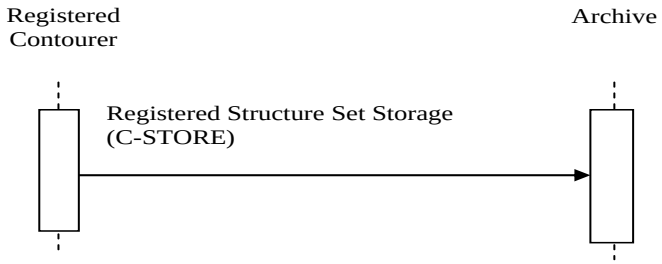
Actor:	Archive
Role:	Receive and store a Structure Set instance from the ***Registered Contourer***
Actor:	Registered Contourer
Role:	Send a Structure Set instance for storage

3.14.3 Referenced standards

DICOM 2007 PS3.4: Storage Service Class

DICOM 2007 PS 3.4: RT Structure Set Storage

3.14.4 Interaction Diagram



3.14.4.1 Registered Structure Set Storage

3.14.4.1.1 Trigger Events

The user of the Registered Contourer selects a one or more Structure Sets to store.

3.14.4.1.2 Message Semantics

The message semantics are defined by the DICOM Storage SOP Class. The Registered Contourer is the storage SCU and the Archive is the storage SCP.

The Contours in the ROI Contour module are restricted to Geometric Type POINT and CLOSED_PLANAR. ROI contours must correspond to exported image plane locations. If a system does not support unequally-spaced slices, for example, that system is responsible for creating a resampled image set (see RO-11) and creating a structure set in which the ROI contours reference the resampled image set. Absence of an ROI contour on a slice between slices on which contours are defined implies that the ROI does not intersect that slice.

An RT Structure Set object generated by a Registered Contourer will reference images from a single series and share the Frame of Reference UID of that series. It is implied that the coordinates in that object will exist in the coordinate system identified by the FoR UID. Finally, contours will exist on the same plane as the referenced image slices.

To make ROI's available to the downstream planning process or to the 2007 Basic RT Objects Interoperability Profile's Contourer actor, the Registrator actor shall be able not only to transform contours from a source Frame of Reference to the Registered Frame of Refererence, but also to resample the contour to the planes of the images referenced in the RT Structure Set which cororesponds to the Registered Frame of Reference.

The set of contours transmitted in an RT Structure Set must not assume interpolation of contours across image slices. Absence of an ROI contour on a slice between slices on which contours are defined implies that the ROI does not intersect that slice.

The MMRO profile has implicit limitations imposed by its dependency on the IHE-RO BRTO profile. These limitations are described in the MMRO Profile description in Volume 1 of the IHE-RO Technical Frameworks.

Also refer to appendix B for an overview of the specific requirements on the DICOM attributes that are included in an RT Structure Set object. In particular, the structure set must share a single frame of reference UID with the images.

3.14.4.1.3 Expected Actions

Upon receipt of the Structure Set, the Archive shall store it. This Structure Set is then available for subsequent retrieval (RO-7 and MMRO-4).

3.14.5 Security Considerations

3.14.5.1 Security Audit Considerations

3.14.5.1.(z) Actor Specific Security Considerations

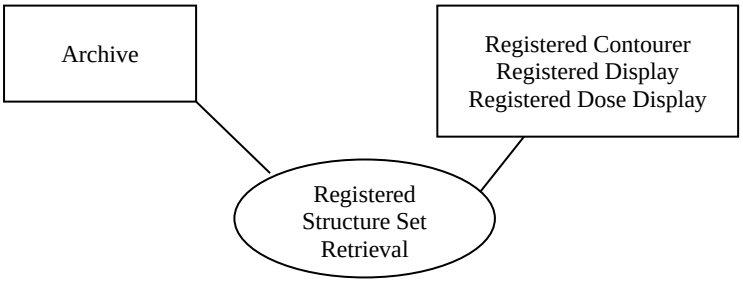
3.15 MMRO-4: Registered Structure Set Retrieval

This section corresponds to Transaction MMRO-4 of the IHE-RO Technical ***Framework. Transaction MMRO-4 is used by the Registered Contourer, Registered Display, Registered Dose Display***, and ***Archive*** actors.

