Digital Imaging and Communications in Medicine (DICOM)

Supplement 255: Microscopy Bulk Enhanced Annotation

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On behalf of:

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Scope and Field

Overview

This document describes a proposal to create the Microscopy Bulk Enhanced Annotation SOP Class to extend the capabilities of the existing bulk Microscopy Bulk Simple Annotation IOD to enable the definition of annotations that define overlapping vector graphics with mutually exclusive meaning. Examples of annotations that this proposal will enable include: heatmaps, holes/voids, and other nested mutually exclusive concepts, e.g., tumor tissue contained within healthy tissue.

Background

The Microscopy Bulk Simple Annotation SOP Class and IOD (Supplement 222) were added to the DICOM Standard to provide a mechanism to efficiently encode machine learning (ML) and human generated vector graphics annotations for slide microscopy imaging. The Microscopy Bulk Simple Annotation IOD supports vector graphic definitions of points, lines, polylines, rectangles, ellipses, and polygons. The SOP Class has been successfully tested by WG 26 in the 2024 and 2025 connectathons. Examples of annotations encoded using the SOP Class are available from Imaging Data Commons and the 2024 and 2025 DICOM WG-26 connectathon archives.

The Microscopy Bulk Simple Annotation SOP Class does not provide a mechanism to encode mutually exclusive overlapping regions. Examples of such concepts are: 1) quantized heat maps and 2) is a hole(s)/void(s) within a closed polygon tissue region. Supplement 222 explicitly
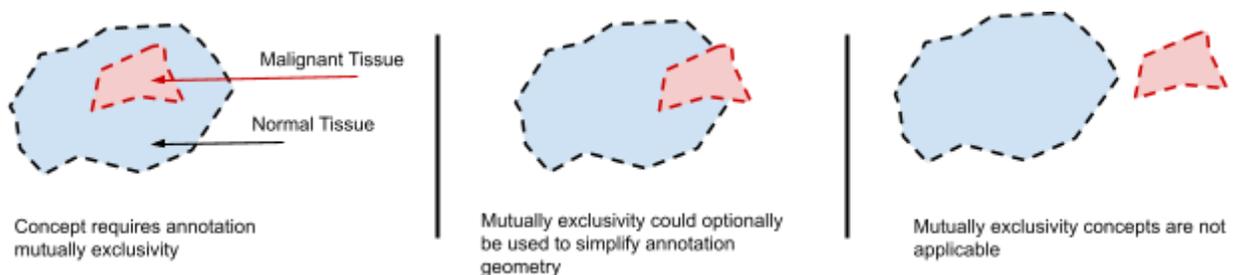
excluded the definition of holes/voids within an annotation and forbade the use of polygon "key holeling" to describe holes. The absence of a mechanism to describe vector graphic annotation with mutually exclusive regions significantly limits the type of annotations which can be described using the SOP Class.

The change proposal described here introduces a new SOP Class, Microscopy Bulk Enhanced Annotation and adds tags to the existing Microscopy Bulk Simple Annotation IOD that are conditional on the definition of Microscopy Bulk Enhanced Annotation SOP Class.

The changes introduced here extend the capabilities of the Microscopy Bulk Simple Annotation Module to enable it to describe annotations that contain mutually exclusive overlapping concepts that are conditional on the definition of the proposed SOP class. The proposal introduces mutually exclusivity by enabling the annotation author to describe a set of annotation groups across which mutual exclusivity is exhibited. These changes will enable multiple mutually exclusive and non-mutually exclusive annotations to be described together and will enable the Microscopy Bulk Enhanced SOP Class backward compatible with the Microscopy Bulk Simple SOP Class.

Vector graphic annotation mutual exclusivity is communicated by defining a set of vector graphics annotations across which mutual exclusivity is exhibited. Mutually exclusive annotations are defined by setting the Mutual Exclusivity Group UID (006A, XXX1) tag, within the annotation group of mutually exclusive annotation groups to the same Value. Annotations with different Mutual Exclusivity Group UID Values or undefined Values are not mutually exclusive with each other.

