# OpenVG Specification

Version 1.0

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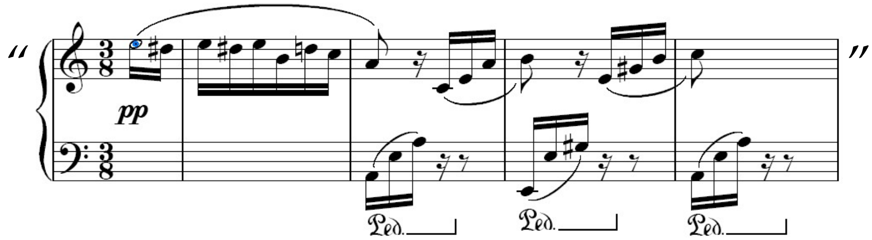


*For Ilise – DSR*

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# 1 Introduction

OpenVG is a new application programming interface (API) for hardware-accelerated two-dimensional vector and raster graphics developed under the auspices of the Khronos Group (www.khronos.org). It provides a device-independent and vendor-neutral interface for sophisticated 2D graphical applications, while allowing device manufacturers to provide hardware acceleration where appropriate.

This document defines the C language binding to OpenVG. Other language bindings may be defined by Khronos in the future. We use the term "implementation" to refer to the software and/or hardware that implements OpenVG functionality, and the term "application" to refer to any software that makes use of OpenVG.

## *1.1 Feature Set*

OpenVG provides a drawing model similar to those of existing two-dimensional drawing APIs and formats, such as Adobe PostScript [ADOB99] and PDF [ADOB03], Sun Microsystems Java2D [SUN04], MacroMedia Flash [MACR04], and SVG [SVGF04][SVGT05]. It is specifically intended to support all drawing features required by a SVG Tiny 1.2 renderer, and additionally to support functions that may be of use for implementing an SVG Basic renderer.

## *1.2 Target Applications*

Several classes of target applications were used to define requirements for the design of the OpenVG API.

### *SVG Viewers*

OpenVG must provide the drawing functionality required for a high-performance SVG document viewer that is conformant with version 1.2 of the SVG Tiny profile. It does not need to provide a one-to-one mapping between SVG syntactic features and API calls, but it must provide efficient ways of implementing all SVG Tiny features.

### *Portable Mapping Applications*

OpenVG can provide dynamic features for map display that would be difficult or impossible to do with an SVG viewer alone, such as dynamic placement and sizing of street names and markers, and efficient viewport culling.

### *E-book Readers*

The OpenVG API must provide fast rendering of readable text in Western, Asian, and other scripts. It does not need to provide advanced text layout features.

### Games

The OpenVG API must be useful for defining sprites, backgrounds, and textures for use in both 2D and 3D games. It must be able to provide two-dimensional overlays (*e.g.*, for maps or scores) on top of 3D content.

### Scalable User Interfaces

OpenVG may be used to render scalable user interfaces, particularly for applications that wish to present users with a unique look and feel that is consistent across different screen resolutions.

### Low-Level Graphics Device Interface

OpenVG may be used as a low-level graphics device interface. Other graphical toolkits, such as windowing systems, may be implemented above OpenVG.

## 1.3 Target Devices

OpenVG is designed to run on devices ranging from wrist watches to full microprocessor-based desktop and server machines. It should be possible to implement OpenVG on any device that is capable enough to support OpenGL ES 1.1. Over time, it is expected that OpenGL ES hardware manufacturers will be able to provide inexpensive incremental acceleration for OpenVG functionality.

Realistically, to obtain the full benefit of OpenVG, a device should provide a display with at least 128 x 128 non-indexed RGB color pixels with 4 or more bits per channel.

## 1.4 Design Philosophy

OpenVG is intended to provide a hardware abstraction layer that will allow accelerated performance on a variety of application platforms. Functions that are not expected to be amenable to hardware acceleration in the near future were either not included, or included as part of the optional VGU utility library.

Where possible, the syntax of OpenVG is intended to be reminiscent of that of OpenGL, in order to make learning OpenVG as easy as possible for OpenGL developers. Most of the OpenVG state is encapsulated in a set of primitive-valued variables that are manipulated using the **vgSet** and **vgGet** functions. Extensions may add new state variables in order to add new features to the pipeline without needing to add new functions.

Paint, path, and image objects in OpenVG are referenced using opaque handles. This allows implementations to store such objects using their own preferred representation, in whatever form of memory they choose. This is intended to simplify hardware design, and to minimize processing and bus traffic for frequently-used objects.

## 1.5 Naming and Typographical Conventions

OpenVG uses a consistent set of conventions for API names and symbols. In this document, additional typographic conventions are used to help indicate the type of each symbol, as shown in Table 1 below.

| *Symbol Type* | *Name/Case* | *Type Style* | *Example* |
|---|---|---|---|
| API Function | vgXxxYyy | Boldface | **vgLoadMatrix** |
| API Function with Varying Parameter Types | vgXxx{f,i,fv,iv} | Boldface | **vgSetfv** |
| Utility Function | vguXxxYyy | Boldface | **vguRoundRect** |
| Primitive Datatype | VGxxx | Typewriter | `VGfloat` |
| Enumerated Datatype | VGXxxYyy | Typewriter | `VGCapStyle` |
| Enumerated Value | VG_XXX_YYY | Typewriter | `VG_BLEND_MODE` |
| Utility Enumerated Value | VGU_XXX_YYY | Typewriter | `VGU_ARC_CHORD` |
| Function Argument | xxxYyy | Typewriter | `paintMode` |

*Table 1: Naming and Typographical Conventions*

## 1.6 Library Naming

The library name is defined as `libOpenVG.`*z* where *z* is a platform-specific library suffix (*i.e.*, `.a`, `.so`, `.lib`, `.dll`, etc.).

# 2 The OpenVG Pipeline

This section defines the OpenVG pipeline mechanism by which primitives are rendered. Implementations are not required to match the ideal pipeline stage-for-stage; they may take any approach to rendering so long as the final results match the results of the ideal pipeline within the tolerances defined by the conformance testing process.

Figure 1 below Provides an overview of the OpenVG pipeline, focusing on the various steps involved in drawing a thick, dashed line into a scene using a radial gradient paint.