3.15.1 Scope

In the Registered Structure Set Retrieval Transaction, the ***Archive*** stores a Structure Set on a ***Registered Contourer***, ***Registered Display*** or ***Registered Dose Display***.

3.15.2 Use Case Roles



Actor:	Archive
Role:	Send Registered Structure Set instance(s) to the receiving actor
Actor:	Registered Contourer, Registered Display, Registered Dose Display

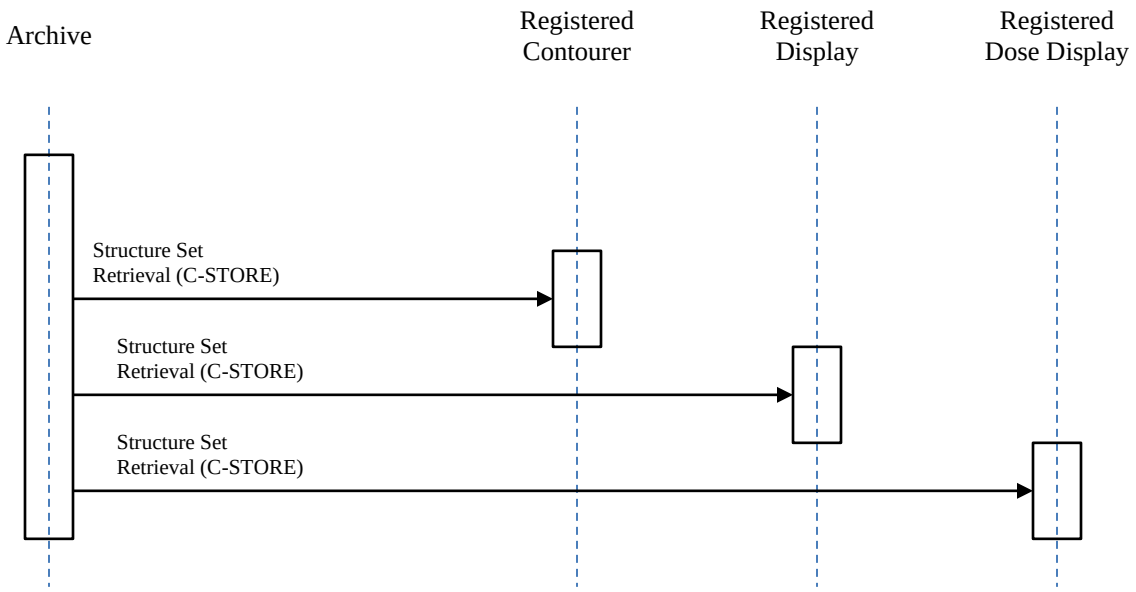
Role:	Receive Registered Structure Set instances from the ***Archive***

3.15.3 Referenced standards

DICOM 2007 PS3.4: Storage Service Class

DICOM 2007 PS 3.4: RT Structure Set Storage

3.15.4 Interaction Diagram



3.15.4.1 Registered Structure Set Retrieval

3.15.4.1.1 Trigger Events

The user of the ***Registered Contourer*** determines that a new set of contours is to be based upon an existing Structure Set, and requests that the ***Archive*** send this Structure Set to the ***Registered Contourer***.

The user of the ***Registered Display*** determines that a display is to be based upon an existing Structure Set, and requests that the ***Archive*** send this Structure Set to the ***Registered Display***.

The user of the ***Registered Dose Display*** determines that a dose display is to be based upon an existing Structure Set, and requests that the ***Archive*** send this Structure Set to the ***Registered Dose Display***.

The mechanism(s) by which these transfers are initiated is outside the scope of this profile.

3.15.4.1.2 Message Semantics

The message semantics are defined by the DICOM Storage SOP Class. The ***Registered Contourer***, ***Registered Display*** or ***Registered Dose Display*** is the storage SCP and the ***Archive*** is the storage SCU.

Absence of an ROI contour on a slice between slices on which contours are defined implies that the ROI does not intersect that slice.

Also refer to appendix B for an overview of the specific requirements on the DICOM attributes that are included in an RT Structure Set object. In particular, the structure set must have the same study instance UID, but a different series instance UID, than the CT image series upon which the contours are based.

