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## **Digital Imaging and Communications in Medicine (DICOM)**

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*Supplement 112: Deformable Spatial Registration Storage SOP Class*

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*Prepared by:*

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**DICOM Standards Committee, Working Group 17, 3D**

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1300 N. 17<sup>th</sup> Street, Suite 1752

Rosslyn, Virginia 22209 USA

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## Foreword

4 This Supplement describes a Deformable Spatial Registration Storage SOP Class. This new  
SOP Class allows for the description of more complex spatial registrations than the current  
Spatial Registration IOD via the introduction of a deformation grid to the registration information.

6 The deformation is described as a grid of offset vectors. Each grid element contains 3 values  
representing offset distances in the X, Y, and Z directions at the center position of the deformation  
8 grid element. The relationship between the data being deformed and the deformation grid is  
purely spatial. Therefore the resolution of the grid is independent of the data being deformed.

10 Deformations for positions other than the center of a grid element will be determined by  
interpolating between neighboring grid vectors.

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

- |    |         |                                  |
|----|---------|----------------------------------|
| 14 | PS 3.2  | - Conformance                    |
|    | PS 3.3  | - Information Object Definitions |
| 16 | PS 3.4  | - Service Class Specifications   |
|    | PS 3.6  | - Data Dictionary                |
| 18 | PS 3.17 | - Explanatory Information        |

20

**Changes to NEMA Standards Publication PS 3.2-2006**

22

**Digital Imaging and Communications in Medicine (DICOM)**

**Part 2: Conformance**

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24

**Item: Add SOP Class to Table A.1-2**

<b>UID Value</b>	<b>UID NAME</b>	<b>Category</b>
...		
<b><u>1.2.840.10008.5.1.4.1.1.66.3</u></b>	<b><u>Deformable Spatial Registration SOP Class</u></b>	<b><u>Transfer</u></b>
...		

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**Changes to NEMA Standards Publication PS 3.3-2006  
Digital Imaging and Communications in Medicine (DICOM)**

44

**Part 3: Information Object Definitions**

**Item: Add the following reference to Section 2.**

46 IEEE 754:1985 32-bit and 64-bit Floating Point Number Representations

**Item: Add the following definition to Section 4.**

48 NaN Not a Number (See IEEE 754)

**Item: Add the following columns to table A.1-2.**

50 **A.1.4 Overview of the Composite IOD Module Content**

<b>IODs Modules</b>	<b>REG</b>	<b><u>DREG</u></b>
Patient	M	<u>M</u>
Clinical Trial Subject	U	<u>U</u>
General Study	M	<u>M</u>
Patient Study	U	<u>U</u>
Clinical Trial Study	U	<u>U</u>
Clinical Trial Series	U	<u>U</u>
Spatial Registration Series	M	<u>M</u>
Frame Of Reference	M	<u>M</u>
General Equipment	M	<u>M</u>
Enhanced Equipment		<u>M</u>
Spatial Registration	M	
<b><u>Deformable Spatial Registration</u></b>		<u>M</u>
Common Instance Reference	M	<u>M</u>
SOP Common	M	<u>M</u>

52 **Item: Add a new section in Annex A.39 and nest the existing sections**

**A.39 SPATIAL REGISTRATION INFORMATION OBJECT DEFINITIONS**

54 **A.39.1 Spatial Registration Information Object Definition**

**A.39.1.1 Spatial Registration IOD Description**

56 ...

**A.39.1.2 Spatial Registration IOD Entity-Relationship Model**

58 ...

**Figure A.39-1 SPATIAL REGISTRATION INFORMATION OBJECT DEFINITION E-R MODEL**

60 **A.39.1.3 Spatial Registration IOD Module Table**

**Table A.39.1-1 SPATIAL REGISTRATION IOD MODULES**

62 ...

**A.39.2 Deformable Spatial Registration information object definition**

64 **A.39.2.1 Deformable Spatial Registration IOD Description**

66 The Deformable Spatial Registration Information Object Definition (IOD) describes spatial  
relationships between images in one or more frames of reference via deformation grids and  
transformation matrices. The deformations and transformations describe to an application how to  
68 sample data from one or more *Source* RCSs into the *Registered* RCS.

70 The *Registered* RCS is the Frame of Reference specified within an instance of this IOD. The IOD  
may specify that only a subset of the entire *Source* RCS Frame of Reference is affected by the  
transformation, by specifying specific frames of image SOP Instances that use the *Source* Frame  
72 of Reference.

74 The deformation is described as a grid of offset vectors. Each grid element contains 3 values  
representing offset distances in the X, Y, and Z directions at the center position of the deformation  
grid element. The relationship between the data being deformed and the deformation grid is  
76 purely spatial. Therefore the resolution of the grid is independent of the data being deformed.

**A.39.2.1.1 Deformable Spatial Registration IOD Entity-Relationship Model**

78 The E-R Model for the Deformable Spatial Registration IOD is identical to the E-R Model for the  
Spatial Registration IOD in Figure A.39-1.

80 **A.39.2.1.2 Deformable Spatial Registration IOD Module Table**

**Table A.39.2-1 DEFORMABLE SPATIAL REGISTRATION IOD MODULES**

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	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	Clinical Trial Series	C.7.3.2	U
	Spatial Registration Series	C.20.1	M
Frame of Reference	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced Equipment	C.7.5.2	M
Deformable Registration	Deformable Spatial Registration	C.20.3	M
	Common Instance Reference	C.12.2	M
	SOP Common	C.12.1	M

82



84

**Item: Add in the following new text in C.7.3.1.1.1**

**C.7.3.1.1.1      Modality**

86

Defined Terms for the Modality (0008,0060) are:

...

REG = Registration

88 **Item: Change section C.20.2, modify text as shown:**

**C.20.2 Spatial Registration Module**

90 Table C.20.2-1 defines the general Attributes of the Spatial Registration Module.

**Table C.20.2-1  
 SPATIAL REGISTRATION MODULE ATTRIBUTES**

Attribute Name	Tag	Type	Attribute Description
...			
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.
...			
>Used Fiducials Sequence	(0070,0314)	3	The fiducials used to determine the Frame of Reference Transformation Matrix. One or more Items may be present.
<b>&gt;&gt; <u>Include 'SOP Instance Reference Macro' Table 10-8</u></b>			<b><u>Reference to the Spatial Fiducial SOP Instance identifying the Used Fiducial(s)</u></b>
>>Fiducial UID	(0070,031A)	1	The UID that identifies the fiducial used as registration input.

94

94

**Item: In C.20, insert the following section:**

96 **C.20.3 Deformable Spatial Registration Module**

Table C.20.3-1 defines the general Attributes of the Deformable Spatial Registration Module.

98

**Table C.20.3-1  
DEFORMABLE SPATIAL REGISTRATION MODULE ATTRIBUTES**

<b>Attribute Name</b>	<b>Tag</b>	<b>Type</b>	<b>Attribute Description</b>
Content Date	(0008,0023)	1	The date the vector grid data creation started.
Content Time	(0008,0033)	1	The time the vector grid data creation started.
<i>Include Content Identification Macro Table 10-12</i>			
Deformable Registration Sequence	(0064,0002)	1	A sequence of one or more registration items. Each item defines a spatial registration to the referenced images in that item. At least one item shall have a Deformable Registration Grid Sequence (0064,0005) with one item. See C.20.3.1.1.
>Source Frame of Reference UID	(0064,0003)	1	Identifies the Frame of Reference of a Source RCS. The Source RCS may or may not include an image set (e.g. atlas). See C.7.4.1.1.1 for further explanation.
>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 the registration applies to a subset of images within the specified Source Frame of Reference UID (0064,0003). All referenced images shall be in the same spatial frame of reference.
<i>&gt;&gt;Include 'Image SOP Instance Reference Macro' Table 10-3</i>			
>Frame of Reference Transformation Comment	(3006,00C8)	3	User description or comments about the registration.
>Registration Type Code Sequence	(0070,030D)	2	Describes the method used for the registration process. Zero or one item shall be present.
<i>&gt;&gt;Include 'Code Sequence Macro' Table 8.8-1</i>		<i>Baseline Context ID is 7100</i>	
>Pre Deformation Matrix Registration Sequence	(0064,000F)	1C	A sequence that specifies one spatial registration to be applied prior to the deformation. Exactly one item shall be present. Required if a matrix transformation is to be applied prior to deformation.

>>Frame of Reference Transformation Matrix	(3006,00C6)	1	A 4x4 homogeneous transformation matrix. Matrix elements shall be listed in row-major order. See C.20.2.1.1.
>>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.20.2.1.2
>Post Deformation Matrix Registration Sequence	(0064,0010)	1C	A sequence that specifies one spatial registration to be applied after the application of the deformation. Exactly one item shall be present. Required if matrix transformation is to be performed after application of the deformation.
>>Frame of Reference Transformation Matrix	(3006,00C6)	1	A 4x4 homogeneous transformation matrix. Matrix elements shall be listed in row-major order. See C.20.2.1.1.
>>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.20.2.1.2
>Deformable Registration Grid Sequence	(0064,0005)	1C	Describes the deformation grid used to sample into the Source RCS. Exactly one item shall be present. Required if deformation is performed. See C.20.3.1.2.
>>Image Orientation (Patient)	(0020,0037)	1	The direction of cosines of the first row and first column of the Vector Grid Data (0064,0009) with respect to the patient. See C.7.6.2.1.1 for further explanation.
>>Image Position (Patient)	(0020,0032)	1	The x, y, and z coordinates of the upper left hand voxel (center of the first voxel transmitted) of the grid, in mm in the Registered Frame of Reference. See C.7.6.2.1.1 for further explanation.
>>Grid Dimensions	(0064,0007)	1	The dimensions of the grid, in voxels. A triple representing the number of voxels along the X, Y, and Z axes.
>>Grid Resolution	(0064,0008)	1	The resolution of the grid voxels. A triple representing the size of a deformation voxel in along the X, Y, and Z dimension, in mm.

>>Vector Grid Data	(0064,0009)	1	A data stream of vectors. See C.20.3.1.3 for further explanation.
>Used Fiducials Sequence	(0070,0314)	3	The fiducials used to determine the registration. One or more Items may be present.
>> Include 'Image SOP Instance Reference Macro' Table 10-3			Reference to the Spatial Fiducial SOP Instance identifying the Used Fiducial(s)
>>Fiducial UID	(0070,031A)	1	The UID that identifies the fiducial used as registration input.

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### C.20.3.1 Deformable Spatial Registration Module Attribute Descriptions

102

#### C.20.3.1.1 Deformable Registration Sequence Application

104

The registrations in this module are applied to the Registered RCS coordinates in the following order. First, transform the coordinates using the matrix described in the Pre Deformation Matrix Registration Sequence (0064,000F). Next apply the deformation offsets to the resulting coordinates. Finally, transform those coordinates using the matrix described in the Post Deformation Matrix Registration Sequence (0064,0010). The resulting coordinate addresses the sample point within the Source RCS.

106

108

Thus a source coordinate may be calculated using the following equation:

110

(This assumes that the center position of each deformation voxel will be transformed)

$$\begin{bmatrix} X_{Source} \\ Y_{Source} \\ Z_{Source} \\ 1 \end{bmatrix} = M_{Post} \left( M_{Pre} \begin{bmatrix} X_{Start} + i * X_R \\ Y_{Start} + j * Y_R \\ Z_{Start} + k * Z_R \\ 1 \end{bmatrix} + \begin{bmatrix} \Delta X_{ijk} \\ \Delta Y_{ijk} \\ \Delta Z_{ijk} \\ 0 \end{bmatrix} \right)$$

112

Where:

$\begin{bmatrix} X & Y & Z \end{bmatrix}_{Source}$  The spatial coordinate in the Source RCS.

114

$\begin{bmatrix} X & Y & Z \end{bmatrix}_{Start}$  The start coordinate, in the Registered RCS, of the deformation grid as specified in the Image Position (Patient) attribute (0020,0032).

116

$\begin{bmatrix} i & j & k \end{bmatrix}$  The index into the deformation grid in the X, Y, and Z dimension.

118

$\begin{bmatrix} X & Y & Z \end{bmatrix}_R$  The resolution of the deformation grid in the X, Y, and Z dimension as specified in the Grid Resolution attribute (0064,0008).

120

$\begin{bmatrix} \Delta X_{ijk} & \Delta Y_{ijk} & \Delta Z_{ijk} \end{bmatrix}$  The deformation specified at index (i,j,k) in the deformation grid. If the Deformation Registration Grid Sequence (0064,0005) has no items, the  $\Delta$  values are zero.

122

$M_{Pre}$  The transformation matrix specified in the Pre Deformation Matrix Registration Sequence (0064,000F).

124  $M_{Post}$  The transformation matrix specified in the Post Deformation Matrix  
Registration Sequence (0064,0010).

126 **C.20.3.1.2 Deformable Registration Grid Sequence**

128 The vector represents the deformation at the center of the voxel. Deformations between voxel  
centers shall be determined through interpolation of the surrounding vectors in an implementation  
dependent manner.

130 **C.20.3.1.3 Vector Grid Data**

132 The Vector Grid Data attribute (0064,0009) contains the vector data. Each voxel in the Vector  
Grid Data attribute (0064,0009) is represented by an  $\begin{bmatrix} \Delta X_{ijk} & \Delta Y_{ijk} & \Delta Z_{ijk} \end{bmatrix}$  vector. The vector  
describes the direction and magnitude of the deformation at the center of the deformation voxel.

134 The order of vectors sent for each vector plane shall be left to right, top to bottom, i.e., the upper  
left vector (labeled 1,1) is sent first followed by the remainder of row 1, followed by the first vector  
136 of row 2 (labeled 2,1) then the remainder of row 2 and so on.

138 A vector triple with values of (NaN,NaN,NaN) shall indicate that the transformation at that point of  
the deformation grid is undefined.

140 The size of this attribute value is determined by the dimensions specified in the Grid Dimensions  
attribute (0064,0007). For dimensions of  $X_D \setminus Y_D \setminus Z_D$ , the size of the attribute value can be  
calculated with the equation:

142 
$$\text{Number of Bytes} = X_D * Y_D * Z_D * 3 * 4$$

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**Changes to NEMA Standards Publication PS 3.4-2006  
Digital Imaging and Communications in Medicine (DICOM)**

150

**Part 4: Service Class Specifications**

Item: Add the following to Table B.5-1

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#### B.5 STANDARD SOP CLASSES

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Table B.5-1  
STANDARD SOP CLASSES

SOP Class Name	SOP Class UID	IOD Specification (defined in PS 3.3)
<u>Deformable Spatial Registration Storage</u>	<u>1.2.840.10008.5.1.4.1.1.66.3</u>	<u>Deformable Spatial Registration</u>

156

Item: Add the following to Table I.4-1

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#### I.4 MEDIA STORAGE STANDARD SOP CLASSES

160

Table I.4-1  
Media Storage Standard SOP Classes

SOP Class Name	SOP Class UID	IOD Specification
<u>Deformable Spatial Registration Storage</u>	<u>1.2.840.10008.5.1.4.1.1.66.3</u>	<u>Deformable Spatial Registration</u>

162



164

**Changes to NEMA Standards Publication PS 3.6-2006**

166

**Digital Imaging and Communications in Medicine (DICOM)**

**Part 6: Data Dictionary**

168

168

**Item: Add the following Data Elements to Part 6 Section 6:**

## 6 Registry of DICOM data elements

<b>Tag</b>	<b>Name</b>	<b>VR</b>	<b>VM</b>
<u>(0064,0002)</u>	<u>Deformable Registration Sequence</u>	<u>SQ</u>	<u>1</u>
<u>(0064,0003)</u>	<u>Source Frame of Reference UID</u>	<u>UI</u>	<u>1</u>
<u>(0064,0005)</u>	<u>Deformable Registration Grid Sequence</u>	<u>SQ</u>	<u>1</u>
<u>(0064,0007)</u>	<u>Grid Dimensions</u>	<u>UL</u>	<u>3</u>
<u>(0064,0008)</u>	<u>Grid Resolution</u>	<u>FD</u>	<u>3</u>
<u>(0064,0009)</u>	<u>Vector Grid Data</u>	<u>OF</u>	<u>1</u>
<u>(0064,000F)</u>	<u>Pre Deformation Matrix Registration Sequence</u>	<u>SQ</u>	<u>1</u>
<u>(0064,0010)</u>	<u>Post Deformation Matrix Registration Sequence</u>	<u>SQ</u>	<u>1</u>

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**Changes to NEMA Standards Publication PS 3.16-2006**

180

**Digital Imaging and Communications in Medicine (DICOM)**

**Part 16: DICOM Content Mapping Resource**

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**Item: Add to Annex B**

184

**CID 29 Acquisition Modality**

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This Context Group includes codes that may be used to identify an image or waveform acquisition modality, as used in Attribute Modality (0008,0060) of a Composite SOP Instance Series Module (see PS3.3). It generally corresponds to a class of diagnostic equipment, or to a specific acquisition function or technique in a device.

188

190

**Context ID 29**  
**Acquisition Modality**  
**Type: Extensible Version: 20040921**

<b>Coding Scheme Designator</b>	<b>Code Value</b>	<b>Code Meaning</b>
...		
<b><u>DCM</u></b>	<b><u>REG</u></b>	<b><u>Registration</u></b>

192

194

**Item: Add Annex D**

## **Annex D DICOM Controlled Terminology Definitions (Normative)**

196

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.

198

### **DICOM Code Definitions (Coding Scheme Designator “DCM” Coding Scheme Version “01”)**

<b>Code Value</b>	<b>Code Meaning</b>	<b>Definition</b>	<b>Notes</b>
...			
REG	Registration	Registration	

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**Changes to NEMA Standards Publication PS 3.17-2006  
Digital Imaging and Communications in Medicine (DICOM)**

212

**Part 17: Explanatory Information**

**Item: Replace Section O.1 with:**

214 **O.1 SPATIAL REGISTRATION AND SPATIAL FIDUCIALS SOP CLASSES**

216 These SOP Classes allow describing spatial relationships between sets of images. Each  
218 instance can describe any number of registrations as shown in Figure O.1-1. It may also  
reference prior registration instances that contributed to the creation of the registrations in the  
instance.

220 A Reference Coordinate System (RCS) is a spatial Frame of Reference described by the DICOM  
222 Frame of Reference Module. The chosen Frame of Reference of the Registration SOP Instance  
224 may be the same as one or more of the Referenced SOP Instances. In this case, the Frame of  
Reference UID (0020,0052) is the same, as shown by the Registered RCS in the figure. The  
226 registration information is a sequence of spatial transformations, potentially including deformation  
information. The composite of the specified spatial transformations defines the complete  
transformation from one RCS to the other.

228 Image instances may have no DICOM Frame of Reference, in which case the registration is to  
that single image (or frame, in the case of a multi-frame image). The Spatial Registration IOD may  
230 also be used to establish a coordinate system for an image that has no defined Frame of  
Reference. To do this, the center of the top left pixel of the source image is treated as being  
232 located at (0, 0, 0). Offsets from the first pixel are computed using the resolution specified in the  
Source IOD. Multiplying that coordinate by the Transformation matrix gives the patient coordinate  
234 in the new Frame of Reference.

236 A special case is an atlas. DICOM has defined Well-Known Frame of Reference UIDs for several  
common atlases. There is not necessarily image data associated with an atlas.

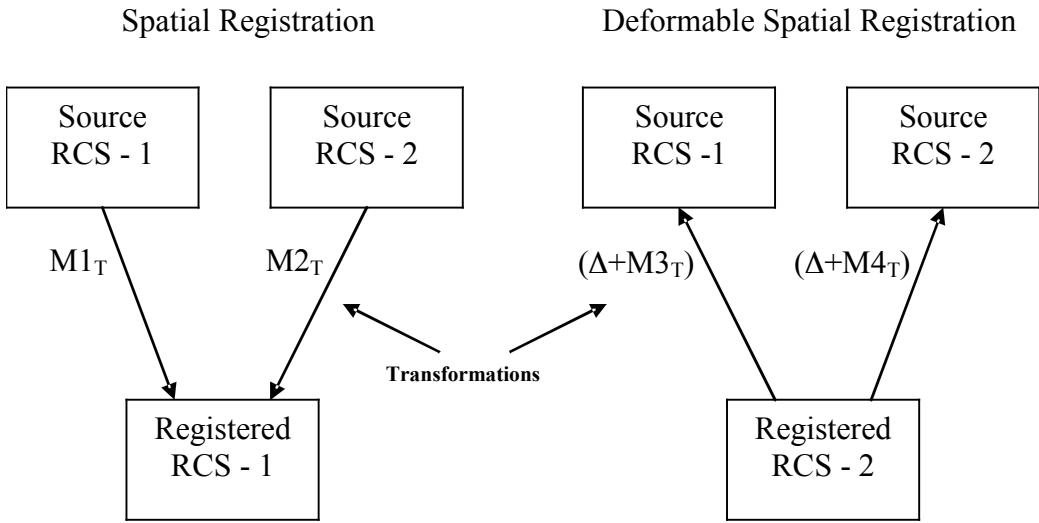
238  
240 When using the Spatial Registration or Deformable Registration SOP Classes there are two types  
of coordinate systems. The coordinate system of the referenced data is the *Source RCS*. The  
coordinate system established by the SOP instance is the *Registered RCS*.

242  
244 The sense of the direction of transformation differs between the Spatial Registration SOP Class  
and the Deformable Spatial Registration SOP Class. The Spatial Registration SOP Class  
246 specifies a transformation that maps Source coordinates, in the Source RCS, to Registered  
coordinates, in the Registered RCS. The Deformable Spatial Registration SOP Class specifies  
248 transformations that map Registered coordinates, in the Registered RCS, to coordinates in the  
Source RCS.

250 The Spatial Fiducials SOP Class stores spatial fiducials as implicit registration information.

252

**Figure O.1-1**



254

**Item: Add Figure O.4-2 and preceding paragraph as:**

256

**(Figures O.4-1 and O.4-3 have been converted from Visio drawings.)**

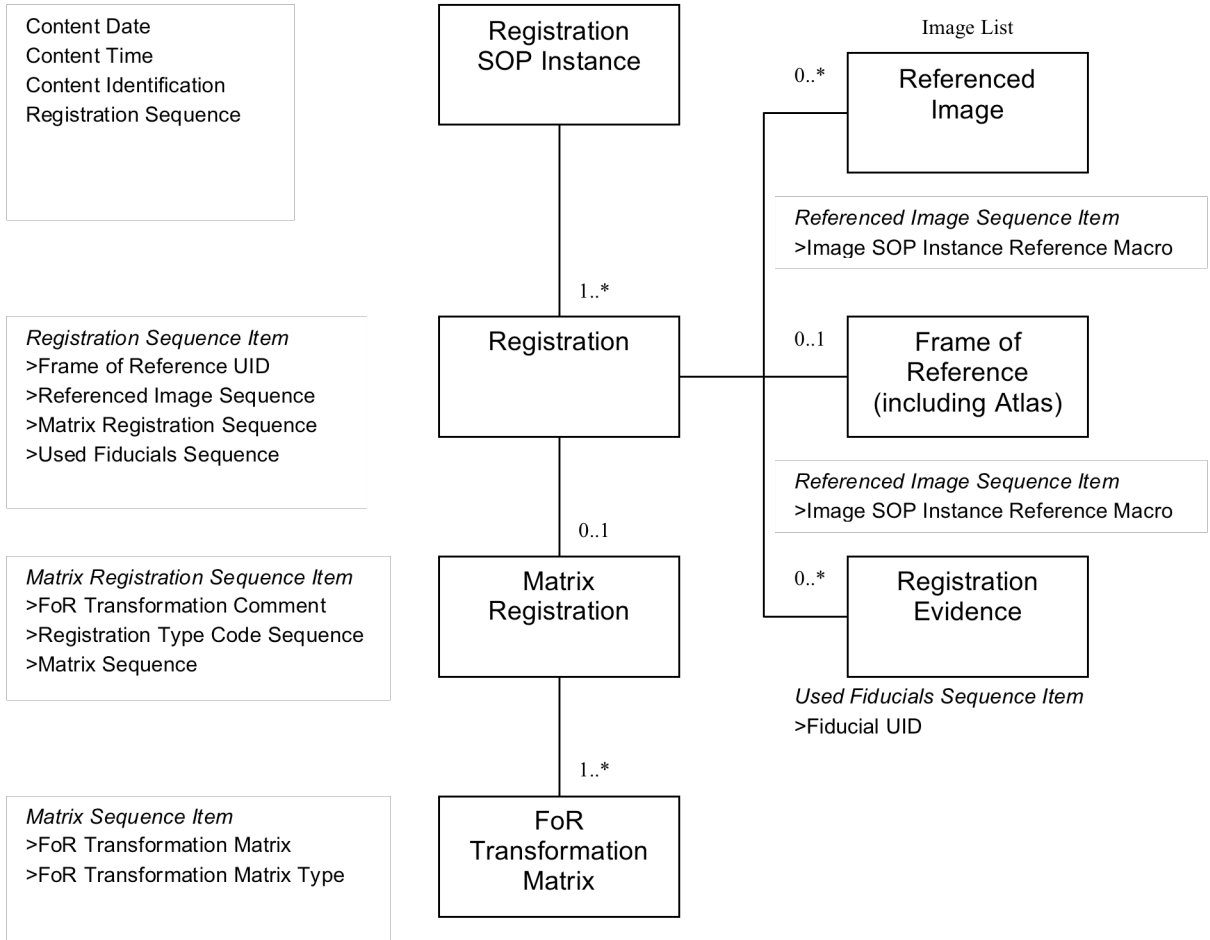
#### **O.4 OVERVIEW OF ENCODING**

258

Figure O.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.

260

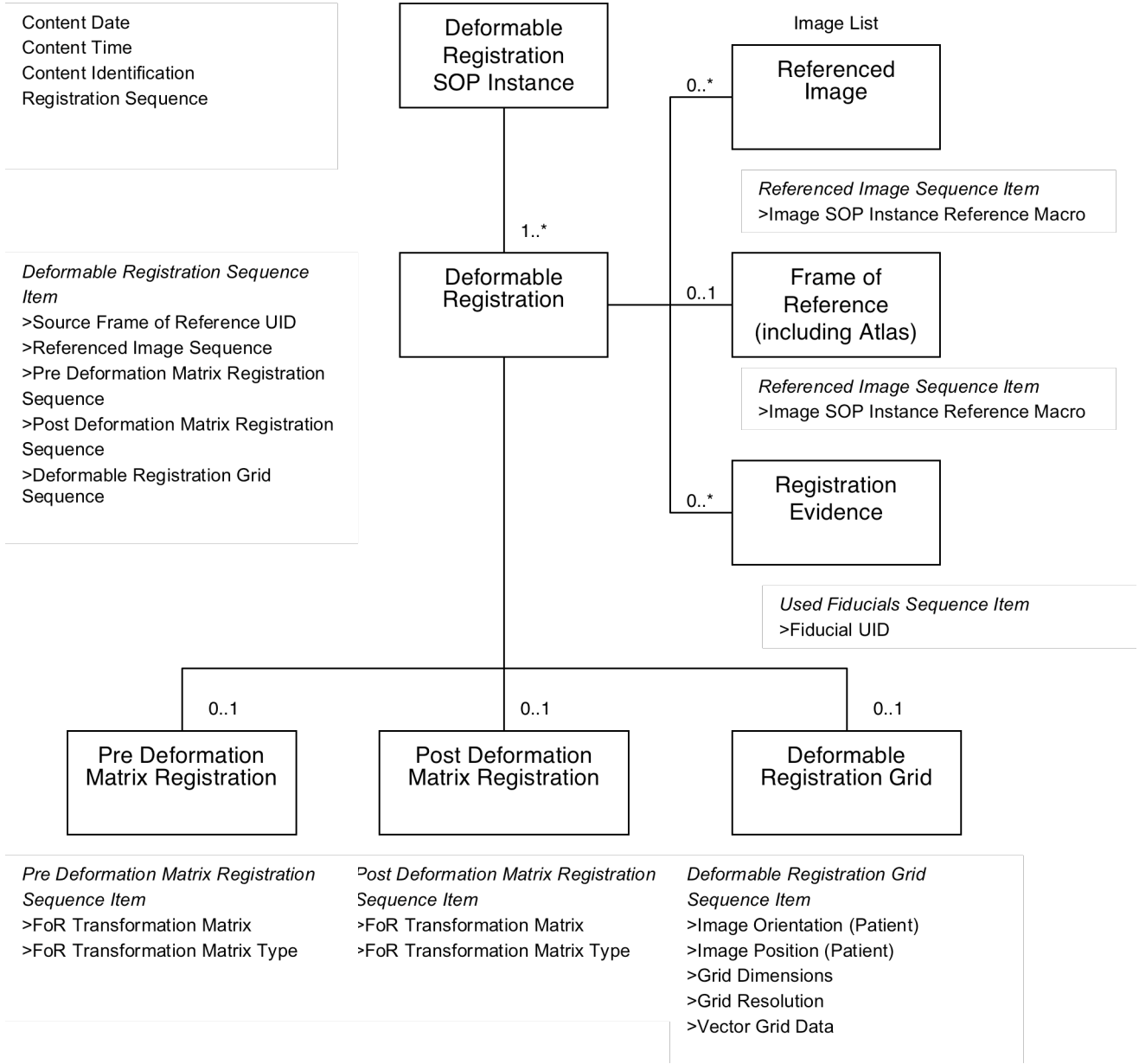




262

**Figure O.4-1 Spatial Registration Encoding**

264 **Figure O.4-2 shows an information model of a Deformable Spatial Registration to illustrate**  
 266 **the relationship of the attributes to the objects of the model. The DICOM attributes that**  
**describe each object are adjacent to the object.**