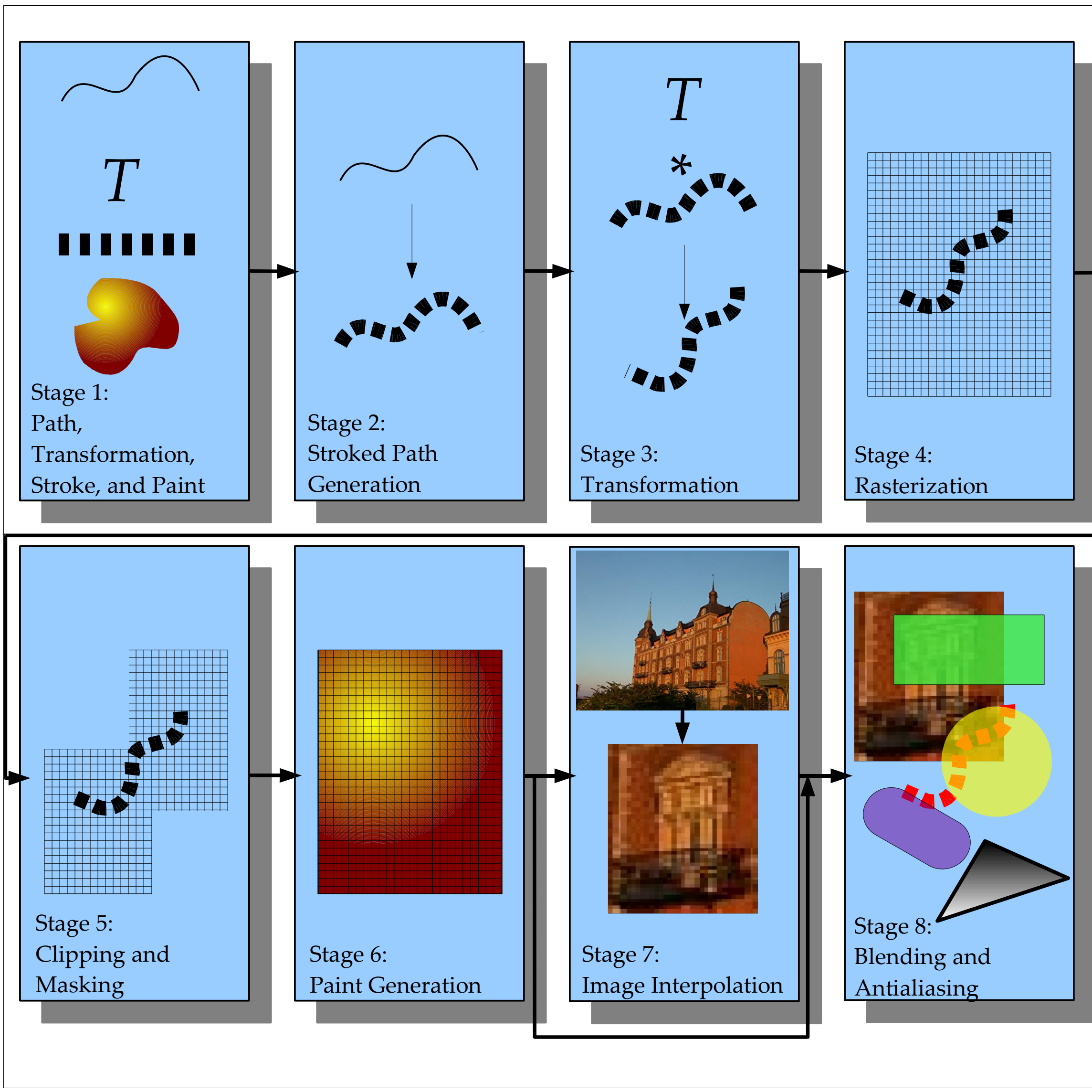


*Figure 1: The OpenVG Pipeline*

## 2.1 Stage 1: Path, Transformation, Stroke, and Paint

The application defines the path to be drawn, and sets any transformation, stroke, and paint parameters or leaves them at their default settings. When all parameters have been set, the application initiates the rendering process by calling **vgDrawPath**, indicating whether the path is to be filled, stroked, or both. If the path is to be both filled and stroked, the remainder of the pipeline is invoked twice in a serial fashion, first to fill and then to stroke the path.

If an image is being drawn (via the **vgDrawImage** function), the current path is set to a rectangle bounding the image.

## 2.2 Stage 2: Stroked Path Generation

If the path is to be stroked, the stroke parameters are applied in the user coordinate system to generate a new path that describes the stroked geometry. This path is then substituted for the original path in the remainder of the pipeline, and the fill rule is set to non-zero.

## 2.3 Stage 3: Transformation

The current path-user-to-surface transformation is applied to the geometry of the current path, producing drawing surface coordinates. For an image, the outline of the image is transformed using the image-user-to-surface transformation. Non-uniform transformations may result in skewed stroke outlines.

## 2.4 Stage 4: Rasterization

A coverage value is computed at pixels affected by the current path using a filtering process, and saved for use in the antialiasing step.

Conceptually, a set of sample positions are evaluated for inclusion within the path. At each pixel center that is no more than 1½ pixels away from some portion of the path geometry, a reconstruction filter is applied to the binary inclusion values at nearby sample points to obtain a filtered coverage value for the pixel. If only a single sample per pixel is evaluated, the sample position must be coincident with the pixel center.

Note that for a box filter (a filter that gives equal positive weight to all samples within a rectangle centered on the pixel center, and zero weight elsewhere), this filtering process amounts to estimating the area of the intersection of the path geometry with the filter rectangle.

If antialiasing is disabled, only pixel centers are used as sample points and the reconstruction filter has value 1 at the pixel center and 0 elsewhere.

In the case where a sample point lies exactly on the boundary of a path, the implementation must enforce a consistent "tie-breaking" rule. For any two paths that share a common boundary segment, but whose interiors lie on opposite sides of the segment, a sample point that lies exactly on the boundary must be considered to be included in exactly one of the two paths. If the interiors of the two paths lie on the same side of the common segment, the sample point must belong to both paths, or neither path. Note that the common boundary segment must be specified in exactly the same manner (*i.e.,* with bit-for-bit identical control point values, scale and bias, and transformation matrix settings) for both paths in order for this guarantee to hold.

## 2.5 Stage 5: Clipping and Masking

Pixels not lying within the bounds of the drawing surface, and (if scissoring is enabled) within the union of the current set of scissor rectangles are assigned a coverage value of 0.

An application-specified alpha mask image is used to modify the coverage values generated by the previous stage. Each coverage value is multiplied by the mask value for the corresponding pixel to obtain a masked coverage value. If the resulting coverage value is zero, the remainder of the pipeline is skipped.

## 2.6 Stage 6: Paint Generation

At each pixel of the drawing surface, the relevant current paint (depending on whether the original path was to be filled or stroked) is used to define a color and an alpha value. For gradient and pattern paints, the paint-to-user transformation is concatenated with the path-user-to-surface transformation to define the paint transformation that will geometrically transform the paint. Paint generation may be skipped for operations that do not utilize paint values.

## 2.7 Stage 7: Image Interpolation

If an image is being drawn, an image color and alpha value is computed at each pixel by interpolating image values using the inverse of the current image-user-to-surface transformation. The results are combined with the paint color and alpha values according to the current image drawing mode. If image drawing is not taking place, the results from the preceding stage are passed through unchanged.

## 2.8 Stage 8: Blending and Antialiasing

At each pixel, the source color and alpha values from the preceding stage are converted into the destination color space and blended with the corresponding destination color and alpha values according to the current blending rule. A special blending rule is used when drawing an image using the "stencil" image drawing mode. The computed coverage value from stage 5 is used to linearly interpolate between the blended result and the previously assigned color at the pixel to produce an antialiased result.

# 3 Constants, Functions and Data Types

OpenVG type definitions and function prototypes are found in an `openvg.h` header file, located in a `vg` subdirectory of a platform-specific header file location. OpenVG makes use of 8-, 16-, and 32-bit data types. A 64-bit data type is not required. If the `khronos_types.h` header file is provided, the primitive data types will be compatible across all Khronos APIs on the same platform.

## 3.1 Versioning

The `openvg.h` header file defines constants indicating the version of the specification. Future versions will continue to define the constants for all previous versions with which they are backward compatible.

### OPENVG_VERSION_1_0

For the current specification, the constant `OPENVG_VERSION_1_0` is defined. The version may be queried at runtime using the **vgGetString** function (see Section 14.3.2).

```
#define OPENVG_VERSION_1_0 1
```

## 3.2 Primitive Data Types

OpenVG defines a number of primitive data types by means of C `typedef`s. The actual data types used are platform-specific.

### VGbyte

`VGbyte` defines an 8-bit two's complement signed integer, which may contain values between -128 and 127, inclusive. If `khronos_types.h` is defined, `VGbyte` will be defined as `khronos_int8_t`.

### VGubyte

`VGubyte` defines an 8-bit unsigned integer, which may contain values between 0 and 255, inclusive. If `khronos_types.h` is defined, `VGubyte` will be defined as `khronos_uint8_t`.

### VGshort

`VGshort` defines a 16-bit two's complement signed integer, which may contain values between -32768 and 32767, inclusive. If `khronos_types.h` is defined, `VGshort` will be defined as `khronos_int16_t`.

### VGint

`VGint` defines a 32-bit two's complement signed integer. If khronos_types.h is defined, VGint will be defined as khronos_int32_t.

### VGuint

VGuint defines a 32-bit unsigned integer. Overflow behavior is undefined. If khronos_types.h is defined, VGuint will be defined as khronos_uint32_t.

### VGbitfield

VGbitfield defines a 32-bit unsigned integer value, used for parameters that may combine a number of independent single-bit values. A VGbitfield must be able to hold at least 32 bits. If khronos_types.h is defined, VGbitfield will be defined as khronos_uint32_t.

### VGboolean

VGboolean is an enumeration that only takes on the values of VG_FALSE (0) or VG_TRUE (1). Any non-zero value used as a VGboolean will be interpreted as VG_TRUE.

```
typedef enum {
  VG_FALSE = 0,
  VG_TRUE  = 1
} VGboolean;
```

### VGfloat

VGfloat defines a 32-bit IEEE 754 floating-point value. If khronos_types.h is defined, VGfloat will be defined as khronos_float_t.

## 3.3 Floating-Point and Integer Representations

All floating-point values are specified in standard IEEE 754 format. However, implementations may clamp extremely large or small values to a restricted range, and internal processing may be performed with lesser precision. At least 16 bits of mantissa, 6 bits of exponent, and a sign bit must be present, allowing values from $\pm 2^{\pm 31}$ to be represented with a fractional precision of at least 1 in $2^{16}$.

Path data (*i.e.*, vertex and control point coordinates and ellipse parameters) may be specified in one of four formats: 8-, 16-, or 32-bit signed integer, or floating-point. Floating-point scale and bias factors are used to map the incoming integer and floating-point values into a desired range when path processing occurs.

Handling of special values is as follows. Positive and negative 0 values must be treated identically. Values of +Infinity, -Infinity, or NaN (not a number) yield unspecified results. Optionally, incoming floating-point values of NaN may be treated as 0, and values of +Infinity and -Infinity may be clamped to the largest and smallest available values within the implementation, respectively.

Denormalized numbers may be truncated to 0. Passing any arbitrary value as input to any floating-point argument must not lead to OpenVG interruption or termination.

#### VG_MAXSHORT

The macro `VG_MAXSHORT` contains the largest positive value that may be represented by a `VGshort`. `VG_MAXSHORT` is defined to be equal to $2^{15} - 1$, or 32,767. The smallest negative value that may be represented by a `VGshort` is given by (–`VG_MAXSHORT` – 1), or -32,768.

#### VG_MAXINT

The macro `VG_MAXINT` contains the largest positive value that may be represented by a `VGint`. `VG_MAXINT` is defined to be equal to $2^{31} - 1$, or 2,147,483,647. The smallest negative value that may be represented by a `VGint` is given by (–`VG_MAXINT` – 1), or -2,147,483,648.

#### VG_MAX_FLOAT

The parameter `VG_MAX_FLOAT` contains the largest floating-point number that will be accepted by an implementation. To query the parameter, use the **vgGetf** function with a `paramType` argument of `VG_MAX_FLOAT` (see Section 5.2). All implementations must define `VG_MAX_FLOAT` to be at least $10^{10}$.

## 3.4 Colors

Colors in OpenVG other than those stored in image pixels (*e.g.*, colors for clearing, painting, and edge extension for convolution) are represented as non-premultiplied sRGBA [sRGB99] color values. Image pixels may be defined in a number of color spaces, including sRGB, linear RGB, linear grayscale (or *luminance*) and non-linearly coded, perceptually-uniform grayscale, in premultiplied or non-premultiplied form. Color and alpha values lie in the range [0,1] unless otherwise noted.

Non-linear quantities are denoted using primed (′) symbols below. An excellent discussion of the rationale for using non-linear coding of colors to achieve perceptual uniformity may be found in [POYN03].

### 3.4.1 Linear and Non-Linear Color Representations

In a linear color representation, the numeric values associated with a color channel value measure the rate at which light is emitted by an object, multiplied by some constant scale factor. Informally, it can be thought of as counting the number of photons emitted in a given amount of time. Linear representations are useful for computation, since light values may be added together in a physically meaningful way.

However, the human visual system responds non-linearly to the light power ("intensity") of an image, and accordingly many common image coding standards (*e.g.*, the EXIF JPEG format used by many digital still cameras and the MPEG format used for video) involve non-linear relationships between light power and code values in order to represent a larger number of distinguishable colors in a given number of bits than is possible with a linear encoding. Common display devices such as CRTs and LCDs also emit light whose power at each pixel component is proportional to a non-linear *power function* (*i.e.*, a function of the form $x^a$ where $a$ is constant) of the applied code value, whether due to the properties of analog CRT electronics or to the deliberate application of a non-linear transfer function elsewhere in the signal path. The exponent, or *gamma*, of this power function is typically between 2.2 and 2.5. OpenVG makes use of the non-linear sRGB color specification described below.

Although computing directly with non-linear representations may lead to significant errors compared with the results of first converting to a linear representation, it is common industry practice in many imaging domains to do so. Because the cost of performing linearization on pixel values to be interpolated or blended is considered prohibitive for mobile devices in the near future, OpenVG performs these operations directly on non-linear code values. A future version of this specification may introduce flags to force values to be converted to a linear representation prior to interpolation and blending.

### 3.4.2 Color Space Definitions

The linear lRGB color space is defined in terms of the standard CIE XYZ color space [WYSZ00], following ITU Rec. 709 [ITU90] using a D65 white point:

$$R = 3.240479\ X - 1.537150\ Y - 0.498535\ Z$$

$$G = -0.969256\ X + 1.875992\ Y + 0.041556\ Z$$

$$B = 0.055648\ X - 0.204043\ Y + 1.057311\ Z$$

The sRGB color space defines values $R'_{sRGB}$, $G'_{sRGB}$, $B'_{sRGB}$ in terms of the linear lRGB primaries by applying a gamma ($\gamma$) mapping consisting of a linear segment and an offset power function:

If $x \le 0.00304$

$$\gamma(x) = 12.92\ x$$

else

$$\gamma(x) = 1.0556\ x^{1/2.4} - 0.0556$$

The inverse mapping $\gamma^{-1}$ is defined as:

If $x \le 0.03928$

$$\gamma^{-1}(x) = x / 12.92$$

else

$$\gamma^{-1}(x) = [(x + 0.0556) / 1.0556]^{2.4}$$

To convert from lRGB to sRGB, the gamma mapping is used:

$$\begin{aligned} R'_{sRGB} &= \gamma(R) \\ G'_{sRGB} &= \gamma(G) \\ B'_{sRGB} &= \gamma(B) \end{aligned} \qquad (1)$$

To convert from sRGB to lRGB, the inverse gamma mapping is used:

$$\begin{aligned} R &= \gamma^{-1}(R'_{sRGB}) \\ G &= \gamma^{-1}(G'_{sRGB}) \\ B &= \gamma^{-1}(B'_{sRGB}) \end{aligned} \qquad (2)$$

Because the gamma function involves offset and scaling factors, it behaves similarly to a pure power function with an exponent of 1/2.2 (or approximately 0.45) rather than the "advertised" exponent of 1/2.4, (or approximately 0.42).

The linear grayscale (luminance) color space (which we denote as lL) is related to the linear lRGB color space by the equations:

$$L = 0.2126\ R + 0.7152\ G + 0.0722\ B \qquad (3)$$

$$R = G = B = L \qquad (4)$$

The perceptually-uniform grayscale color space (which we denote as sL) is related to the linear grayscale (luminance) color space by the gamma mapping:

$$L' = \gamma(L) \qquad (5)$$

$$L = \gamma^{-1}(L') \qquad (6)$$

Conversion from perceptually-uniform grayscale to sRGB is performed by replication:

$$R' = G' = B' = L' \tag{7}$$

The remaining conversions take place in multiple steps, as shown in Table 2 below. The source format is indicated by the left column, and the destination format is indicated by the top row. The numbers indicate the equations from this section that are to be applied, in left-to-right order.

| ***Source/Dest*** | ***lRGB*** | ***sRGB*** | ***lL*** | ***sL*** |
|---|---|---|---|---|
| ***lRGB*** | — | 1 | 3 | 3,5 |
| ***sRGB*** | 2 | — | 2,3 | 2,3,5 |
| ***lL*** | 4 | 4,1 | — | 5 |
| ***sL*** | 7,2 | 7 | 6 | — |

*Table 2: Pixel Format Conversions*

### 3.4.3 Premultiplied Alpha

In *premultiplied alpha* (or simply *premultiplied*) formats, a pixel ($R$, $G$, $B$, $\alpha$) is represented as ($\alpha*R$, $\alpha*G$, $\alpha*B$, $\alpha$). Alpha is always coded linearly, regardless of the color space.

In OpenVG, color interpolation takes place in premultiplied format in order to obtain correct results for translucent pixels.

### 3.4.4 Color Format Conversion

Color values are converted between different formats and bit depths as follows. First, premultiplied alpha values are divided out to obtain a non-premultiplied representation for the color.

If the source and destination color formats are of differing color spaces (*i.e.*, linear RGB, sRGB, linear grayscale, perceptually-uniform grayscale), each source channel is divided by the maximum channel value to produce a number between 0 and 1. The color space conversion is performed as described above. The resulting values are then scaled by the maximum value for each destination channel.

If the source and destination formats have the same color format, but differ in the number of bits per color channel, a special rule is used. If the source channel has a greater number of bits than the destination, the most significant bits are preserved and the least significant bits are discarded. If the source channel has a lesser number of bits than the destination, the value is shifted left and the most significant bits are replicated in the less significant bit positions. For example, a 5-bit source value *b4b3b2b1b0* will be converted to an 8-bit destination value *b4b3b2b1b0b4b3b2*. (This rule approximates multiplication of the source value by the quotient $(2^d - 1)/(2^s - 1)$ where $d$ is the number of bits in the destination and $s$ is the number of bits in the source. When $d = k*s$ for some integer $k > 1$ this quotient will be an integer of the form $2^{(k-1)*s} + 2^{(k-2)*s} + ... + 2^s + 1$, and multiplication of an $s$-bit value by this value will be exactly equivalent to bit replication. When the destination bit depth is not an integer multiple of the source bit depth, this rule still provides greater accuracy than other possible rules such as padding the source with zeros or with copies of the rightmost bit.)

Note that converting from a lesser to a greater number of bits and back again will result in an unchanged value.

If the destination format has stored alpha, the previously saved alpha value is stored into the destination. If the destination format has premultiplied alpha, each color channel value is multiplied by the corresponding alpha value.

## 3.5 Enumerated Data Types

A number of data types are defined using the C `enum` keyword. In all cases, this specification assigns each enumerated constant a particular integer value. Extensions to the specification wishing to add new enumerated values must register with the Khronos Group to receive a unique value (see Section 14).

Applications making use of extensions should cast the extension-defined integer value to the proper enumerated type.

The enumerated types (apart from `VGboolean`) defined by OpenVG are:

- `VGBlendMode`
- `VGCapStyle`
- `VGColorRampSpreadMode`
- `VGErrorCode`
- `VGFillRule`
- `VGHardwareQueryResult`
- `VGHardwareQueryType`
- `VGImageChannel`
- `VGImageFormat`
- `VGImageMode`
- `VGImageParamType`
- `VGImageQuality`
- `VGJoinStyle`
- `VGMaskOperation`
- `VGMatrixMode`
- `VGPaintMode`
- `VGPaintParamType`
- `VGPaintType`
- `VGParamType`
- `VGPathAbsRel`
- `VGPathCapabilities`
- `VGPathCommand`
- `VGPathDatatype`
- `VGPathParamType`
- `VGPathSegment`
- `VGPixelLayout`
- `VGRenderingQuality`
- `VGStringID`
- `VGTilingMode`

The VGU utility library defines the enumerated types:

- `VGUArcType`
- `VGUErrorCode`

## 3.6 Handle-based Data Types

Images, paint objects, and paths are accessed using opaque *handles*. The use of handles allows these potentially large and complex objects to be stored under API control. For example, they may be stored in special memory and/or formatted in a way that is suitable for use by a hardware implementation. Handles are created relative to the current context, and may only be used as OpenVG function parameters when that context or one of its shared contexts is current.