3.15.4.1.3 Expected Actions

The ***Registered Contourer*** will upload image data sets, related structure sets and spatial registration objects. It will present the user with a ***Registered Display***, and allow the user to then construct a new set of contours which will later be exported as a new structure set (MMRO-3: Registered Structure Set Storage). The new structure set will have the same Frame of Reference UID and Study Instance UID of the original base image data set and structure set.

The ***Registered Display*** will load image data sets, related structure sets and spatial registration objects. It will display the information to the user.

The ***Registered Dose Display*** will load image data sets, related structure sets, dose and spatial registration objects. It will display the information to the user.

The ***Registered Contourer*** will load all of the Structure Set, and will relate it to images based on the Frame of Reference UID. The contours contained will then be available to the user of the ***Registered Contourer*** for use in construction a new set of contours which will later be exported as a structure set (MMRO-3: Registered Structure Set Storage). This new structure set will have the same frame of reference UID and study instance UID of the original images and structure set.

3.15.5 Security Considerations

3.15.5.1 Security Audit Considerations

3.15.5.1.(z) Actor Specific Security Considerations

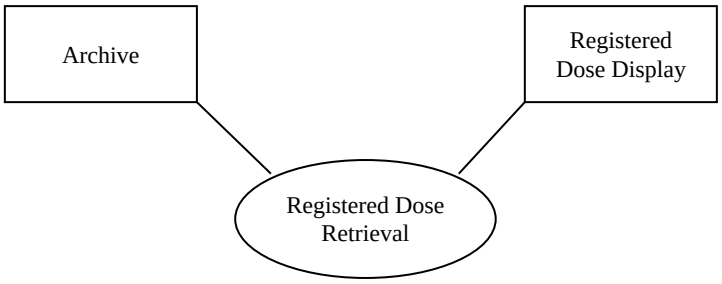
3.16 MMRO-5: Registered Dose Retrieval

This section corresponds to MMRO-5 of the IHE-RO technical framework. Transaction MMRO-5 is used by the ***Archive*** and ***Registered Dose Display*** actor.

3.16.1 Scope

In the Registered Dose Retrieval Transaction, the requested RT Dose is transferred from the ***Archive*** to the ***Registered Dose Display*** actor.

3.16.2 Use Case Roles



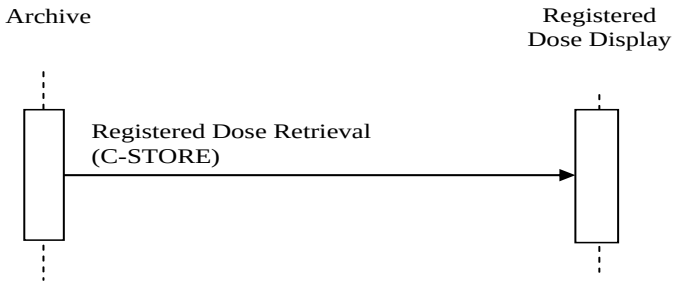
Actor:	Archive
Role:	Sends Registered Dose instance to the ***Registered Dose Display***
Actor:	Registered Dose Display
Role:	Receives the Registered Dose instance from the ***Archive***

3.16.3 Referenced Standards

DICOM 2007 PS3.4: Storage Service Class

DICOM 2007 PS 3.4: RT Dose Storage

3.16.4 Interaction Diagram



3.16.4.1 Registered Dose Retrieval

3.16.4.1.1 Trigger Events

The user of the ***Registered Dose Display*** selects an RT Dose instance for display in the context of a one or more CT Image Sets and the targets and avoidance structures defined by corresponding RT Structure Set.

3.16.4.1.2 Message Semantics

The ***Archive*** uses the DICOM C-STORE message to transfer the dose. The ***Archive*** is the DICOM Storage SCU and the ***Registered Dose Display*** is the DICOM Storage SCP.

This transaction shall support Dose represented as a three-dimensional dose array sampled onto axial image planes in the same DICOM Patient coordinate system Frame of Reference as the diagnostic images used to compute it. The dose image shall be orthogonal with respect to the DICOM patient coordinate system: the value of Image Orientation (Patient) (0020,0037) shall be [±1, 0, 0, 0, ±1, 0], within an uncertainty of 0.001 Radians. Dose Planes may be irregularly spaced, and they need not correspond to image planes.

