Digital Imaging and Communications in Medicine (DICOM)

Supplement 73: Spatial Registration Storage SOP Classes

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DICOM Working Group 17

DICOM Standards Committee

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Foreword

This Supplement to the DICOM Standard proposes a Registration SOP Class to align the DICOM Frames of Reference and spatially register image data from independent SOP Class Instances.

This document is a Supplement to the DICOM Standard. It is an extension to the following parts of the published DICOM Standard:

Part 3	Information Object Definitions
Part 4	Service Class Specifications
Part 6	Data Dictionary
Part 16	Content Mapping Resource

Scope and Field of Application

This Supplement introduces a new Registration Information Entity and a Fiducials Information Entity with associated IOD and SOP Classes to specify the spatial relationship between DICOM Frames of Reference and Images using rigid space transformation matrices, scale or affine transformations, and fiducials.

Overview of Registration Encoding

The Registration IOD stores data that registers the Reference Coordinate System of the Registration instance to one or more referenced image Series. This data is in the form of spatial transformation matrices.

The Spatial Fiducials IOD stores spatial fiducials recorded in one or more referenced images.

LIMITATIONS OF CURRENT STANDARD

Limitations include:

- There is no provision to specify the spatial registration of one set of images to another. The concept of DICOM Frame of Reference has no meaning other than to identify that a spatial relationship exists.
- There is no provision to specifiy points in space, independent of pixel or voxel sampling. Because different image sets of the same patient may have different spatial sampling, this capability is important for registration and reporting in multi-modality applications. Moreover, the mapping between physical space and image samples (pixels, voxels, etc.) is ambiguous, except perhaps, for images using the Image Plane Module.
- It is not possible to specifiy the locations of common spatial fiducials for the purpose of specifying the spatial correlation of features in one set of images to another

- It is not possible to specify the results of fusion operation between the objects in different DICOM
60 Frames of Reference

Table of Contents

Part 3 Addendum

1. Add the following informative Annex to PS 3.3

ANNEX X Registration (INFORMATIVE)

X.1 SPATIAL REGISTRATION AND SPATIAL FIDUCIALS SOP CLASSES

These SOP Classes allow describing spatial relationships between sets of referenced images. Each instance can describe any number of registrations created during the course of the work in the current procedural context, as shown in Figure X.1-1. It may also reference prior registration instances that contribute to the creation of the registrations in the instance.

The Spatial Registration instance specifies a transformation from its own local Reference Coordinate System to that of the referenced image sets or atlas. The Reference Coordinate System is a Frame of Reference described by the DICOM Frame of Reference Module. The chosen Frame of Reference of the Registration SOP Instance may be the same as the Referenced SOP Instances. In this case, the Frame of Reference UID (0020,0052) is the same, as shown by Registration A in the figure. The registration information is a sequence of spatial transformation matrices. Images may have no DICOM Frame of Reference in which case the registration is to that single image. A special case is an atlas. An atlas has a Frame of Reference UID defined by DICOM.

The Spatial Fiducials SOP Class stores spatial fiducials as implicit registration information. It is otherwise similar to Spatial Registration.

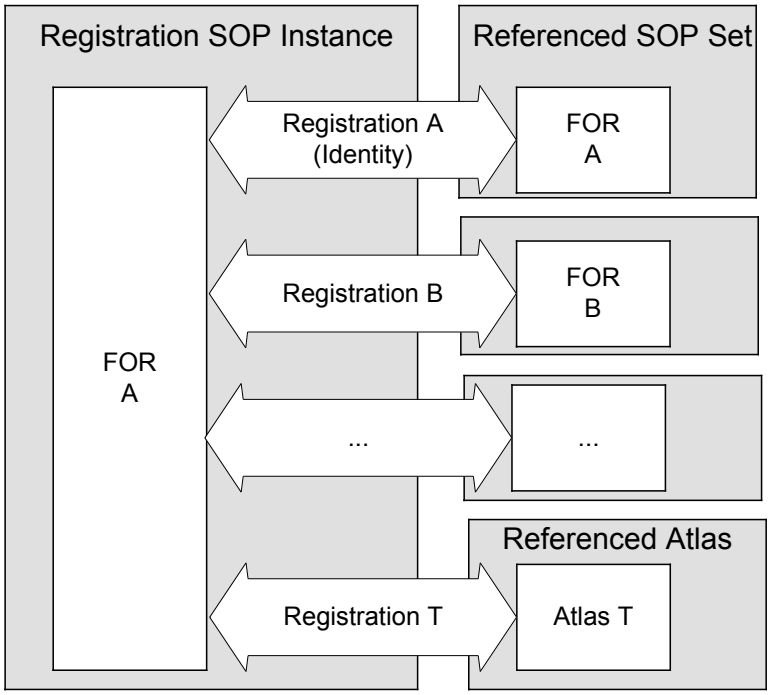


Figure X.1-1 Registration of Image SOP Instances

X.2 FUNCTIONAL USE CASES

Multi-Modality Fusion: A workstation or modality performs a registration of images from independent acquisition modalities—PET, CT, MR, NM, and US—from multiple series. The workstation stores the registration data for subsequent visualization and image processing. Such visualization may include side-by-side synchronized display, or overlay (fusion) of one modality image on the display of another. The processes for such fusion are beyond the scope of the Standard. The workstation may also create and store a ready-for-display fused image, which references both the source image instances and the registration instance that describes their alignment.

Prior Study Fusion: Using post processing or a manual process, a workstation creates a spatial object registration of the current Study's Series from prior Studies for comparative evaluation.

Atlas Mapping: A workstation or a CAD device specifies fiducials of anatomical features in the brain such as the anterior commissure, posterior commissure, and points that define the hemispheric fissure plane. The system stores this information in the Spatial Fiducials SOP Instance. Subsequent retrieval of the fiducials enables a device or workstation to register the patient images to a functional or anatomical atlas, presenting the atlas information as overlays.

CAD: A CAD device creates fiducials of features during the course of the analysis. It stores the locations of the fiducials for future analysis in another imaging procedure. In the subsequent CAD procedure, the CAD device performs a new analysis on the new data set. As before, it creates comparable fiducials, which it may store in a Spatial Fiducials SOP Instance. The CAD device then performs additional analysis by registering the images of the current exam to the prior exam. It does so by correlating the fiducials of the prior and current exam. The CAD device may store the registration in Registration SOP Instance.

Adaptive Radiotherapy: A CT Scan is taken to account for variations in patient position prior to radiation therapy. A workstation performs the registration of the most recent image data to the prior data, corrects the plan, and stores the registration and revised plan.

Image Stitching: An acquisition device captures multiple images, e.g. DX images down a limb. A user identifies fiducials on each of the images. The system stores these in one or more Fiducial SOP Instances. Then the images are "stitched" together algorithmically by means that utilize the Fiducial SOP Instances as input. The result is a single image and optionally a Registration SOP Instance that indicates how the original images can be transformed to a location on the final image.

X.3 SYSTEM INTERACTION

Figure X.3-1 shows the system interaction of storage operations for a registration of MR and CT using the Spatial Registration SOP Class. The Image Plane Module attributes of the CT Series specify the spatial mapping to the RCS of its DICOM Frame of Reference.

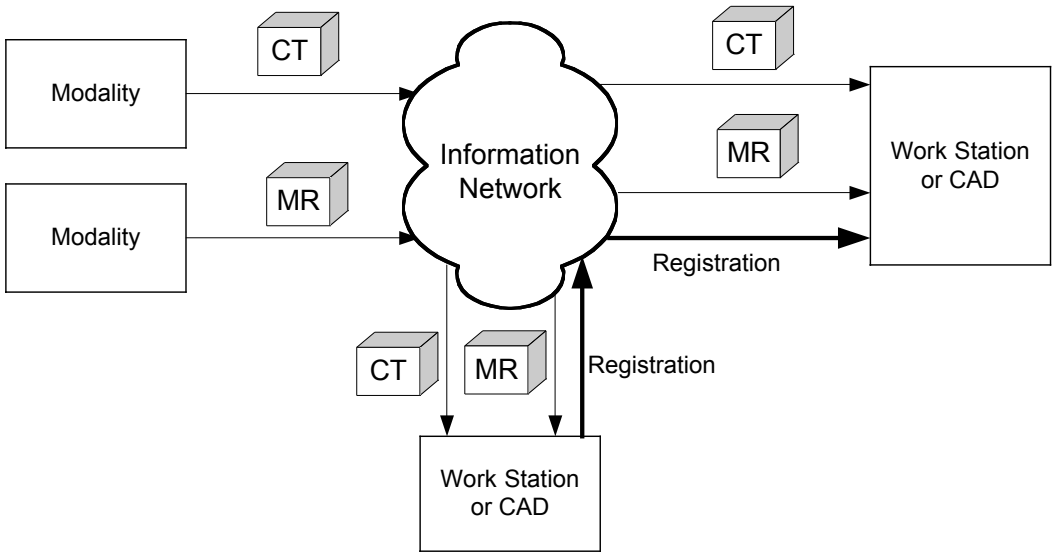


Figure X.3-1 Stored Registration System Interaction

The receiver of the Registration SOP Instance may use the spatial transformation to display or process the referenced image data in a common coordinate system. This enables interactive display in 3D during interpretation or planning, tissue classification, quantification, or Computer Aided Detection. Figure X.3-2 shows a typical interaction scenario.

