ROI Specification [DRAFT]

Release 0.0.1

Roger Leigh

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CONTENTS

CHAPTER

ONE

INTRODUCTION

1.1 Purpose

This document is a formal specification for the definition, storage and exchange of regions of interest (ROIs). This specification will be implementable in any programming language, and is intended to provide a common set of ROI types which will be usable in all image analysis software programs.

1.2 Scope

This specification defines abstract definitions of regions of interest, including details of how certain data structures and algorithms must be defined and behave, in order to ensure that ROIs work uniformly between the different programs and libraries implementing the specification. It also provides examples of serialised forms which may be used for storage and/or exchange. However, it does not define a file format; it is the responsibility of the implementors to integrate this model into their file formats as they see fit.

1.3 Reference implementation

This specification is accompanied by a reference implementation of the model. This implementation is intended to validate and test the correctness of the specification. It may be usable directly, however this is not the primary intention for its existence. Note that the reference implementation strives for complete correctness, and implementors of this specification may wish to provide additional optimisations to improve performance.

1.4 Concepts

- A ROI is an evaluation of a shape object
- A shape is defined by the rules which transform its representation (e.g. geometry, range within a dimension) into a a bitmask and/or greymask
- Each shape has a unique name (type) and number; the number is used for serialisation and versioning
- Each shape is described by one (or more) representations, these are the primitives which define the geometry or range within a dimension

- A shape object can be composed of one or more shapes, which can include transforms and shapes in arbitrary dimensions
- Each representation has a unique name and number; the number is used for serialisation and versioning
- Shapes which share representations may be freely interconverted; conversion is not required to be possible in both directions (e.g. square to rectangle or polyline to/from polygon)
- A shape is essentially a serialised expression which must be evaluated to create a usable ROI; given that certain shapes can contain other shapes, this provides for ROIs which are both extensible and of arbitrary complexity.
- All shapes can be serialised as a sequence of numbers
- Given that each shape can be reconstructed using its shape and representation numbers, which specify the exact sequence of numbers to deserialise to reconstruct the object, it is possible to exchange ROIs as simple text, or alternately as binary; more structured (but space inefficient) representations could be realised using XML.
- The object/function serialisation methodology used here is inspired by (but not derived from) the SSH FXP specification which defines the wire protocol for SFTP.

CHAPTER

TWO

REQUIREMENTS

2.1 Barcelona meeting

The following points are taken from the meeting notes.

Note: These may be incomplete, please do correct if necessary.

- Iterate through all points in a ROI. Order is important for some use cases, but not all.
- Type mechanism needed. Use concrete types.
- Version types to allow for deprecation, and translation to new versions.
- Define a persistent data model.
- ROIs must be serialisable. Needed for exchange and persistence.
- Serialisation may be implementation dependent. This could be XML, text or binary. Which should be used as a transfer format (if any)?
- Allow conversion between different ROI types.
- Need the ability to specify an interval in an arbitrary dimension.
- **Hierarchy of interfaces.**
  - Interval, Renderable.
- Need to specify how to draw and display (and edit?) types such as curves so that it does not vary between implementations.
- Persistence and drawing are separate problems.
- **Transforms**
  - **Non-affine transforms.**
    - Need examples to understand the problem better.
  - Store transforms with ROI?
- Needs to be able to scale up to millions-billions of ROIs
- **Specific ROI types**
  - Include checkerboard (uneven integers)

CHAPTER

THREE

ROI DISCUSSION

3.1 ROIs in three dimensions

Some of the 3D primitives described below may appear to be redundant; it's certainly possible for example, to represent a shape in 3D right now using multiple shapes, one per z plane. However, being able to use native 3D primitives is more powerful: it permits additional measurements involving volume, surface area and shape.

Some shapes may be represented equivalently in different ways; it might be worth considering adding support for these because it firstly allows the shape to be computed in different ways, which can differ depending upon the problem being solved, and it also contains information about how the measurement was made, i.e. the intent of the person doing the measuring, which is lost if converted to a canonical form.

3.2 Bitmasks

Mask Could we have a pointer to an IFD/file reference plus two coordinates so specify a clip region, then we can pack potentially hundreds of masks in a single plane.

3.3 Meshes

Mesh 2D mesh described as e.g a face-vertex mesh.

3DMesh 3D mesh described as e.g. a face-vertex mesh.

Meshes could be computed from masks, polygons, extruded shapes where there is a z range, or from thresholding.

3.4 Paths

3DPath As for Path, but with additional vector to describe motion along the prescribed plane?

CHAPTER

FOUR

2D PRIMITIVES IN 3D

4.1 Conversion to 3D primitives

The existing 2D primitives may be represented by the equivalent 3D primitive for the 2D primitive, extruded in z to a single z plane thickness.

While this is desirable for reducing code complexity, retaining the 2D primitives is necessary for 2D measurements (area/perimeter). These can be obtained from the 3D shape by dividing the volume or surface area by the z thickness, respectively. Having the 2D primitives will provide the context for conversion of measurements from 3D volume to 2D surface, since these are otherwise meaningless for 3D ROIs which are not extruded 2D ROIs.

3D ROIs, where appropriate, could provide alternative forms for 2D use. For example, a 3D cylinder would, when extruded from a 2D circle, not have end faces (i.e. would be open), in order for 2D surface area measurements to be correct.

4.2 Use of 2D primitives in 3D space

While it would be possible to translate and rotate 2D primitives in 3D using a 4×4 matrix, it would be simpler for users if rotation could be specified using a unit vector which can specify the angle of the primitive in 3D space; the matrix transform can be trivially construct ed from the vector. However, note that while current transforms occur only in 2D, where the x and y pixel sizes are typically the same, this is not usually the case in z, and so the transformations may need performing in physical units; therefore adding proper support for units would also be desirable to fully support 3D transforms. Note that this would also solve the existing problem in 2D that prevents ellipses and rectangles being rotated (without the use of a matrix transform), though where the rotation centre should be may be shape- and context-dependent. The unit vector to (0,0,-1) which would specify the existing behaviour.

Note: Define behaviour of orientation of unit vector for rotation; which direction are primitives facing by default?

4.2.1 2D extrusion

Reconstruction of 3D shapes from 2D planes distributed in z/t. -> set of 3D objects in t.

4.2.2 2D decomposition

Decompose 3D shape into 3D planes distributed in z.

CHAPTER

FIVE

FUNDAMENTAL DATA TYPES

The following defined types are used in the subsequent sections. Implementors should treat these sizes as minimium requirements.

Note: Roger Leigh Depending upon how we wish to persue interoperability between implementations, these may be required to be exact. Using plain text would mitigate this to an extent.

5.1 Basic primitives

Table 5.1: Primitives

Primitive	Type	Description
ShapeID	uint16	Numeric shape identifier
RepID	uint16	Numeric shape representation identifier
Count	uint32	Number of objects
Index	uint32	Index into an array
Value	double	Numerical value
Operator	uint8	Mathematical operator
BLogic	uint8	Bitwise binary logical operator
Vertex1D	double[1]	Vertex in 1D
Vertex2D	double[2]	Vertex in 2D
Vertex3D	double[3]	Vertex in 3D
Vector1D	double[1]	Vector in 1D
Vector2D	double[2]	Vector in 2D
Vector3D	double[3]	Vector in 3D
Affine1D	double[2][2]	Affine transform in 1D
Affine2D	double[3][3]	Affine transform in 2D
Affine3D	double[4][4]	Affine transform in 3D

Table 5.2: Compound primitives

Primitive	SeqNo	Type	Name	Description
String	0	NCHAR	Count	Number of octets
String	1	uint8[NCHAR]	CHARS	Array of octets (UTF-8)
# Per-shape state also includes: shape- and representation- specific data				
Shape	0	NCHAR	Count	Number of octets
Shape	1	SID	ShapeID	Shape identifier
# Also used for re-serialisation; may be converted to canonical form internally				
Shape	2	RID	RepID	Representation identifier
# Internal				
# Shape	3	NDIM	Count	Number of dimensions
# Shape	4	DIMS	Index[NDIM]	Object dimensionality (dimension numbers in use)
# Shape	5	PROPS	Props	Shape properties (point size, line width, text font/size etc.)

Note: **Barry DeZonia** Support different coordinate spaces as needed (int, long, double). Should be possible to iterate some regions.

5.2 Basic operators

Operator	Value	Description
=	0	Equals
≠	1	Not equals
<	2	Less than
≤	3	Less than or equal to
>	4	Greater than
≥	5	Greater than or equal to

5.3 Binary bitwise operators

Operator	Value	Description
AND	0	And
OR	1	Or
NOT	2	Not
XOR	3	Exclusive or

All shape primitives are described in terms of the above fundamental primitives. This means that all shape descriptions are serialisable as a list of integer and double-precision floating point values. The specifics of this are implementation-defined. Example formats:

- Plain text, as a list of values

- XML, as element content or a string attribute
- Binary data stream, using big-endian/network byte order

This also means that for compatible shape types, the shape type may be changed while retaining the following data unchanged (e.g. polyline to polygon spline with the same point list).

Note: **Roger Leigh** All 2D shape primitives could be oriented in 3D or using a unit Vector3D, which would allow all 2D shapes to be used as surfaces in 3D. They would additionally require a depth in order to be meaningful (or assume a depth of one z slice).

Or, 2D shapes should specify the pair of x/y/z axes they are using, and will be extruded along the third axis.

CHAPTER

SIX

GEOMETRIC SHAPE PRIMITIVES

6.1 Overview

This section specifies how shapes are described in the model. For some shapes, there are several alternative ways of specifying them; which are worth supporting needs further discussion. One point to consider is that the different ways preserve the intent behind the original measurement and what is in the original metadata where this makes sense, even if this does mean some redundancy; this won't impact on the actual drawing/analysis code, which can deal with each shape in a canonical form. This records how the measurement was made by the user, which may have implications in further analysis and/or verification that the measurement was correct.

While some shapes have been included here for completeness, it's quite possible that not all are needed, particularly in all dimensions.

If anyone wants to check the maths behind the geometry, that would be much appreciated, because I'm firstly not an expert in this area, and it's also quite possible I've made some typos. The naming of the shapes is probably also wanting some improvement.

6.2 Alternative shape representations

Using the current ROI model is that there is only one way to describe each shape. e.g. a polyline can only be described as a series of points; it might in some cases be more natural to specify one as a starting point and a series of vectors; while either are fine just to draw the ROI, it would desirable to store what was measured, since converting it to a canonical representation is lossy, and removes the original measurements taken, and hence the intent of the original annotation. This applies to other shapes as well. For example, a circle or ellipse can be described by a bounding box (which may itself be a point and one or two vectors, or a set of points), or by a point and radius or half-axes, or by the Mahalanobis distance (typically for computing from a normal distribution of points). For a cylinder/cone, we can specify this in multiple ways also from a circle/ellipse plus length, or point plus vector (length and direction) plus radius (or half-axes).

The current model is focussed on drawing shapes, while making measurements involves drawing only for visualisation; the important parts are the values for making the measurement, and of course the results. Some programs (e.g. AxioVision) have separate sets of objects for drawing (annotation) and measurement. These are a largely overlapping set, but the former are not used for any length/area/volume/pixel measurements. Objects such as scale bars and labels are for drawing only.

Todo

Common methods for all primitives: Bounding box [AlignedCuboid3D] Rotation centre [Vertex2D/Vertex3D] Control points [may use points and vertex to describe position and movement path] Conversion to 2D (slab through); equivalent to intersection with cuboid. Should all primitives support a minimum of intersection with AlignedCuboid3D? Or Mesh3D for non-square images. Can 2D methods use alternative axes to project in xz/yz? Default to xy. If all 2D shapes must be represented by 3D forms (i.e. are just proxies), then the equivalent 3D can be used quite simply. Get greymap/bitmap. Get 2D/3D mesh. Intersect (only for cuboid?) Need to clip to image volume (optionally). Also useful to reduce to 2D (which can be a cuboid for a single plane). Non-aligned shapes inherit/implement the aligned forms. Shrink and grow: move polygons along surface normals for meshes. For other shapes, this will require recalculation of the geometry.

Add triangle as special case of polygon, which can be a special case of mesh?

Meshes: Need to be able to triangulate if higher order polygons are possible.

Add representation number to start of number list; this will allow shapes to be embedded in other shapes and be self-describing. e.g. all circle types may be used to specify a circular cylinder end. This will simplify the specification of more complex shapes by limiting the number of variants.

6.3 Shape serialisation

Key considerations:

- A shape exists in a set of dimensions e.g. xy, xyz, xyt. The shape must define the number of dimensions it exists in, and their identity.
- A shape must be identifiable unambiguously
- A shape must be versioned (to permit correction of any design/analysis bugs without altering any data retrospectively); this permits the replacement of the buggy implementation while not removing it.
- In order to allow code reuse and flexible use of shapes, shapes may include other shapes as part of their primitive specification.

In the following shape descriptions, all shapes are identified by a Shape ID and Representation ID. The shape specifies the geometric shape type. The representation specifies both the primitives required for serialisation, and can also be used for versioning the shape–i.e. it also specifies the behaviour for conversion to greymaps and bitmaps.

6.4 Shape

An abstract description of a shape.

Representation:

Name	Type	Description
S1	ShapeID	Shape
R1	RepID	Representation

Concrete implementations of shapes provide further elements in their representation. The above are only sufficient to describe the shape and its representation. The combination of shape and representation specifies the data required to construct the shape.

Note that one disadvantage of this method is that a reader will be required to understand how to deserialise all shape types; it's not possible to skip unknown shapes due to not knowing their lengths (which may be variable). However, this would be an issue for a purely XML-based implementation as well, so may not be a problem in practice.

Alignment Aligned shape variants are aligned at right-angles to the x and y (2D) or x, y and z (3D) axes.

6.5 Text placement and alignment

In order to annotate text next to measurements, it would be ideal if it were possible to control text placement and orientation. Currently the coordinate of the first letter is required. However, it would be nicer if the text could be also placed to the right of the point or centred on the point. And additionally, to the top, middle or bottom for vertical placement. Rotation would also be useful, though it's probably achievable indirectly via the transformation matrix, i.e. you would effectively have these anchors for placement, where 1 is the current behaviour.

```
7       8       9
4Text h5ere...6
1       2       3
```

This is needed to e.g. align text along measurement lines. Having a rotation angle specified directly would also save the need for complex calculations to work out the rotation origin and transform every time you want to just place a label along a line. It also makes it possible to place text in the centre of a shape.

6.6 Scale bars

Note: A 3D scale may need to be a 3D grid to allow visualisation of perspective, in which case the representation will define the grid bounding cuboid; inherit AlignedCuboid3D representations. Permit scale rotation with Cuboid3D? Allow specification of grid size and only allow sizing in discrete units?

6.7 Additional primitives

3D spline surfaces Natural cubic spline (Catmull-Rom)

The axiovision curve type is most likely a natural cubic spline, the curve passing smoothly through all points, but without local control. It is simply represented as a list of points through which the curve must pass; there are no additional control points. Depending upon if they are doing any custom stuff, it might not be possible to represent with pixel-perfect accuracy.

Curves might be more generally applicable to other formats, and useful in their own right. It might be worth considering adding a spline type with local control where the curve passes straight through the control points such as Catmull-Rom splines. This would make it very simple for non-experts to fit smooth lines while annotating their images.

CHAPTER

SEVEN

REGIONS IN ARBITRARY DIMENSIONS

While it is possible to use geometric shapes to specify regions in physical dimensions, this does not translate meaningfully to arbitrary dimensions. The following primitives work in any "dimension" with a discrete or continuous range by permitting the selection of specific values, or sub-ranges.

These "nD" shapes (Value, Values, Range) and the extrusion and combining shapes (Extrude, Combine), permit the specification of ROIs in multiple arbitrary dimensions, and their combination with geometry in 1D, 2D and 3D.

Just as all 1D, 2D and 3D geometry can be converted to the respective 1D, 2D or 3D bitmask or greymask representing the described shape, all nD primitives in higher dimensions can be converted to 1D bitmask or greymask. A 1D bitmask for each dimension will allow efficient iteration over the higher-order dimensions using the resulting bitmaps.

By default, a ROI is unconstrained within all dimensions. The addition of constraints restricts it to particular dimensions, or subsets thereof.

Note: RL. Should we be unconstrained by default, or completely constrained? Should this behaviour be different for "real" dimensions (xyzt) compared with virtual dimensions such as channels?

CHAPTER

EIGHT

COMPOUND ROIS

A ROI may consist of multiple shapes combined in different ways. The result is also a shape.

8.1 Set primitives

Shapes may combined using set operators:

- union
- intersection
- difference
- symmetric difference

The shape is the result of the set operation.

Note: Restrict to combinations of 2D or 3D shapes only?

Note: **J-M Burel** Union in the mathematical sense or aggregation.

8.1.1 Set

A simple collection of shapes. There is no implied relationship unless used with the set operators.

Representation:

Name	Type	Description
S1	ShapeID	Shape
R1	RepID	Representation
NSHAPE	Count	Number of shapes
SHAPE1	Shape	First shape
…	Shape	Further shapes
SHAPEn	Shape	Last shape

8.1.2 Union

Produce the union of the shapes in the provided set.

Representation:

Name	Type	Description
S1	ShapeID	Shape
R1	RepID	Representation
SET	Set*	Set of shapes

8.1.3 Intersection

Produce the intersection of the shapes in the provided set.

Representation:

Name	Type	Description
S1	ShapeID	Shape
R1	RepID	Representation
SET	Set*	Set of shapes

8.1.4 Difference

Produce the set difference of the shapes in the provided set.

Representation:

Name	Type	Description
S1	ShapeID	Shape
R1	RepID	Representation
SET	Set*	Set of shapes

8.1.5 Symmetric difference

Produce the symmetric difference of the shapes in the provided set.

Representation:

Name	Type	Description
S1	ShapeID	Shape
R1	RepID	Representation
SET	Set*	Set of shapes

- Restrict to either 2D or 3D, but not both?

How do we detect if shapes intersect? Edge cases for set operations using masks-false positives for partially occupied pixels.

Event/Events: A simple list of points. The point size/style/colour may be changed to permit different sets to be distinguished.

Caliper/Distance/Multi-Caliper/Multi-Distance. These are all the same measurement(s), a baseline followed by a list of points. The measurement is the distance from each point to the baseline. The differences between the types are solely the visual presentation of the measurements.

Angle3/Angle4. These measure the angle between two lines. Angle4 is two separate lines, while Angle3 is two lines with a common point (i.e. a special case of Angle4). Angle3 could be represented with a three-point polyline. Angle4 would need to be two separate lines. Given that Angle3 is a special case of Angle4, it is not clear that it should be represented as a polyline.

Circle. While the OME model represents this as an ellipse with equal x and y radii, there are three ways to represent a circle here: - radius defined as a line from centre to edge - radius defined as a line from edge to centre (stored as the first type with the point order reversed) - circumference defined using three points. The first two are representable in the model as an ellipse plus a line. The latter is representable as an ellipse plus three points.

Polyline is directly translatable.

Aligned Rectangle is directly translatable as a rectangle (with some trivial differences in coordinates). However, additional tags define metadata to display inside the rectangle (optional) such as channel/slide/acquisition time/exposure time/etc. The verbatim text can be put into a Label, but the specific meaning would be lost–this is an overlay which would change as you navigate through a stack or timecourse etc, varying with the plane-specific parameters. While the specific tags would be retained, a more generic means to overlay image- and plane-specific OME metadata might be generally useful within the context of the OME model.

Ellipse is directly translatable.

Outline/closed polyline is directly translatable.

Text is convertible to Label. However, the OME Label type lacks the alignment attributes mentioned in my earlier mail. This makes it difficult to control the placement of text in complex compound ROIs.

Length is a single line distance measurement line like, but with additional end lines to make it like a technical drawing line outside the object itself, i.e.

```
|******OBJECT*******|
|                   |
|<----------------->|
        50 µm
```

Representable in the model as a simple line, across OBJECT, but with loss of the other lines. It is representable as three separate lines, but with loss of the context of the specific measurement.

Open and closed splines: these are probably natural splines (not Bezier). ZVI currently stores them as polylines given that we don't support splines. But having a spline type would permit them to be stored.

LUT and Profile: Covered in previous mail.

8.2 Storing and manipulating complex compound objects

With these measurements, one thing perhaps worth considering is that there are up to four types of object here:

1. Result context: the object(s) representing the physical measurement. This is what we currently store in the model.
2. Measurement context: line along radius of circle, points along circumference of circle etc. This is "how the measurement was made"
3. Visual context: such as visual cues such as construction lines. This is the visual presentation of the measurement to the viewer.
4. Editing context: values which control the placement of the above. Information for generation of UI manipulation handles, and of the other contexts while editing.

We can represent the actual measurements in most cases using the existing ROI types. However, if we store the additional types, it is no longer possible to distinguish between the measurement and the additional context.

If it was possible to distinguish between these in the model, it would be possible for the objects to be displayed without any advanced knowledge of how an object should be edited. It would also be possible to extract the primitive measurement values. However, the measurement context would provide additional information to editors for manipulation of the object, which would then be able to update all three contexts appropriately.

Doing this would provide a simple but effective means for additional ROI types to be added without requiring support in all programs displaying/modifying ROIs. This does not of course replace the need for namespaces to identify ROI categories, but it does supplement it by allowing programs to selectively display different contexts without any knowledge of the underlying type.

As an example, using this length measurement:

```
|******OBJECT*******|
|                   |
|<----------------->|
        50 µm
```

1. Result context

```
 #******OBJECT*******#

(where the #s are the start and end points of a Line at either end
of the object.  This is the value of the physical measurement.)
```

2. Measurement context

   No additional information needed in this case.

3. Visual context

```
 |                   |
 |                   |
 |<----------------->|
         50 µm

Three lines, one with arrow end markers, plus text label.
This is the visual representation of the measurement.
```

4. Editing context

```
#******OBJECT*******
#
#
```

```
(where the #s represent a distance between the measured line and
the drawn line in the visual context.  This information is used to
generate the visual context from the measurement context.)
```

I hope the above does not sound too way out. But the current system is limited to storing only the first of these four contexts, which loses information. While it is possible to delegate all of the presentation and editing to the viewer, the reality is that this is stuff people want. If I'm annotating an image for a paper, I want the annotations to appear exactly the same as I see them if I send them to someone else. And if I'm doing physical measurements, I want the specifics of how I made the measurement to be recorded. All we are doing here is providing additional information to the viewer/editor that it is free to use and/or ignore as it chooses.

Thinking about this a little more, in many cases it will be possible to omit some contexts and infer them from the others. For example, if I have a simple line I will store a line in the result context. The measurement context is the same two points, and so we may simply use the result context points in its place. Likewise, if the measurement is a simple one, the visual context may be omitted and inferred from the result context also. The different contexts really only come into play when we want a more sophisticated visual representation (for example with overlaid textual representations of the measurement value or to visualise the measurement in a more complex manner than the result context alone can provide). And they are essential when using more complex compound ROIs as the last example attached shows.

In the last example, all the information is provided to allow the user to edit the object in a UI. For example, they can adjust the end points of the baseline, and the start points of the lines in the measurement context can be retriangulated from the end points and baseline. The measurement context can be inferred from the endpoints of the lines in the result context. And the endpoints can also be adjusted independently. Following any adjustment, the updated baseline can be stored in the editing context, the measurement lines in the measurement context, and the visual representation in the visual context. The visual context is shown here to include end markers on the distance lines, and text labels with the measured values. But these could be toggled on or off and the settings stored in an annotation specific for this measurement type–there's really no limit to the "extra stuff" you can add here, but the basic measurement remains the same in the result context.

(In this example, the baseline could actually be in the measurement context, since it's part of the measurement; the first example is a better illustration of the editing context.)

The important point is that anyone should be able to open the file and display the visual representation without any knowledge of the specifics of the ROI type or measurements being made. Likewise they can also look at the measured distances in the results context and use them without any knowledge of how they were measured. Only a UI which supports the ROI type in question will need to use the editing and/or measurements context, and they will know how to regenerate the other contexts when editing.

CHAPTER

NINE

COMPOUND TYPES

Line Profile LUT Scale bar

LUT/gradient boxes are quite specialist. However, they are also quite common in published figures, so it would make sense to have a general implementation. These are particularly useful when you have false colour heat maps where you need a visual scale to interpret the figure. We already support LUTs, so this is really just a view of the LUT for a given channel inside a rectangle.

Line profiles are quite common. But I guess supporting this would depend upon whether you classify the profile as the result of analysis of a ROI, or part of a ROI. It might be handy to be able to overlay a line profile as a set of coloured polylines, for example.

9.1 Zeiss AxioVision ROI types

For the Zeiss types, we can represent these in the model using:

Zeiss type	ROI model type
Event	Point2D
Events	Point2D (union of points)
Line	Line2D
Caliper	Line2D (union of lines)
Multiple caliper	Line2D (union of lines)
Distance	Line2D (union of lines)
Multiple distance	Line2D (union of lines)
Angle3	Line2D and Arc2D
Angle4	Line2D and Arc2D
Circle	Circle2D and Line2D
Scale Bar	Line2D (with end markers)
Polyline [open]	Polyline2D
Aligned Rectangle	AlignedRectangle2D
Rotated Rectangle	Rectangle2D
Ellipse	AlignedEllipse2D
Polyline [closed]	Polygon2D
Text	Label2D
Length	Line2D (union of lines)
Spline [open]	PolylineSpline2D
Spline [closed]	PolygonSpline2D
LUT	AlignedRectangle2D and Label2D
Line profile	Line2D and Polyline2D/Rectangle2D

Annotations don't typically have labels (with the exception of scale bars). Measurements would have one or more labels in the union as well displaying the value(s) of the measurement.

CHAPTER

TEN

AFFINE TRANSFORMS

To support proper 3D operation, it would make sense to extend the existing support for 3×3 2D affine transforms to 4×4 3D transforms.

For both 2D and 3D transforms, translation, rotation and scaling are supported. Skewing, using the bottom row of the matrix, is not.

10.1 2D transforms

$$\begin{bmatrix} a & c & e \\ b & d & f \\ 0 & 0 & 1 \end{bmatrix}$$

10.2 3D transforms

$$\begin{bmatrix} a & d & g & j \\ b & e & h & k \\ c & f & i & l \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

CHAPTER

ELEVEN

SHAPES

11.1 Overview

Table 11.1: Shapes

ID	Shape	Dims	Description
0	*Point*	2D	A single point
1	*Point*	3D	A single point
2	*Points*	2D	A set of points
3	*Points*	3D	A set of points
4	*Line*	2D	A single line
5	*Line*	3D	A single line
6	*Lines*	2D	A set of lines
7	*Lines*	3D	A set of lines
8	*Polyline*	2D	A set of connected points
9	*Polyline*	3D	A set of connected points
10	*Polygon*	2D	A polygon (closed polyline)
11	*Polygon*	3D	A "polygon" (closed polyline) [does this make sense to have in 3D?]
14	*AlignedSquare*	2D	A square aligned with all axes
15	*Square*	2D	A square
16	*AlignedCube*	3D	A cube aligned with all axes
17	*Cube*	3D	A cube
18	*AlignedRectangle*	2D	A rectangle aligned with all axes
19	*Rectangle*	2D	A rectangle
20	*AlignedCuboid*	3D	A cuboid aligned with all axes
21	*Cuboid*	3D	A cuboid
22	*Circle*	2D	A circle
23	*Sphere*	3D	A sphere
24	*AlignedEllipse*	2D	An ellipse aligned with all axes
25	*Ellipse*	2D	An ellipse
26	*AlignedEllipsoid*	3D	An ellipsoid aligned with all axes
27	*Ellipsoid*	3D	An ellipsoid
28	*PolylineSpline*	2D	A set of connected splines (open)
29	*PolylineSpline*	3D	A set of connected splines (open)

Continued on next page

Table 11.1 – continued from previous page

ID	Shape	Dims	Description
30	*PolygonSpline*	2D	A set of connected splines (closed)
31	*PolygonSpline*	3D	A set of connected splines (closed)
33	*CircularCylinder*	3D	A circular cylinder
35	*EllipticCylinder*	3D	An elliptic cylinder
36	*Arc*	2D	An arc
37	*Arc*	3D	An arc
38	*BitMask*	1D	A mask with one bit values
39	*BitMask*	2D	A mask with one bit values
40	*BitMask*	3D	A mask with one bit values
41	*GreyMask*	1D	A mask with multiple grey levels
42	*GreyMask*	2D	A mask with multiple grey levels
43	*GreyMask*	3D	A mask with multiple grey levels
44	*Mesh*	2D	A mesh
45	*Mesh*	3D	A mesh
46	*AffineTransform*	1D	Affine transformation of a shape
47	*AffineTransform*	2D	Affine transformation of a shape
48	*AffineTransform*	3D	Affine transformation of a shape
49	*AbstractTransform*	1D	Abstract (implementation-defined) transformation of a shape
50	*AbstractTransform*	2D	Abstract (implementation-defined) transformation of a shape
51	*AbstractTransform*	3D	Abstract (implementation-defined) transformation of a shape
52	*Text*	2D	Text (label)
53	*Value*	nD	A value in an arbitrary dimension
54	*Values*	nD	A set of values in an arbitrary dimension
55	*Range*	nD	A range of values in an arbitrary dimension
56	*Extrude*	nD	Extrude a shape of arbitrary dimensionality into an additional dimension.
57	*Combine*	nD	Combine shapes of differing dimensionality to form a shape combining all subset dimensions.
58	*Scale*	2D	A scale bar between two points
59	*Scale*	3D	A scale bar between two points
60	*Grid*	2D	A scale bar between two points
61	*Grid*	3D	A scale bar between two points
62	*Bitwise*	1D	Binary bitwise operation
63	*Bitwise*	2D	Binary bitwise operation
64	*Bitwise*	3D	Binary bitwise operation

11.2 Definitions

11.2.1 Point (2D)

A single point.

Table 11.2: Point representations (2D)

Representation	Dim	In	Out	Inherited from
RPoint	2D	•	•	**Point (2D)** [self]

Canonical form is RPoint (2D).

11.2.2 Point (3D)

A single point.

Table 11.3: Point representations (3D)

Representation	Dim	In	Out	Inherited from
RPoint	3D	•	•	**Point (3D)** [self]

Canonical form is RPoint (3D).

11.2.3 Points (2D)

A set of points.

Table 11.4: Points representations (2D)

Representation	Dim	In	Out	Inherited from
RPoints	2D	•	•	**Points (2D)** [self]

Canonical form is RPoints (2D).

11.2.4 Points (3D)

A set of points.

Table 11.5: Points representations (3D)

Representation	Dim	In	Out	Inherited from
RPoints	3D	•	•	**Points (3D)** [self]

Canonical form is RPoints (3D).

11.2.5 Line (2D)

A single line.

Table 11.6: Line representations (2D)

Representation	Dim	In	Out	Inherited from
RLinePoints	2D	•	•	**Line (2D)** [self]
RLineVector	2D	•	•	**Line (2D)** [self]

Canonical form is RLinePoints (2D).

11.2.6 Line (3D)

A single line.

Table 11.7: Line representations (3D)

Representation	Dim	In	Out	Inherited from
RLinePoints	3D	•	•	**Line (3D)** [self]
RLineVector	3D	•	•	**Line (3D)** [self]

Canonical form is RLinePoints (3D).

11.2.7 Lines (2D)

A set of lines.

Table 11.8: Lines representations (2D)

Representation	Dim	In	Out	Inherited from
RLinePoints	2D			Line (2D)
RLineVector	2D			Line (2D)
RLinesPoints	2D	•	•	**Lines (2D)** [self]
RLinesVectors	2D	•	•	**Lines (2D)** [self]

Canonical form is RLinesPoints (2D).

11.2.8 Lines (3D)

A set of lines.

Table 11.9: Lines representations (3D)

Representation	Dim	In	Out	Inherited from
RLinePoints	3D			Line (3D)
RLineVector	3D			Line (3D)
RLinesPoints	3D	•	•	**Lines (3D)** [self]
RLinesVectors	3D	•	•	**Lines (3D)** [self]

Canonical form is RLinesPoints (3D).

11.2.9 Polyline (2D)

A set of connected points.

Table 11.10: Polyline representations (2D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	2D	•	•	**Polyline (2D)** [self]
RPolylineVector	2D	•	•	**Polyline (2D)** [self]

Canonical form is RPolylinePoints (2D).

11.2.10 Polyline (3D)

A set of connected points.

Table 11.11: Polyline representations (3D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	3D	•	•	**Polyline (3D)** [self]
RPolylineVector	3D	•	•	**Polyline (3D)** [self]

Canonical form is RPolylinePoints (3D).

11.2.11 Polygon (2D)

A polygon (closed polyline).

Table 11.12: Polygon representations (2D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	2D	•	•	**Polygon (2D)** [self]
RPolylineVector	2D	•	•	**Polygon (2D)** [self]

Canonical form is RPolylinePoints (2D).

11.2.12 Polygon (3D)

A "polygon" (closed polyline) [does this make sense to have in 3D?].

Table 11.13: Polygon representations (3D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	3D	•	•	**Polygon (3D)** [self]
RPolylineVector	3D	•	•	**Polygon (3D)** [self]

Canonical form is RPolylinePoints (3D).

11.2.13 AlignedSquare (2D)

A square aligned with all axes.

Table 11.14: AlignedSquare representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedSquare1	2D	•	•	**AlignedSquare (2D)** [self]
RAlignedSquare2	2D	•	•	**AlignedSquare (2D)** [self]

Canonical form is RAlignedSquare1 (2D).

11.2.14 Square (2D)

A square.

Table 11.15: Square representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedSquare1	2D			AlignedSquare (2D)
RAlignedSquare2	2D			AlignedSquare (2D)
RLinePoints	2D	•	•	**Square (2D)** [self]
RLineVector	2D	•	•	**Square (2D)** [self]

Canonical form is RLinePoints (2D).

11.2.15 AlignedCube (3D)

A cube aligned with all axes.

Table 11.16: AlignedCube representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedCube1	3D	•	•	**AlignedCube (3D)** [self]
RAlignedCube2	3D	•	•	**AlignedCube (3D)** [self]

Canonical form is RAlignedCube1 (3D).

11.2.16 Cube (3D)

A cube.

Table 11.17: Cube representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedCube1	3D			AlignedCube (3D)
RAlignedCube2	3D			AlignedCube (3D)
RLinePoints	3D	•	•	**Cube (3D)** [self]
RLineVector	3D	•	•	**Cube (3D)** [self]

Canonical form is RLinePoints (3D).

11.2.17 AlignedRectangle (2D)

A rectangle aligned with all axes.

Table 11.18: AlignedRectangle representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedHalfAxes	2D			AlignedEllipse (2D)
RLinePoints	2D	•	•	**AlignedRectangle (2D)** [self]
RLineVector	2D	•	•	**AlignedRectangle (2D)** [self]

Canonical form is RLinePoints (2D).

11.2.18 Rectangle (2D)

A rectangle.

Table 11.19: Rectangle representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedHalfAxes	2D			AlignedEllipse (2D)
RAlignedSquare1	2D			AlignedSquare (2D)
RAlignedSquare2	2D			AlignedSquare (2D)
RCircle0	2D			Circle (2D)
RCircle1	2D			Circle (2D)
RCircle2	2D			Circle (2D)
RCircle3	2D			Circle (2D)
RCircle4	2D			Circle (2D)
RCircle5	2D			Circle (2D)
REllipseCovariance	2D			Ellipse (2D)
RHalfAxes	2D			Ellipse (2D)
RLinePoints	2D			AlignedRectangle (2D), Line (2D), Square (2D)
RLineVector	2D			AlignedRectangle (2D), Line (2D), Square (2D)
RPoint	2D			Point (2D)
RRectangle1	2D	•	•	**Rectangle (2D)** [self]
RRectangle2	2D	•	•	**Rectangle (2D)** [self]

Canonical form is RRectangle1 (2D).

11.2.19 AlignedCuboid (3D)

A cuboid aligned with all axes.

Table 11.20: AlignedCuboid representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedHalfAxes	3D			AlignedEllipsoid (3D)
RLinePoints	3D	•	•	**AlignedCuboid (3D)** [self]
RLineVector	3D	•	•	**AlignedCuboid (3D)** [self]

Canonical form is RLinePoints (3D).

11.2.20 Cuboid (3D)

A cuboid.

Table 11.21: Cuboid representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedCube1	3D			AlignedCube (3D)
RAlignedCube2	3D			AlignedCube (3D)
RAlignedHalfAxes	3D			AlignedEllipsoid (3D)
RCuboid1	3D	•	•	**Cuboid (3D)** [self]
RCuboid2	3D	•	•	**Cuboid (3D)** [self]
REllipsoidCovariance	3D			Ellipsoid (3D)
RHalfAxes	3D			Ellipsoid (3D)
RLinePoints	3D			AlignedCuboid (3D), Cube (3D), Line (3D)
RLineVector	3D			AlignedCuboid (3D), Cube (3D), Line (3D)
RPoint	3D			Point (3D)
RSphere0	3D			Sphere (3D)
RSphere1	3D			Sphere (3D)
RSphere2	3D			Sphere (3D)
RSphere3	3D			Sphere (3D)
RSphere4	3D			Sphere (3D)
RSphere5	3D			Sphere (3D)
RSphere6	3D			Sphere (3D)

Canonical form is RCuboid1 (3D).

11.2.21 Circle (2D)

A circle.

Table 11.22: Circle representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedSquare1	2D			AlignedSquare (2D)
RAlignedSquare2	2D			AlignedSquare (2D)
RCircle0	2D	•	•	**Circle (2D)** [self]
RCircle1	2D	•	•	**Circle (2D)** [self]
RCircle2	2D	•	•	**Circle (2D)** [self]
RCircle3	2D	•	•	**Circle (2D)** [self]
RCircle4	2D	•	•	**Circle (2D)** [self]
RCircle5	2D	•	•	**Circle (2D)** [self]
RLinePoints	2D			Square (2D)
RLineVector	2D			Square (2D)
RPoint	2D			Point (2D)

Canonical form is RCircle1 (2D).

11.2.22 Sphere (3D)

A sphere.

Table 11.23: Sphere representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedCube1	3D			AlignedCube (3D)
RAlignedCube2	3D			AlignedCube (3D)
RLinePoints	3D			Cube (3D)
RLineVector	3D			Cube (3D)
RPoint	3D			Point (3D)
RSphere0	3D	•	•	**Sphere (3D)** [self]
RSphere1	3D	•	•	**Sphere (3D)** [self]
RSphere2	3D	•	•	**Sphere (3D)** [self]
RSphere3	3D	•	•	**Sphere (3D)** [self]
RSphere4	3D	•	•	**Sphere (3D)** [self]
RSphere5	3D	•	•	**Sphere (3D)** [self]
RSphere6	3D	•	•	**Sphere (3D)** [self]

Canonical form is RSphere1 (3D).

11.2.23 AlignedEllipse (2D)

An ellipse aligned with all axes.

Table 11.24: AlignedEllipse representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedHalfAxes	2D	•	•	**AlignedEllipse (2D)** [self]
RLinePoints	2D			AlignedRectangle (2D)
RLineVector	2D			AlignedRectangle (2D)

Canonical form is RAlignedHalfAxes (2D).

11.2.24 Ellipse (2D)

An ellipse.

Table 11.25: Ellipse representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedHalfAxes	2D			AlignedEllipse (2D)
RAlignedSquare1	2D			AlignedSquare (2D)
RAlignedSquare2	2D			AlignedSquare (2D)
RCircle0	2D			Circle (2D)
RCircle1	2D			Circle (2D)
RCircle2	2D			Circle (2D)
RCircle3	2D			Circle (2D)
RCircle4	2D			Circle (2D)
RCircle5	2D			Circle (2D)
REllipseCovariance	2D	•	•	**Ellipse (2D)** [self]
RHalfAxes	2D	•	•	**Ellipse (2D)** [self]
RLinePoints	2D			AlignedRectangle (2D), Line (2D), Square (2D)
RLineVector	2D			AlignedRectangle (2D), Line (2D), Square (2D)
RPoint	2D			Point (2D)
RRectangle1	2D			Rectangle (2D)
RRectangle2	2D			Rectangle (2D)

Canonical form is RHalfAxes (2D).

11.2.25 AlignedEllipsoid (3D)

An ellipsoid aligned with all axes.

Table 11.26: AlignedEllipsoid representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedHalfAxes	3D	•	•	**AlignedEllipsoid (3D)** [self]
RLinePoints	3D			AlignedCuboid (3D)
RLineVector	3D			AlignedCuboid (3D)

Canonical form is RAlignedHalfAxes (3D).

11.2.26 Ellipsoid (3D)

An ellipsoid.

Table 11.27: Ellipsoid representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedCube1	3D			AlignedCube (3D)
RAlignedCube2	3D			AlignedCube (3D)
RAlignedHalfAxes	3D			AlignedEllipsoid (3D)
RCuboid1	3D			Cuboid (3D)
RCuboid2	3D			Cuboid (3D)
REllipsoidCovariance	3D	•	•	**Ellipsoid (3D)** [self]
RHalfAxes	3D	•	•	**Ellipsoid (3D)** [self]
RLinePoints	3D			AlignedCuboid (3D), Cube (3D), Line (3D)
RLineVector	3D			AlignedCuboid (3D), Cube (3D), Line (3D)
RPoint	3D			Point (3D)
RSphere0	3D			Sphere (3D)
RSphere1	3D			Sphere (3D)
RSphere2	3D			Sphere (3D)
RSphere3	3D			Sphere (3D)
RSphere4	3D			Sphere (3D)
RSphere5	3D			Sphere (3D)
RSphere6	3D			Sphere (3D)

Canonical form is RHalfAxes (3D).

11.2.27 PolylineSpline (2D)

A set of connected splines (open).

Table 11.28: PolylineSpline representations (2D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	2D	•	•	**PolylineSpline (2D)** [self]
RPolylineVector	2D	•	•	**PolylineSpline (2D)** [self]

Canonical form is RPolylineVector (2D).

11.2.28 PolylineSpline (3D)

A set of connected splines (open).

Table 11.29: PolylineSpline representations (3D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	3D	•	•	**PolylineSpline (3D)** [self]
RPolylineVector	3D	•	•	**PolylineSpline (3D)** [self]

Canonical form is RPolylineVector (3D).

11.2.29 PolygonSpline (2D)

A set of connected splines (closed).

Table 11.30: PolygonSpline representations (2D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	2D	•	•	**PolygonSpline (2D)** [self]
RPolylineVector	2D	•	•	**PolygonSpline (2D)** [self]

Canonical form is RPolylineVector (2D).

11.2.30 PolygonSpline (3D)

A set of connected splines (closed).

Table 11.31: PolygonSpline representations (3D)

Representation	Dim	In	Out	Inherited from
RPolylinePoints	3D	•	•	**PolygonSpline (3D)** [self]
RPolylineVector	3D	•	•	**PolygonSpline (3D)** [self]

Canonical form is RPolylineVector (3D).

11.2.31 CircularCylinder (3D)

A circular cylinder.

Table 11.32: CircularCylinder representations (3D)

Representation	Dim	In	Out	Inherited from
RCircularCylinder1	3D	•	•	**CircularCylinder (3D)** [self]
RCircularCylinder2	3D	•	•	**CircularCylinder (3D)** [self]
RCircularCylinder3	3D	•	•	**CircularCylinder (3D)** [self]
RCircularCylinder4	3D	•	•	**CircularCylinder (3D)** [self]

Canonical form is RCircularCylinder1 (3D).

11.2.32 EllipticCylinder (3D)

An elliptic cylinder.

Table 11.33: EllipticCylinder representations (3D)

Representation	Dim	In	Out	Inherited from
RCircularCylinder1	3D			CircularCylinder (3D)
RCircularCylinder2	3D			CircularCylinder (3D)
RCircularCylinder3	3D			CircularCylinder (3D)
RCircularCylinder4	3D			CircularCylinder (3D)
REllipticCylinder1	3D	•	•	**EllipticCylinder (3D)** [self]
REllipticCylinder2	3D	•	•	**EllipticCylinder (3D)** [self]
REllipticCylinder3	3D	•	•	**EllipticCylinder (3D)** [self]
REllipticCylinder4	3D	•	•	**EllipticCylinder (3D)** [self]

Canonical form is REllipticCylinder1 (3D).

11.2.33 Arc (2D)

An arc.

Table 11.34: Arc representations (2D)

Representation	Dim	In	Out	Inherited from
RArc1	2D	•	•	**Arc (2D)** [self]
RArc2	2D	•	•	**Arc (2D)** [self]
RArc3	2D	•	•	**Arc (2D)** [self]

Canonical form is RArc1 (2D).

11.2.34 Arc (3D)

An arc.

Table 11.35: Arc representations (3D)

Representation	Dim	In	Out	Inherited from
RArc1	3D	•	•	**Arc (3D)** [self]
RArc2	3D	•	•	**Arc (3D)** [self]
RArc3	3D	•	•	**Arc (3D)** [self]

Canonical form is RArc1 (3D).

11.2.35 BitMask (1D)

A mask with one bit values.

Table 11.36: BitMask representations (1D)

Representation	Dim	In	Out	Inherited from
RBitMask	1D	•	•	**BitMask (1D)** [self]

Canonical form is RBitMask (1D).

11.2.36 BitMask (2D)

A mask with one bit values.

Table 11.37: BitMask representations (2D)

Representation	Dim	In	Out	Inherited from
RBitMask	2D	•	•	**BitMask (2D)** [self]

Canonical form is RBitMask (2D).

11.2.37 BitMask (3D)

A mask with one bit values.

Table 11.38: BitMask representations (3D)

Representation	Dim	In	Out	Inherited from
RBitMask	3D	•	•	**BitMask (3D)** [self]

Canonical form is RBitMask (3D).

11.2.38 GreyMask (1D)

A mask with multiple grey levels.

Table 11.39: GreyMask representations (1D)

Representation	Dim	In	Out	Inherited from
RGreyMask	1D	•	•	**GreyMask (1D)** [self]

Canonical form is RGreyMask (1D).

11.2.39 GreyMask (2D)

A mask with multiple grey levels.

Table 11.40: GreyMask representations (2D)

Representation	Dim	In	Out	Inherited from
RGreyMask	2D	•	•	**GreyMask (2D)** [self]

Canonical form is RGreyMask (2D).

11.2.40 GreyMask (3D)

A mask with multiple grey levels.

Table 11.41: GreyMask representations (3D)

Representation	Dim	In	Out	Inherited from
RGreyMask	3D	•	•	**GreyMask (3D)** [self]

Canonical form is RGreyMask (3D).

11.2.41 Mesh (2D)

A mesh.

Table 11.42: Mesh representations (2D)

Representation	Dim	In	Out	Inherited from
RMesh	2D	•	•	**Mesh (2D)** [self]

Canonical form is RMesh (2D).

11.2.42 Mesh (3D)

A mesh.

Table 11.43: Mesh representations (3D)

Representation	Dim	In	Out	Inherited from
RMesh	3D	•	•	**Mesh (3D)** [self]

Canonical form is RMesh (3D).

11.2.43 AffineTransform (1D)

Affine transformation of a shape.

Table 11.44: AffineTransform representations (1D)

Representation	Dim	In	Out	Inherited from
RAffineTransform	1D	•	•	**AffineTransform (1D)** [self]
RScaleTransform	1D	•		**AffineTransform (1D)** [self]
RTranslateTransform	1D	•		**AffineTransform (1D)** [self]

Canonical form is RAffineTransform (1D).

11.2.44 AffineTransform (2D)

Affine transformation of a shape.

Table 11.45: AffineTransform representations (2D)

Representation	Dim	In	Out	Inherited from
RAffineTransform	2D	•	•	**AffineTransform (2D)** [self]
RRotateTransform	2D	•		**AffineTransform (2D)** [self]
RScaleTransform	2D	•		**AffineTransform (2D)** [self]
RTranslateTransform	2D	•		**AffineTransform (2D)** [self]

Canonical form is RAffineTransform (2D).

11.2.45 AffineTransform (3D)

Affine transformation of a shape.

Table 11.46: AffineTransform representations (3D)

Representation	Dim	In	Out	Inherited from
RAffineTransform	3D	•	•	**AffineTransform (3D)** [self]
RRotateTransform	3D	•		**AffineTransform (3D)** [self]
RScaleTransform	3D	•		**AffineTransform (3D)** [self]
RTranslateTransform	3D	•		**AffineTransform (3D)** [self]

Canonical form is RAffineTransform (3D).

11.2.46 AbstractTransform (1D)

Abstract (implementation-defined) transformation of a shape.

Table 11.47: AbstractTransform representations (1D)

Representation	Dim	In	Out	Inherited from
RAbstractTransform	1D	•	•	**AbstractTransform (1D)** [self]
RAffineTransform	1D			AffineTransform (1D)
RScaleTransform	1D			AffineTransform (1D)
RTranslateTransform	1D			AffineTransform (1D)

Canonical form is RAbstractTransform (1D).

11.2.47 AbstractTransform (2D)

Abstract (implementation-defined) transformation of a shape.

Table 11.48: AbstractTransform representations (2D)

Representation	Dim	In	Out	Inherited from
RAbstractTransform	2D	•	•	**AbstractTransform (2D)** [self]
RAffineTransform	2D			AffineTransform (2D)
RRotateTransform	2D			AffineTransform (2D)
RScaleTransform	2D			AffineTransform (2D)
RTranslateTransform	2D			AffineTransform (2D)

Canonical form is RAbstractTransform (2D).

11.2.48 AbstractTransform (3D)

Abstract (implementation-defined) transformation of a shape.

Table 11.49: AbstractTransform representations (3D)

Representation	Dim	In	Out	Inherited from
RAbstractTransform	3D	•	•	**AbstractTransform (3D)** [self]
RAffineTransform	3D			AffineTransform (3D)
RRotateTransform	3D			AffineTransform (3D)
RScaleTransform	3D			AffineTransform (3D)
RTranslateTransform	3D			AffineTransform (3D)

Canonical form is RAbstractTransform (3D).

11.2.49 Text (2D)

Text (label).

Table 11.50: Text representations (2D)

Representation	Dim	In	Out	Inherited from
RText	2D	•	•	**Text (2D)** [self]

Canonical form is RText (2D).

11.2.50 Value (nD)

A value in an arbitrary dimension.

Table 11.51: Value representations (nD)

Representation	Dim	In	Out	Inherited from
RValue	nD	•	•	**Value (nD)** [self]

Canonical form is RValue (nD).

11.2.51 Values (nD)

A set of values in an arbitrary dimension.

Table 11.52: Values representations (nD)

Representation	Dim	In	Out	Inherited from
RValues	nD	•	•	**Values (nD)** [self]

Canonical form is RValues (nD).

11.2.52 Range (nD)

A range of values in an arbitrary dimension.

Table 11.53: Range representations (nD)

Representation	Dim	In	Out	Inherited from
RRange1	nD	•	•	**Range (nD)** [self]
RRange2	nD	•	•	**Range (nD)** [self]

Canonical form is RRange2 (nD).

11.2.53 Extrude (nD)

Extrude a shape of arbitrary dimensionality into an additional dimension..

Table 11.54: Extrude representations (nD)

Representation	Dim	In	Out	Inherited from
RExtrude	nD	•	•	**Extrude (nD)** [self]

Canonical form is RExtrude (nD).

11.2.54 Combine (nD)

Combine shapes of differing dimensionality to form a shape combining all subset dimensions..

Table 11.55: Combine representations (nD)

Representation	Dim	In	Out	Inherited from
RCombine	nD	•	•	**Combine (nD)** [self]

Canonical form is RCombine (nD).

11.2.55 Scale (2D)

A scale bar between two points.

Table 11.56: Scale representations (2D)

Representation	Dim	In	Out	Inherited from
RLinePoints	2D			Line (2D)
RLineVector	2D			Line (2D)

11.2.56 Scale (3D)

A scale bar between two points.

Table 11.57: Scale representations (3D)

Representation	Dim	In	Out	Inherited from
RLinePoints	3D			Line (3D)
RLineVector	3D			Line (3D)

11.2.57 Grid (2D)

A scale bar between two points.

Table 11.58: Grid representations (2D)

Representation	Dim	In	Out	Inherited from
RAlignedHalfAxes	2D			AlignedEllipse (2D)
RAlignedSquare1	2D			AlignedSquare (2D)
RAlignedSquare2	2D			AlignedSquare (2D)
RCircle0	2D			Circle (2D)
RCircle1	2D			Circle (2D)
RCircle2	2D			Circle (2D)
RCircle3	2D			Circle (2D)
RCircle4	2D			Circle (2D)
RCircle5	2D			Circle (2D)
REllipseCovariance	2D			Ellipse (2D)
RHalfAxes	2D			Ellipse (2D)
RLinePoints	2D			AlignedRectangle (2D), Line (2D), Square (2D)
RLineVector	2D			AlignedRectangle (2D), Line (2D), Square (2D)
RPoint	2D			Point (2D)
RRectangle1	2D			Rectangle (2D)
RRectangle2	2D			Rectangle (2D)

11.2.58 Grid (3D)

A scale bar between two points.

Table 11.59: Grid representations (3D)

Representation	Dim	In	Out	Inherited from
RAlignedCube1	3D			AlignedCube (3D)
RAlignedCube2	3D			AlignedCube (3D)
RAlignedHalfAxes	3D			AlignedEllipsoid (3D)
RCuboid1	3D			Cuboid (3D)
RCuboid2	3D			Cuboid (3D)
REllipsoidCovariance	3D			Ellipsoid (3D)
RHalfAxes	3D			Ellipsoid (3D)
RLinePoints	3D			AlignedCuboid (3D), Cube (3D), Line (3D)
RLineVector	3D			AlignedCuboid (3D), Cube (3D), Line (3D)
RPoint	3D			Point (3D)
RSphere0	3D			Sphere (3D)
RSphere1	3D			Sphere (3D)
RSphere2	3D			Sphere (3D)
RSphere3	3D			Sphere (3D)
RSphere4	3D			Sphere (3D)
RSphere5	3D			Sphere (3D)
RSphere6	3D			Sphere (3D)

11.2.59 Bitwise (1D)

Binary bitwise operation.

Table 11.60: Bitwise representations (1D)

Representation	Dim	In	Out	Inherited from
RBitwise	1D	•	•	**Bitwise (1D)** [self]

Canonical form is RBitwise (1D).

11.2.60 Bitwise (2D)

Binary bitwise operation.

Table 11.61: Bitwise representations (2D)

Representation	Dim	In	Out	Inherited from
RBitwise	2D	•	•	**Bitwise (2D)** [self]

Canonical form is RBitwise (2D).

11.2.61 Bitwise (3D)

Binary bitwise operation.

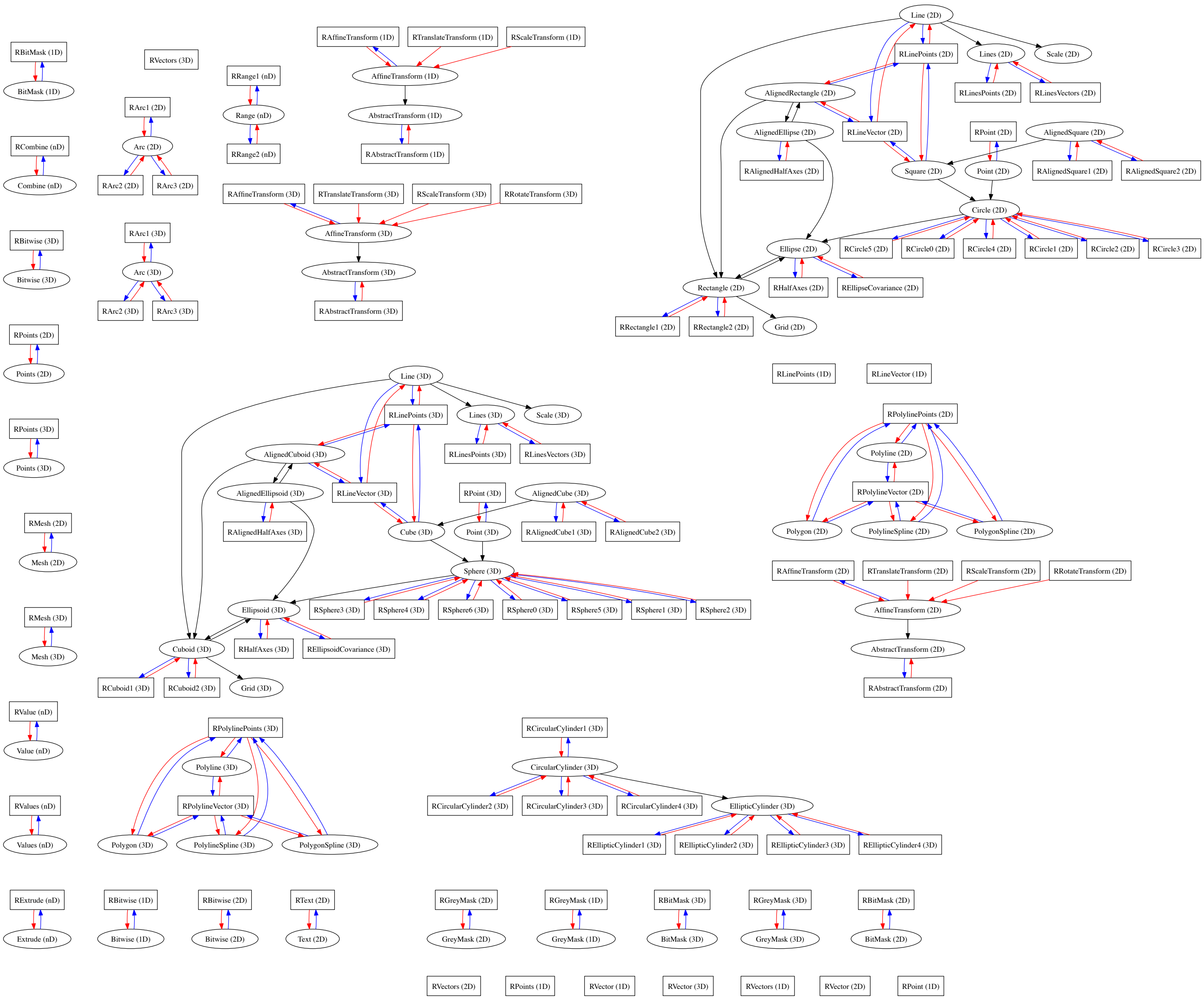
Table 11.62: Bitwise representations (3D)

Representation	Dim	In	Out	Inherited from
RBitwise	3D	•	•	**Bitwise (3D)** [self]

Canonical form is RBitwise (3D).

11.3 Relationships

The following figure illustrates the relationships detailed in the above tables. Ellipses are shapes, while representations are rectangles. Black arrows indicate inheritance of shape representations, while red and blue arrows indicate the representations possible to provide as input to and obtain as output from a shape, respectively.



CHAPTER

TWELVE

SHAPE REPRESENTATIONS

12.1 Overview

Table 12.1: Representations

ID	Representation	Dims	Description
0	*RPoint*	1D	A single point in 1D
1	*RPoint*	2D	A single point in 2D
2	*RPoint*	3D	A single point in 3D
3	*RPoints*	1D	A list of points in 1D
4	*RPoints*	2D	A list of points in 2D
5	*RPoints*	3D	A list of points in 3D
6	*RVector*	1D	A vector in 1D
7	*RVector*	2D	A vector in 2D
8	*RVector*	3D	A vector in 3D
9	*RVectors*	1D	A list of vectors in 1D
10	*RVectors*	2D	A list of vectors in 2D
11	*RVectors*	3D	A list of vectors in 3D
12	*RLinePoints*	1D	A line described by two points in 1D
13	*RLinePoints*	2D	A line described by two points in 2D
14	*RLinePoints*	3D	A line described by two points in 3D
15	*RLineVector*	1D	A line described by a point and a vector
16	*RLineVector*	2D	A line described by a point and a vector
17	*RLineVector*	3D	A line described by a point and a vector
18	*RLinesPoints*	2D	A list of lines described by two points in 2D
19	*RLinesPoints*	3D	A list of lines described by two points in 3D
20	*RLinesVectors*	2D	A list of lines described by a point and a vector in 2D; can be used to represent a vector field
21	*RLinesVectors*	3D	A list of lines described by a point and a vector in 3D; can be used to represent a vector field
22	*RPolylinePoints*	2D	A list of points in a polyline in 2D [could use RPoints2D directly]
23	*RPolylinePoints*	3D	A list of points in a polyline in 3D [could use RPoints3D directly]
24	*RPolylineVector*	2D	A list of points in a polyline represented by a starting point and list of vectors in 2D

Continued on next page

Table 12.1 – continued from previous page

ID	Representation	Dims	Description
25	*RPolylineVector*	3D	A list of points in a polyline represented by a starting point and list of vectors in 3D
26	*RAlignedSquare1*	2D	A square in 2D aligned with the axes described by a corner point and adjacent corner
27	*RAlignedSquare2*	2D	A square in 2D aligned with the axes described by a corner point and vector to an adjacent corner
28	*RAlignedCube1*	3D	A cube in 3D aligned with the axes described by a corner point and adjacent corner
29	*RAlignedCube2*	3D	A cube in 3D aligned with the axes described by a corner point and vector to an adjacent corner
30	*RRectangle1*	2D	A rectangle in 2D described by two corner points and a vector
31	*RRectangle2*	2D	A rectangle in 2D described by a corner point and two vectors
32	*RCuboid1*	3D	A cuboid in 3D described by two adjacent corners and two vectors
33	*RCuboid2*	3D	A cuboid in 3D described by a corner and three vectors
34	*RCircle1*	2D	A circle in 2D described by a centre point and 1D radius
35	*RCircle2*	2D	A circle in 2D described by a centre point and 2D radius
36	*RCircle3*	2D	A circle in 2D described by a circumference point and vector to the centre point
37	*RCircle5*	2D	A circle in 2D described by three circumference points
38	*RSphere1*	3D	A sphere in 3D described by a centre point and 1D radius
39	*RSphere2*	3D	A sphere in 3D described by a centre point and 2D radius
40	*RSphere3*	3D	A sphere in 3D described by a centre point and 3D radius
41	*RSphere4*	3D	A sphere in 3D described by a surface point and vector to the centre point
42	*RSphere6*	3D	A sphere in 3D described by a four surface points
43	*RAlignedHalfAxes*	2D	An ellipse in 2D aligned with the axes described by two half axes
44	*RHalfAxes*	2D	An ellipse in 2D described by two half axes
45	*REllipseCovariance*	2D	An ellipse in 2D described by a centre point and covariance matrix (Mahalanbobis distance)
46	*RAlignedHalfAxes*	3D	An ellipsoid in 3D aligned with the axes
47	*RHalfAxes*	3D	An ellipsoid in 3D described by three half axes
48	*REllipsoidCovariance*	3D	An ellipsoid in 3D described by a centre point and covariance matrix (Mahalanbobis distance)
49	*RCircularCylinder1*	3D	A circular cylinder in 3D described by the centres of both faces and a radius

Continued on next page

Table 12.1 – continued from previous page

ID	Representation	Dims	Description
50	*RCircularCylinder2*	3D	A circular cylinder in 3D described by the centre of one face, vector to second face and a radius
51	*RCircularCylinder3*	3D	A circular cylinder in 3D with faces at different angles described by the centres of both faces and vectors specifying the radius and angles of the faces
52	*RCircularCylinder4*	3D	A circular cylinder in 3D with faces at different angles described by the centre of one face, vector to second face and vectors specifying the radius and angles of the faces
53	*REllipticCylinder1*	3D	An elliptic cylinder in 3D described by the centres both faces and half axes
54	*REllipticCylinder2*	3D	An elliptic cylinder in 3D described by the centre of one face, vector to second face and half axes
55	*REllipticCylinder3*	3D	An elliptic cylinder in 3D with faces at different angles described by the centres both faces and half axes and angles
56	*REllipticCylinder4*	3D	An elliptic cylinder in 3D with faces at different angles described by the centre of one face, vector to second face and half axes and angles
57	*RArc1*	2D	An arc in 2D described by a line (points) and vector
58	*RArc2*	2D	An arc in 2D described by a line (vector) and a vector
59	*RArc3*	2D	An arc in 2D described by three points; vector inferred from third point
60	*RArc1*	3D	An arc in 3D described by a line (points) and vector
61	*RArc2*	3D	An arc in 3D described by a line (vector) and a vector
62	*RArc3*	3D	An arc in 3D described by three points; vector inferred from third point
63	*RBitMask*	1D	A bitmask in 1D described by bounding line, dimensions and mask data
64	*RBitMask*	2D	A bitmask in 2D described by bounding rectangle, dimensions and mask data
65	*RBitMask*	3D	A bitmask in 3D described by bounding cuboid, dimensions and mask data
66	*RGreyMask*	1D	A greymask in 1D described by bounding line, dimensions and mask data
67	*RGreyMask*	2D	A greymask in 2D described by bounding rectangle, dimensions and mask data
68	*RGreyMask*	3D	A greymask in 3D described by bounding cuboid, dimensions and mask data
69	*RMesh*	2D	A face-vertex mesh in 2D described by face and vertex lists
70	*RMesh*	3D	A face-vertex mesh in 3D described by face and vertex lists
71	*RAffineTransform*	1D	An affine transform in 1D described by a transformation matrix and 1D shape to transform

Continued on next page

Table 12.1 – continued from previous page

ID	Representation	Dims	Description
72	*RAffineTransform*	2D	An affine transform in 2D described by a transformation matrix and 2D shape to transform
73	*RAffineTransform*	3D	An affine transform in 3D described by a transformation matrix and 3D shape to transform
74	*RTranslateTransform*	1D	A translation transformation in 1D
75	*RTranslateTransform*	2D	A translation transformation in 2D
76	*RTranslateTransform*	3D	A translation transformation in 3D
77	*RScaleTransform*	1D	A scaling transformation in 1D
78	*RScaleTransform*	2D	A scaling transformation in 2D
79	*RScaleTransform*	3D	A scaling transformation in 3D
80	*RRotateTransform*	2D	A rotation transformation in 2D
81	*RRotateTransform*	3D	A rotation transformation in 3D
82	*RAbstractTransform*	1D	An abstract (implementation-defined) transform in 1D
83	*RAbstractTransform*	2D	An abstract (implementation-defined) transform in 2D
84	*RAbstractTransform*	3D	An abstract (implementation-defined) transform in 3D
85	*RText*	2D	Text
87	*RValue*	nD	A single value
88	*RValues*	nD	A set of values
89	*RRange1*	nD	A range of values specified as the half-open range [V1, V2)
90	*RRange2*	nD	A range of valuea specified as an inequality (or equality)
91	*RExtrude*	nD	A shape extruded in an additional dimension
92	*RCombine*	nD	A shape combined from shapes in different dimensions
93	*RBitwise*	1D	Binary bitwise operation
94	*RBitwise*	2D	Binary bitwise operation
95	*RBitwise*	3D	Binary bitwise operation
341	*RCircle0*	2D	A circle in 2D described by a centre point and circumference point
371	*RCircle4*	2D	A circle in 2D described by two circumference points [diameter]
381	*RSphere0*	3D	A sphere in 3D described by a centre point and surface point
421	*RSphere5*	3D	A sphere in 3D described by a two surface points [diameter]

12.2 Definitions

12.2.1 RPoint (1D)

A single point in 1D.

Table 12.2: RPoint members (1D)

SeqNo	Name	Type	Description
0	P1	Vertex1D	Point coordinate

12.2.2 RPoint (2D)

A single point in 2D.

Table 12.3: RPoint members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Point coordinates

12.2.3 RPoint (3D)

A single point in 3D.

Table 12.4: RPoint members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Point coordinates

12.2.4 RPoints (1D)

A list of points in 1D.

Table 12.5: RPoints members (1D)

SeqNo	Name	Type	Description
0	NPOINTS	Count	Number of points
1	POINTS	Vertex1D[NPOINTS]	Array of point coordinates

12.2.5 RPoints (2D)

A list of points in 2D.

Table 12.6: RPoints members (2D)

SeqNo	Name	Type	Description
0	NPOINTS	Count	Number of points
1	POINTS	Vertex2D[NPOINTS]	Array of point coordinates

12.2.6 RPoints (3D)

A list of points in 3D.

Table 12.7: RPoints members (3D)

SeqNo	Name	Type	Description
0	NPOINTS	Count	Number of points
1	POINTS	Vertex3D[NPOINTS]	Array of point coordinates

12.2.7 RVector (1D)

A vector in 1D.

Table 12.8: RVector members (1D)

SeqNo	Name	Type	Description
0	V1	Vector1D	Vector

12.2.8 RVector (2D)

A vector in 2D.

Table 12.9: RVector members (2D)

SeqNo	Name	Type	Description
0	V1	Vector2D	Vector

12.2.9 RVector (3D)

A vector in 3D.

Table 12.10: RVector members (3D)

SeqNo	Name	Type	Description
0	V1	Vector3D	Vector

12.2.10 RVectors (1D)

A list of vectors in 1D.

Table 12.11: RVectors members (1D)

SeqNo	Name	Type	Description
0	NVEC	Count	Number of vectors
1	VA1	Vector1D[NVEC]	Array of vectors

12.2.11 RVectors (2D)

A list of vectors in 2D.

Table 12.12: RVectors members (2D)

SeqNo	Name	Type	Description
0	NVEC	Count	Number of vectors
1	VA1	Vector2D[NVEC]	Array of vectors

12.2.12 RVectors (3D)

A list of vectors in 3D.

Table 12.13: RVectors members (3D)

SeqNo	Name	Type	Description
0	NVEC	Count	Number of vectors
1	VA1	Vector3D[NVEC]	Array of vectors

12.2.13 RLinePoints (1D)

A line described by two points in 1D.

Table 12.14: RLinePoints members (1D)

SeqNo	Name	Type	Description
0	P1	Vertex1D[2]	Line start and end points

12.2.14 RLinePoints (2D)

A line described by two points in 2D.

Table 12.15: RLinePoints members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D[2]	Line start and end points

12.2.15 RLinePoints (3D)

A line described by two points in 3D.

Table 12.16: RLinePoints members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D[2]	Line start and end points

12.2.16 RLineVector (1D)

A line described by a point and a vector.

Table 12.17: RLineVector members (1D)

SeqNo	Name	Type	Description
0	P1	Vertex1D	Line start

12.2.17 RLineVector (2D)

A line described by a point and a vector.

Table 12.18: RLineVector members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Line start
1	V1	Vector2D	Line end (relative to P1)

12.2.18 RLineVector (3D)

A line described by a point and a vector.

Table 12.19: RLineVector members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Line start
1	V1	Vector3D	Line end (relative to P1)

12.2.19 RLinesPoints (2D)

A list of lines described by two points in 2D.

Table 12.20: RLinesPoints members (2D)

SeqNo	Name	Type	Description
0	NLINES	Count	Number of lines
1	LINES	RLinePoints2D[NLINES]	Array of line points

12.2.20 RLinesPoints (3D)

A list of lines described by two points in 3D.

Table 12.21: RLinesPoints members (3D)

SeqNo	Name	Type	Description
0	NLINES	Count	Number of lines
1	LINES	RLinePoints3D[NLINES]	Array of line points

12.2.21 RLinesVectors (2D)

A list of lines described by a point and a vector in 2D; can be used to represent a vector field.

Table 12.22: RLinesVectors members (2D)

SeqNo	Name	Type	Description
0	NLINES	Count	Number of lines
1	LINES	RLineVector2D[NLINES]	Array of line vectors

12.2.22 RLinesVectors (3D)

A list of lines described by a point and a vector in 3D; can be used to represent a vector field.

Table 12.23: RLinesVectors members (3D)

SeqNo	Name	Type	Description
0	NLINES	Count	Number of lines
1	LINES	RLineVector3D[NLINES]	Array of line vectors

12.2.23 RPolylinePoints (2D)

A list of points in a polyline in 2D [could use RPoints2D directly].

Table 12.24: RPolylinePoints members (2D)

SeqNo	Name	Type	Description
0	P1	RPoints2D	Array of points

12.2.24 RPolylinePoints (3D)

A list of points in a polyline in 3D [could use RPoints3D directly].

Table 12.25: RPolylinePoints members (3D)

SeqNo	Name	Type	Description
0	P1	RPoints3D	Array of points

12.2.25 RPolylineVector (2D)

A list of points in a polyline represented by a starting point and list of vectors in 2D.

Table 12.26: RPolylineVector members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	First point
1	V1	RVectors2D	Array of vectors

12.2.26 RPolylineVector (3D)

A list of points in a polyline represented by a starting point and list of vectors in 3D.

Table 12.27: RPolylineVector members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	First point
1	V1	RVectors3D	Array of vectors

12.2.27 RAlignedSquare1 (2D)

A square in 2D aligned with the axes described by a corner point and adjacent corner.

Table 12.28: RAlignedSquare1 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	First corner
1	P2	Vertex1D	x coordinate of adjacent/opposing corner

12.2.28 RAlignedSquare2 (2D)

A square in 2D aligned with the axes described by a corner point and vector to an adjacent corner.

Table 12.29: RAlignedSquare2 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	First corner
1	P2	Vector1D	distance to adjacent corner on x axis (relative to P1)

12.2.29 RAlignedCube1 (3D)

A cube in 3D aligned with the axes described by a corner point and adjacent corner.

Table 12.30: RAlignedCube1 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	First corner
1	P2	Vertex1D	x coordinate of adjacent/opposing corner

12.2.30 RAlignedCube2 (3D)

A cube in 3D aligned with the axes described by a corner point and vector to an adjacent corner.

Table 12.31: RAlignedCube2 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	First corner
1	P2	Vector1D	distance to adjacent corner on x axis (relative to P1)

12.2.31 RRectangle1 (2D)

A rectangle in 2D described by two corner points and a vector.

Table 12.32: RRectangle1 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	First corner
1	P2	Vertex2D	Adjacent corner
2	V1	Vector1D	Distance to corner opposing P1 (relative to P2)

12.2.32 RRectangle2 (2D)

A rectangle in 2D described by a corner point and two vectors.

Table 12.33: RRectangle2 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	First corner
1	V1	Vector2D	Distance to adjacent corner (relative to P1)
2	V2	Vector1D	Distance to corner opposing P1 (relative to P2)

12.2.33 RCuboid1 (3D)

A cuboid in 3D described by two adjacent corners and two vectors.

Table 12.34: RCuboid1 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	First corner
1	P2	Vertex3D	Second corner (adjacent to P1)
2	V1	Vector2D	Distance to third corner (adjacent to P2)
3	V2	Vector1D	Distance to fourth corner (opposing P1, adjacent to V1)

12.2.34 RCuboid2 (3D)

A cuboid in 3D described by a corner and three vectors.

Table 12.35: RCuboid2 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	First corner
1	V1	Vector3D	Distance to second corner (relative to P1)
2	V2	Vector2D	Distance to third corner (relative to V1)
3	V3	Vector1D	Distance to fourth corner (relative to V2, opposing P1)

12.2.35 RCircle1 (2D)

A circle in 2D described by a centre point and 1D radius.

Table 12.36: RCircle1 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Centre point
1	V1	Vector1D	Radius

12.2.36 RCircle2 (2D)

A circle in 2D described by a centre point and 2D radius.

Table 12.37: RCircle2 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Centre point
1	V1	Vector2D	Radius

12.2.37 RCircle3 (2D)

A circle in 2D described by a circumference point and vector to the centre point.

Table 12.38: RCircle3 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Point on circumference
1	V1	Vector2D	Vector to centre

12.2.38 RCircle5 (2D)

A circle in 2D described by three circumference points.

Table 12.39: RCircle5 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D[3]	Three points on circumference

12.2.39 RSphere1 (3D)

A sphere in 3D described by a centre point and 1D radius.

Table 12.40: RSphere1 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre point
1	V1	Vector1D	Radius

12.2.40 RSphere2 (3D)

A sphere in 3D described by a centre point and 2D radius.

Table 12.41: RSphere2 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre point
1	V1	Vector2D	Radius

12.2.41 RSphere3 (3D)

A sphere in 3D described by a centre point and 3D radius.

Table 12.42: RSphere3 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre point
1	V1	Vector3D	Radius

12.2.42 RSphere4 (3D)

A sphere in 3D described by a surface point and vector to the centre point.

Table 12.43: RSphere4 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Point on surface
1	V1	Vector3D	Vector to centre

12.2.43 RSphere6 (3D)

A sphere in 3D described by a four surface points.

Table 12.44: RSphere6 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D[4]	Four points on surface

12.2.44 RAlignedHalfAxes (2D)

An ellipse in 2D aligned with the axes described by two half axes.

Table 12.45: RAlignedHalfAxes members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Centre point
1	V1	Vector2D	Half axes (x,y)

12.2.45 RHalfAxes (2D)

An ellipse in 2D described by two half axes.

Table 12.46: RHalfAxes members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Centre point
1	V1	Vector2D	Half axes (xy)
2	V1	Vector1D	Half axes (x)

12.2.46 REllipseCovariance (2D)

An ellipse in 2D described by a centre point and covariance matrix (Mahalanbobis distance).

Table 12.47: REllipseCovariance members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Centre point (mean)
1	COV1	double[2][2]	2×2 covariance matrix

12.2.47 RAlignedHalfAxes (3D)

An ellipsoid in 3D aligned with the axes.

Table 12.48: RAlignedHalfAxes members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre point
1	V1	Vector3D	Half axes (x,y,z)

12.2.48 RHalfAxes (3D)

An ellipsoid in 3D described by three half axes.

Table 12.49: RHalfAxes members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre point
1	V1	Vector3D	Half axes (xyz)
2	V2	Vector2D	Half axes (xy)
3	V3	Vector1D	Half axes (x)

12.2.49 REllipsoidCovariance (3D)

An ellipsoid in 3D described by a centre point and covariance matrix (Mahalanbobis distance).

Table 12.50: REllipsoidCovariance members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre point (mean)
1	COV1	double[3][3]	3×3 covariance matrix

12.2.50 RCircularCylinder1 (3D)

A circular cylinder in 3D described by the centres of both faces and a radius.

Table 12.51: RCircularCylinder1 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	P2	Vertex3D	Centre of second face
2	V1	Vector1D	Radius

12.2.51 RCircularCylinder2 (3D)

A circular cylinder in 3D described by the centre of one face, vector to second face and a radius.

Table 12.52: RCircularCylinder2 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	V1	Vector3D	Distance to centre of second face
2	V2	Vector1D	Radius

12.2.52 RCircularCylinder3 (3D)

A circular cylinder in 3D with faces at different angles described by the centres of both faces and vectors specifying the radius and angles of the faces.

Table 12.53: RCircularCylinder3 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	P2	Vertex3D	Centre of second face
2	V1	Vector3D	Radius and angle of first face
3	V2	Vector3D	Angle of second face

12.2.53 RCircularCylinder4 (3D)

A circular cylinder in 3D with faces at different angles described by the centre of one face, vector to second face and vectors specifying the radius and angles of the faces.

Table 12.54: RCircularCylinder4 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	V1	Vector3D	Distance to centre of second face
2	V2	Vector3D	Radius and angle of first face
3	V3	Vector3D	Angle of second face

12.2.54 REllipticCylinder1 (3D)

An elliptic cylinder in 3D described by the centres both faces and half axes.

Table 12.55: REllipticCylinder1 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	P2	Vertex3D	Centre of second face
2	V1	Vector2D	Half axes (xy)
3	V2	Vector1D	Half axes (x)

12.2.55 REllipticCylinder2 (3D)

An elliptic cylinder in 3D described by the centre of one face, vector to second face and half axes.

Table 12.56: REllipticCylinder2 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	V1	Vector3D	Distance to second face
2	V2	Vector3D	Half axes (xy)
3	V3	Vector2D	Half axes (x)

12.2.56 REllipticCylinder3 (3D)

An elliptic cylinder in 3D with faces at different angles described by the centres both faces and half axes and angles.

Table 12.57: REllipticCylinder3 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	P2	Vertex3D	Centre of second face
2	V1	Vector3D	Half axes of first face (xyz)
3	V2	Vector2D	Half axes of first face (xy)
4	V3	Vector3D	Angle of second face

12.2.57 REllipticCylinder4 (3D)

An elliptic cylinder in 3D with faces at different angles described by the centre of one face, vector to second face and half axes and angles.

Table 12.58: REllipticCylinder4 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre of first face
1	V1	Vector3D	Distance to second face
2	V2	Vector3D	Half axes (xyz)
3	V3	Vector2D	Half axes (xy)
4	V4	Vector3D	Angle of second face

12.2.58 RArc1 (2D)

An arc in 2D described by a line (points) and vector.

Table 12.59: RArc1 members (2D)

SeqNo	Name	Type	Description
0	P1	RLinePoints2D	Centre point and arc start
1	V1	Vector2D	Arc end

12.2.59 RArc2 (2D)

An arc in 2D described by a line (vector) and a vector.

Table 12.60: RArc2 members (2D)

SeqNo	Name	Type	Description
0	P1	RLineVector2D	Centre point and arc start
1	V1	Vector2D	Arc end

12.2.60 RArc3 (2D)

An arc in 2D described by three points; vector inferred from third point.

Table 12.61: RArc3 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D[3]	Centre point, arc start and arc end (vector inferred)

12.2.61 RArc1 (3D)

An arc in 3D described by a line (points) and vector.

Table 12.62: RArc1 members (3D)

SeqNo	Name	Type	Description
0	P1	RLinePoints3D	Centre point and arc start
1	V1	Vector3D	Arc end

12.2.62 RArc2 (3D)

An arc in 3D described by a line (vector) and a vector.

Table 12.63: RArc2 members (3D)

SeqNo	Name	Type	Description
0	P1	RLineVector3D	Centre point and arc start
1	V1	Vector3D	Arc end

12.2.63 RArc3 (3D)

An arc in 3D described by three points; vector inferred from third point.

Table 12.64: RArc3 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D[3]	Centre point, arc start and arc end (vector inferred)

12.2.64 RBitMask (1D)

A bitmask in 1D described by bounding line, dimensions and mask data.

Table 12.65: RBitMask members (1D)

SeqNo	Name	Type	Description
0	B1	RLinePoints2D	Bounding line
1	DIM1	Vector1D	Mask dimensions (x)
2	DATA	bool[x]	Mask data

12.2.65 RBitMask (2D)

A bitmask in 2D described by bounding rectangle, dimensions and mask data.

Table 12.66: RBitMask members (2D)

SeqNo	Name	Type	Description
0	B1	RLinePoints2D	Bounding box
1	DIM1	Vector2D	Mask dimensions (x,y)
2	DATA	bool[x,y]	Mask data

12.2.66 RBitMask (3D)

A bitmask in 3D described by bounding cuboid, dimensions and mask data.

Table 12.67: RBitMask members (3D)

SeqNo	Name	Type	Description
0	B1	RLinePoints3D	Bounding box
1	DIM1	Vector3D	Mask dimensions (x,y,z)
2	DATA	bool[x,y,z]	Mask data

12.2.67 RGreyMask (1D)

A greymask in 1D described by bounding line, dimensions and mask data.

Table 12.68: RGreyMask members (1D)

SeqNo	Name	Type	Description
0	B1	RLinePoints1D	Bounding line
1	DIM1	Vector1D	Mask dimensions (x)
2	DATA	double[x]	Mask data

12.2.68 RGreyMask (2D)

A greymask in 2D described by bounding rectangle, dimensions and mask data.

Table 12.69: RGreyMask members (2D)

SeqNo	Name	Type	Description
0	B1	RLinePoints2D	Bounding box
1	DIM1	Vector2D	Mask dimensions (x,y)
2	DATA	double[x,y]	Mask data

12.2.69 RGreyMask (3D)

A greymask in 3D described by bounding cuboid, dimensions and mask data.

Table 12.70: RGreyMask members (3D)

SeqNo	Name	Type	Description
0	B1	RLinePoints3D	Bounding box
1	DIM1	Vector3D	Mask dimensions (x,y,z)
2	DATA	double[x,y,z]	Mask data

12.2.70 RMesh (2D)

A face-vertex mesh in 2D described by face and vertex lists.

Table 12.71: RMesh members (2D)

SeqNo	Name	Type	Description
0	NFACE	Count	Number of faces
1	VREF	double[NFACE][3]	Vertex references per face, counterclockwise winding
2	NVERT	Count	Number of vertices
3	VERTS	Vertex2D[NVERT]	Vertex coordinates

12.2.71 RMesh (3D)

A face-vertex mesh in 3D described by face and vertex lists.

Table 12.72: RMesh members (3D)

SeqNo	Name	Type	Description
0	NFACE	Count	Number of faces
1	VREF	double[NFACE][3]	Vertex references per face, counterclockwise winding
2	NVERT	Count	Number of vertices
3	VERTS	Vertex3D[NVERT]	Vertex coordinates

12.2.72 RAffineTransform (1D)

An affine transform in 1D described by a transformation matrix and 1D shape to transform.

Table 12.73: RAffineTransform members (1D)

SeqNo	Name	Type	Description
0	TRANS	Affine1D	Transform
1	SHAPE	Shape	Shape

12.2.73 RAffineTransform (2D)

An affine transform in 2D described by a transformation matrix and 2D shape to transform.

Table 12.74: RAffineTransform members (2D)

SeqNo	Name	Type	Description
0	TRANS	Affine2D	Transform
1	SHAPE	Shape	Shape

12.2.74 RAffineTransform (3D)

An affine transform in 3D described by a transformation matrix and 3D shape to transform.

Table 12.75: RAffineTransform members (3D)

SeqNo	Name	Type	Description
0	TRANS	Affine3D	Transform
1	SHAPE	Shape	Shape

12.2.75 RTranslateTransform (1D)

A translation transformation in 1D.

Table 12.76: RTranslateTransform members (1D)

SeqNo	Name	Type	Description
0	TR1	Vector1D	Translation in x
1	SHAPE	Shape1D	Shape

12.2.76 RTranslateTransform (2D)

A translation transformation in 2D.

Table 12.77: RTranslateTransform members (2D)

SeqNo	Name	Type	Description
0	TR1	Vector2D	Translation in x,y
1	SHAPE	Shape1D	Shape

12.2.77 RTranslateTransform (3D)

A translation transformation in 3D.

Table 12.78: RTranslateTransform members (3D)

SeqNo	Name	Type	Description
0	TR1	Vector3D	Translation in x,y,z
1	SHAPE	Shape1D	Shape

12.2.78 RScaleTransform (1D)

A scaling transformation in 1D.

Table 12.79: RScaleTransform members (1D)

SeqNo	Name	Type	Description
0	SF1	double[1]	Scale factor for x
1	SHAPE	Shape1D	Shape

12.2.79 RScaleTransform (2D)

A scaling transformation in 2D.

Table 12.80: RScaleTransform members (2D)

SeqNo	Name	Type	Description
0	SF1	double[2]	Scale factor for x,y
1	SHAPE	Shape1D	Shape

12.2.80 RScaleTransform (3D)

A scaling transformation in 3D.

Table 12.81: RScaleTransform members (3D)

SeqNo	Name	Type	Description
0	SF1	double[3]	Scale factor for x,y,z
1	SHAPE	Shape	Shape

12.2.81 RRotateTransform (2D)

A rotation transformation in 2D.

Table 12.82: RRotateTransform members (2D)

SeqNo	Name	Type	Description
0	RA	double[1]	Rotation angle in z
1	SHAPE	Shape	Shape

12.2.82 RRotateTransform (3D)

A rotation transformation in 3D.

Table 12.83: RRotateTransform members (3D)

SeqNo	Name	Type	Description
0	RA	double[3]	Rotation angle in x,y,z
1	SHAPE	Shape	Shape

12.2.83 RAbstractTransform (1D)

An abstract (implementation-defined) transform in 1D.

Table 12.84: RAbstractTransform members (1D)

SeqNo	Name	Type	Description
0	NAME	String	Name of transformation
1	ARGS	String	Arguments
2	SHAPE	Shape	Shape

12.2.84 RAbstractTransform (2D)

An abstract (implementation-defined) transform in 2D.

Table 12.85: RAbstractTransform members (2D)

SeqNo	Name	Type	Description
0	NAME	String	Name of transformation
1	ARGS	String	Arguments
2	SHAPE	Shape	Shape

12.2.85 RAbstractTransform (3D)

An abstract (implementation-defined) transform in 3D.

Table 12.86: RAbstractTransform members (3D)

SeqNo	Name	Type	Description
0	NAME	String	Name of transformation
1	ARGS	String	Arguments
2	SHAPE	Shape	Shape

12.2.86 RText (2D)

Text.

Table 12.87: RText members (2D)

SeqNo	Name	Type	Description
0	B1	RRectangle2	Text bounds
1	TEXT	String	Text

12.2.87 RValue (nD)

A single value.

Table 12.88: RValue members (nD)

SeqNo	Name	Type	Description
0	D1	Index	Dimension
1	V1	Index	Value within dimension

12.2.88 RValues (nD)

A set of values.

Table 12.89: RValues members (nD)

SeqNo	Name	Type	Description
0	D1	Index	Dimension
1	NVAL	Count	Number of values
2	V1	Index[NVAL]	Values within dimension

12.2.89 RRange1 (nD)

A range of values specified as the half-open range [V1, V2).

Table 12.90: RRange1 members (nD)

SeqNo	Name	Type	Description
0	D1	Index	Dimension
1	V1	Index	Starting value within dimension
2	V2	Index	Ending value +1 within dimension

12.2.90 RRange2 (nD)

A range of valuea specified as an inequality (or equality).

Table 12.91: RRange2 members (nD)

SeqNo	Name	Type	Description
0	D1	Index	Dimension
1	O1	Operator	Mathematical operator
2	V1	Value	Value for operation

12.2.91 RExtrude (nD)

A shape extruded in an additional dimension.

Table 12.92: RExtrude members (nD)

SeqNo	Name	Type	Description
0	D1	Index	Dimension
1	SHAPE	Shape	Shape

12.2.92 RCombine (nD)

A shape combined from shapes in different dimensions.

Table 12.93: RCombine members (nD)

SeqNo	Name	Type	Description
0	S1	Shape	Dimension
1	S2	Shape	Dimension

12.2.93 RBitwise (1D)

Binary bitwise operation.

Table 12.94: RBitwise members (1D)

SeqNo	Name	Type	Description
0	O1	BLogic	Bitwise logic operator
1	M1	RBitMask1D	Mask 1
2	M2	RBitMask1D	Mask 2

12.2.94 RBitwise (2D)

Binary bitwise operation.

Table 12.95: RBitwise members (2D)

SeqNo	Name	Type	Description
0	O1	BLogic	Bitwise logic operator
1	M1	RBitMask2D	Mask 1
2	M2	RBitMask2D	Mask 2

12.2.95 RBitwise (3D)

Binary bitwise operation.

Table 12.96: RBitwise members (3D)

SeqNo	Name	Type	Description
0	O1	BLogic	Bitwise logic operator
1	M1	RBitMask3D	Mask 1
2	M2	RBitMask3D	Mask 2

12.2.96 RCircle0 (2D)

A circle in 2D described by a centre point and circumference point.

Table 12.97: RCircle0 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D	Centre point
1	P2	Vertex2D	Circumference point

12.2.97 RCircle4 (2D)

A circle in 2D described by two circumference points [diameter].

Table 12.98: RCircle4 members (2D)

SeqNo	Name	Type	Description
0	P1	Vertex2D[2]	Two points on circumference

12.2.98 RSphere0 (3D)

A sphere in 3D described by a centre point and surface point.

Table 12.99: RSphere0 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D	Centre point
1	P2	Vertex3D	Surface point

12.2.99 RSphere5 (3D)

A sphere in 3D described by a two surface points [diameter].

Table 12.100: RSphere5 members (3D)

SeqNo	Name	Type	Description
0	P1	Vertex3D[2]	Two points on surface

CHAPTER

THIRTEEN

LAYERS

In the Zeiss AxioVision formats, ROIs (shapes) are contained within Layers. Sets of ROIs are collected in different layers. The UI only uses a single layer, but uses separate layers for acquisition and post-acquisition ROIs. But in the file format one may define arbitrary numbers of layers to act as a grouping mechanism for ROIs.

Adding layers as a top level grouping would permit related ROIs to be grouped together. However, this would also be possible using ROI-ROI links; it could be implemented using Layer-ROI links. Maybe layer could be a ROI type used solely for grouping?

CHAPTER

FOURTEEN

ROI-ROI LINKS

ROI relationships: When segmenting cell contents, shown as cytoplasm, actin filaments, nucleus and nucleolus, these fall into a strict hierarchy (a nucleus can only be in one cell, though one cell could have more than one nucleus). If we added a ROI type that was a container of ROIs (note: not a union), and added a means of classifying ROIs with tags/labels, this would be very useful for HCS and other types of analysis. Additionally, some relationships are not hierarchical, e.g. tree-like branching and merging in a vessel bed, but could be represented if a ROI could point to one or more other ROIs, which would permit a directed graph of relationships between ROIs.

Tracking Containment User modification (branch/merge) Inherit properties Layer DAG

CHAPTER

FIFTEEN

STORAGE OF VERTEX DATA

For quite a number of the shape primitives, it is possible to support 3D very simply–we just increase the number of dimensions in each vertex, and that's it (obviously just for storage; it will still require some work for rendering). From the point of view of storing the list of vertices, it would be nice if we could specify the dimensions being used e.g. XZT, and then allow missing dimensions to be specified as constants as we now do for theZ. This will also mean that will will be possible to use a 2D primitive with theZ set as equivalent to a 3D primitive with the z value specified separately to the (x,y) points. This would provide one means of keeping the representation compact. Additionally, it is undesirable to have a separate element for each vertex, since for complex shapes e.g. meshes, this would waste a lot of space: when scaling up to thousands of vertices, this would waste multi-megabytes of XML markup for no good reason.

15.1 XML schema

Shape type and representation are stored as unsigned 16 bit integers, counts as unsigned 32 bit integers, and vertices and vectors as double-precision floating point.

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema" elementFormDefault="qualifie
    <xsd:simpleType name="shapeDetailElement">
        <xsd:union memberTypes="xsd:unsignedShort xsd:unsignedInt xsd:double" />
    </xsd:simpleType>
    <xsd:simpleType name="shapeDetail">
        <xsd:list itemType="shapeDetailElement"/>
    </xsd:simpleType>
    <xsd:element name="shape">
        <xsd:complexType>
            <xsd:simpleContent>
                <xsd:extension base="shapeDetail">
                </xsd:extension>
            </xsd:simpleContent>
        </xsd:complexType>
    </xsd:element>
</xsd:schema>
```

15.2 Properties

Store at the level of the ROI, not the shape. Since all the shapes within a ROI describe a single entity, there is no need for separate properties (colour, line thickness/style/endings etc.) on each shape.

Note: **J-M Burel**: previous discussion about that. Need to review the notes taken at the time.

CHAPTER SIXTEEN

DEFINITION OF TERMS

ROI Region of interest. A subset of samples within an image. This is specified by the boundary or surface of the object.

Shape Geometric shape or mask. A shape is a geometric primitive or bitmask. A ROI is composed of one or more shapes.

CHAPTER

SEVENTEEN

INDICES AND TABLES

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- *search*

INDEX

Symbols

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