Not supported are point doses, projection of dose onto an oblique plane, iso-dose contours and dose-volume histograms. The dose pixels shall represent absolute physical dose in units of Gray. The value of Dose Units (3004,0002) shall be GY. The value of Pixel Representation (0016,0103) shall be 0; negative dose values shall not be present.

The MMRO profile has implicit limitations imposed by its dependency on the IHE-RO BRTO profile. These limitations are described in the MMRO Profile description in Volume 1 of the IHE-RO Technical Frameworks.

3.16.4.1.3 Expected Actions

Upon receiving the request for retrieval, the ***Archive*** shall return the requested RT Dose to the ***Registered Dose Display***. The ***Registered Dose Display*** shall validate the received RT Dose. If the received RT Dose is valid, it shall be loaded in the ***Registered Dose Display***. If it is not valid, a warning message shall be displayed to the user, indicating the reason why it is not valid.

The received Dose will be displayed in the same coordinate system as the image set on which it was computed.

3.16.5 Security Considerations

3.16.5.1 Security Audit Considerations

3.16.5.1.(z) Actor Specific Security Considerations

A Attribute Consistency between Composite IODs

A.1 Radiation Oncology Critical Attribute Mapping

Add the 2nd column of the following table to Table A.1-1 structure

Attribute (Tag)	Spatial Registration
Patient's Name (0010,0010)	Copy
Patient ID (0010,0020)	Copy
Patient's Birth Date (0010,0030)	Copy
Patient's Sex (0010,0040)	Copy
Study Instance UID (0020,000D)	Copy from Base Study Images **
Study Date (0008,0020)	Copy from Base Study Images **
Study Time (0008,0030)	Copy from Base Study Images **
Referring Physician's Name (0008,0090)	Copy from Base Study Images **
Study ID (0020,0010)	Copy from Base Study Images **
Accession Number (0008,0050)	Copy from Base Study Images **
Study Description (0008,1030)	Copy from Base Study Images **
Frame of Reference UID (0020,0052)	Copy from Base Study Images **
Position Reference Indicator (0020,1040)	Copy from Base Study Images **

** The Base Study Images are identified as the images which establish the Registered Frame of Reference of the Spatial Registration objects.

A.2 Radiation Oncology Critical Modules

Add the following at the end of Appendix A.2

Table A.2-3 describes requirements, recommendations or explanations on integration-critical DICOM modules for radiation oncology cases. It defines which integration-critical modules need

to be populated for the Spatial Registration IOD. The table follows the structure defined in DICOM PS3.3 section A.1.3.

Table A.2-3 Spatial Registration IOD Modules

IE	Module	Reference	Usage	IHE-RO Usage
Patient	Patient	C.7.1.1	M	M
	Clinical Trial Subject	C.7.1.3	U	U
Study	General Study	C.7.2.1	M	M
	Patient Study	C.7.2.2	U	U
	Clinical Trial Study	C.7.2.3	U	U
Series	General Series	C.7.3.1	M	M
	Clinical Trial Series	C.7.3.2	U	U
	Spatial Registration Series	C.20.1	M	M
Frame of Reference	Frame of Reference	C.7.4.1	M	M
Equipment	General Equipment	C.7.5.1	M	M
Spatial Registration	Spatial Registration	C.20.2	M	M
	Common Instance Reference	C.12.2	M	M
	SOP Common	C.12.1	M	M

A.3 Radiation Oncology Critical Attributes

Edit the tables in A.3 per the instructions below:

The following tables lists redefinitions of attributes within the Multimodality Image Registration for Radiation Oncology Integration Profile, which have already been defined in other integration profiles. Attributes displayed in a light grey value are not modified but only added to provide the context in which a certain attribute enhancement is defined.

Table A.3-12 Structure Set Module Attributes

Attribute	Tag	Type	Attribute Note
Structure Set Label	(3006,0002)	R+	
Structure Set Date	(3006,0008)	R+	
Structure Set Time	(3006,0009)	R+	
Referenced Frame of Reference Sequence	(3006,0010)	R+*	This element is required for all 3D RT Structure Sets which are image based. It is to contain a set of references to the entire set of images which comprise the volume from which the Structure Set was constructed, and which is to be used for planning. There should only be one item in this sequence, as a BRTO Profile-based structure is based on a single set of images, which are all in the same frame of reference.
>Frame of Reference UID	(0020,0052)	R+*	This frame of reference UID shall be the same as the frame of reference of the CT series from which the Structure Set was constructed. It will also be the same as the frame of reference of any related RTPLAN's or RTDOSE's.
>RT Referenced Study Sequence	(3006,0012)	R+*	Shall be present and contain the series sequence. Only one item allowed in this sequence.