The meaning of dimensionally overlapping mutually exclusive annotations is determined by annotation ordering. The order of annotations is defined using either Mutually Exclusive Annotation Group Order (006A, XXX2) or Mutually Exclusive Annotation Order (006A, XXX3) tags. The annotation with the greatest order value takes precedence and determines the meaning. Conceptually mutual exclusivity could also be used to simplify stored annotation geometry for cases where complex annotations overlap at the annotation edge. Mutually exclusive concepts do not apply when annotations do not overlap.

Concept requires annotation mutually exclusivity

Mutually exclusivity could optionally be used to simplify annotation geometry

Mutually exclusivity concepts are not applicable

The creation of a new SOP class, Microscopy Bulk Enhanced IOD, is proposed here because correct interpretation of annotations that require the mutually exclusive concept will require

additional logic beyond what is required to correctly interpret Microscopy Bulk Simple IOD annotations.

For a given annotation group interpretation will require:
1. Determining if an annotation group is mutually exclusive. This concept is determined by the presence of a defined MutualExclusivityGroupUID Attribute that has the same Value across multiple annotation groups.

2. For the mutually exclusive annotation groups the meaning of overlapping annotations then requires the sorting of the overlapping annotations by annotation ordering defined within the annotation group. There are multiple methods which could be used to determine if a mutually exclusive annotation applies to a given region of imaging, these methods are not limited to: set based constructive vector graphics operations (*e.g.*, Python Shapely library) and buffered rasterization approaches).

DICOM PS 3.2 Conformance

Add SOP Class to Table A.1-2

UID Value		Category
UUU1	Microscopy Bulk Enhanced Annotations Storage SOP Class	Transfer

DICOM PS 3.3: Information Object Definitions

Modify to Table C.37.1-2. Microscopy Bulk Simple Annotations Module Attributes adding tags to Annotation Group Sequence (006A,0002); Annotation Group Sequence shown for reference purposes only.

Attribute Name	Tag	Type	Attribute Description
Annotation Group Sequence	(006A,0002)	1	Groups of Annotations sharing common characteristics, such as graphic type, properties or measurements. One or more Items shall be included in this Sequence.
…			
>Mutual Exclusivity Group UID	**(006A, XXX1)**	**1C**	**Identifies that this annotation group contains items that are mutually exclusive with other annotation groups that share the same Value of the Mutual Exclusivity Group UID (006A, XXX1) and have a different value for Mutually Exclusive Annotation Group Order (006A, XXX2) or Mutually Exclusive Annotation Order (006A, XXX3). Mutually exclusive relationships across multiple SOP Instances are not allowed. If not present within the Annotation Group, the Annotation Group does not exhibit mutually exclusivity.** **Required if SOP Class UID (0008, 0016) is UUU1 and any annotations are mutually exclusive.**
>Mutually Exclusive Annotation Group Order	**(006A, XXX2)**	**1C**	**A single unsigned integer value that defines the mutually exclusive ordering for all annotations within the Annotation Group. Mutual exclusivity applies to annotation groups with the same Value of Mutual Exclusivity Group UID (006A, XXX3).**

			Refer to C.37.1.X for a discussion on how to interpret annotation mutual exclusivity. **Required if SOP Class UID is UUU1 and any annotations are mutually exclusive and Mutual Exclusivity Group UID (006A, XXX1) is present and Mutually Exclusive Annotation Order (006A, XXX3) is not present.** **Not allowed if Mutually Exclusive Annotation Order (006A, XXX3) is present.**
>Mutually Exclusive Annotation Order	**(006A, XXX3)**	**1C**	**An array of unsigned integer Values that define the mutually exclusive order of individual annotations defined in the Annotation Group within this Item.** **There shall be Number of Annotations (006A,000C) Values in this Attribute.** **Refer to C.37.1.X for a discussion on how to interpret annotation mutual exclusivity.** **Required if SOP Class UID is UUU1 and any annotations are mutually exclusive and Mutual Exclusivity Group UID (006A, XXX1) is present and Mutually Exclusive Annotation Group Order (006A, XXX2) is not present.** **Not allowed if Mutually Exclusive Annotation Group Order (006A, XXX2) is present.**

C.37.1.X Mutual Exclusivity

In the absence of mutual exclusivity all overlapping annotations apply.

Annotation groups with the same Value of Mutual Exclusivity Group UID (006A, XXX1) are defined as being mutually exclusive with each other. Mutual Exclusivity Group UID (006A, XXX1) may not be defined across multiple SOP Instances.

Mutually exclusive concepts apply where two or more mutually exclusive annotations overlap (Figure C.37.1.X-1). Overlapping annotation(s) with the greatest ordering define the meaning for the region of overlap (Figure C.37.1.X-1-E). Mutually exclusive annotation order is defined using either the Mutually Exclusive Annotation Group Order (006A, XXX2) tag or the Mutually Exclusive Annotation Order (006A, XXX3) tag. Mutual exclusivity does not alter annotation meaning outside of regions of mutual exclusive annotation overlap (Figure C.37.1.X-2).

Mutual exclusive relationships do not apply for:
- Across annotations with different Mutual Exclusivity Group UID (006A, XXX1) Values.
- Mutually exclusive annotation annotations that do not overlap (Figure C.37.1.X-1-A and C.37.1.X-1-B).
- Mutually exclusive annotations with equal annotation ordering (Figure C.37.1.X-1-C and Figure C.37.1.X-1-D).

The meaning of additional overlapping annotations that are not part of a Mutual Exclusivity Group UID (006A, XXX1) apply, subject to their own mutual exclusivity constraints (Figure C.37.1.X-1-F).

Description	Graphic	Meaning of region of overlap (perimeter defined by red dots)
A) Single annotation:	1	NA
B) Non-overlapping annotations:	1 2	NA
C) Overlapping mutually exclusive annotation with equal order:	1 1	Green and blue have same order both apply.
D) Overlapping mutually exclusive annotations from Same the same annotation group:	1 2	Overlapping annotations are both blue, order doesn't matter.
E) Overlapping mutually exclusive annotations with different order:	1 2	Green annotation has greater annotation ordering
F) Overlapping mutually exclusive annotations with a different order and a non-mutually exclusive annotation:	1 2	Green has greatest ordering. Yellow is not not a mutually exclusive annotation and applies everywhere it is defined.
G) Overlapping mutually annotations with equal and different orders:	1 2 2	Green and blue annotations both have greatest annotation ordering.

Figure C.37.1.X-1: Example meaning of overlapping annotations. Colors defines annotation groups. Rectangles define annotation geometry. Annotation mutually exclusive ordering is defined by the number within the box. Annotations with mutually exclusive ordering define the same Value for Mutual Exclusivity Group UID (006A, XXX1). Unnumbered boxes are not mutually exclusive.

Meaning of Mutually Exclusive Annotation at Locations
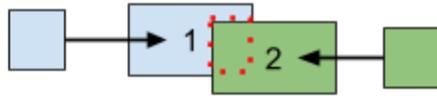Outside of the Region of Overlap

Figure C.37.1.X-2: Mutually exclusive annotations define meaning at regions
not not subject to mutual exclusivity constraints.

DICOM PS 3.4: Service Class Specification

Amend DICOM PS 3.4 Annex B.5 Standard SOP Classes as follows:

Table B.5-1. Standard SOP Classes

SOP Class Name	SOP Class UID	IOD Specification (defined in PS3.3)
Microscopy Bulk Enhanced Annotations Storage	**UUU1**	**Microscopy Bulk Enhanced Annotations IOD**

DICOM PS 3.6: Data Dictionary

> *Amend DICOM PS 3.6 – Data Dictionary – Section 6 Registry of DICOM Data Elements as follows:*

Table 6-1. Registry of DICOM Data Elements

Tag	Name	Keyword	VR	VM	
(006A, XXX1)	Mutual Exclusivity Group UID	MutualExclusivityGroupUID	UI	1	
(006A, XXX2)	Mutually Exclusive Annotation Group Order	MutuallyExclusiveAnnotationGroupOrder	UL	1	
(006A, XXX3)	Mutually Exclusive Annotation Order	MutuallyExclusiveAnnotationOrder	OL	1	

> *Amend DICOM PS 3.6 - Data Dictionary - Annex A - Registry of DICOM Unique Identifiers (UIDs) as 280 follows:*

Table A-1. UID Values

UID Value	UID Name	UID Type	Part
…	…	…	…
UUU1	Microscopy Bulk Enhanced Annotations Storage	SOP Class	PS 3.4
…	…	…	…

DICOM PS 3.17: Explanatory Information

VVVV.N1 Microscopy Bulk Enhanced Annotation Introduction

The Microscopy Bulk Enhanced SOP Class extends the capabilities of the Microscopy Bulk Simple Annotation to enable the definition of vector graphics annotations that encode mutual exclusive concepts. Mutual exclusive concepts are spatially nested, overlapping annotations and that describe concepts that do not overlap (Figure VVVV.N2-2).

VVVV.N2 Microscopy Bulk Enhanced Annotation Encoding Examples

Example 1: Tissue Classification

A real world example of a digital pathology annotation which requires mutually exclusive annotation is shown in Figure VVVV.N2-1. The annotations shown describe concepts where tissue is defined as belonging to at most one category (*e.g.,* membrane, cytoplasm, nuclei, or etc.) and the concepts are spatially nested.
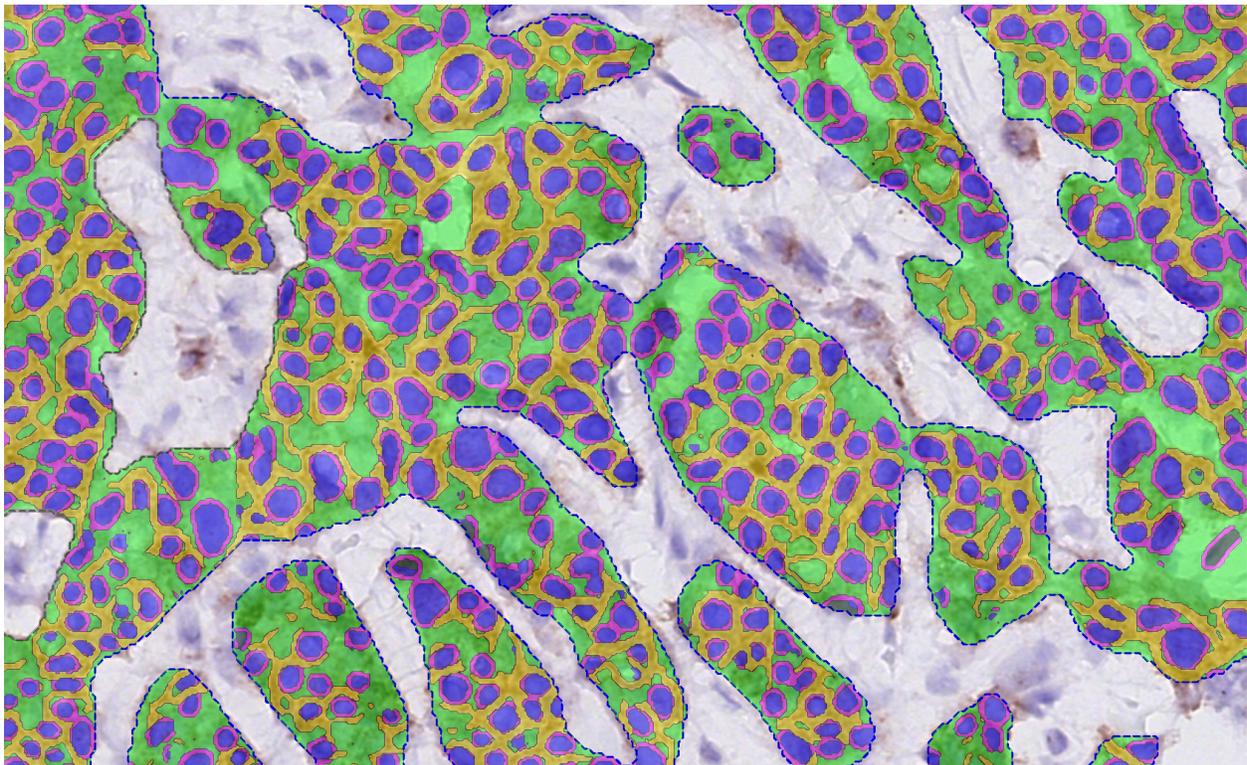

Figure VVVV.N2-1: Example real-world annotation of digital pathology concept exhibiting mutual exclusivity, tissue defined as being in one class (membrane, cytoplasm, nuclei, etc.).

Using the Bulk Microscopy Enhanced SOP Class, regardless of complexity, the annotations like Figure VVVV.N2-1 could be defined using one annotation group per classification. For simplicity the concept is illustrated as a two class problem in Figure VVVV.N2-2. Figure VVVV.N2-2 illustrates an annotation that describes the spatial location of normal and malignant tissue.
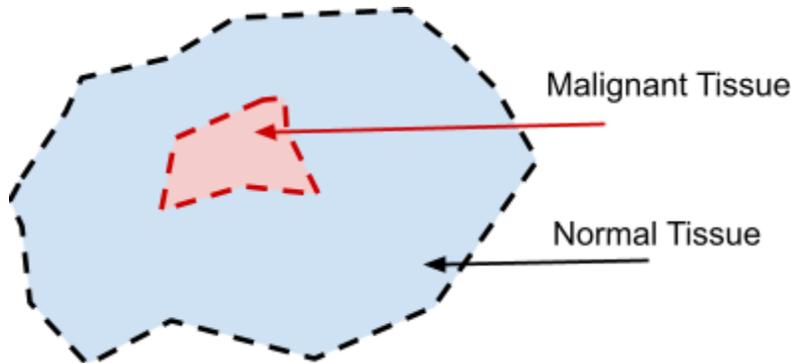

Figure VVVV.N2-2: Example conceptual annotation of digital pathology concept exhibiting 2-class mutual exclusivity, tissue defined as being either malignant or normal.

This section illustrates the usage of the Section C.37.1.2 Microscopy Bulk Simple Annotations Module in PS3.3 using Microscopy Bulk Enhanced Annotation Storage SOP Class in PS3.4 to define a mutually exclusive annotation that describes Figure VVVV.N2-2.

The example, Table VVVV.N2-1, defines the annotation using two annotation group sequence elements to describe the annotation shown in Figure VVVV.N2-2. Annotation group sequence element 1 describes the location of normal tissue. Annotation group sequence element 2 describes the location of malignant tissue. The two annotations are mutually exclusive, the malignant tissue annotation falls spatially within the boundaries of normal tissue and is not also classified as normal tissue. To indicate that normal tissue, group sequence element 1, and malignant tissue, group sequence element 2, are mutually exclusive they both have the Mutual Exclusivity Group UID (006A, XXX1) set to the same Value, 1.2.3.254.3434.5334.

The spatial order of the two annotations is described using the MutuallyExclusiveAnnotationGroupOrder (006A, XXX2) tag. In the example, normal tissue, group sequence element 1, surrounds malignant tissue so it has a lower MutuallyExclusiveAnnotationGroupOrder (006A, XXX2) Value, 1, than malignant tissue, group sequence element 2, 2.

Table VVVV.N2-1 shows the encoding of the Microscopy Bulk Enhanced Annotations Module for the example 1 above.

Name	Tag	Value	Comment

SOP Class UID	(0008, 0016)	UUU1	Microscopy Bulk Enhanced Annotation SOPClass UID
...			
Frame of Reference UID	(0020, 0052)	1.2.3.254.97824…	
...			
Annotation Coordinate Type	(006A, 0001)	2D	
Annotation Group Sequence	(006A, 0002)		
Annotation Group Sequence Element 1			
>Annotation Group Number	(0040, A180)	1	
>Mutual Exclusivity Group UID	(006A, XXX1)	1.2.3.254.3434.5334	UID match Making annotations mutually exclusive
>Mutually Exclusive Annotation Group Order	(006A, XXX2)	1	
>Point Coordinates Data	(0066, 0016)	0.66675, 0.032, 0.6665, 0.03225, 0.6665, 0.03275, 0.66675, 0.033, 0.66725, 0.033, 0.66725, 0.03275, 0.6675, 0.0325, 0.6675, 0.03225, 0.66725, 0.032, ...	
>Long Primitive Point Index List	(0066, 0040)	0x00000001	
>Annotation Group UID	(006A, 0003)	1.2.3.255.9782.4…	

>Annotation Group Label	(006A, 0005)	NormalTissue	
>Annotation Group Description	(006A, 0006)	Normal tissue detected on H&E	
>NumberOfAnnotations	(006A,000C)	Number of annotations in group	1
…	…	…	,,,
>Graphic Type	(0070, 0023)	POLYGON	
Annotation Group Sequence Element 2			
>Annotation Group Number	(0040, A180)	2	
>Mutual Exclusivity Group UID	(006A, XXX1)	1.2.3.254.3434.5334	UID match Making annotations mutually exclusive
>MutuallyExclusiveAnnotationGroupOrder	(006A, XXX2)	2	Precedence over normal tissue
>Point Coordinates Data	(0066, 0016)	0.0001, 0.0003, 0.0001, 0.0005, 0.0009 ...	
>Long Primitive Point Index List	(0066, 0040)	0x00000001	
> Annotation Group UID	(006A, 0003)	1.2.3.255.9782.5…	
>Annotation Group Label	(006A, 0005)	MalignantTissue	
>Annotation Group Description	(006A, 0006)	Malignant tissue detected on H&E	
>NumberOfAnnotations	(006A,000C)	Number of annotations in group	1
…	…	…	…
>Graphic Type	(0070, 0023)	POLYGON	

Example 2: Quantized probability (e.g., vector graphics heatmap)

Another real world example of a digital pathology annotation which requires mutually exclusive annotation is shown in Figure VVVV.N2-3. The annotations shown illustrate a quantized vector graphics heatmap that describes the predicted probabilities of a finding (e.g., tumor likelihood).
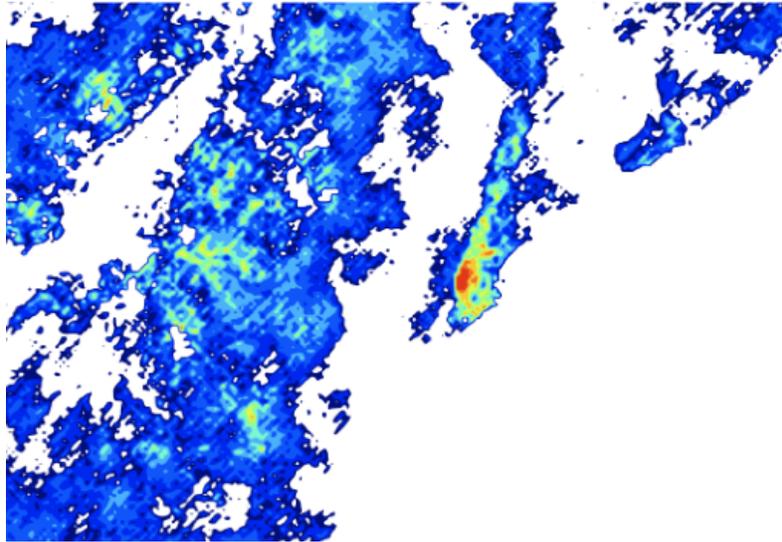

Figure VVVV.N2-3: Example quantized vector graphic heatmap.

Using the Bulk Microscopy Enhanced SOP Class, regardless of complexity, the annotation could be defined using one annotation group sequence dataset per quantized probability. For simplicity the concept is illustrated for figure VVVV.N2-4 which represents an example of an annotation of overlapping two classes (low and high probability) described across two independent regions.
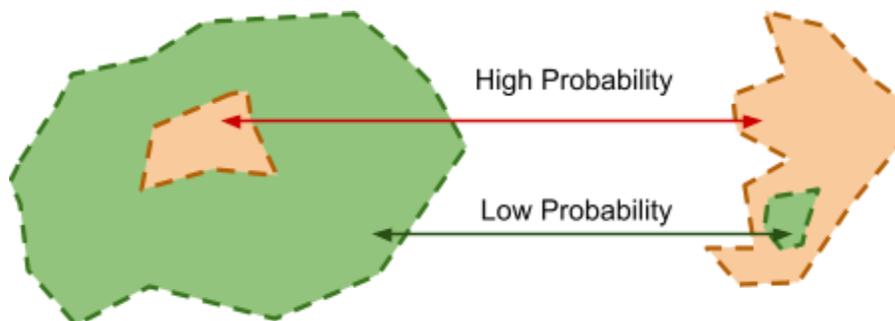

Figure VVVV.N2-4: Example quantized vector graphics heat map exhibiting two regions of 2-class mutual exclusivity, tissue defined as being either high or low likelihood of an outcome, across two disconnected regions.

The example, Table VVVV.N2-2, defines the annotation using two annotation group sequence elements to describe the annotations illustrated in Figure VVVV.N2-4. Annotation group sequence Element 1 describes the location of tissue at low probability using two polygons. Annotation group sequence element 2 describes tissue at high probability using two polygons.

The annotations are mutually exclusive and to indicate this both elements have the Mutual Exclusivity Group UID (006A, XXX1) set to the same Value, 1.2.3.254.3434.5335.

The ordering of the low probability annotations is defined at the polygon level to enable the low probability annotations to be defined using a single group sequence element above and below the high probability annotations as shown in Figure VVVV.N2-4. To do this the low probability annotation, group sequence element 1, defines annotation order at the polygon level using the MutuallyExclusiveAnnotationOrder (006A, XXX3) tag and sets it to encode values 1 and 3. The ordering of the two high probability annotation polygons is set to the same Value, 2, using the MutuallyExclusiveAnnotationGroupOrder (006A, XXX2) tag.

Table VVVV.N2-2 shows the encoding of the Microscopy Bulk Enhanced Annotations Module for the example above.

Name	Tag	Value	Comment
SOP Class UID	(0008, 0016)	UUU1	Microscopy Bulk Enhanced Annotation SOPClass UID
...			
Frame of Reference UID	(0020, 0052)	1.2.3.254.97829…	
...			
Annotation Coordinate Type	(006A, 0001)	2D	
Annotation Group Sequence	(006A, 0002)		
Annotation Group Sequence Element 1			
>Annotation Group Number	(0040, A180)	1	

>MutualExclusivityGroup UID	(006A, XXX1)	1.2.3.254.3434.5335	UID match Making annotations mutually exclusive
>MutuallyExclusiveAnnotationOrder	(006A, XXX3)	1, 3	Left, then right annotations
>Point Coordinates Data	(0066, 0016)	0.66675, 0.032, 0.6665, 0.03225, 0.6665, 0.03275, 0.66675, 0.033, 0.66725, 0.033, 0.66725, 0.03275, 0.6675, 0.0325, 0.6675, 0.03225, 0.66725, 0.032, ...	
>Long Primitive Point Index List	(0066, 0040)	0x00000001, 0x0000001A	
> Annotation Group UID	(006A, 0003)	1.2.3.255.9782.7…	
>Annotation Group Label	(006A, 0005)	LowProb	
>Annotation Group Description	(006A, 0006)	Low probability of finding.	
>NumberOfAnnotations	(006A,000C)	Number of annotations in group	2
…	…	…	,,,
>Graphic Type	(0070, 0023)	POLYGON	
Annotation Group Sequence Element 2			
>Annotation Group Number	(0040, A180)	2	
>Mutual ExclusivityGroupUID	(006A, XXX1)	1.2.3.254.3434.5335	UID match Making annotations mutually exclusive