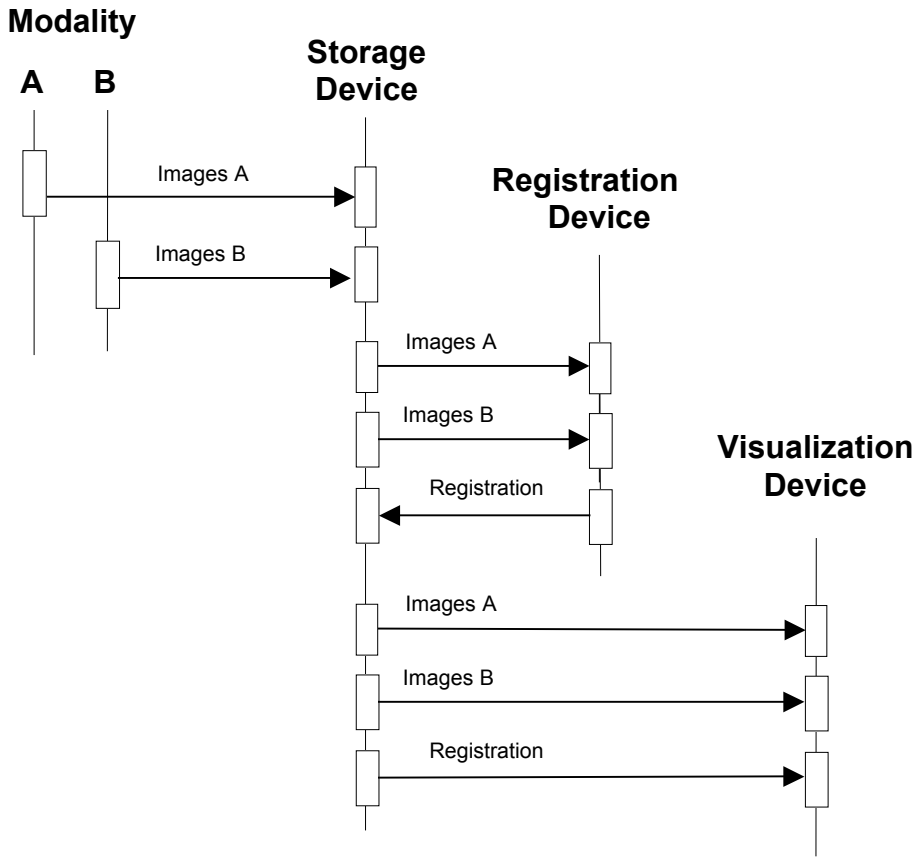


Figure X.3-2 Interaction Scenario

204 In the case of coupled acquisition modalities, one acquisition device may know the spatial relationship of its image data relative to the other. The acquisition device may use the Registration SOP Class to specify the relationship of modality B images to modality A images as shown below in Figure X.3-3. In the most direct case, the data of both modalities are in the same DICOM Frame of Reference for each SOP Class
208 Instance.

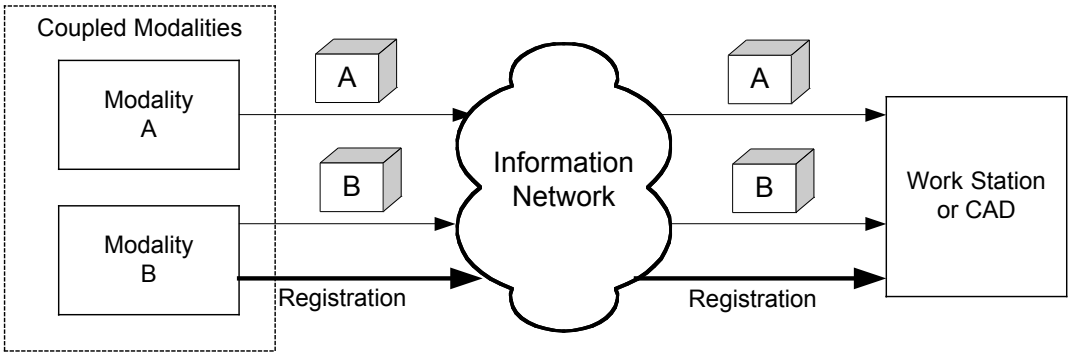


Figure X.3-3 Coupled Modalities

A Spatial Registration instance consists of one or more instances of a Registration. Each Registration specifies a transformation from the RCS of the Referenced Image Set, to the RCS of this Spatial Registration instance (see C.X.2 in Part 3) identified by the Frame of Reference UID (0020,0052).

X.4 OVERVIEW OF ENCODING

Figure X.4-1 shows an information model of a Spatial Registration to illustrate the relationship of the attributes to the objects of the model. The DICOM attributes that describe each object are adjacent to the object.

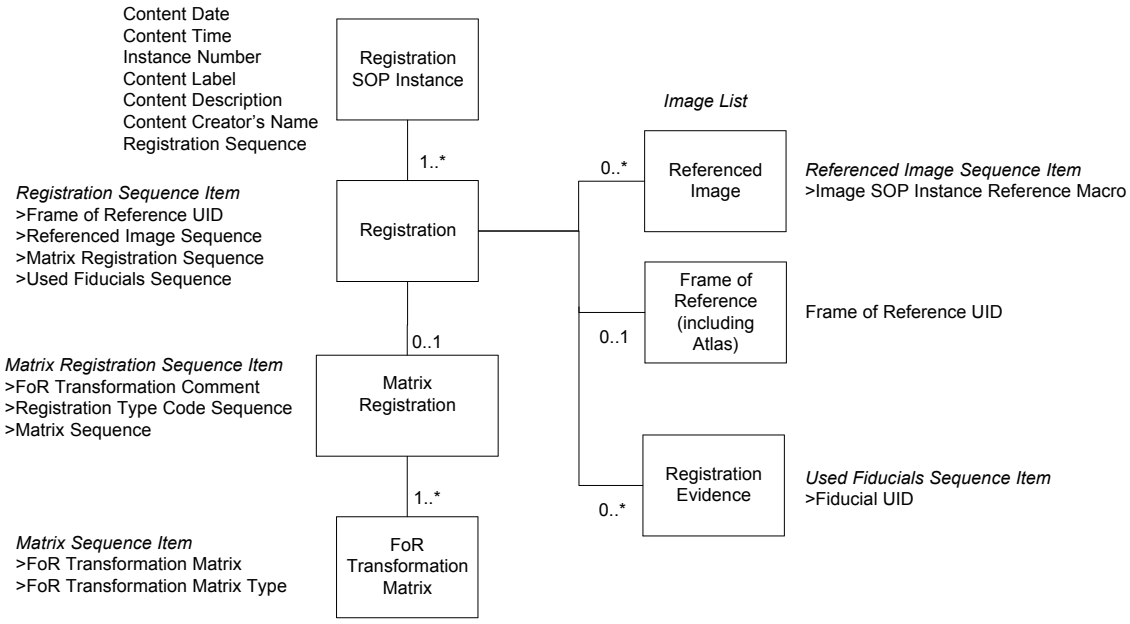


Figure X.4-1 Spatial Registration Encoding

Figure X.4-2 shows a Spatial Fiducials information model to illustrate the relationship of the attributes to the objects of the model. The DICOM attributes that describe each object are adjacent to the object.

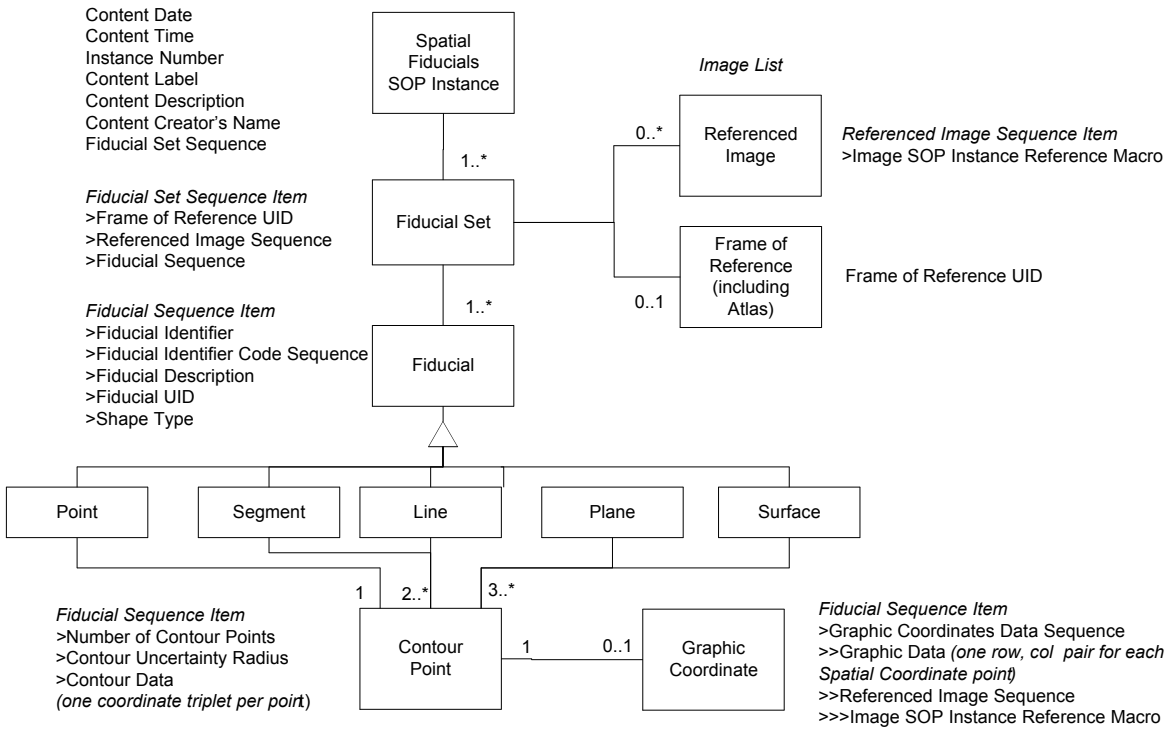


Figure X.4-2 Spatial Fiducials Encoding

X.5 MATRIX REGISTRATION

A 4x4 homogeneous transformation matrix describes spatial rotation, translation, scale changes and affine transformations that register referenced images to the Registration IE's RCS. These steps are expressible in a single matrix, or as a sequence of multiple independent rotations, translations, or scaling, each expressed in a separate matrix. Normally, registrations are rigid body, involving only rotation and translation. Changes in scale or affine transformations occur in atlas registration or to correct minor mismatches.

X.6 SPATIAL FIDUCIALS

Fiducials are image-derived reference markers of location, orientation, or scale. These may be labeled points or collections of points in a data volume that specify a shape. Most commonly, fiducials are individual points.

Correlated fiducials of separate image sets may serve as inputs to a registration process to estimate the spatial registration between similar objects in the images. The correlation may, or may not, be expressed in the fiducial identifiers. A fiducial identifier may be an arbitrary number or text string to uniquely identify each fiducial from others in the set. In this case, fiducial correlation relies on operator recognition and control.

Alternatively, coded concepts may identify the acquired fiducials so that systems can automatically correlate them. Examples of such coded concepts are points of a stereotactic frame, prosthesis points, or well-resolved anatomical landmarks such as bicuspid tips. Such codes could be established and used locally by a department, over a wider area by a society or research study coordinator, or from a standardized set.

The table below shows each case of identifier encoding. A and B represent two independent registrations: one to some image set A, and the other to image set B.

	Fiducial Identifier (0070,0310)	Fiducial Identifier Code Sequence (0070,0311)
Uncorrelated	A: 1, 2, 3 B: 4, 5, 6	A: (1, 99_A_CSD, *label A1*) … B: (4, 99_B_CSD, *label B4*) …
Correlated	A: 1, 2, 3 … B: 1, 2, 3 …	A: (1, 99_MY_CSD, *label 1*) … B: (1, 99_MY_CSD, *label 1*)…

Fiducials may be a point or some other shape. For example, three or more arbitrarily chosen points might designate the inter-hemispheric plane for the registration of head images. Many arbitrarily chosen points may identify a surface such as the inside of the skull.

A fiducial also has a Fiducial UID. This UID identifies the creation of the fiducial and allows other SOP Instances to reference the fiducial assignment.

2. Add Definitions to PS 3.3 of Section 3 Definitions

3.Y MULTI-DIMENSIONAL DEFINITIONS

3.Y.1 Reference Coordinate System (RCS): The RCS is the spatial coordinate system in a DICOM Frame of Reference. It is the chosen origin, orientation and spatial scale of an Image IE in a Cartesian space. The RCS is a right-handed Cartesian coordinate system i.e. the vector cross product of a unit vector along the positive x-axis and a unit vector along the positive y-axis is equal to a unit vector along the positive z-axis. The unit length is one millimeter. Typically, the Image IE contains a spatial mapping that specifies the relationship of the image samples to the Cartesian spatial domains of the RCS.

3.Y.2 Fiducial: A fiducial is some unique feature or landmark suitable as a spatial reference or correlation between similar objects. The fiducial may contribute to the definition of the origin and orientation of a chosen coordinate system. Identifying fiducials in different data sets is a common means to establish the spatial relationship between similar objects.

3.Y.3 Fiducial Point: A Fiducial Point defines a specific location of a Fiducial. A Fiducial Point is relative an image or to an RCS.

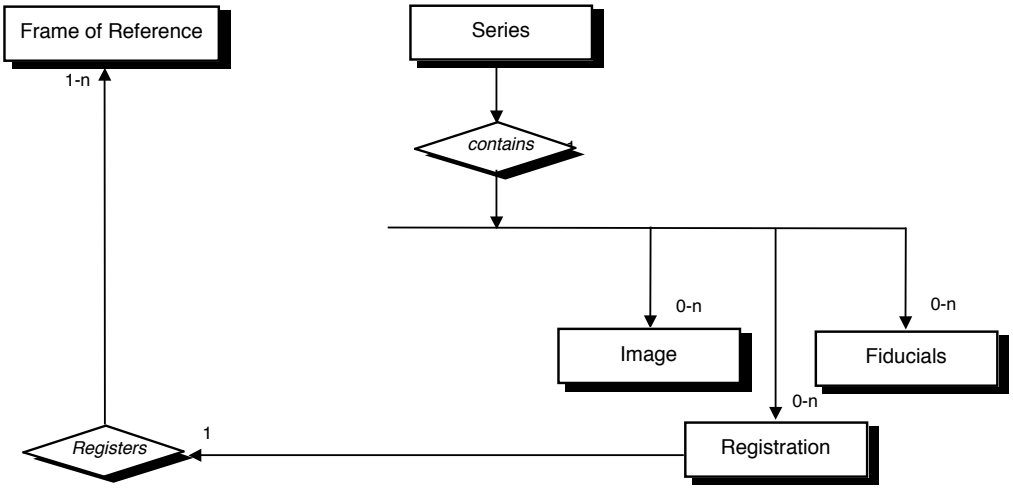
3. Add acronym to Section 4

4 Symbols and abbreviations

The following symbols and abbreviations are used in this Part of the Standard.

…	…
RCS	**Reference Coordinate System**
ROI	Region of interest
…	…

4. Add Spatial Registration IOD into Figure 7-1a and 7-2a.



280

Figure 7-1a DICOM Model of the Real World

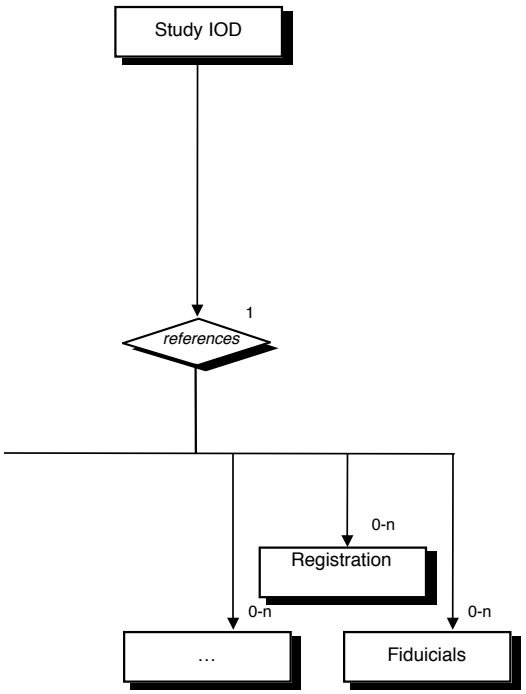


Figure 7-2a DICOM Information Model

5. Add Image SOP Instance Reference Macro

10.2 IMAGE SOP INSTANCE REFERENCE MACRO

Table 10-2
IMAGE SOP INSTANCE REFERENCE MACRO ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Referenced SOP Class UID	(0008,1150)	1	Uniquely identifies the referenced SOP Class.
Referenced SOP Instance UID	(0008,1155)	1	Uniquely identifies the referenced SOP Instance.
Referenced Frame Number	(0008,1160)	1C	Identifies the frame numbers within the Referenced SOP Instance to which the reference applies. The first frame shall be denoted as frame number 1. Note: This Attribute may be multi-valued. Required if the Referenced SOP Instance is a multi-frame image and the reference does not apply to all frames.

10.3 SERIES AND INSTANCE REFERENCE MACRO

Table 10-3 defines the Attributes that list Series and SOP Instances within those Series.

Table 10-3
SERIES AND INSTANCE REFERENCE MACRO ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Referenced Series Sequence	(0008,1115)	1	Sequence of Items each of which includes the Attributes of one Series. One or more Items shall be present.
>Series Instance UID	(0020,000E)	1	Unique identifier of the Series containing the referenced Instances.
>Referenced Instance Sequence	(0008,114A)	1	Sequence of Items each providing a reference to an Instance that is part of the Series defined by Series Instance UID (0020,000E) in the enclosing Item. One or more Items shall be present.
>>Referenced SOP Class UID	(0008,1150)	1	Uniquely identifies the referenced SOP Class.
>>Referenced SOP Instance UID	(0008,1155)	1	Uniquely identifies the referenced SOP Instance.

Annex A Composite information Object Definitions (NORMATIVE)

6. Add new Information Entities in Figure A.1-1

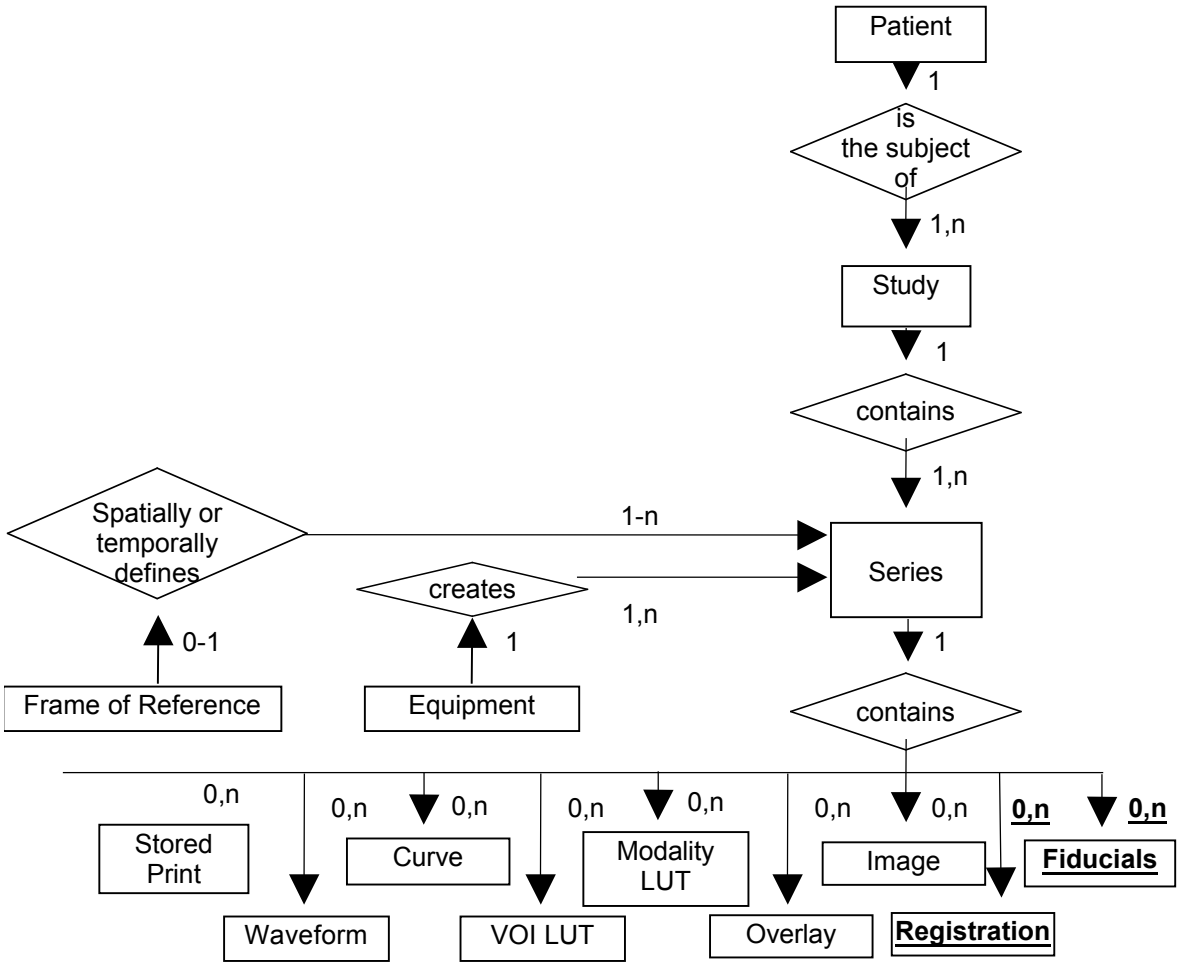


Figure A.1-1
DICOM COMPOSITE INSTANCE IOD INFORMATION MODEL

7. Modify A.1.2.5 Frame of Reference IE

A.1.2.5 FRAME OF REFERENCE IE

The Frame of Reference IE identifies the coordinate system that conveys spatial and/or temporal information of composite instances in a series.