Attribute	Tag	Type	Attribute Note
>>Referenced SOP Instance UID	(0008,1155)	R+*	This Study Instance UID shall be the same as the Study Instance UID of the related CT instances.
>>RT Referenced Series Sequence	(3006,0014)	R+*	Shall be present to contain the Contour Image Sequence. Only one item allowed in this sequence.
>>>Series Instance UID	(0020,000E)	R+*	Shall be present and contain the series to which the set of CT images upon which the structure set is based belong.
>>>Contour Image Sequence	(3006,0016)	R+*	Shall be present. Contains an item for each CT image in the volume upon which the Structure Set is based.
>>>>Referenced SOP Class UID	(0008,1155)	R+*	Must be present with a value of enhancement '1.2.840.10008.5.1.4.1.1.2', '1.2.840.10008.5.1.4.1.1.4' or '1.2.840.10008.5.1.4.1.1.128'
>>>>Referenced Frame Number	(0008,1160)	O+*	Shall not be present
Structure Set ROI Sequence	(3006,0020)	R+*	This sequence shall be present. It defines the ROI's in this Structure Set.
>ROI Number	(3006,0022)	R*	This defines an index to be used for referencing a particular ROI item from other sequences. It is required to be unique within the Structure Set in which it is created. No limitation on values other than uniqueness within sequence.
>Referenced Frame of Reference UID	(3006,0024)	R*	This frame of reference UID shall be the same as the frame of reference UID of the CT series from which the Structure Set was constructed. It will also be the same as the frame of reference of any related RTPLAN or RTDOSE instances.
>ROI Name	(3006,0026)	R+	This is the primary identifier for an ROI (from user perspective). Shall be present and should match UI display. Shall be unique within the Structure Set ROI sequence.
>ROI Description	(3006,0028)	O+*	Not required - no compliant implementation shall rely on this element being present for proper operation.
>ROI Volume	(3006,002C)	O+*	Not required - no compliant implementation shall rely on this element being present for proper operation.
>ROI Generation Algorithm	(3006,0036)	R+	Must be present, with a value of AUTOMATIC, SEMIAUTOMATIC, MANUAL, or RESAMPLED. This information may be presented to a user, but no semantics for handling an RTSTRUCT is required for this profile. RESAMPLED indicates that the ROI Contours have been resampled onto a different set of images from those on which the contours were originally created. Implementations which create RTSTRUCT instances must provide an appropriate value.

Add the following at the end of Appendix A.3

Table A.3-16 Spatial Registration Module Attributes

Attribute	Tag	Type	Attribute Note

Attribute	Tag	Type	Attribute Note
Registration Sequence	(0070,0308)	R	A sequence of 2 registration items. The first Frame of Reference will be to the Registered Frame of Reference, the second will define the spatial registration from the specified Frame of Reference to the Registered Frame of Reference.
>Frame of Reference UID	(0020,0052)	R*	Identifies a Frame of Reference that may or may not be an image set (e.g. atlas or physical space). See C.7.4.1.1.1 for further explanation. Shall be present.
>Referenced Image Sequence	(0008,1140)	1C	Identifies the set of images registered in this sequence item.. May be present. No semantics may be inferred from the presence of the image references.
>>Include 'Image SOP Instance Reference Macro' Table 10-3			
>Matrix Registration Sequence	(0070,0309)	R	A sequence that specifies one spatial registration. Exactly one item shall be present
>>Matrix Sequence	(0070,030A)	R	One item shall be present. The item specifies a transformation. See C.20.2.1.1.
>>>Frame of Reference Transformation Matrix	(3006,00C6)	R	A 4x4 homogeneous transformation matrix that registers the referenced images to the Registered Frame of Reference. Matrix elements shall be listed in row-major order. See C.20.2.1.1.
>>>Frame of Reference Transformation Matrix Type	(0070,030C)	R	The only type of Frame of Reference Transformation Matrix (3006,00C6) supported in this profile is RIGID. See C.20.2.1.2

Name Space Additions

Add the following terms to the IHE Namespace: