Complementing layout information with render information in SBML files

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1 Introduction

In 2003 we proposed an extension to the SBML file format that allowed programs to include layout and render information in SBML files to store one or more graphical representations of the SBML model. During the discussions on the SBML mailing list, it soon became evident that a consensus for both layout and render information would not be reached easily, therefore we separated the layout from the render part of the specification and concentrated on the inclusion of layout information into SBML files. Now three years later, we consider the layout extension to be ready for general usage and as a matter of fact, it has been accepted as an official extension to the upcoming SBML Level 3. There are several implementations for it and some programs already use it to exchange layout information on reaction networks. With the growing interest in graphical representations of reaction networks we feel that it is now time to complement the layout extension with a render extension that builds on it and allows the user to define not only the size and location of the objects, but also how they are to be rendered.

2 Design decisions

The first and as we think natural decision was to base the render extension on the existing layout extension. Secondly, we tried to make the render extension as flexible as possible in order to not impose any artificial limits on how programs can display their reaction networks.

We wanted to keep the render extension independent of the SBML model as well as of the layout extension, therefore the render information will be stored as one or more separate blocks. There can be one block of render information that applies to all layouts and an additional block for each layout. In the beginning this render information will be stored in the annotation of the `listOfLayouts` element or the annotation of a `layout` element respectively.

The render information consists of a set of styles that are associated with objects from the layout either by a list of ids of layout objects or by roles of layout objects or ids of their corresponding model elements. For example you can define a style that can be applied to all SpeciesReference objects or to all objects that have the role *product*.

Global render information included in the annotation of the `listOfLayouts` element will only be able to define styles that associate render information with roles of elements, it can not associate styles with individual objects from a layout.

Many of the elements used in the current render specification are based on corresponding elements from the SVG specification. This allows us to easily convert a combination of layout information and render information into a SVG drawing. At the same time we profit from the work that has already been done while creating the SVG specification.

3 Render information

The render extension provides two locations where styles can be defined. First each layout can have its own set of render information located in the annotation of the `layout` element (local render information). Second, a set of global render information located in the annotation of the `listOfLayouts` element can be defined.

It is important to note that each layout can have more than one set of local render information and that it is also possible to define more then one global style. Each style can also reference another style that complements it, this way the user can create styles that are based on other styles. In contrast to local styles, the global styles can not reference individual layout elements by an id, they can only define role based or type based styles.

3.1 Local render information

The top level element for the local render information is called `listOf-RenderInformation` which can contain a list of one or more `renderInformation` elements of type LocalRenderInformation. The LocalRenderInformation data type is based on the RenderInformationBase data type. The RenderInformationBase class is derived from SBMLs SBase type and has five attributes. The `id` attribute is of type SId like the ids in SBML. It is used to give the `renderInformation` element a unique id through which it can be referenced from other LocalRenderInformation objects. The optional attribute `name` gives a LocalRenderInformation object a more user friendly name that can be displayed in programs.

The attributes `programName` and `programVersion` are optional and can be used to store information about the program that created the render information. Another optional attribute called `referenceRenderInformation` can be used to specify the id of another local or global render information object that complements the current render information object. So if a program can find no fitting render information in the current render information object, it can go on to the one referenced and see if it can find fitting information there. In order to avoid loops, only render information objects that have already been defined before may be referenced. So local render information objects may reference any global render information object as well as any local render information object that has already been defined and belongs to the same layout.

In addition to those five attributes, the RenderInformationBase object has three elements. The first element is called `listOfColorDefinitions` and is used to predefine a set of colors to be referenced in styles. The second element `listOfGradientDefinitions` contains linear and radial gradients to be referenced in styles. How colors and gradients can be defined is explained in the section called "Colors and gradients".

The third element is called `listOfLineEndings` and it is used to define a set of line endings that can be applied to path objects. This is explained in more detail in the section called "Line endings".

The LocalRenderInformation class extends the RenderInformationBase class by one element. The element is called `listOfStyles` and it can hold one or more local style objects. Each local style object is located in an element called `style` and is of type LocalStyle.

A LocalStyle object has an attribute called `id` that uniquely identifies it. It also has an optional `roleList` attribute which lists all the roles the style applies to and it can have a `typeList` attribute which lists all the element types the style applies to. The valid types for the `typeList` attribute are a combination of one or more of the following values separated by whitespaces:

- COMPARTMENTGLYPH,
- SPECIESGLYPH,
- REACTIONGLYPH,
- SPECIESREFERENCEGLYPH
- TEXTGLYPH,
- GRAPHICALOBJECT and
- ANY

The ANY keyword specifies that this styles applies to any type of glyph and would be equivalent to listing all the other keywords. Concerning the valid keywords for the `roleList` attribute we had thought about taking those from some kind of controlled vocabulary. Preferably, this would be some kind of ontology like SBO. The specifics of this will have to be discussed with other interested parties.

For the time being, all layout objects derived from GraphicalObject will get an additional attribute called `objectRole`. This attribute can be used to specify a string that specifies the role of the given object. If the same string appears in the roleList of some render information object, the render information applies to the object, but only if there is no render information object that is more specific (see ”Style resolution” and ”Role resolution” below).

LocalStyle objects can have one more optional attribute which is called `idList`. This is simply a list of ids of layout objects the style applies to.

The only subelement of a style is a `g` element which specifies how the element(s) covered by the `idList, roleList` and `typeList` are to be rendered. The details of this element are described in the section about grouping below.

ListOfLocalRenderInformation inherits from **SBase**		
renderInformation	:	LocalRenderInformation[1..∗]

RenderInformationBase inherits from **SBase**		
id	:	SId
name	:	string {use=”optional”}
programName	:	string {use=”optional”}
programVersion	:	string {use=”optional”}
referenceRenderInformation	:	string {use=”optional”}
listOfColorDefinitions	:	ListOfColorDefinitions {use=”optional”}
listOfGradientDefinitions	:	ListOfGradientDefinitions {use=”optional”}
listOfLineEndings	:	ListOfLineEndings {use=”optional”}

LocalRenderInformation inherits from **RenderInformationBase**		
listOfStyles	:	ListOfLocalStyles {use=”optional”}

ListOfLocalStyles inherits from **SBase**		
style	:	LocalStyle[1..∗]

example:

LocalStyle inherits from **Style**		
idList	:	string[1..∗] {use=”optional”}

Style inherits from **SBase**		
id	:	SId
roleList	:	string[1..∗] {use=”optional”}
typeList	:	string[1..∗] {use=”optional”}
g	:	Group

```
<listOfLayouts xmlns="http://projects.eml.org/bcb/sbml/level2"
         xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <layout id="Layout_1">
    <annotation>
      <listOfRenderInformation
           xmlns="http://projects.eml.org/bcb/sbml/render/level2">
        <renderInformation id="FancyRenderer_Default"
                            name="default style"
                           programName="FancyRenderer"
                           programVersion="0.1.1">
          <listOfColorDefinitions>
            <colorDefinition ... />
                  ...
          </listOfColorDefinitions>
          <listOfGradientDefinitions>
            <linearGradient ... >
                 ...
            </linearGradient>
            <radialGradient ... >
                 ...
            </radialGradient>
                  ...
          </listOfGradientDefinitions>
          <listOfLineEndings>
               ...
          </listOfLineEndings>
          <listOfStyles>
            <style id="CompartmentGlyphStyle" typeList="COMPARTMENTGLYPH">
              <g ...>
                ...
              </g>
            </style>
             ...
          </listOfStyles>
        </renderInformation>
      </listOfRenderInformation>
    </annotation>
```

```
      ...
  </layout>
</listOfLayouts>
```

3.2 Global render information

Global render information is specified very similar to local render information there are only some slight differences that one has to be aware of. Global render information is stored in an element called `listOfGlobalRender-Information` which contains one ore more `renderInformation` elements of type GlobalRenderInformation. The attribute and elements of GlobalRenderInformation objects and LocalRenderInformation objects are the same. The only difference here is the fact that GlobalRenderInformation objects in their `referenceRenderInformation` attribute may only reference ids of other GlobalRenderInformation objects that have already been defined.

The `listOfStyles` element of the GlobalRenderInformation object contains one or more `style` elements but this time these are of type GlobalStyle. The GlobalStyle data type is also very similar to the LocalStyle data type but the GlobalStyle does not have an `idList` attribute since referencing individual ids from a layout does not make sense for a global render information object. Otherwise global and local render information is specified in the same way.

ListOfGlobalRenderInformation inherits from **SBase**		
renderInformation	:	GlobalRenderInformation[1..∗]

GlobalRenderInformation inherits from **RenderInformationBase**		
listOfStyles	:	ListOfGlobalStyles {use="optional"}

example:

```
<listOfLayouts xmlns="http://projects.eml.org/bcb/sbml/level2"
         xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <annotation>
    <listOfGlobalRenderInformation
          xmlns="http://projects.eml.org/bcb/sbml/render/level2">
      <renderInformation id="FancyRenderer_GlobalDefault"
                         name="default global style"
                         programName="FancyRenderer"
                         programVersion="0.1.1">
        <listOfColorDefinitions>
```

```
          ...
      </listOfColorDefinitions>
      <listOfGradientDefinitions>
          ...
      </listOfGradientDefinitions>
      <listOfLineEndings>
          ...
      </listOfLineEndings>
      <listOfStyles>
          ...
      </listOfStyles>
    </renderInformation>
  </listOfGlobalRenderInformation>
 </annotation>
</listOfLayouts>
```

4 Styles

4.1 Positions and sizes

Positions and sizes for render elements can be specified as a combination of absolute values where the default unit is pt (1/72 inch) and relative values in % where the % symbol has to be added to the value. Each coordinate can have zero or one relative component and zero or one absolute component. For example to specify a coordinate that is 5 points left of the right edge of the current viewport the user could specify $-5 + 100\%$.

In order to make parsing of coordinate information easier, the absolute component has to be specified before the relative component. If the absolute component is 0.0, only the relative part has to be specified. All values are relative to the bounding box of the corresponding element in the layout. This bounding box basically specifies a canvas for the render elements to be drawn on.

When applying transformations to elements with relative values, the relative values have to be converted to absolute values first.

4.2 Colors and gradients

Although, it is possible to specify the color for a graphical primitive directly, colors and especially gradients can be specified in a so called `listOfColorDefinitions` and `listOfGradientDefinitions` element which are subelements of the RenderInformation data type. The `listOfColorDefinitions` element holds one or more elements called `colorDefinition` of type ColorDefinition. The ColorDefinition data type is derived from SBase and has two additional attributes. One `id` attribute which uniquely identifies the ColorDefinition object within a RenderInformation object and an attribute called `value` which holds a color value.

Color values are specified as a 6 to 8 digit hex string which defines the RGBA value of the color. If only the first six digits for the RGB value are given, the alpha value is assumed to be 0xFF which means that the color is totally opaque. Instead of specifying a color value, the value '**none**' can be given which is equal to no drawing at all. To specify '**none**' for the stop-color of a gradient is not allowed.

ColorDefinition inherits from **SBase**		
id	:	SId
value	:	string

example:

```
<listOfColorDefinitions>
  <colorDefinition id="darkred" value="#200000" />
       ...
</listOfColorDefinitions>
```

All graphical primitives in the render extension have a `stroke` attribute that is used to specify the color of the stroke that is used to draw the curve or the outline of ellipses, rectangles or polygons. This `stroke` attribute can either hold a color value or it can hold the id of a predefined ColorDefinition object.

The `listOfGradientDefinitions` element holds one or more `linear-Gradient` or `radialGradient` subelements of type LinearGradient or RadialGradient respectively.

The base class for both gradient types is called GradientBase and it has the two attributes `id` and `spreadMethod`. As well as a list of so called "gradient stops". The id attribute is used to identify and reference a gradient within a render information.

GradientBase inherits from **SBase**		
id	:	SId
spreadMethod	:	string {use="optional" default="pad"}
stop	:	GradientStop[1..∗]

The `spreadMethod` attribute is optional and specifies the method that is used to continue the gradient pattern if the vector points do not span the whole bounding box of the object the gradient is applied to (see example below). The attribute can have three values called **pad**, **reflect** or **repeat**:

- **pad:** the gradient color at the endpoint of the vector defines how the gradient is continued beyond that point (default value).
- **reflect:** the gradient continues from end to start and then from start to end again and again.
- **repeat:** the gradient pattern is repeated from start to end over and over again.

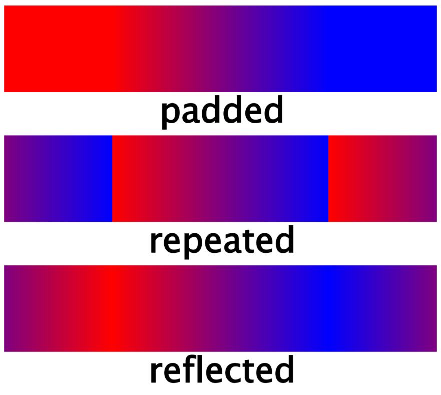


Figure 1: example of different SVG spreadMethod values

To specify "gradient stops" the a gradient element can hold one or more subelements called `stop` which are of type GradientStop. The GradientStop data type has two attributes. The first attribute, called `offset`, represents the relative distance from the starting point of the gradient. Depending on the type of gradient, this is either the point defined by the `x1`,`y1` and `z1` attributes (linear gradient) or the `fx`,`fy` and `fz` attributes (radial gradient). The value is given as a positive percentage value (usually somewhere between 0% and 100%). The other attribute is called `stop-stroke` and defines the color for the given gradient stop. The attributes value can either be given as a hexadecimal color value or as the id of a ColorDefinition object from the `listOfColorDefinitions` (see above). To specify the id of another gradient as the value of a stop-color attribute is considered an error. In case the two points that define the gradient vector are identical, the area is to be painted with a single color taken from the last gradient stop element.

A `linearGradient` element has six attributes. The attributes `x1`, `y1`, `z1`, `x2`, `y2` and `z2` are all optional and define a vector on which the gradient stops are mapped. If not specified, `x1`, `y1` and `z1` default to 0% and `x2`,`y2` and `z2` default to 100%.

LinearGradient inherits from **GradientBase**		
x1	:	string {use="optional" default="0%"}
y1	:	string {use="optional" default="0%"}
z1	:	string {use="optional" default="0%"}
x2	:	string {use="optional" default="100%"}
y2	:	string {use="optional" default="100%"}
z2	:	string {use="optional" default="100%"}

GradientStop inherits from **SBase**		
offset	:	string
stop-color	:	string

example:

```
<listOfGradientDefinitions>
  <linearGradient x1="30%" y1="50%" x2="70%" y2="50%">
    <stop offset="0%" stop-color="#0000A0" />
    <stop offset="100%" stop-color="darkred" />
  </linearGradient>
        ...
</listOfGradientDefinitions>
```

The RadialGradient data type has seven additinal attributes. The attributes `cx`, `cy` and `cz` define the center of the radial gradient. The attributes are optional and can either be given in absolute or relative coordinates. The default value for all three attributes is 50%. The `r` attribute defines the radius of the gradient and it can also be specified in either absolute or relative coordinates. Specifying negative values for `r` is considered an error. The attributes `fx`, `fy` and `fz` specify the focal point of the gradient. The gradient will be drawn such that the 0% stop is mapped to (fx,fy,fz). The attributes `fx`, `fy` and `fz` are optional. If one is omitted it is considered to equal to the value of `cx`, `cy` and `cz` respectively.

example:

```
<listOfGradientDefinitions>
  <radialGradient cx="50%" cy="50%" r="20" spreadMethod="repeat">
    <stop offset="10%" stop-color="#000040" />
```

RadialGradient inherits from **GradientBase**		
cx	:	string {use="optional" default="50%"}
cy	:	string {use="optional" default="50%"}
cz	:	string {use="optional" default="50%"}
r	:	string {use="optional" default="50%"}
fx	:	string {use="optional"}
fy	:	string {use="optional"}
fz	:	string {use="optional"}

```
    <stop offset="90%" stop-color="#0000C0" />
  </radialGradient>
      ...
</listOfGradientDefinitions>
```

4.3 Graphical primitives

The graphical primitives polygons, rectangles and ellipses are based on the corresponding elements from SVG. For lines, arcs and general path primitives, we basically reuse the curve element from the layout extension. There is however one difference to the Curve data type from the layout extension. Whereas Point objects in the layout extension could only contain absolute values for their coordinates, Point objects in the render extension can contain relative coordinate values. Since polygons are very similar to general path primitives, we also make use of the Curve data type to specify polygons in the render extension.

All graphical primitives have attributes in common that specify some drawing properties. As mentioned in the "Colors and gradients" section, each graphical primitive has a `stroke` attribute that defines the color used for curves and outlines of geometric shapes. In addition to that, the `stroke-width` attribute specifies the width of the stroke and the `stroke-dasharray` is a list of numbers that specifies the lengths of dashes and gaps that are used to draw the line. The individual numbers in the list are separated by commas.

In addition to those attributes, ellipses, polygons, curves and rectangles have an attribute called `fill` that specifies the fill style of those elements. The fill style can either be a hexadecimal color value or the id of a ColorDefinition object or the id of a GradientDefinition object. Instead of a color or gradient id, '**none**' can be specified which means that the object is unfilled.

Additionally, an attribute called `fill-rule` can be used to specify how the shape should be filled. Allowed values for fill-rule are:

- `nonzero` (default),

- `evenodd` or
- `inherit`.

For a detailed description on how those attributes work in detail, we would like to refer you to the corresponding documentation in the SVG specification. As time permits we will add our own documentation.

As a common base class for all elements that can be drawn, we introduce the class **Transformation3D** which contains one attribute called *transform* that specifies an affine transformation matrix in 3D consisting of exactly twelve double values. Since the layou and render extension are only 2D so far, this class is only used as a base class for **Transformation2D** and we leave the complete specification of this class for a future version of this document.

Transformation3D inherits from **SBase**		
transform	:	double[12] {use=”optional”}

Since the current render information specification only defined 2D objects, we derive a second class called Transformation2D from Transformation3D. This new class restricts the transformation matrix to specify the six values of a 2D affine transformation. The class Transformation2D serves as the base class for all drawable 2D objects.

Transformation2D inherits from **Transformation3D**		
transform	:	double[6] {use=”optional”}

4.4 Transformations

In order to be able to display text that is not aligned horizontally or vertically or to effectively compose groups of objects from primitives, transformation like rotation, translation and scaling are needed. SVG, among other options, allows the user to specify a 3x3 matrix transformation matrix:

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

Since the last row of the matrix is always 0 0 1, the matrix is specified as a six value vector. Therefore, in the render extension each group or graphical primitive is derived from the class **Transformation2D** and can have a `transform` attribute just as in SVG. The allowed value for the attribute has the form: `a, b, c, d, e, f`.

The values for `a`,`b`,`c`,`d`,`e` and `f` depend on the transformation operation components and the order in which those transformation components are executed.

There are five basic transformation operations that can be combined in a affine transformation matrix.

4.4.1 Translation

Translating something means moving it some distance along one or more of the axes. The corresponding 2D tranformation matrix is

$$\begin{bmatrix} 1 & 0 & tx \\ 0 & 1 & ty \\ 0 & 0 & 1 \end{bmatrix}$$

where tx and ty are the distance along the x and y axes by which the object shall be moved.

4.4.2 Scaling

Scaling means to multiply all coordintate components of an object by a certain value. The corrsponding 2D transformation matrix is

$$\begin{bmatrix} sx & 0 & 0 \\ 0 & sy & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where sx and sy are the scaling factors along the x and y axis respectively.

4.4.3 Rotation

With a rotation, an object can be rotated around the origin of the coordinate system. The corrsponding 2D transformation matrix is

$$\begin{bmatrix} cos(\alpha) & -sin(\alpha) & 0 \\ sin(\alpha) & cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where α is the angle of rotation around the origin.

4.4.4 Skewing

Skewing is the least used operation and we have to distinguish between skewing along the x or the y axis. The corrsponding 2D transformation matrices are

$$\begin{bmatrix} 1 & tan(\alpha) & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ tab(\beta) & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where α is the skewing angle of skewing along the x axis and β is the angle for skewing along the y axis.

Combining several of the operations above means multiplying the transformation matrices that belong to the individual operations. Depending on the matrices that are multiplied, the order of the operations matter, e.g. it makes a difference if an object is tranlated before it is rotatet or if it is rotatet first.

example:

```
 <g ...>
   <text x="50%" y="50%" text-anchor="middle" stroke="#FF0000"
         font-family="serif" font-size="20.0"
         transform="1.0, 3.0, 2.5, 1.4, 4.0, 5.0">This is a Text</text>
       ...
</g>
```

GraphicalPrimitive1D inherits from colorred**Transformation2D**		
stroke	:	string {use="optional"}
stroke-width	:	string {use="optional"}
stroke-dasharray	:	double[1..*] {use="optional"}

GraphicalPrimitive2D inherits from **GraphicalPrimitive1D**		
fill	:	string {use="optional"}
fill-rule	:	string {use="optional" default="nonzero"}

4.4.5 Curves

Simple lines and complex curves are represented by the curve element introduced in the layout extension. A curve has a `listOfCurveSegments` element that can hold an arbitrary number of line segments and cubic bezier elements in any order . With this, any path can be represented.

As mentioned earlier, Point objects used to specify the individual curve segments can contain relative values for their coordinates as well as absolute values. The coordinate values are always with respect to the bounding box of the layout object the render information applies to.

To assign line endings to the start and end of a path object, two new attributes were introduced. They are called `startHead` and `endHead` and specify the id of the line ending that shall be applied to the start and the end of the curve respectively. Both attributes are optional. How line endings are defined is described in the section called "Line endings".

Curve inherits from **GraphicalPrimitive2D**		
startHead	:	SId {use="optional"}
endHead	:	SId {use="optional"}
listOfCurveSegments	:	ListOfCurveSegments

ListOfCurveSegments inherits from **SBase**		
curveSegment	:	LineSegment[1..*]

example:

```
<g ...>
 <curve stroke-width="2.0" stroke="#000000" >
```

Point inherits from **SBase**		
id	:	SId {use=”optional”}
x	:	string
y	:	string
z	:	string {use=”optional” default=”0.0”}

LineSegment inherits from **SBase**		
start	:	Point
end	:	Point

CubicBezier inherits from **LineSegment**		
basePoint1	:	Point {use=”optional”}
basePoint2	:	Point {use=”optional”}

```
    <listOfCurveSegments>
      <curveSegment xsi:type="LineSegment">
        <start x="0%" y="50%" />
        <end x="100%" y="50%" />
      </curveSegment>
    </listOfCurveSegments>
  </curve>
     ...
</g>
```

4.4.6 Polygons

A polygon object is made up of a `polygon` element which contains a listOf-CurveSegments that defines the edge of the polygon.

The major difference to the curve object is that the individual curve segments can only be straight lines and the last point of the curve is connected to the first, so the polygon is always closed. Therfore, the polygon can have a fill style that determines how the inside of the polygon is to be rendered.

Polygon inherits from **GraphicalPrimitive2D**		
listOfCurveSegments	:	ListOfCurveSegments

example:

```
 <g ...>
  <polygon fill="darkred" stroke="#000000" >
    <listOfCurveSegments>
      <curveSegment xsi:type="LineSegment">
```

```
        <start x="0%" y="50%" />
        <end x="30%" y="0%" />
      </curveSegment>
      <curveSegment xsi:type="LineSegment">
        <start x="30%" y="0%" />
        <end x="70%" y="0%" />
      </curveSegment>
      <curveSegment xsi:type="LineSegment">
        <start x="70%" y="0%" />
        <end x="100%" y="50%" />
      </curveSegment>
      <curveSegment xsi:type="LineSegment">
        <start x="100%" y="50%" />
        <end x="70%" y="100%" />
      </curveSegment>
      <curveSegment xsi:type="LineSegment">
        <start x="70%" y="100%" />
        <end x="30%" y="100%" />
      </curveSegment>
    </listOfCurveSegments>
  </polygon>
     ...
</g>
```

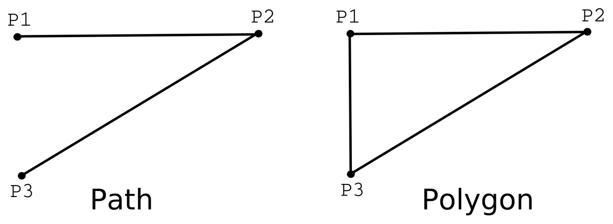


Figure 2: Rendering of a Path vs. rendering of a Polygon with the same base points

4.4.7 Rectangles

The rectangle object was taken from the SVG specification and allows the definition of rectangles with or without rounded edges.

The rectangle has the attributes `x`, `y` and `z` to specify its position within the bounding box of the enclosing layout object and a `width` and `height` attribute that specifies the width and height of the rectangle, either in absolute values or as a percentage of the width and height of the enclosing bounding box. The default value for the optional `z` attribute is 0.0.

Additionally the rectangle has two optional attributes `rx` and `ry` that specify the radius of the corner curvature. If only `rx` or `ry` is specified, the other is presumed to have the same value as the one given. The default value for `rx` and `ry` is 0.0 which means that the edges are not rounded.

Rectangle inherits from **GraphicalPrimitive2D**		
x	:	string
y	:	string
z	:	string {use="optional" default="0.0"}
width	:	string
height	:	string
rx	:	string {use="optional" default="0.0"}
ry	:	string {use="optional" default="0.0"}

example:

```
 <g ...>
  <rectangle x="0%" y="0%" width="100%" height="100%" rx="5%"
             fill="darkred" stroke="#000000" />
      ...
</g>
```

4.4.8 Ellipses

The definition of an ellipse was also taken directly from SVG. The ellipse has the attributes `cx`, `cy` and `cz` to specify the center of the ellipse and `rx` and `ry` to specify the radius of the ellipse along the x-axis and the y-axis respectively. If only rx or ry is specified, the other is presumed to have the same value. Circles are a special case of an ellipse where `rx` and `ry` are equal. Again `cz` is optional and its default value is 0.0.

Ellipse inherits from **GraphicalPrimitive2D**		
cx	:	string
cy	:	string
cz	:	string {use="optional" default="0.0"}
rx	:	string
ry	:	string {use="optional" default=rx}

example:

```
 <g ...>
  <ellipse cx="50%" cy="50%" rx="30%" fill="#00FF00" stroke="#000000" />
      ...
</g>
```

4.4.9 Text elements

In order to draw text, we use the text element from SVG with slight modifications. Like the text element in SVG, our text element has the optional attributes `font-family` to specify which font to use and `font-size` to specify the size of the font. If specified, `font-size` must be a positive value. It can be either an absolute value or a relative value. In the case of a relative value it specifies a percentage of the height of the corresponding object. Combinations of absolute and relative values as for the point objects in other objects are not allowed.

For reasons of simplicity, we limit the display of text to normal text, outlined or filled-outlined text are not supported. Also in order to simplify the text display we think it would be best practice if programs would limit the choice of the font-family attribute to the generic families serif, sansserif and monospace. But since those only apply to western languages, it make sense to use other values for font-familie in certain cases.

The horizontal alignment of a text element can be specified by the `text-anchor` attribute. Allowed values are start, middle and end. SVG does not seem to provide any means for the vertical alignment of text, therefore in order to make it easier for implementers we did not add it either. On the other hand if people think that this is a necessary feature, we can either extend the allowed values for the `text-anchor` attribute, or we can add a second attribute with the same allowed values to do vertical text alignment. Depending on the value of the `text-anchor` attribute, the `x`, `y` and `z` attributes of the text element either specify the left bottom corner, the middle bottom position or the right bottom corner of the text. As in rectangles and ellipses, the `z` attribute is optional and its default value is 0.0.

The `text` element has two more attributes. One is called `font-weight` and specifies whether a font is to be drawn bold. The only values allowed for `font-weight` are **bold** and **normal**. Likewise the `font-style` attribute determines whether a font is to be drawn italic or normal and consequently the only allowed values are **italic** and **normal**. Both attributes are optional.

example:

```
 <g ...>
  <text x="50%" y="50%" text-anchor="middle" stroke="#FF0000"
        font-family="serif" font-size="20.0" >This is a Text</text>
```

Text inherits from **GraphicalPrimitive1D**		
x	:	string
y	:	string
z	:	string {use="optional" default="0.0"}
font-family	:	string {use="optional"}
font-size	:	string {use="optional"}
font-weight	:	string {use="optional"}
font-style	:	string {use="optional"}
text-anchor	:	string {use="optional"}

```
    ...
</g>
```

4.4.10 Bitmaps

To include bitmaps into a graphical representation we use the image element from SVG. The image element in SVG can also be used to include complete SVG vector images which we explicitly exclude in this version of the proposal since we think it would be too complex. If the need for the inclusion of SVG drawings arises, it is only a matter of rephrasing this specification.

The image element has six attributes. The `x`, `y` and `z` attributes specify the position of the image within the bounding box and the `width` and `height` attributes specify its width and height. The `z` attribute is optional and its default value is 0.0. The actual image data is not embedded in the render information, but the image element has an attribute called `xlink:href` that references an external JPEG or PNG file. If the referenced image is larger then the given width and height, it has to be scaled to the given dimensions.

Image inherits from **Transformation2D**		
x	:	string
y	:	string
z	:	string {use="optional" default="0.0"}
width	:	string
height	:	string
href	:	string

example:

```
<g ...>
 <image x="10%" y="10%" width="80" height="100" href="Glucose.png" />
```

```
    ...
</g>
```

4.5 Grouping

Like in SVG, several graphical primitives can be grouped inside a `g` element to generate more complex render information.

Group inherits from **GraphicalPrimitve2D**		
font-family	:	string {use="optional"}
font-size	:	string {use="optional"}
font-weight	:	string {use="optional"}
font-style	:	string {use="optional"}
text-anchor	:	string {use="optional"}
startHead	:	SId {use="optional"}
endHead	:	SId {use="optional"}

`stroke`, `stroke-width`, `stroke-dasharrays`, `transform`, `fill`,`fill-rule`, `font-family`, `font-size`, `font-weight`, `font-style` and `text-anchor` attributes can be applied to groups. If any of those attributes is specified for a Group object, it specifies the corresponding attribute for all graphical primitives and groups defined within this group. If a graphical primitive or a group redefines one or more of those attributes, the newly defined values take effect. If an object within the group does not redefine those values, those of the enclosing group apply. If an attribute is not defined in any object of a style, its default values take effect. These default values are listed in Table 1.

It might seem a little unusual that the default values for stroke-width and text-size are set to 0. The reason for this is that a style that only contains an empty group is meant to define that the element the style applies to is not to be rendered. Since the render information for curves in SpeciesReferenceGlyphs and ReactionGlyphs as well as the render information for TextGlyphs is defined via attributes from the outermost group element of a style (see below), the group would explicitly have to define the `stroke-width` or the `font-size` to be 0 which would be inconsistent with the implied meaning of an empty group. The outermost group can also contain information about arrow heads to be used on curves specified in the layout. This information is given via the `startHead` and `endHead` attributes just like for curve elements. These attributes only apply to curve objects from the layout, not to curve

attribute	**default value**
stroke-width	0.0
stroke-dasharrays	*empty list*
transform	1.0, 0.0, 0.0, 0.0, 1.0, 0.0
fill	**none**
fill-rule	string {use=”optional” default=”nonzero”}
font-family	sans-serif
font-size	0
font-weight	normal
font-style	normal
text-anchor	start
startHead	**none**
endHead	**none**

Table 1: Attribute default values.

objects within the group. Since those two attributes only make sense on the outermost group of a style, they are to be ignored on all other groups. The default value for those attributes is **none** which means that no line ending is to be drawn.

Each group also has an id through which it can be identified. In addition to those attributes a Group object can contain 0 or more child elements that form the render information. These child elements have to be elements derived from Transformation2D, so right now this would be Images or everything derived from raphicalPrimitive1D, e.g. rectangles, ellipses, curves, polygons, text elements or groups.

Group inherits from **GraphicalPrimitive1D**		
fill	:	string
fill-rule	:	string
font-family	:	string
font-size	:	string {use=”optional” default=”0.0”}
font-weight	:	string
font-style	:	string
text-anchor	:	string
children	:	Transformation[0..∗]

example:

```
 <g stroke="#000000" font-family="serif" >
   <rectangle x="0%" y="0%" width="100%" height="100%"
              fill="blueLinearGradient"  />
   <text x="50%" y="50%" font-size="80%" text-anchor="middle"
         stroke="#FF0000" />
</g>
```

5 Line endings

In many graphs the relations between nodes are depicted by lines and often the type of relation is encoded in the line ending. For this reason, the render extension provides ways to specify a set of arbitrary line endings and means to apply those to path objects. The individual line endings are defined in an element called `listOfLineEndings` which comes right before the `listOf-Styles`.

The individual line endings are defined as group objects just like styles. Therefore, arbitrarily complex line endings can be defined. Each line ending is encapsulated in an element called `lineEnding` and contains two subelements.

The first element is called `boundingBox` and it specifies the viewport that is used to draw the line ending. Just like the bounding boxes of the layout extension, this bounding box contains a `position` and a `dimensions` subelement. The `dimensions` element specifies the size of the viewport for the line ending along each of the axes. The position specifies the offset from the end of the curve that the line ending is applied to. A position of $(0.0, 0.0, 0.0)$ means that the origin of the line endings bounding box is mapped directly to the end of the curve. For a description on how the mapping is calculated in all other cases see the section called ”Mapping line endings to curves”.

The second subelement is a group element that holds the render information for the line ending.

The two attributes of the `lineEnding` element are the `id` attribute which is used to specify a unique id for the line ending by which it can be referenced and an attribute called `enableRotationalMapping`. The `enable-RotationalMapping` attribute specifies whether a line ending will be rotated depending on the slope of the line it is applied to or if it is drawn just the way it was specified. The default value for the attribute is **true** which means that the line ending is rotated depending on the slope of the line. A more detailed description of this mapping is given in figure 5.1.

In order to declare that a certain line ending is to be used on a path object, the `curve` element has two attributes called `startHead` and `endHead` which hold the id of a line ending definition for the start and for the end of the path respectively.

5.1 Mapping line endings to curves

In order to apply a line ending which is defined using only 2D coordinates onto a line which has been defined using 3D coordinates, we need to define a kind of mapping. The first definition we make is that the origin of the line ending viewport is mapped to the end of the line to which the line ending is applied. If the `enableRotationalMapping` attribute is set to **false**, the line endings coordinate system is the same as the global coordinate system used to draw the layout, only the origin is moved to that end of the line the line ending is applied to. If the `enableRotationalMapping` attribute is set to **`true`**, which is the default, we define that the x,y-plane of the line endings viewport is mapped to the plane that results from taking the unit vector of the slope of the line and unit vector that results from orthonormalizing the slope vector and a second vector that has no component along the z axis. If the slope of the line has a positive component along the x axis, the orthonormalized vector also has to have a positive component along the y axis. In order to retain the right handed coordinate system, the z axis of the line endings coordinate system is perpendicular to the plane created by the other two vectors and has a positive component along the global coordinate systems z-axis. Likewise if the slope has a negative component along the global coordinate systems x axis, the y component of the orthonormalized second vector has a negative component along the y axis of the global coordinate system and to retain the right handed coordinate system, the third vector which is perpendicular to the plane made by the slope and its orthonormalized vector, has a positive component along the global coordinate systems z axis.

If the slope of the line points directly along the positive z axis of the global coordinate system, the line endings coordinate system is mapped to the line ending by a -90 rotation around the y axis of the line endings coordinate system and a translation of the origin of the line endings coordinate system to the end of the line. If the slope points directly down the negative z axis, the line endings coordinate system has to be rotated by +90 around its y axis before translation to the position of the curves end.

This may all sound very complicated, but in the end, the calculations to be done are not difficult and straight forward. A mathematical description of the calculations necessary is given in Appendix A.

If we define $Q = -\frac{dy_s}{dx_s}$ and $D =$ "$\frac{1}{\sqrt{Q^2+1}}$" then the transformation of any point $P = (x, y, z)$ in the line endings coordinate system to the global coordinate system depending on the slope of the curve $\vec{S} = \begin{pmatrix} dx_s \\ dy_s \\ dz_s \end{pmatrix}$ and the curves endpoint $O = \begin{pmatrix} x_O \\ y_O \\ z_O \end{pmatrix}$ can be described by:

$$P_{new} = \begin{pmatrix} dx_s * x + SGN(dx_s) * Q * D * y - dz_s * SGN(dx_s) * D * z + x_O \\ dy_s * x + SGN(dx_s) * D * y + dz_s * SGN(dx_s) * Q * D * z + y_O \\ dz_s * x + (dx_s * SGN(dx_s) * D - dy_s * SGN(dx_s) * Q * D) * z + z_O \end{pmatrix}$$

This is for the cases where the slope vector $\vec{S}$ does run parallel to the global coordinate systems z axis. For this species case, the new point is calculated by:

$$P_{new} = \begin{pmatrix} SGN(dz_s) * -z + x_O \\ y + y_O \\ SGN(dz_s) * x + z_O \end{pmatrix}$$

The SGN function describes the sign of its argument. It returns 1 for positive numbers, 0 for 0 and -1 for negative numbers. For the details of how this transformation was calculated and the definition of the SGN function see Appendix A.

Note that the mapping of line endings to lines is to be done before all transformations defined for the line have been applied. Transformations defined on the line ending itself or on any of its components are to be applied before the line ending is mapped to the curve.

LineEnding inherits from **GraphicalPrimitive2D**		
id	:	SId
enableRotationalMapping	:	boolean default=true
boundingBox	:	BoundingBox
g	:	Group

example:

```
<lineEnding id="SimpleArrowHead">
 <boundingBox>
   <position x="-10.0" y="-4.0" />
   <dimensions width="12.0" height="8.0"/>
 </boundingBox>
 <g>
   <polygon>
     <curve>
       <listOfCurveSegments>
```

```
          <curveSegment xsi:type="LineSegment">
            <start x="100%" y="50%" />
            <end x="0%" y="100%" />
          </curveSegment>
          <curveSegment xsi:type="LineSegment">
            <start x="0%" y="100%" />
            <end x="0%" y="0%" />
          </curveSegment>
        </listOfCurveSegments>
      </curve>
    </polygon>
  </g>
</lineEnding>
```

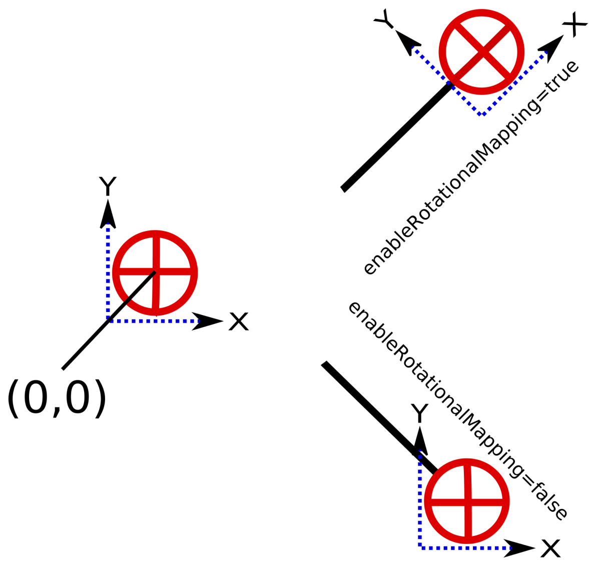


Figure 3: example of a line ending with and without rotation mapping enabled

6 Style resolution

To resolve which style applies to a certain object, one should follow the rule that more specific style definitions take precedence over less specific ones and that if there are several styles with the same specificity, the first one encountered in the file is to be used. In essence, this means that a program first has to search the local render information for a style that references the id of the object. If none is found, it searches for a style that mentions the role of the object. If it has one, see next section. If it does not find one, it searches for a style for the type of the object.

If a render information references another render information object via its `referenceRenderInformation` attribute, the program has to go through that one as well to see if a more specific render information is present there. If the chain of referenced RenderInformation objects has been searched and no style has been found that fits, it is up to the program how the object is rendered.

If several type based styles are found that would fit, a style that applies to only one type takes precedence over a style that applies to several types.

If a program explicitly wants to define render information that states that some objects are not to be rendered at all, it has to define a style that does nothing, i.e. has no render information but applies to the objects that should not be rendered.

7 Role resolution

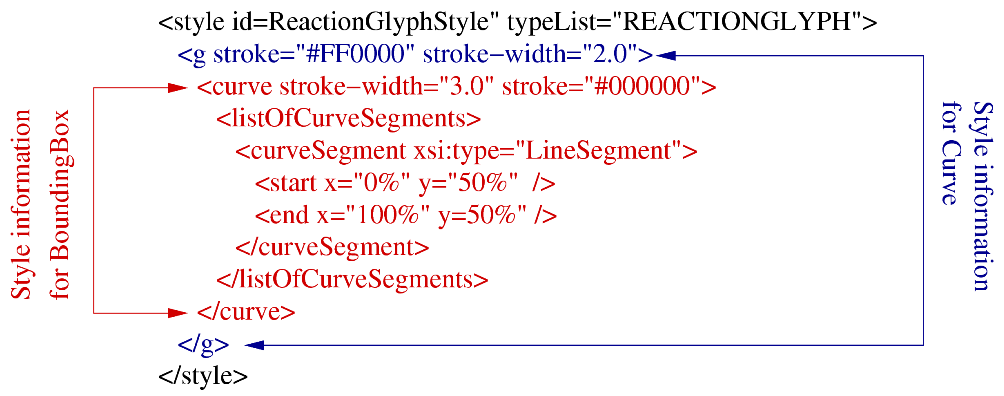
This render extension explicitly provides means to write render information that renders layout objects based on certain roles those render objects or their corresponding model objects have. So far SBML models or layouts do not contain such role information or only for a limited number of objects if one would consider the role attribute of SpeciesReferenceGlyph objects to fall into this category. Although there is currently no means to specify these roles, there are already initiatives underway that try to complement SBML files with more biological information based on ontologies. One of these initiatives, the sboTerms, is about to be included into SBML Level 2 Version 2. This ontology or a similar one could provide this role information for layout objects in the future.

For the time being, we define an additional attribute called objectRole for all layout objects derived from GraphicalObject including GraphicalObject itself. The attribute specifies a user defined role string. render information including the same roleString in its roleList applies to the object. This is only true if no more specific render information takes precedence (see "Style resolution").

A specific style can reference one or more roles to which it applies. When a program tries to determine which style applies to a specific object it might have to determine the role of the object layout first. If the layout object itself has a role, this will be taken, otherwise if the layout object is associated with an object in the model, the program should get the role from the associated object. If none of them has a role, no role based style can be applied to the object.

8 Style information for reaction glyphs and species reference glyphs

When defining a style for a ReactionGlyph or SpeciesReferenceGlyph object, one has to distinguish between layout objects that only specify a bounding box for the object and those that specify a curve. In the case of a bounding box, you want to define complete render information, whereas in the case of a curve, you only want to set certain attributes that determine certain aspects of how the curve should be drawn, e.g. its color. To resolve this conflict, the style for such an object has to define render information for both cases. The render information for the case of a bounding box is specified just like render information for any other object within a Group. Render information for the case of a curve is defined by the appropriate attributes that are in effect in the outermost Group object itself. Those attributes include `stroke`, `stroke-width` and `stroke-dasharray`. Additionally `startHead` and `endHead` can be specified to define line endings for layout curve objects. If the group does not define one or more of these attributes, the default value is used (see section "Grouping").



```
<style id=ReactionGlyphStyle" typeList="REACTIONGLYPH">
  <g stroke="#FF0000" stroke-width="2.0">
    <curve stroke-width="3.0" stroke="#000000">
      <listOfCurveSegments>
        <curveSegment xsi:type="LineSegment">
          <start x="0%" y="50%"  />
          <end x="100%" y=50%" />
        </curveSegment>
      </listOfCurveSegments>
    </curve>
  </g>
</style>
```

Style information for BoundingBox
Style information for Curve

Figure 4: style with render information for objects with curve or bounding box

9 Style information for TextGlyphs

Just as in the case of curves in ReactionGlyphs and SpeciesReferenceGlyphs, TextGlyphs can be considered render information which is located in the layout. A TextGlyph specifies the text to be rendered, it therefore does not need additional render information in the form of a `text` element. On the other hand, it needs render information in the form of font properties. Just as for the Curve object for ReactionGlyphs and SpeciesReferenceGlyphs, this render information is taken from the font related attributes of the outermost group element of the style that is used to render a TextGlyph. Any additional information within the group is ignored. If the group does not specify any of the `font-family`, `font-size`, `font-weight`, `font-style` or `text-anchor` attributes, the default values are to be used.

10 Uniqueness of IDs

Since local and global render information objects can reference other render information objects, programs creating render information need to make sure that all the IDs are unique within the reference history. In other words, a render information object that references another render information object must make sure that none of its IDs is equal to an ID in any of the directly or indirectly referenced render information objects.

An exception to this rule is to create e.g. a color definition with the same ID as the color definition in a referenced style in this case interpreting programs can assume that this color definition is supposed to override the color definition with the same name in the referenced render information object. Likewise it is also possible to override a color definition with a gradient and vice versa, line ending definitions on the other hand can only be replaced by other line ending definitions.

11 Appendix A

Position of line end: $O(x_O, y_O, z_O)$

Normalized slope vector at end: $\vec{S} = \begin{pmatrix} dx_s \\ dy_s \\ dz_s \end{pmatrix}$

Orthogonal vector to $\vec{S}$ with $z = 0$:

$$\begin{aligned} dx_s * x_2 + dy_s * y_2 &= 0 \\ dx_s * x_2 &= -dy_s * y_2 \\ x_2 &= -\frac{dy_s * y_2}{dx_s} \end{aligned}$$

Choosing $y_2 = 1 \Rightarrow x_2 = -\frac{dy_s}{dx_s}$

$\vec{V_2} = (-\frac{dy_s}{dx_s}, 1, 0)$

Normalize $\vec{V_2}$: Length of $\vec{V_2}$: $l_{\vec{V_2}} = \sqrt{\left(-\frac{dy_s}{dx_s}\right)^2 + 1}$

$$\vec{V}_{2N} = \left(\begin{array}{c} -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ 0 \end{array} \right)$$

Retain right handed coordinate system:

$$\vec{V}_{2N} = \left(\begin{array}{c} SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{\left(-\frac{dy_s}{dx_s}\right)^2 + 1}} \\ SGN(dx_s) * \frac{1}{\sqrt{\left(-\frac{dy_s}{dx_s}\right)^2 + 1}} \\ 0 \end{array} \right)$$

$SGN(x)$ is defined as:

$$SGN(x) = \begin{cases} 1 \text{ for } x > 0 \\ 0 \text{ for } x = 0 \\ -1 \text{ for } x < 0 \end{cases}$$

Calculation of the third vector:

$$\begin{aligned}
\vec{V}_{3N} &= \vec{S} \times \vec{V}_{2N} \\
&= \left(\begin{array}{c} dx_s \\ dy_s \\ dz_s \end{array} \right) \times \left(\begin{array}{c} SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ SGN(dx_s) * \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ 0 \end{array} \right) \\
&= \left(\begin{array}{c} dy_s * 0 - dz_s * SGN(dx_s) * \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ dz_s * SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} - dx_s * 0 \\ dx_s * SGN(dx_s) * \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} - dy_s * SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \end{array} \right) \\
&= \left(\begin{array}{c} -dz_s * SGN(dx_s) * \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ dz_s * SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ dx_s * SGN(dx_s) * \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} - dy_s * SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \end{array} \right)
\end{aligned}$$

Now we have to map the line endings coordinate system to the coordinate system specified by $\vec{S}$, $\vec{V}_{2N}$ and $\vec{V}_{3N}$. This basically involves rotations around the x,y and z axis of the line endings coordinate system:

$$T \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \left(\vec{S}\ \vec{V}_{2N}\ \vec{V}_{3N}\right)$$

$$T = \begin{pmatrix} dx_s & SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{\left(-\frac{dy_s}{dx_s}\right)^2 + 1}} & -dz_s * SGN(dx_s) * \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ dy_s & SGN(dx_s) * \frac{1}{\sqrt{\left(-\frac{dy_s}{dx_s}\right)^2 + 1}} & dz_s * SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \\ dz_s & 0 & dx_s * SGN(dx_s) * \frac{1}{\sqrt{-\frac{dy_s}{dx_s}^2 + 1}} - dy_s * SGN(dx_s) * -\frac{dy_s}{dx_s * \sqrt{-\frac{dy_s}{dx_s}^2 + 1}} \end{pmatrix}$$

And last but not least, we have to translate the coordinate system to the endpoint of the curve. So the overall transformation to map a point $P(x, y, z)$ in the line endings coordinate system to the curve is:

$$P_T = (T \cdot P) + O$$

$$P_T = \left(T \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}\right) + \begin{pmatrix} x_O \\ y_O \\ z_O \end{pmatrix}$$

Let $D = \frac{1}{\sqrt{\left(-\frac{dy_s}{dx_s}\right)^2 + 1}}$

$$T = \begin{pmatrix} dx_s & SGN(dx_s) * -\frac{dy_s}{dx_s} * D & -dz_s * SGN(dx_s) * D & x_O \\ dy_s & SGN(dx_s) * D & dz_s * SGN(dx_s) * -\frac{dy_s}{dx_s *} * D & y_O \\ dz_s & 0 & dx_s * SGN(dx_s) * D - dy_s * SGN(dx_s) * -\frac{dy_s}{dx_s} * D & z_O \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$P_T = \begin{pmatrix} dx_s & SGN(dx_s) * -\frac{dy_s}{dx_s} * D & -dz_s * SGN(dx_s) * D & x_O \\ dy_s & SGN(dx_s) * D & dz_s * SGN(dx_s) * -\frac{dy_s}{dx_s} * D & y_O \\ dz_s & 0 & dx_s * SGN(dx_s) * D - dy_s * SGN(dx_s) * -\frac{dy_s}{dx_s} * D & z_O \\ 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$

12 Changes

12.1 Draft 01/30/2008

- The LocalRenderInformation and the GlobalRenderInformation type now have a common base class called RenderInformationBase.
- All classes for rendered 2D objects are now derived from the new class Transformation2D. The transformation2D now holds the transform attribute which has been part of GraphicalPrimitive1D. The consequence

of this is that Images which are now also derived from Transformation2D can be transformed.

- The section on transformations has been extended to explain what the six elements of the transform attribute represent.
- The fill-rule attribute has been missing from the Group class and has now been added. Some more small changes in the section about grouping.

Thanks to Frank Bergmann for the valuable suggestions.