When present, a Frame of Reference IE may be related to one or more series. In this case, it provides the ability to spatially or temporally relate multiple series to each other. **In such cases, the series may share the UID of the Frame of Reference, or alternatively, a Registration SOP Instance may specify the spatial relationship explicitly, as a spatial transformation. A Frame of Reference IE may also spatially register a Frame of Reference to an atlas.**

8. Add new Information Entity in A.1.2.X

A.1.2.X SPATIAL REGISTRATION IE

The Spatial Registration IE specifies a Reference Coordinate System and its spatial relationship to Image IE's that may be in different Frames of Reference. The Frame of Reference Transformation Matrix $^{A}M_{B}$ describes how to transform a point ($^{B}x,^{B}y,^{B}z$) with respect to RCS_B into ($^{A}x,^{A}y,^{A}z$) with respect to RCS_A. ($^{A}x,^{A}y,^{A}z$) = $^{A}\mathbf{M}_{B}$ * ($^{B}x,^{B}y,^{B}z$). The transformation may be orthonormal (no scaling), accounting for rotation and translation, or may be an affine transformation and allow scaling and shearing. The most common example of the use of Registration is registration of multi-modality image sets.

A.1.2.Y SPATIAL FIDUCIALS IE

The Fiducials IE specifies identified common features in referenced images.

9. Add new IOD and Module in Table A.1-2 in section A.1.4

IODs **Modules**	**REG**	**FID**
Patient	**M**	**M**
Specimen Identification	**U**	**U**
Clinical Trial Subject	**U**	**U**
General Study	**M**	**M**
Patient Study	**U**	**U**
Clinical Trial Study	**U**	**U**
General Series	**M**	**M**
Clinical Trial Series	**U**	**U**
Spatial Registration Series	**M**	
Spatial Fiducials Series		**M**
Frame Of Reference	**M**	
…		
General Equipment	**M**	**M**
Spatial Registration	**M**	
Spatial Fiducials		**M**
…		
Common Instance Reference	**M**	**M**
SOP Common	**M**	**M**

10. Add the following to PS 3.3 Annex A

A.X SPATIAL REGISTRATION INFORMATION OBJECT DEFINITION

A.X.1 Spatial Registration IOD Description

The Registration IOD specifies the spatial relationship between Frames of Reference..

A.X.2 Spatial Registration IOD Entity-Relationship Model

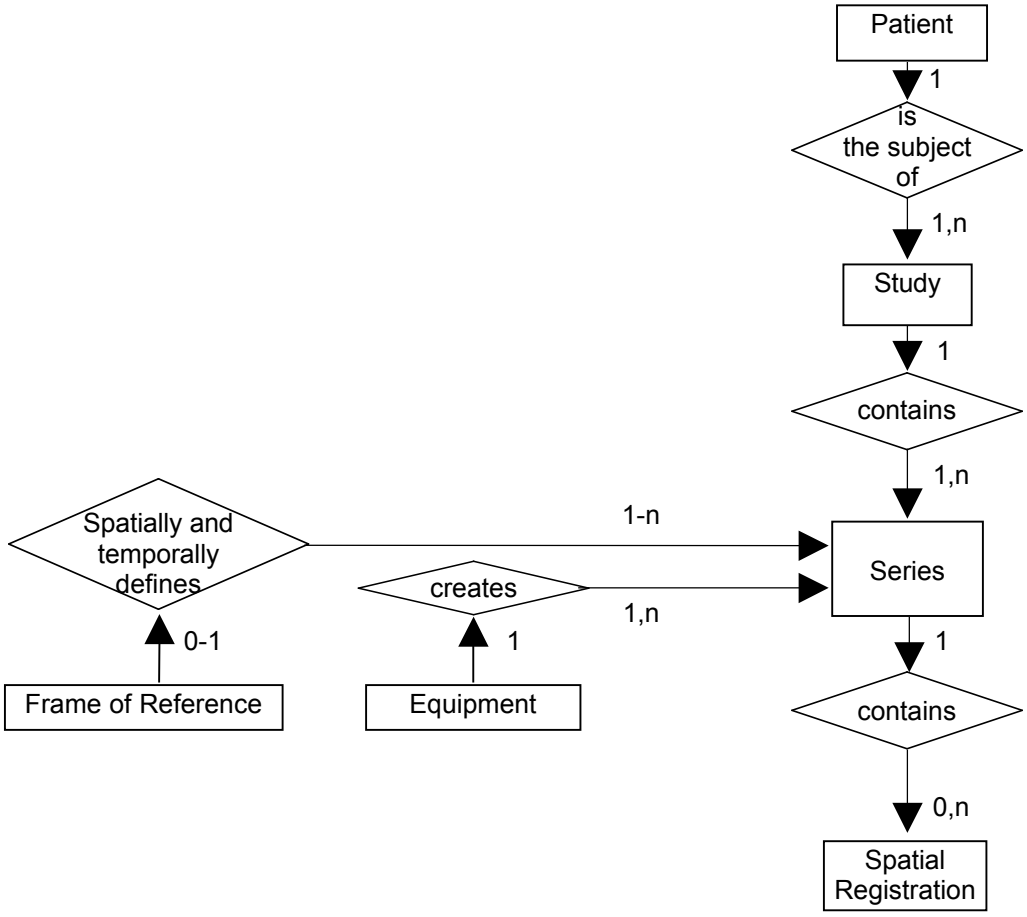


Figure A.X-1 SPATIAL REGISTRATION INFORMATION OBJECT DEFINITION E-R MODEL

A.X.3 Spatial Registration IOD Module Table

Table A.X-1 SPATIAL REGISTRATION 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

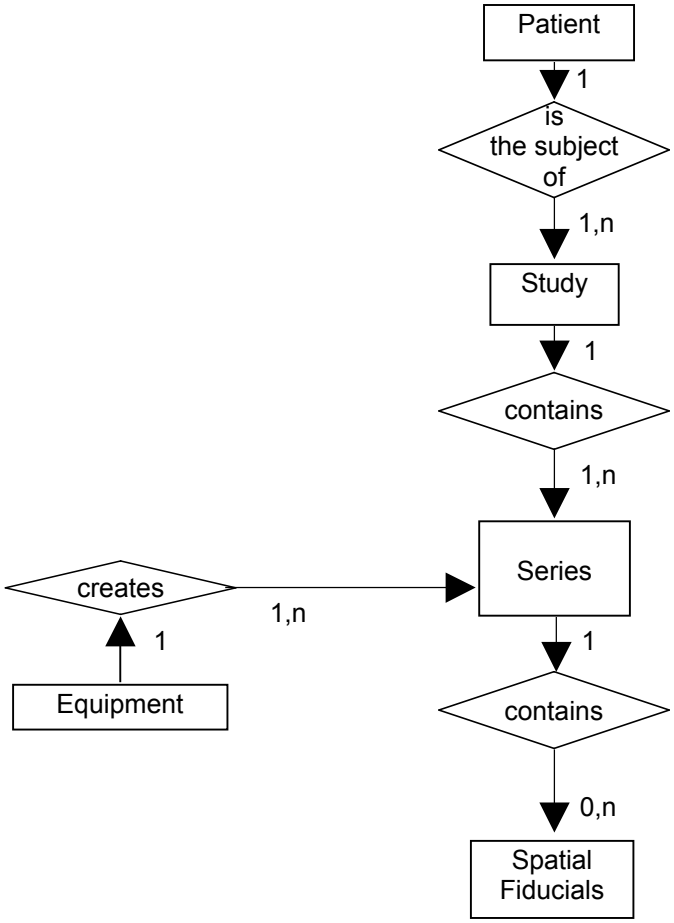
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	General Series	C.7.3.1	M
	Clinical Trial Series	C.7.3.2	U
	Spatial Registration Series	C.X.0	M
Frame of Reference	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
Spatial Registration	Spatial Registration	C.X.1	M
	Common Instance Reference	C.12.2	M
	SOP Common	C.12.1	M

A.Y SPATIAL FIDUCIALS INFORMATION OBJECT DEFINITION

A.Y.1 Spatial Fiducials IOD Description

336 The Fiducials IOD specifies the spatial relationship between the Composite Fiducial instance, to one or more images.

A.Y.2 Spatial Fiducials IOD Entity-Relationship Model



340 **Figure A.Y-1 SPATIAL FIDUCIALS INFORMATION OBJECT DEFINITION E-R MODEL**

A.Y.3 Spatial Fiducials IOD Module Table

Table A.Y-1 SPATIAL FIDUCIALS 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	General Series	C.7.3.1	M
	Clinical Trial Series	C.7.3.2	U
	Spatial Fiducials Series	C.Y.0	M
Equipment	General Equipment	C.7.5.1	M

Spatial Fiducials	Spatial Fiducials	C.Y.1	M
	Common Instance Reference	C.12.2	M
	SOP Common	C.12.1	M

Annex C INFORMATION MODULE DEFINITIONS (NORMATIVE)

11. Append the following paragraph to C.7.6.2.1.1 to clarify with consistent notation of Spatial Mapping in Image Plane Module. This section does not change the meaning of the attributes.