### VGHandle

Handles make use of the `VGHandle` data type. For reasons of binary compatibility between different OpenVG implementations on a given platform, a `VGHandle` is defined as a `VGuint`.

```
typedef VGuint VGHandle;
```

Handles to distinct objects must compare as unequal using the C == operator.

The `VGHandle` subtypes defined in the API are:

- `VGImage` – a reference to image data (see Section 10)
- `VGPaint` – a reference to a paint specification (see Section )
- `VGPath` – a reference to path data (see Section 8)

### VG_INVALID_HANDLE

The symbol `VG_INVALID_HANDLE` represents an invalid `VGHandle` that is used as an error return value from functions that return a `VGHandle`. `VG_INVALID_HANDLE` is defined as (`VGHandle`)`0`.

```
#define VG_INVALID_HANDLE ((VGHandle)0)
```

# 4 The Drawing Context

OpenVG functions that perform drawing, or that modify or query drawing state make use of an implicit *drawing context* (or simply a *context*). A context is created, attached to a drawing surface, and bound to a running application thread outside the scope of the OpenVG API, for example by the Khronos EGL API. OpenVG API calls are executed with respect to the context currently bound to the thread in which they are executed. A call to any OpenVG API function when no drawing context is bound to the current thread has no effect. The drawing context currently bound to a running thread is referred to as the *current context*.

When an image, paint, or path handle is defined, it is permanently attached to the context that is current at that time. It is an error to use the handle as an argument to any OpenVG function when a different context is active, unless that context has been designated as a *shared context* of the original context by the API responsible for context creation (usually EGL).

Images created by OpenVG may be used as the rendering target of a drawing context. All drawing performed by any API that makes use of that context, such as OpenVG or OpenGL ES, will use that image as the drawing surface.

Passing an image that is currently the rendering target of a drawing context to any OpenVG function will result in a `VG_IMAGE_IN_USE_ERROR`. The image may once again be used by OpenVG when it is no longer in use as a rendering target.

An image that shares storage with any other image (via use of the **vgChildImage** function), or that is set as a paint pattern image on a paint object, may not be used as a rendering target. The image may once again be used as a rendering target when all other images that share storage with it have been destroyed and it is no longer set as a paint pattern image on any paint object.

It is possible to provide OpenVG on a platform without supporting EGL. In this case, the host operating system must provide some alternative means of creating a context and binding it to a drawing surface and a rendering thread.

The context is responsible for maintaining the API state, as shown in Table 3.

| ***State Element*** | ***Description*** |
|---|---|
| Drawing Surface | Surface for drawing |
| Matrix Mode | Transformation to be manipulated |
| Path user-to-surface Transformation | Affine transformation for filled and stroked geometry |
| Image user-to-surface Transformation | Affine or projective transformation for images |

| *State Element* | *Description* |
|---|---|
| Paint-to-user Transformation | Affine transformation for paint applied to geometry |
| Fill Rule | Rule for filling paths |
| Quality Settings | Image and rendering quality, pixel layout |
| Blend Mode | Pixel blend function |
| Image Mode | Image/paint combination function |
| Scissoring | Current scissoring rectangles and enable/disable |
| Stroke | Stroke parameters |
| Tile fill color | Color for FILL tiling mode |
| Clear color | Color for fast clear |
| Filter Parameters | Image filtering parameters |
| Paint | Paint definitions |
| Mask | Alpha stencil mask and enable/disable |
| Error | Oldest unreported error code |

*Table 3: State Elements of a Context*

## 4.1 Errors

Some OpenVG functions may encounter errors. Unless otherwise specified, any value returned from a function following an error is undefined.

All OpenVG functions may signal `VG_OUT_OF_MEMORY_ERROR`. This allows implementations to defer memory allocation until it is needed, rather than requiring them to proactively allocate memory only in certain functions that are allowed to generate an error. Such an error may occur midway through the execution of an OpenVG function, in which case the function may have caused changes to the state of OpenVG or to drawing surface pixels prior to failure.

When an OpenVG function encounters an error other than a `VG_OUT_OF_MEMORY_ERROR`, the context state is not modified and no drawing takes place.

An error condition within an OpenVG function must never result in process termination, with the exception of illegal memory accesses taking place within functions that accept an application-provided pointer. Applications should take care to check return values where provided. Functions that do not provide return values may still flag errors that may be retrieved using the **vgGetError** function described below. Errors are stored in the context in which the function was called.

All pointer arguments must be aligned according to their datatype, *e.g.*, a `VGfloat *` argument must be a multiple of 4 bytes.

#### VGErrorCode

The error codes and their numerical values are defined by the `VGErrorCode` enumeration:

```
typedef enum {
  VG_NO_ERROR                       = 0,
  VG_BAD_HANDLE_ERROR               = 0x1000,
  VG_ILLEGAL_ARGUMENT_ERROR         = 0x1001,
  VG_OUT_OF_MEMORY_ERROR            = 0x1002,
  VG_PATH_CAPABILITY_ERROR          = 0x1003,
  VG_UNSUPPORTED_IMAGE_FORMAT_ERROR = 0x1004,
  VG_UNSUPPORTED_PATH_FORMAT_ERROR  = 0x1005,
  VG_IMAGE_IN_USE_ERROR             = 0x1006
} VGErrorCode;
```

#### vgGetError

**vgGetError** returns the oldest error code provided by an API call on the current context since the previous call to **vgGetError** on that context (or since the creation of the context). No error is indicated by a return value of 0 (`VG_NO_ERROR`). After the call, the error code is cleared to 0. The possible errors that may be generated by each OpenVG function (apart from `VG_OUT_OF_MEMORY_ERROR`) are shown below the definition of the function.

```
VGErrorCode vgGetError(void)
```

## 4.2 Manipulating the Context Using EGL

Most OpenVG implementations are expected to make use of version 1.2 or later of the EGL API to obtain drawing contexts. This section provides only a partial, non-normative description of some aspects of the use of EGL that are specific to OpenVG. Refer to the EGL 1.2 specification for more details.

### 4.2.1 EGLConfig Attributes

An `EGLConfig` describes the capabilities of a configuration. Each `EGLConfig` encapsulates a set of *attributes* and their values.

#### EGL_OPENVG_BIT

`EGLConfig`s that may be used with OpenVG will have the bit `EGL_OPENVG_BIT` set in their attribute `EGL_RENDERABLE_TYPE` attribute.

#### EGL_ALPHA_MASK_SIZE

The `EGL_ALPHA_MASK_SIZE` attribute contains the bit depth of the alpha mask associated with a configuration. Alpha masking will take place in the OpenVG pipeline only if the alpha mask bit depth for the drawing surface is greater than zero.

### 4.2.2 EGL Functions

#### eglBindAPI

EGL has a notion of the *current rendering API*. This setting acts as an implied parameter to some EGL functions. To set OpenVG as the current rendering API in EGL, it is necessary to call **eglBindAPI** with an `api` argument of `EGL_OPENVG_API`:

```
EGLBoolean eglBindAPI(EGLenum api)
```

#### eglCreateContext

Once **eglBindAPI** has been called to set OpenVG as the current rendering API, an EGL context that is suitable for use with OpenVG may be obtained by calling **eglCreateContext**. An existing OpenVG context may be passed in as the `share_context` parameter; any `VGPath` and `VGImage` objects defined in `share_context` will be accessible from the new context, and vice versa. If no sharing is desired, the value `EGL_NO_CONTEXT` should be used.

```
EGLContext eglCreateContext(EGLDisplay dpy,
                            EGLConfig config,
                            EGLContext share_context,
                            const EGLint * attrib_list)
```

#### eglCreateWindowSurface

Drawing takes place onto an `EGLSurface`. An `EGLSurface` may be created from a platform native window using **eglCreateWindowSurface**. It is possible to request *single-buffered* rendering, in which drawing takes place directly to the visible window, using the `attrib_list` parameter to set the `EGL_RENDER_BUFFER` attribute to a value of `EGL_SINGLE_BUFFER`. Implementations that do not support single-buffered rendering may ignore this setting. Applications should query the returned surface to determine if it is single- or double-buffered.

```
EGLSurface eglCreateWindowSurface(EGLDisplay dpy,
                                  EGLConfig config,
                                  NativeWindowType win,
                                  const EGLint *attrib list);
```

### *eglCreatePbufferFromClientBuffer*

An EGLSurface that allows rendering into a `VGImage` (see Section 10) may be created by binding the `VGImage` to a *pbuffer* (off-screen buffer). The EGL function **eglCreatePbufferFromClientBuffer** is used with a `buftype` argument of `EGL_OPENVG_IMAGE`. The `VGImage` to be targeted is cast to the `EGLClientBuffer` type and passed as the `buffer` parameter.

```
EGLSurface eglCreatePbufferFromClientBuffer(EGLDisplay dpy,
                                            EGLenum buftype,
                                            EGLClientBuffer buffer,
                                            EGLConfig config,
                                            const EGLint *attrib_list)
```

### *eglMakeCurrent*

The **eglMakeCurrent** function causes a given context to become current on the running thread. Any context that is current on the thread prior to the call is flushed and marked as no longer current.

```
EGLBoolean eglMakeCurrent(EGLDisplay dpy,
                          EGLSurface draw,
                          EGLSurface read,
                          EGLContext ctx)
```

### *eglGetCurrentContext*

The OpenVG context for the current rendering API that is bound to the current thread may be retrieved by calling **eglGetCurrentContext**:

```
EGLContext eglGetCurrentContext()
```

### *eglDestroyContext*

An EGL context is destroyed by calling **eglDestroyContext**.

```
EGLBoolean eglDestroyContext(EGLDisplay display, EGLContext context)
```

### *eglSwapBuffers*

When drawing occurs in *double-buffered* mode, all drawing takes place into an invisible back buffer, and it is necessary to call **eglSwapBuffers** to force the buffer contents to be copied to the visible window. If the visible buffer has a lesser color bit depth than the back buffer, dithering may be performed as part of the buffer copy operation.

```
EGLBoolean eglSwapBuffers(EGLDisplay dpy,
                          EGLSurface surface);
```

## 4.3 Forcing Drawing to Complete

OpenVG provides functions to force the completion of rendering, in order to allow applications to synchronize between multiple rendering APIs.

### vgFlush

The **vgFlush** function ensures that all outstanding requests on the current context will complete in finite time. **vgFlush** may return prior to the actual completion of all requests.

```
void vgFlush(void)
```

### vgFinish

The **vgFinish** function forces all outstanding requests on the current context to complete, returning only when the last request has completed.

```
void vgFinish(void)
```

# 5 Setting API Parameters

API parameters may be set and retrieved using generic *get* and *set* functions. The use of generic functions allows for extensibility of the API without the addition of additional functions. Extensions may receive unique identifier values for new parameter types by registering with the Khronos group.

Parameters take two forms: some are set relative to a rendering context, and others are set on a particular `VGHandle`-based object. The former make use of the **vgSet** and **vgGet** functions and the latter make use of the **vgSetParameter** and **vgGetParameter** functions.

## 5.1 Context Parameter Types

Parameter types that are set on a rendering context are defined in the `VGParamType` enumeration. The datatype and default value associated with each parameter is shown in Table 4.

### VGParamType

The `VGParamType` enumeration defines the parameter type of the value to be set or retrieved using **vgSet** and **vgGet**:

```
typedef enum {
  /* Mode settings */
  VG_MATRIX_MODE                  = 0x1100,
  VG_FILL_RULE                    = 0x1101,
  VG_IMAGE_QUALITY                = 0x1102,
  VG_RENDERING_QUALITY            = 0x1103,
  VG_BLEND_MODE                   = 0x1104,
  VG_IMAGE_MODE                   = 0x1105,

  /* Scissoring rectangles */
  VG_SCISSOR_RECTS                = 0x1106,

  /* Stroke parameters */
  VG_STROKE_LINE_WIDTH            = 0x1110,
  VG_STROKE_CAP_STYLE             = 0x1111,
  VG_STROKE_JOIN_STYLE            = 0x1112,
  VG_STROKE_MITER_LIMIT           = 0x1113,
  VG_STROKE_DASH_PATTERN          = 0x1114,
  VG_STROKE_DASH_PHASE            = 0x1115,

  /* Edge fill color for VG_TILE_FILL tiling mode */
  VG_TILE_FILL_COLOR              = 0x1120,

  /* Color for vgClear */
  VG_CLEAR_COLOR                  = 0x1121,
```

```
  /* Enable/disable alpha masking and scissoring */
  VG_MASKING                       = 0x1130,
  VG_SCISSORING                    = 0x1131,

  /* Pixel layout hint information */
  VG_PIXEL_LAYOUT                  = 0x1140,

  /* Source format selection for image filters */
  VG_FILTER_FORMAT_LINEAR          = 0x1150,
  VG_FILTER_FORMAT_PREMULTIPLIED   = 0x1151,

  /* Destination write enable mask for image filters */
  VG_FILTER_CHANNEL_MASK           = 0x1152,

  /* Implementation limits (read-only) */
  VG_MAX_SCISSOR_RECTS             = 0x1160,
  VG_MAX_DASH_COUNT                = 0x1161,
  VG_MAX_KERNEL_SIZE               = 0x1162,
  VG_MAX_SEPARABLE_KERNEL_SIZE     = 0x1163,
  VG_MAX_COLOR_RAMP_STOPS          = 0x1164,
  VG_MAX_IMAGE_WIDTH               = 0x1165,
  VG_MAX_IMAGE_HEIGHT              = 0x1166,
  VG_MAX_IMAGE_PIXELS              = 0x1167,
  VG_MAX_IMAGE_BYTES               = 0x1168,
  VG_MAX_FLOAT                     = 0x1169
} VGParamType;
```

## 5.2 Setting and Querying Context Parameter Values

Each **vgGet/vgGetParameter** or **vgSet/vgSetParameter** function has four variants, depending on the data type of the value being set, differentiated by a suffix: **i** for scalar integral values, **f** for scalar floating-point values, and **iv** and **fv** for vectors of integers and floating-point values, respectively. The vector variants may also be used to set scalar values using a `count` of 1. When setting a value of integral type using a floating-point **vgSet** variant (ending with **f** or **fv**), or retrieving a floating-point value using an integer **vgGet** function (ending with **i** or **iv**), the value is converted to an integer using a mathematical *floor* operation. If the resulting value is outside the range of integer values, the closest valid integer value is substituted.