268

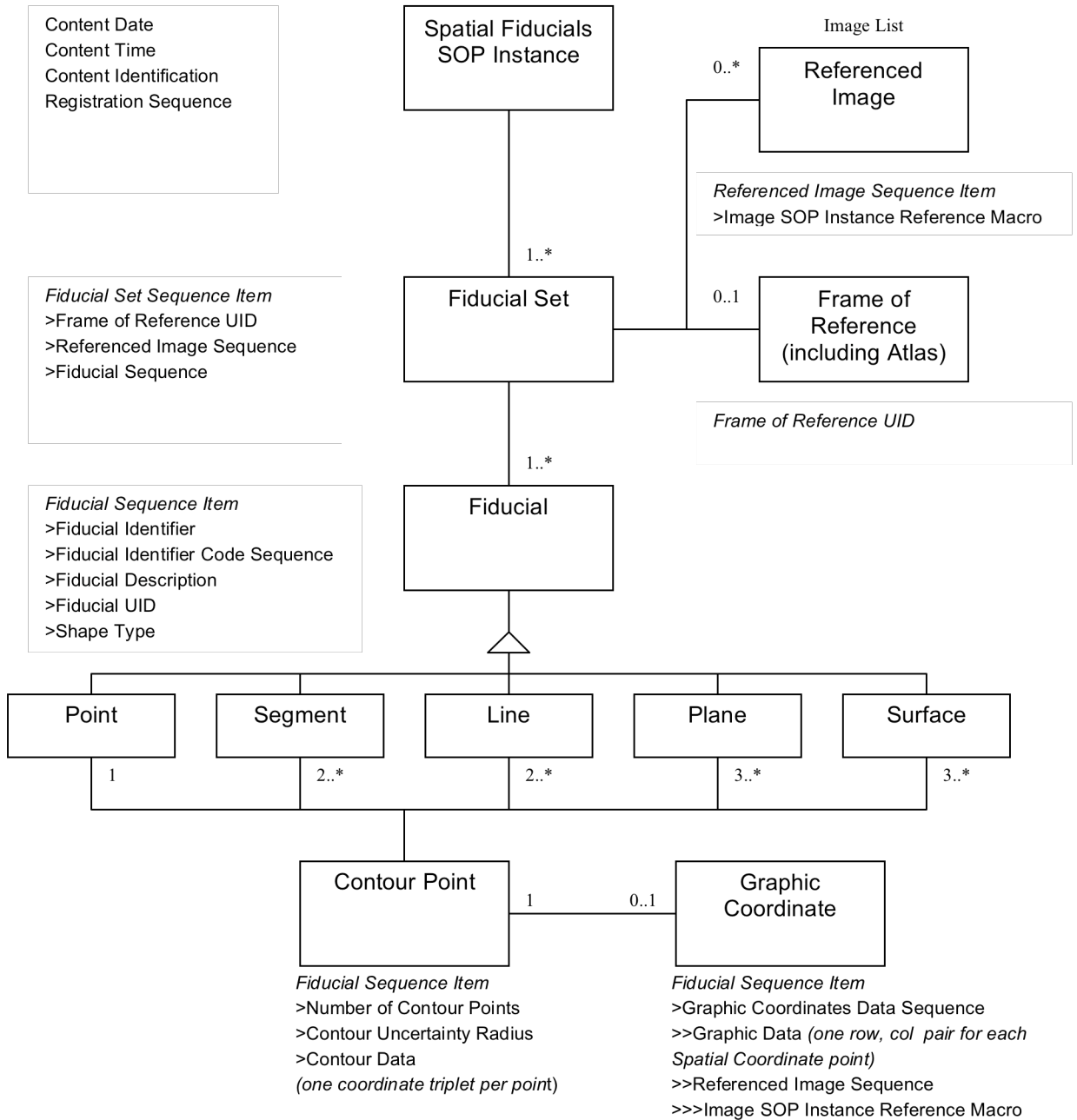
270

**Figure O.4-2 Deformable Spatial Registration Encoding**

272

Figure O.4-23 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.

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**Figure O.4-23 Spatial Fiducials Encoding**

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