The Image Plane Attributes, in conjunction with the Pixel Spacing Attribute, describe the position and orientation of the image slices relative to the patient-based coordinate system. In each image frame the Image Position (Patient) (0020,0032) specifies the origin of the image with respect to the patient-based coordinate system. RCS and the Image Orientation (Patient) (0020,0037) attribute values specify the orientation of the image frame rows and columns. The mapping of pixel location (i, j) to the RCS is calculated as follows:

$$\begin{bmatrix} P_x \\ P_y \\ P_z \\ 1 \end{bmatrix} = \begin{bmatrix} X_x\Delta i & Y_x\Delta j & 0 & S_x \\ X_y\Delta i & Y_y\Delta j & 0 & S_y \\ X_z\Delta i & Y_z\Delta j & 0 & S_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i \\ j \\ 0 \\ 1 \end{bmatrix} = \mathbf{M} \begin{bmatrix} i \\ j \\ 0 \\ 1 \end{bmatrix}$$

Where:

P_{xyz} The coordinates of the voxel (i,j) in the frame's image plane in units of mm.

S_{xyz} The three values of the Image Position (Patient) (0020,0032) attributes. It is the location in mm from the origin of the RCS.

X_{xyz} The values from the row (X) direction cosine of the Image Orientation (Patient) (0020,0037) attribute.

Y_{xyz} The values from the column (Y) direction cosine of the Image Orientation (Patient) (0020,0037) attribute.

i Column index to the image plane. The first column is index zero.

Δi Column pixel resolution of the Pixel Spacing (0028,0030) attribute in units of mm.

j Row index to the image plane. The first row index is zero.

Δj Row pixel resolution of the Pixel Spacing (0028,0030) attribute in units of mm.

Additional constraints apply:

1) The row and column direction cosine vectors shall be orthogonal, i.e. their dot product shall be zero.

2) The row and column direction cosine vectors shall be normal, i.e. the dot product of each direction cosine vector with itself shall be unity.

12. Add the Registration Module C.X

C.12 GENERAL MODULES

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C.12.2 Common Instance Reference Module

376 Table C.12-7 defines the Attributes that describe the hierarchical relationships of any SOP Instances referenced from other Modules within the Instance in which this Module occurs.

Table C.12-7
COMMON INSTANCE REFERENCE MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Include Series and Instance Reference Macro, Table 10-3.			Identifies all Series within the Study of which this Instance is a part, which Series contain Instances that are referenced elsewhere in this Instance.
Studies Containing Other Referenced Instances Sequence	(0008,1200)	1C	Sequence of items each identifying a Study other than the Study of which this Instance is a part, which Studies contain Instances that are referenced elsewhere in this Instance. One or more Items shall be present. Required if this Instance references Instances in other Studies.
>Study Instance UID	(0020,000D)	1	Unique identifier of the Study containing the referenced Instances.
>Include Series and Instance Reference Macro, Table 10-3.			

380

13. Rename Attributes in Presentation State Module

C.11.10 Presentation State Module

Table C.11.10-1 contains Attributes that identify and describe a Presentation State.

Table C.11.10-1
PRESENTATION STATE MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
…	…	…	…
~~**Presentation**~~ **Content** Label	(0070,0080)	1	A label that is used to identify this presentation. Note: This value may be used by an application as a Defined Term in order to imply some grouping of different presentation states, i.e. it may have the same value for different presentation state instances that share some common concept.
~~**Presentation**~~ **Content** Description	(0070,0081)	2	A description of this presentation.
…	.	…	…
~~**Presentation**~~ **Content** Creator's Name	(0070,0084)	2	Name of operator saving the presentation state (such as a technologist or physician).

14. Add the Registration Modules C.X

C.X SPATIAL REGISTRATION

C.X.0 Spatial Registration Series Module

Table C.X.0-1 defines the general Attributes of the Spatial Registration Series Module.

Table C.X.0-1
SPATIAL REGISTRATION MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Modality	(0008,0060)	1	Modality type. Enumerated Value: REG

C.X.1 Spatial Registration Module

Table C.X.1-1 defines the general Attributes of the Spatial Registration Module.

Table C.X.1-1
SPATIAL REGISTRATION MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Content Date	(0008,0023)	1	The date the content creation started.
Content Time	(0008,0033)	1	The time the content creation started.
Instance Number	(0020,0013)	1	A number that identifies this instance
Content Label	(0070,0080)	1	A label that is used to identify this registration.
Content Description	(0070,0081)	2	A description of this registration.
Content Creator's Name	(0070,0084)	2	Name of operator performing the registration (such as a technologist or physician).
Registration Sequence	(0070,0308)	1	A sequence of one or more registration items. Each item defines a spatial registration to the referenced images in that item. All referenced images are in the same spatial frame of reference or atlas.
>Frame of Reference UID	(0020,0052)	1C	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. Required if Referenced Image Sequence (0008,1140) is absent. May be present otherwise.
>Referenced Image Sequence	(0008,1140)	1C	Identifies the set of images registered in this sequence item. One or more items shall be present. Required if Frame of Reference UID (0020,0052) is absent. May be present otherwise.
>>Include 'Image SOP Instance Reference Macro' Table 10-2			
>Matrix Registration Sequence	(0070,0309)	1	A sequence that specifies one spatial registration. Exactly one item shall be present
>>Frame of Reference Transformation Comment	(3006,00C8)	3	User description or comments about the registration.
>>Registration Type Code Sequence	(0070,030D)	2	Describes the information input into the registration process. Only one item may be present.
>>>Include 'Code Sequence Macro' Table 8.8-1			*Baseline Context ID is 7100*
>>Matrix Sequence	(0070,030A)	1	One or more items shall be present. Each item specifies a transformation. The item order is significant and corresponds to matrix multiplication order. See C.X.1.1.1.
>>>Frame of Reference Transformation Matrix	(3006,00C6)	1	A 4x4 homogeneous transformation matrix that registers the referenced images to the local RCS. Matrix elements shall be listed in row-major order. See C.X.1.1.1.

>>>Frame of Reference Transformation Matrix Type	(0070,030C)	1	Type of Frame of Reference Transformation Matrix (3006,00C6). Defined terms: RIGID RIGID_ SCALE AFFINE See C.X.1.1.2
>Used Fiducials Sequence	(0070,0314)	3	The fiducials used to determine the Frame of Reference Transformation Matrix. One or more Items may be present.
>>Fiducial UID	(0070,031A)	1	The UID that identifies the fiducial used as registration input.

400

C.X.1.1 Registration Module Attribute Descriptions

C.X.1.1.1 Frame of Reference Transformation Matrix

The Frame of Reference Transformation Matrix (3006,00C6) ${}^{A}M_{B}$ describes how to transform a point
404 $({}^{B}x,{}^{B}y,{}^{B}z)$ with respect to RCS_B into $({}^{A}x,{}^{A}y,{}^{A}z)$ with respect to RCS_A according to the equation below.

$$\begin{bmatrix} {}^{A}x \\ {}^{A}y \\ {}^{A}z \\ 1 \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & T_x \\ M_{21} & M_{22} & M_{23} & T_y \\ M_{31} & M_{32} & M_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} {}^{B}x \\ {}^{B}y \\ {}^{B}z \\ 1 \end{bmatrix}$$

The Frame of Reference Transformation Matrix is expressible as multiple matrices, each in a separate item of the Matrix Sequence (0070,030A). The equation below specifies the order of the matrix
408 multiplication where $\mathbf{M_1}$, $\mathbf{M_2}$ and $\mathbf{M_3}$ are the first, second and third items in the sequence.

$$\begin{bmatrix} x' & y' & z' & 1 \end{bmatrix}^T = \mathbf{M}_3 \left(\mathbf{M}_2 \left(\mathbf{M}_1 \begin{bmatrix} x & y & z & 1 \end{bmatrix}^T \right) \right)$$

$$\text{where } \begin{bmatrix} x & y & z & 1 \end{bmatrix}^T = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Registration often involves two or more RCS, each with a corresponding Frame of Reference
412 Transformation Matrix. For example, another Frame of Reference Transformation Matrix ${}^{A}M_{C}$ can describe how to transform a point $({}^{C}x,{}^{C}y,{}^{C}z)$ with respect to RCS_C into $({}^{A}x,{}^{A}y,{}^{A}z)$ with respect to RCS_A. It is straightforward to find the Frame of Reference Transformation Matrix ${}^{B}M_{C}$ that describes how to transform the point $({}^{C}x,{}^{C}y,{}^{C}z)$ with respect to RCS_C into the point $({}^{B}x,{}^{B}y,{}^{B}z)$ with respect to RCS_B. The solution is to
416 invert ${}^{A}M_{B}$ and multiply by ${}^{A}M_{C}$, as shown below:

$$\begin{bmatrix} {}^{B}x \\ {}^{B}y \\ {}^{B}z \\ 1 \end{bmatrix} = ({}^{A}\grave{\mathbf{I}}_{B})^{-1} * {}^{A}\mathbf{M}_{C} \begin{bmatrix} {}^{C}x \\ {}^{C}y \\ {}^{C}z \\ 1 \end{bmatrix}$$

C.X.1.1.2 Frame of Reference Transformation Matrix Type

There are three types of Registration Matrices:

RIGID: This is a registration involving only translations and rotations. Mathematically, the matrix is constrained to be orthonormal and describes six degrees of freedom: three translations, and three rotatations.

RIGID_SCALE: This is a registration involving only translations, rotations and scaling. Mathematically, the matrix is constrained to be orthogonal and describes nine degrees of freedom: three translations, three rotations and three scales. This type of transformation is sometimes used in atlas mapping.

AFFINE: This is a registration involving translations, rotations, scaling and shearing. Mathematically, there are no constraints on the elements of the Frame of Reference Transformation Matrix, so it conveys twelve degrees of freedom. This type of transformation is sometimes used in atlas mapping.

See the Annex Z on Transforms and Mappings for more detail.

15. Add the Fiducial Modules C.Y

C.Y SPATIAL FIDUCIALS

C.Y.0 Spatial Fiducials Series Module

Table C.Y.0-1 defines the general Attributes of the Spatial Fiducials Series Module.