The `count` parameter used by the array variants (ending with **iv** or **fv**) limits the number of values that are read from the `values` array parameter. For parameters that require a fixed number of values (*e.g.*, color values of type `VGfloat[4]`), required values beyond the first `count` values are given a value of 0; if `count` is larger than the number of required values, the extra values are ignored. For parameters that require an indeterminate number of values, all `count` specified values are used. If the count parameter is 0, the pointer argument is not dereferenced. For example, the call `vgSet(VG_CLEAR_COLOR, 0, (void *) 0)` sets the four color channel values (red, green, blue, and alpha) of the clear color to 0 without dereferencing the third `(void *)` parameter. The call `vgSet(VG_STROKE_DASH_PATTERN, 0, (void *) 0)` sets the dash pattern to a zero-length array, which has the effect of disabling dashing, again without dereferencing the third parameter.

Certain parameter values are read-only. Calling **vgSet** or **vgSetParameter** on these values has no effect.

### *vgSet*

The **vgSet** functions set the value of a parameter on the current context.

```
void vgSetf (VGParamType paramType, VGfloat value)
void vgSeti (VGParamType paramType, VGint value)
void vgSetfv(VGParamType paramType, VGint count,
             const VGfloat * values)
void vgSetiv(VGParamType paramType, VGint count,
             const VGint * values)
```

*ERRORS*

`VG_ILLEGAL_ARGUMENT_ERROR`

- if `paramType` is not a valid value from the `VGParamType` enumeration
- if `paramType` refers to a vector parameter in **vgSetf** or **vgSeti**
- if `paramType` refers to a scalar parameter in **vgSetfv** or **vgSetiv** and `count` is not equal to 1
- if `value` is not a legal enumerated value for the given parameter in **vgSetf** or **vgSeti**, or if `values[i]` is not a legal enumerated value for the given parameter in **vgSetfv** or **vgSetiv** for $0 \le i <$ `count`
- if `values` is `NULL` in **vgSetfv** or **vgSetiv** and `count` is greater than 0
- if `values` is not properly aligned in **vgSetfv** or **vgSetiv**
- if `count` is less than 0 in **vgSetfv** or **vgSetiv**

For example, to set the blending mode to the integral value `VG_BLEND_SRC_OVER` (see Section 12.5), the application would call:

```
vgSeti(VG_BLEND_MODE, VG_BLEND_SRC_OVER);
```

### *vgGet and vgGetVectorSize*

The **vgGet** functions return the value of a parameter on the current context.

The **vgGetVectorSize** function returns the number of elements in the vector that will be returned by the **vgGetiv** or **vgGetfv** functions if called with the given `paramType` argument. For scalar values, 1 is returned.

The original value passed to **vgSet** (except as specifically noted, and provided the call to **vgSet** completed without error) is returned by **vgGet**, even if the implementation makes use of a truncated or quantized value internally. This rule ensures that OpenVG state may be saved and restored without degradation.

```
VGfloat vgGetf (VGParamType paramType)
VGint   vgGeti (VGParamType paramType)

VGint   vgGetVectorSize(VGParamType paramType)

void    vgGetfv(VGParamType paramType, VGint count, VGfloat * values)
void    vgGetiv(VGParamType paramType, VGint count, VGint * values)
```

***ERRORS***

VG_ILLEGAL_ARGUMENT_ERROR

– if `paramType` is not a valid value from the `VGParamType` enumeration

– if `paramType` refers to a vector parameter in **vgGetf** or **vgGeti**

– if `values` is `NULL` in **vgGetfv** or **vgGetiv**

– if `values` is not properly aligned in **vgGetfv** or **vgGetiv**

– if `count` is less than or equal to 0 in **vgGetfv** or **vgGetiv**

### 5.2.1 Default Context Parameter Values

When a new OpenVG context is created, it contains default values as shown in Table 4. Note that some tokens have been split across lines for reasons of space.

| *Parameter* | *Datatype* | *Default Value* |
|---|---|---|
| VG_MATRIX_MODE | VGMatrixMode | VG_MATRIX_PATH_USER_<br>TO_SURFACE |
| VG_FILL_RULE | VGFillRule | VG_EVEN_ODD |
| VG_IMAGE_QUALITY | VGImageQuality | VG_IMAGE_QUALITY_FASTER |
| VG_RENDERING_QUALITY | VGRendering<br>Quality | VG_RENDERING_QUALITY_BETTER |
| VG_BLEND_MODE | VGBlendMode | VG_BLEND_SRC_OVER |
| VG_IMAGE_MODE | VGImageMode | VG_DRAW_IMAGE_NORMAL |
| VG_SCISSOR_RECTS | VGint * | { } (array of length 0) |
| VG_STROKE_LINE_WIDTH | VGfloat | 1.0f |
| VG_STROKE_CAP_STYLE | VGCapStyle | VG_CAP_BUTT |

| Parameter | Datatype | Default Value |
|---|---|---|
| VG_STROKE_JOIN_STYLE | VGJoinStyle | VG_JOIN_MITER |
| VG_STROKE_MITER_LIMIT | VGfloat | 4.0f |
| VG_STROKE_DASH_PATTERN | VGfloat * | { } (array of length 0) (disabled) |
| VG_STROKE_DASH_PHASE | VGfloat | 0.0f |
| VG_TILE_FILL_COLOR | VGfloat[4] | { 0.0f, 0.0f, 0.0f, 0.0f } |
| VG_CLEAR_COLOR | VGfloat[4] | { 0.0f, 0.0f, 0.0f, 0.0f } |
| VG_MASKING | VGboolean | VG_FALSE (disabled) |
| VG_SCISSORING | VGboolean | VG_FALSE (disabled) |
| VG_PIXEL_LAYOUT | VGPixelLayout | VG_PIXEL_LAYOUT_UNKNOWN |
| VG_FILTER_FORMAT_LINEAR | VGboolean | VG_TRUE (enabled) |
| VG_FILTER_FORMAT_PREMULTIPLIED | VGboolean | VG_FALSE (disabled) |
| VG_FILTER_CHANNEL_MASK | VGbitfield | (VG_RED \| VG_GREEN \| VG_BLUE \| VG_ALPHA) |

*Table 4: Default Parameter Values for a Context*

The read-only parameter values VG_MAX_SCISSOR_RECTS, VG_MAX_DASH_COUNT, VG_MAX_KERNEL_SIZE, VG_MAX_SEPARABLE_KERNEL_SIZE, VG_MAX_COLOR_RAMP_STOPS, VG_MAX_IMAGE_WIDTH, VG_MAX_IMAGE_HEIGHT, VG_MAX_IMAGE_PIXELS, VG_MAX_IMAGE_BYTES, and VG_MAX_FLOAT are initialized to implementation-defined values.