>MutuallyExclusiveAnnotationGroupOrder	(006A, XXX2)	2	Set all polygons to common level
>Point Coordinates Data	(0066, 0016)	0.0001, 0.0003, 0.0001, 0.0005, 0.0009 ...	
>Long Primitive Point Index List	(0066, 0040)	0x00000001, 0x00000015	
> Annotation Group UID	(006A, 0003)	1.2.3.255.9782.8…	
>Annotation Group Label	(006A, 0005)	HighProb	
>Annotation Group Description	(006A, 0006)	High probability of finding.	
>NumberOfAnnotations	(006A,000C)	Number of annotations in group	2
…	…	…	…
>Graphic Type	(0070, 0023)	POLYGON	

Discussion of proposal

Open Issues

- Can mutual exclusion be defined across SOP Instances?

  Annotation group sequences that exhibit mutual exclusivity are defined by setting the annotation group sequence elements Mutual Exclusivity Group UID (006A, XXX1) tag to a common Value. Conceptually, annotation mutual exclusivity could be described across multiple SOP instances. The draft currently requires mutually exclusivity concepts to be entirely self contained within a SOP Instance.

  Rational for limiting mutual exclusion concepts to a single SOP Instance:
  - Simplifies understanding of the annotation for consumers of the annotation. All concepts required to understand an annotation are fully self contained within the annotation.

  - The ability to extend annotations with arbitrary concepts greatly complicates the interpretation of measurements encoded within the annotation group sequence's Measurement Sequence (0066,0121). The addition of mutually exclusive annotations through sister SOP instances could alter the meaning of the overall

annotation so as to render measurements embedded within the original source annotation invalid.

Rational for enabling mutual exclusion concepts to be declared across SOP Instances (Not allowed in proposal).
- ● Enables existing annotations to be efficiently extended or enhanced with new understanding without data duplication.

- ● Meaning of measurements on mutually exclusive annotations?

Annotations can optionally contain embedded measurements. The existing proposal does not currently comment on the meaning of measurements. For mutually exclusive annotations the assumption is the measurements will be made in reference to the annotation after the application of mutual exclusive constraints. Assuming mutually exclusive concepts are self contained within the SOP Instance this is straightforward.

Closed Issues

- ● Mechanism through which mutual exclusion is communicated.

The proposal utilizes annotation ordering to describe mutual exclusion. This method was chosen as it is: 1) backwards compatible with the existing Bulk Microscopy Simple Annotation, 2) is compact, space efficient, and 3) has relatively low complexity and can be easily implemented using existing software libraries.

 Alternative Approaches Considered

Radiotherapy Annotations: DICOM Radiotherapy annotations provide mechanisms to use constructive solid geometry (CSG) operations to describe complex annotation concepts from a collection of virtually described shapes using union, difference and intersection operations. This was rejected due to 1) a lack of general lack of compatibility with the existing Bulk Microscopy Simple Annotations, 2) the complexity required during annotation creation and interpretation, and 3) that it would require greater data storage sizes to communicate the same concepts when compared to the proposed mechanism.

XOR: During proposal drafting the proposal was considered to alternatively describe voids within annotations by describing the void using an additional nested annotation within the annotation group. Conceptually annotations within a group could then be composited using a XOR operation. Conceptually this is advantageous in that the concept of annotation order is no longer required as voids within annotations are described within the annotation. However, this concept was rejected because it would greatly increase the data storage sizes for annotations with describing nested concepts,

e.g., heatmap, because it would require duplicate annotation of the contour of each nested concept.

Implicit determination of annotation order on position within the group sequence: This concept was rejected because it could greatly increase the total DICOM file size by requiring an enormous number of annotation groups to represent each novel annotation ordering.