Table C.Y.0-1
SPATIAL FIDUCIALS SERIES MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Modality	(0008,0060)	1	Modality type. Enumerated Value: FID

C.Y.1 Spatial Fiducials Module

Table C.Y.1-1 defines the general Attributes of the Registration.

Table C.Y.1-1
SPATIAL FIDUCIALS MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Content Date	(0008,0023)	1	The date the content creation started.
Content Time	(0008,0033)	1	The time the content creation started.
Instance Number	(0020,0013)	1	A number that identifies this instance
Content Label	(0070,0080)	1	A label that is used to identify this registration.
Content Description	(0070,0081)	2	A description of this registration.
Content Creator's Name	(0070,0084)	2	Name of operator performing the registration (such as a technologist or physician).
Fiducial Set Sequence	(0070,031C)	1	A sequence of one or more items, each of which is a fiducial set.
>Frame of Reference UID	(0020,0052)	1C	Identifies a Frame of Reference that may or may not be an image set (e.g. an atlas or physical space). See C.7.4.1.1.1 for further explanation. Required if Referenced Image Sequence (0008,1140) is absent. May be present otherwise.
>Referenced Image Sequence	(0008,1140)	1C	Identifies the set of images in which the fiducials are located. Required if Frame of Reference UID (0020,0052) is absent. May be present otherwise. One or more Items shall be present. All referenced images shall have the same Frame of Reference UID if present in the images.
>>Include 'Image SOP Instance Reference Macro' Table 10-2			
>Fiducial Sequence	(0070,031E)	1	A sequence that specifies one or more fiducials, one item per fiducial.
>>Fiducial Identifier	(0070,0310)	1	A fiducial assignment identifier that is unique within this Fiducial Sequence item but may match the fiducial identifier of an equivalent feature in another item.
>>Fiducial Identifier Code Sequence	(0070,0311)	1C	A code sequence for a term that identifies a well-known fiducial type (potentially including methodology, anatomy, tools, etc.). Only one item shall be present. Required if Identifier (0070,0310) is absent. May be present otherwise.
>>>Include 'Code Sequence Macro' Table 8.8-1			*DCID 7101*
>>Fiducial UID	(0070,031A)	3	Globally unique identifier for the fiducial instance of this fiducial assignment.
>>Fiducial Description	(0070,030F)	3	User description or comments about the fiducial.

>>Shape Type	(0070,0306)	1	See C.Y.1.1.1 for defined terms.
>>Number of Contour Points	(3006,0046)	1C	Number of points (triplets) in Contour Data (3006,0050). Required if Contour Data is present.
>>Contour Data	(3006,0050)	1C	Specifies the coordinates of this item's fiducial. One triplet (x,y,z) shall be present for each point in the fiducial. See C.Y.1.1.2 for further explanation. Required if Frame of Reference UID (0020,0052) is present in this item of the Fiducial Set Sequence (0070,031C). Shall not be present otherwise.
>>Contour Uncertainty Radius	(0070,0312)	3	The estimated uncertainty radius for the Contour Data in mm. See C.Y.1.1.3
>>Graphic Coordinates Data Sequence	(0070,0318)	1C	The image pixel locations of the fiducial's points. Shall contain one or more items. More than one item shall be present only if a fiducial spans more than one image. Required if Contour Data is not present. May be present otherwise.
>>>Graphic Data	(0070,0022)	1	Graphic point coordinates of the fiducial points in the image of the Referenced Image Sequence. The points correlate to Fiducial's Contour Data (3006,0050), if present, one row-column pair for each point and in the same order. See C.10.5.1.2 for further explanation.
>>>Referenced Image Sequence	(0008,1140)	1	A sequence that specifies the image containing the fiducial's graphic coordinates. Only one item shall be present. Shall be an image within the set of the images in the Referenced Image Sequence (0008,1140) of the encapsulating Fiducial Set Sequence (0070,031C) item.
>>>>Include 'Image SOP Instance Reference Macro' Table 10-2			

C.Y.1.1 Spatial Fiducials Module Attribute Descriptions

444 #### C.Y.1.1.1 Shape Type

For convenient registration, correlated Fiducials exist in each image set of the Registration Sequence. Correlated Fiducials are identified with either Fiducial Identifier (0070,0310) or Fiducial Identifier Code Sequence (0070,0311).

448

Shape Type (0070,0306) defines the geometric interpretation of the Contour Data (3006,0050). Defined Terms are:

POINT = a single triplet (x,y,z) designating a single fiducial point.

452 Note: A point may be the epicenter of a more complex shape such as sphere.

LINE = two points that specify a line or axis such as the inter-orbital line. The point locations have no significance other than identifying the line, i.e. they are not line segment end points.

PLANE = three points that identify a plane such as the laterality plane

SURFACE = three or more points (usually many) that reside on, or near, a region of a curved surface. The surface may be flat or curved, closed or open. The point order has no significance.

RULER = two or more evenly spaced collinear points ordered sequentially along the line, such as a physical ruler placed in the imaging field.

L-SHAPE = three points of two perpendicular line segments, AB and BC, having a common end point B. The order of the points is: ABC. May represent an L-shaped marker placed in the imaging field.

T-SHAPE = three points of two perpendicular line segments AB and CD, such that C bisects AB. The order is ABD.

SHAPE = three or more points that specify the shape of a well-known fiducial type. The term in the Fiducial Identifier Code Sequence (0070,0311) defines the shape and the order of the points that represent it.

C.Y.1.1.2 Contour Data

Contour Data (3006,0050) is an ordered set of triplets that defines a shape. The triplets (x,y,z) denote points in the Reference Coordinate System of the Registration Instance.

Note: Contours may associate observational data with a set of Image features or specify coordinates that are input data for a measurement.

C.Y.1.1.3 Contour Uncertainty Radius

The uncertainty is an estimate of the standard deviation of the fiducial location process.

Add Fiducial and Registration records to Table F.3-3:

476

Table F.3-3
DIRECTORY INFORMATION MODULE

Attribute Name	Tag	Type	Attribute Description
…	…	…	…
>Directory Record Type	(0004,1430)	1C	Defines a specialized type of Directory Record by reference to its position in the Media Storage Directory Information Model (see Section F.4). Required if the Directory Record Sequence (0004,1220) is not zero length. Enumerated Values (see Section F.5): PATIENT STUDY SERIES IMAGE OVERLAY MODALITY LUT VOI LUT CURVE TOPIC VISIT RESULTS INTERPRETATION STUDY COMPONENT STORED PRINT RT DOSE RT STRUCTURE SET RT PLAN RT TREAT RECORD PRESENTATION WAVEFORM SR DOCUMENT KEY OBJECT DOC SPECTROSCOPY RAW DATA **REGISTRATION FIDUCIAL** PRIVATE = Privately defined record hierarchy position. Type shall be defined by Private Record UID (0004,1432). MRDR = Special Directory Record which allows indirect reference to a File by multiple Directory Records. Instead of directly referencing a File by its Referenced File ID (0004,1500), a Directory Record of any of the Types define above (except MRDR) may reference a Multi-Referenced File Directory Record which in turn will reference the File by its File ID. Note: Enumerated Values PRINT QUEUE, FILM SESSION, FILM BOX, and IMAGE BOX were previously defined in DICOM for this Attribute. They are now retired. See PS3.3-1998.
…	…	…	…

480 *Add Spectroscopy and Raw Data records to Table F.4-1:*

Table F.4-1
RELATIONSHIP BETWEEN DIRECTORY RECORDS

Directory Record Type	Section	Directory Record Types which may be included in the

		next lower-level directory Entity
(Root Directory Entity)	—	PATIENT, TOPIC, PRIVATE
PATIENT	F.5.1	STUDY, PRIVATE
STUDY	F.5.2	SERIES, VISIT, RESULTS, STUDY COMPONENT PRIVATE
SERIES	F.5.3	IMAGE, OVERLAY, MODALITY LUT, VOI LUT, CURVE, STORED PRINT, RT DOSE, RT STRUCTURE SET, RT PLAN, RT TREAT RECORD, PRESENTATION, WAVEFORM, SR DOCUMENT, KEY OBJECT DOC, SPECTROSCOPY, RAW DATA, **REGISTRATION, FIDUCIAL,** PRIVATE,
IMAGE	F.5.4	PRIVATE
OVERLAY	F.5.5	PRIVATE
MODALITY LUT	F.5.6	PRIVATE
VOI LUT	F.5.7	PRIVATE
CURVE	F.5.8	PRIVATE
STORED PRINT	F.5.18	PRIVATE
RT DOSE	F.5.19	PRIVATE
RT STRUCTURE SET	F.5.20	PRIVATE
RT PLAN	F.5.21	PRIVATE
RT TREAT RECORD	F.5.22	PRIVATE
PRESENTATION	F.5.23	PRIVATE
WAVEFORM	F.5.24	PRIVATE
SR DOCUMENT	F.5.25	PRIVATE
KEY OBJECT DOC	F.5.26	PRIVATE
SPECTROSCOPY	F.5.27	PRIVATE
RAW DATA	F.5.28	PRIVATE
REGISTRATION	**F.5.29**	**PRIVATE**
FIDUCIAL	**F.5.30**	**PRIVATE**
TOPIC	F.5.9	STUDY, SERIES, IMAGE, OVERLAY, MODALITY LUT, VOI LUT, CURVE, STORED PRINT, RT DOSE, RT STRUCTURE SET, RT PLAN, RT TREAT RECORD, PRESENTATION, WAVEFORM, SR DOCUMENT, KEY OBJECT DOC, SPECTROSCOPY, RAW DATA, **REGISTRATION, FIDUCIAL,** PRIVATE,
VISIT	F.5.10	PRIVATE
RESULTS	F.5.11	INTERPRETATION, PRIVATE
INTERPRETATION	F.5.12	PRIVATE
STUDY COMPONENT	F.5.13	PRIVATE
PRIVATE	F.6.1	PRIVATE, (any of the above as privately defined)
MRDR	F.6.2	(Not applicable)

Note: Directory Record Types PRINT QUEUE, FILM SESSION, FILM BOX, and IMAGE BOX were previously defined in DICOM. They have been retired. See PS 3.3-1998.

Add Registration and Fiducial records to figure F.4-1.

Amend Attribute Names in existing Table F.5-23.

F.5.23 Presentation State Directory Record Definition

…

Table F.5-23
PRESENTATION KEYS

Key	Tag	Type	Attribute Description
…	…	…	…
~~**Presentation**~~ **Content** Label	(0070,0080)	1	A label that is used to identify this presentation.
~~**Presentation**~~ **Content** Description	(0070,0081)	2	A description of this presentation.
…	…	…	…
~~**Presentation**~~ **Content** Creator's Name	(0070,0084)	2	Name of operator saving the presentation state (such as a technologist or physician).
…	…	…	…

Add Registration and Fiducial record definition sections:

F.5.29 Registration directory record definition

The Directory Record is based on the specification of Section F.3. It is identified by a Directory Record Type of Value "REGISTRATION." Table F.5-29 lists the set of keys with their associated Types for such a Directory Record Type. The description of these keys may be found in the Modules related to the Spatial Registration IE of the Spatial Registration IOD. This Directory Record shall be used to reference a Spatial Registration SOP Instance. This type of Directory Record may reference a Lower-Level Directory Entity that includes one or more Directory Records as defined in Table F.4-2.

Table F.5-29
REGISTRATION KEYS

Key	Tag	Type	Attribute Description
Specific Character Set	(0008,0005)	1C	Required if an extended or replacement character set is used in one of the keys.
Content Date	(0008,0023)	1	The date the content creation started.

Content Time	(0008,0033)	1	The time the content creation started.
Instance Number	(0020,0013)	1	A number that identifies this instance
Content Label	(0070,0080)	1	A label that is used to identify this registration.
Content Description	(0070,0081)	2	A description of this registration.
Content Creator's Name	(0070,0084)	2	Name of operator performing the registration (such as a technologist or physician).
Any other Attribute of the Spatial Registration IE Modules		3	

Note: Because (0004,1511) Referenced SOP Instance UID in File may be used as a "pseudo" Directory Record Key (See Table F.3-3), it is not duplicated in this list of keys.

F.5.30 Fiducial directory record definition

The Directory Record is based on the specification of Section F.3. It is identified by a Directory Record Type of Value "FIDUCIAL." Table F.5-30 lists the set of keys with their associated Types for such a Directory Record Type. The description of these keys may be found in the Modules related to the Spatial Fiducials IE of Spatial Fiducials IOD. This Directory Record shall be used to reference a Spatial Fiducials SOP Instance. This type of Directory Record may reference a Lower-Level Directory Entity that includes one or more Directory Records as defined in Table F.4-2.

Table F.5-30
FIDUCIAL KEYS

Key	Tag	Type	Attribute Description
Specific Character Set	(0008,0005)	1C	Required if an extended or replacement character set is used in one of the keys.
Content Date	(0008,0023)	1	The date the content creation started.
Content Time	(0008,0033)	1	The time the content creation started.
Instance Number	(0020,0013)	1	A number that identifies this instance
Content Label	(0070,0080)	1	A label that is used to identify this registration.
Content Description	(0070,0081)	2	A description of this registration.
Content Creator's Name	(0070,0084)	2	Name of operator performing the registration (such as a technologist or physician).
Any other Attribute of the Spatial Fiducials IE Modules		3	

Note: Because (0004,1511) Referenced SOP Instance UID in File may be used as a "pseudo" Directory Record Key (See Table F.3-3), it is not duplicated in this list of keys.

528

532

536

Part 4 Addendum

540

544

16. Add to PS3.4 Section B.5

B.5 STANDARD SOP CLASSES

548 **Table B.5-1**
STANDARD SOP CLASSES

SOP Class Name	SOP Class UID	IOD (See PS 3.3)
…		
Spatial Registration Storage	**1.2.840.10008.5.1.4.1.1.66.1**	**Spatial Registration IOD**
Spatial Fiducials Storage	**1.2.840.10008.5.1.4.1.1.66.2**	**Spatial Fiducials IOD**

17. Add to PS3.4 Section I.4

I.4 MEDIA STANDARD STORAGE SOP CLASSES

552 **Table I.4-1**
Media Storage Standard SOP Classes

SOP Class Name	SOP Class UID	IOD (See PS 3.3)
…		
Spatial Registration Storage	**1.2.840.10008.5.1.4.1.1.66.1**	**Spatial Registration IOD**
Spatial Fiducials Storage	**1.2.840.10008.5.1.4.1.1.66.2**	**Spatial Fiducials IOD**

Part 6 Addendum

18. Change the names of the following Data Elements to Part 6 Annex A:

Tag	Name	VR	VM
(0070,0080)	~~**Presentation**~~ **Content** Label	CS	1
(0070,0081)	~~**Presentation**~~ **Content** Description	LO	1
(0070,0084)	~~**Presentation**~~ **Content** Creator's Name	PN	1

19. Add the following Data Elements to Part 6 Annex A:

Tag	Name	VR	VM
(0008,1200)	Studies Containing Other Referenced Instances Sequence	SQ	1
(0070,0306)	Shape Type	CS	1
(0070,0308)	Registration Sequence	SQ	1
(0070,0309)	Matrix Registration Sequence	SQ	1
(0070,030A)	Matrix Sequence	SQ	1
(0070,030C)	Frame of Reference Transformation Matrix Type	CS	1
(0070,030D)	Registration Type Code Sequence	SQ	1
(0070,030F)	Fiducial Description	ST	1
(0070,0310)	Fiducial Identifier	SH	1
(0070,0311)	Fiducial Identifier Code Sequence	SQ	1
(0070,0312)	Contour Uncertainty Radius	FD	1
(0070,0314)	Used Fiducials Sequence	SQ	1
(0070,0318)	Graphic Coordinates Data Sequence	SQ	1
(0070,031A)	Fiducial UID	UI	1
(0070,031C)	Fiducial Set Sequence	SQ	1
(0070,031E)	Fiducial Sequence	SQ	1

ANNEX A (NORMATIVE): REGISTRY OF DICOM UNIQUE IDENTIFIERS (UID)

20. Add the following UIDs to Part 6 Annex A:

UID Value	UID NAME	UID TYPE	Part
…			
1.2.840.10008.5.1.4.1.1.66.1	Spatial Registration Storage	SOP Class	PS 3.4
1.2.840.10008.5.1.4.1.1.66.2	Spatial Fiducials Storage	SOP Class	PS 3.4
1.2.840.10008.1.4.1.1	Talairach Brain Atlas Frame of Reference	Well-known frame of reference	-
1.2.840.10008.1.4.1.2	SPM2 T1 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.3	SPM2 T2 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.4	SPM2 PD Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.5	SPM2 EPI Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.6	SPM2 FIL T1 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.7	SPM2 PET Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.8	SPM2 TRANSM Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.9	SPM2 SPECT Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.10	SPM2 GRAY Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.11	SPM2 WHITE Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.12	SPM2 CSF Frame of Reference	Well-known frame of reference	

1.2.840.10008.1.4.1.13	SPM2 BRAINMASK Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.14	SPM2 AVG305T1 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.15	SPM2 AVG152T1 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.16	SPM2 AVG152T2 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.17	SPM2 AVG152PD Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.1.18	SPM2 SINGLESUBJT1 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.2.1	ICBM 452 T1 Frame of Reference	Well-known frame of reference	
1.2.840.10008.1.4.2.2	ICBM Single Subject MRI Frame of Reference	Well-known frame of reference	

564

21. Add a new table of Well-known frame of reference references to Part 6 Annex A:

UID Value	UID NAME	Normative Reference
1.2.840.10008.1.4.1.1	Talairach Brain Atlas Frame of Reference	Talairach J. and Tournoux P. *Co-Planar stereotactic atlas of the human brain.* Stutgart: Georg Thieme Verlag, 1988.
1.2.840.10008.1.4.1.2	SPM2 T1 Frame of Reference	SPM2 /templates/T1.mnc
1.2.840.10008.1.4.1.3	SPM2 T2 Frame of Reference	SPM2 /templates/T2.mnc
1.2.840.10008.1.4.1.4	SPM2 PD Frame of Reference	SPM2 /templates/PD.mnc
1.2.840.10008.1.4.1.5	SPM2 EPI Frame of Reference	SPM2 /templates/EPI.mnc
1.2.840.10008.1.4.1.6	SPM2 FIL T1 Frame of Reference	SPM2 /templates/filT1.mnc
1.2.840.10008.1.4.1.7	SPM2 PET Frame of Reference	SPM2 /templates/PET.mnc

1.2.840.10008.1.4.1.8	SPM2 TRANSM Frame of Reference	SPM2 /templates/Transm.mnc
1.2.840.10008.1.4.1.9	SPM2 SPECT Frame of Reference	SPM2 /templates/SPECT.mnc
1.2.840.10008.1.4.1.10	SPM2 GRAY Frame of Reference	SPM2 /apriori/gray.mnc
1.2.840.10008.1.4.1.11	SPM2 WHITE Frame of Reference	SPM2 /apriori/white.mnc
1.2.840.10008.1.4.1.12	SPM2 CSF Frame of Reference	SPM2 /apriori/csf.mnc
1.2.840.10008.1.4.1.13	SPM2 BRAINMASK Frame of Reference	SPM2 /apriori/brainmask.mnc
1.2.840.10008.1.4.1.14	SPM2 AVG305T1 Frame of Reference	SPM2 /canonical/avg305T1.mnc
1.2.840.10008.1.4.1.15	SPM2 AVG152T1 Frame of Reference	SPM2 /canonical/avg152T1.mnc
1.2.840.10008.1.4.1.16	SPM2 AVG152T2 Frame of Reference	SPM2 /canonical/avg152T2.mnc
1.2.840.10008.1.4.1.17	SPM2 AVG152PD Frame of Reference	SPM2 /canonical/avg152PD.mnc
1.2.840.10008.1.4.1.18	SPM2 SINGLESUBJT1 Frame of Reference	SPM2 /canonical/single_subj_T1.mnc
1.2.840.10008.1.4.2.1	ICBM 452 T1 Frame of Reference	ICBM452 T1 Atlas
1.2.840.10008.1.4.2.2	ICBM Single Subject MRI Frame of Reference	ICBM Single Subject MRI Anatomical Template

568 **SPM2 (Statistical Parametric Mapping) templates are available at http://www.fil.ion.ucl.ac.uk/~spm/, and they are described at http://www.fil.ion.ucl.ac.uk/~spm/templates/.**

ICBM templates are available at http://www.loni.ucla.edu/ICBM/ICBM_ICBMAtlases.html.

572

Part 16 Addendum

576

22. Add the following Context Groups to Part 16 Annex B

Annex B DCMR Context Groups (Normative)

CID 7100 RCS Registration Method Type

580 **Context ID 7100**

RCS Registration Method Type

Type: Extensible Version: 20040115

Coding Scheme Designator (0008,0102)	Code Value (0008,0100)	Code Meaning (0008,0104)
DCM	125021	Frame of Reference Identity
DCM	125023	Acquisition Equipment Alignment
DCM	125025	Visual Alignment
DCM	125022	Fiducial Alignment
DCM	125024	Image Content-based Alignment

584 **CID 7101 Brain Atlas Fiducials**

Context ID 7101

Brain Atlas Fiducials

Type: Extensible Version: 20040115

Coding Scheme Designator (0008,0102)	Code Value (0008,0100)	Code Meaning (0008,0104)
DCM	125030	Inter-Hemispheric Plane
SRT	T-A2980	Anterior Commissure
SRT	T-A4904	Posterior Commissure
DCM	125031	Right Hemisphere Most Anterior
DCM	125032	Right Hemisphere Most Posterior
DCM	125033	Right Hemisphere Most Superior
DCM	125034	Right Hemisphere Most Inferior
DCM	125035	Left Hemisphere Most Anterior
DCM	125036	Left Hemisphere Most Posterior
DCM	125037	Left Hemisphere Most Superior
DCM	125038	Left Hemisphere Most Inferior

588

23. Add the following definitions to Part 16 Annex D DICOM Controlled Terminology Definitions (Normative):

592 # Annex D DICOM Controlled Terminology Definitions (Normative)

This Annex specifies the meanings of codes defined in DICOM, either explicitly or by reference to another part of DICOM or an external reference document or standard.

Code Value	Code Meaning	Definition
125021	Frame of Reference Identity	There is a defined equivalence between the Frame of Reference of the Registration SOP instance and the Frame of Reference of the referenced images.
125022	Fiducial Alignment	The registration is based on fiducials that represent patient or specimen features identified in each data set.

125023	Acquisition Equipment Alignment	Registration based on a-priori knowledge of the acquisition geometry. This is not an object registration as in fiducial registration. Rather, it specifies a known spatial relationship.
125024	Image Content-based Alignment	Computed registration based on global image information
125025	Visual Alignment	Registration by visually guided manipulation.
125030	Inter-Hemispheric Plane	A plane fiducial that specifies the location of the plane separating the two hemispheres of the brain.
125031	Right Hemisphere Most Anterior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the anterior limit of the right brain hemisphere
125032	Right Hemisphere Most Posterior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the posterior limit of the right brain hemisphere
125033	Right Hemisphere Most Superior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the superior limit of the right brain hemisphere
125034	Right Hemisphere Most Inferior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the inferior limit of the Right brain hemisphere
125035	Left Hemisphere Most Anterior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the anterior limit of the left brain hemisphere
125036	Left Hemisphere Most Posterior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the posterior limit of the left brain hemisphere
125037	Left Hemisphere Most Superior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the superior limit of the left brain hemisphere
125038	Left Hemisphere Most Inferior	A point fiducial that specifies the location in the plane perpendicular to the Anterior- Posterior-Commissure axis and tangential to the inferior limit of the left brain hemisphere

596

24. Add Informative section on transforms and mappings:

Annex Z
Transforms and Mappings
(Information)

The Homogenous Transform Matrix is of the following form.

$$\begin{bmatrix} M_{11} & M_{12} & M_{13} & T_x \\ M_{21} & M_{22} & M_{23} & T_y \\ M_{31} & M_{32} & M_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

This matrix requires the bottom row to be [0 0 0 1].

The matrix can be of type: RIGID, RIGID_SCALE and AFFINE. These different types represent different conditions on the allowable values for the matrix elements.

RIGID:

This transform requires the matrix obey orthonormal transformation properties:

$\sum_{i=1}^{3} M_{ij} M_{ik} = \delta_{jk}$ for all combinations of j = 1,2,3 and k = 1,2,3 where delta = 1 for i = j and zero otherwise.

The expansion into non-matrix equations is:

$M_{11} M_{11} + M_{21} M_{21} + M_{31} M_{31} = 1$ where j = 1, k = 1

$M_{11} M_{12} + M_{21} M_{22} + M_{31} M_{32} = 0$ where j = 1, k = 2

$M_{11} M_{13} + M_{21} M_{23} + M_{31} M_{33} = 0$ where j = 1, k = 3

$M_{12} M_{11} + M_{22} M_{21} + M_{32} M_{31} = 0$ where j = 2, k = 1

$M_{12} M_{12} + M_{22} M_{22} + M_{32} M_{32} = 1$ where j = 2, k = 2

$M_{12} M_{13} + M_{22} M_{23} + M_{32} M_{33} = 0$ where j = 2, k = 3

$M_{13} M_{11} + M_{23} M_{21} + M_{33} M_{31} = 0$ where j = 3, k = 1

$M_{13} M_{12} + M_{23} M_{22} + M_{33} M_{32} = 0$ where j = 3, k = 2

$M_{13} M_{13} + M_{23} M_{23} + M_{33} M_{33} = 1$ where j = 3, k = 3

The Frame of Reference Transformation Matrix ${}^{A}M_{B}$ describes how to transform a point (${}^{B}x,{}^{B}y,{}^{B}z$) with respect to RCS_B into (${}^{A}x,{}^{A}y,{}^{A}z$) with respect to RCS_A.

$$\begin{bmatrix} {}^{A}X \\ {}^{A}Y \\ {}^{A}Z \\ 1 \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & T_1 \\ M_{21} & M_{22} & M_{23} & T_2 \\ M_{31} & M_{32} & M_{33} & T_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} {}^{B}X \\ {}^{B}Y \\ {}^{B}Z \\ 1 \end{bmatrix}$$

The matrix above consists of two parts: a rotation and translation as shown below;

Rotation: $\begin{bmatrix} M_{11} & M_{12} & M_{13} & 0 \\ M_{21} & M_{22} & M_{23} & 0 \\ M_{31} & M_{32} & M_{33} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ Translation: $\begin{bmatrix} 1 & 0 & 0 & T_1 \\ 0 & 1 & 0 & T_2 \\ 0 & 0 & 1 & T_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

The first column [M_{11},M_{21},M_{31}] are the direction cosines (projection) of the X-axis of RCS_B with respect to RCS_A. The second column [M_{12},M_{22},M_{32}] are the direction cosines (projection) of the Y-axis of RCS_B with respect to RCS_A. The third column [M_{13},M_{23},M_{33}] are the direction cosines (projection) of the Z-axis of RCS_B with respect to RCS_A. The fourth column [T_1,T_2,T_3] is the origin of $RCS_B$with respect to RCS_A.

There are three degrees of freedom representing rotation, and three degrees of freedom representing translation, giving a total of six degrees of freedom.

RIGID_SCALE

The following constraint applies:

$$\sum_{i=1}^{3} M_{ij} M_{ik} = \delta_{jik} S_j^2$$ for all combinations of j = 1,2,3 and k = 1,2,3 where delta = 1 for i=j and zero otherwise.

The expansion into non-matrix equations is:

$M_{11}\ M_{11} + M_{21}\ M_{21} + M_{31}\ M_{31} = S_1^2$ where j = 1, k = 1

$M_{11}\ M_{12} + M_{21}\ M_{22} + M_{31}\ M_{32} = 0$ where j = 1, k = 2

$M_{11}\ M_{13} + M_{21}\ M_{23} + M_{31}\ M_{33} = 0$ where j = 1, k = 3

$M_{12}\ M_{11} + M_{22}\ M_{21} + M_{32}\ M_{31} = 0$ where j = 2, k = 1

$M_{12}\ M_{12} + M_{22}\ M_{22} + M_{32}\ M_{32} = S_2^2$ where j = 2, k = 2

$M_{12}\ M_{13} + M_{22}\ M_{23} + M_{32}\ M_{33} = 0$ where j = 2, k = 3

$M_{13}\ M_{11} + M_{23}\ M_{21} + M_{33}\ M_{31} = 0$ where j = 3, k = 1

$M_{13}\ M_{12} + M_{23}\ M_{22} + M_{33}\ M_{32} = 0$ where j = 3, k = 2

$M_{13}\ M_{13} + M_{23}\ M_{23} + M_{33}\ M_{33} = S_3^2$ where j = 3, k = 3

The above equations show a simple way of extracting the spatial scaling parameters Sj from a given matrix. The units of S_j^2 is the RCS unit dimension of one millimeter.

This type can be considered a simple extension of the type RIGID. The RIGID_SCALE is easily created by pre-multiplying a RIGID matrix by a diagonal scaling matrix as follows:

$$M_{RBWS} = \begin{bmatrix} S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * M_{RB}$$

where M_{RBWS} is a matrix of type RIGID_SCALE and M_{RB} is a matrix of type RIGID.

AFFINE:

No constraints apply to this matrix, so it contains twelve degrees of freedom. This type of Frame of Reference Transformation Matrix allows shearing in addition to rotation, translation and scaling.

For a RIGID type of Frame of Reference Transformation Matrix, the inverse is easily computed using the following formula (inverse of an orthonormal matrix):

$$annex.\ ({}^{A}\mathbf{M}_{B})^{-1} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & T_x \\ M_{21} & M_{22} & M_{23} & T_y \\ M_{31} & M_{32} & M_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1} = \begin{bmatrix} M_{11} & M_{21} & M_{31} & M_{11}T_x + M_{21}T_y + M_{31}T_z \\ M_{12} & M_{22} & M_{32} & M_{12}T_x + M_{22}T_y + M_{32}T_z \\ M_{13} & M_{23} & M_{33} & M_{13}T_x + M_{23}T_y + M_{33}T_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

For RIGID_SCALE and AFFINE types of Registration Matrices, the inverse cannot be calculated using the above equation, and must be calculated using a conventional matrix inverse operation.