The matrices for matrix modes VG_MATRIX_PATH_USER_TO_SURFACE, VG_MATRIX_IMAGE_USER_TO_SURFACE, VG_MATRIX_FILL_PAINT_TO_USER, and VG_MATRIX_STROKE_PAINT_TO_USER are initialized to the identity matrix (see Section 6.4):

$$\begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ w_0 & w_1 & w_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Default paint parameter values are set for the filling and stroking paint modes.

## 5.3 Setting and Querying Object Parameter Values

Objects that are referenced using a `VGHandle` (*i.e.*, `VGImage`, `VGPaint`, and `VGPath` objects) may have their parameters set and queried using a number of **vgSetParameter** and **vgGetParameter** functions. The semantics of these functions are similar to those of the **vgGet** and **vgSet** functions.

### *vgSetParameter*

The **vgSetParameter** functions set the value of a parameter on a given `VGHandle`-based `object`.

```
void vgSetParameterf (VGHandle object, VGint paramType,
                      VGfloat value)
void vgSetParameteri (VGHandle object, VGint paramType,
                      VGint value)
void vgSetParameterfv(VGHandle object, VGint paramType,
                      VGint count, const VGfloat * values)
void vgSetParameteriv(VGHandle object, VGint paramType,
                      VGint count, const VGint * values)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `object` is not a valid handle, or is not shared with the current context

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `paramType` is not a valid value from the appropriate enumeration

– if `paramType` refers to a vector parameter in **vgSetParameterf** or **vgSetParameteri**

– if `paramType` refers to a scalar parameter in **vgSetParameterfv** or **vgSetParameteriv** and `count` is not equal to 1

– if `value` is not a legal enumerated value for the given parameter in **vgSetParameterf** or **vgSetParameteri**, or if `values[i]` is not a legal enumerated value for the given parameter in **vgSetParameterfv** or **vgSetParameteriv** for $0 \leq i <$ `count`

– if `values` is `NULL` in **vgSetParameterfv** or **vgSetParameteriv** and count is greater than 0

– if `values` is not properly aligned in **vgSetParameterfv** or **vgSetParameteriv**

– if `count` is less than 0 in **vgSetParameterfv** or **vgSetParameteriv**

### *vgGetParameter and vgGetParameterVectorSize*

The **vgGetParameter** functions return the value of a parameter on a given `VGHandle`-based object.

The **vgGetParameterVectorSize** function returns the number of elements in the vector that will be returned by the **vgGetParameteriv** or **vgGetParameterfv** functions if called with the given `paramType` argument. For scalar values, 1 is returned.

The original value passed to **vgSetParameter** (provided the call to **vgSetParameter** completed without error) should be returned by **vgGetParameter** (except where specifically noted), even if the implementation makes use of a truncated or quantized value internally.

```
VGfloat vgGetParameterf (VGHandle object,
                         VGint paramType)
VGint   vgGetParameteri (VGHandle object,
                         VGint paramType)

VGint   vgGetParameterVectorSize (VGHandle object,
                                  VGint paramType)

void    vgGetParameterfv(VGHandle object,
                         VGint paramType,
                         VGint count, VGfloat * values)
void    vgGetParameteriv(VGHandle object,
                         VGint paramType,
                         VGint count, VGint * values)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `object` is not a valid handle, or is not shared with the current context

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `paramType` is not a valid value from the appropriate enumeration

– if `paramType` refers to a vector parameter in **vgGetParameterf** or **vgGetParameteri**

– if `values` is `NULL` in **vgGetParameterfv** or **vgGetParameteriv**

– if `values` is not properly aligned in **vgGetParameterfv** or **vgGetParameteriv**

– if `count` is less than or equal to 0 in **vgGetParameterfv** or **vgGetParameteriv**

# 6 Rendering Quality and Antialiasing

Rendering quality settings are available to control implementation-specific trade-offs between quality and performance. For example, an application might wish to use the highest quality setting for still images, and the fastest setting during UI operations or animation. The implementation must satisfy conformance requirements regardless of the quality setting.

A non-antialiased mode is provided in which pixel coverage is always estimated as 0 or 1, based on the inclusion of the pixel center in the geometry being rendered. When antialiasing is disabled, a coverage value of 1 will be assigned to each pixel whose center (infinitesimally perturbed upward and to the right) lies within the path geometry, and a coverage value of 0 will be assigned otherwise. Non-antialiased rendering may be useful for previewing results or for techniques such as *picking* (selecting the geometric primitive that appears at a given screen location) that require a single geometric entity to be associated with each pixel after rendering has completed.

Applications may indicate the sub-pixel color layout of the display in order to optimize rendering quality.

Rendering Quality

The overall rendering quality may be set to one of three settings: non-antialiased, faster, or better.

### *VGRenderingQuality*

The `VGRenderingQuality` enumeration defines the values for setting the rendering quality:

```
typedef enum {
  VG_RENDERING_QUALITY_NONANTIALIASED = 0x1200,
  VG_RENDERING_QUALITY_FASTER         = 0x1201,
  VG_RENDERING_QUALITY_BETTER         = 0x1202  /* Default */
} VGRenderingQuality;
```

The `VG_RENDERING_QUALITY_NONANTIALIASED` setting disables antialiasing. The `VG_RENDERING_QUALITY_FASTER` setting causes rendering to be done at the highest available speed, while still satisfying all API conformance criteria. The `VG_RENDERING_QUALITY_BETTER` setting causes rendering to be done with the highest available quality.

The **vgSet** function is used to control the quality setting to one of `VG_RENDERING_QUALITY_NONANTIALIASED`, `VG_RENDERING_QUALITY_FASTER`, or `VG_RENDERING_QUALITY_BETTER`:

```
vgSeti(VG_RENDERING_QUALITY, VG_RENDERING_QUALITY_NONANTIALIASED);
vgSeti(VG_RENDERING_QUALITY, VG_RENDERING_QUALITY_FASTER);
vgSeti(VG_RENDERING_QUALITY, VG_RENDERING_QUALITY_BETTER);
```

## 6.1 Additional Quality Settings

### VGPixelLayout

The `VGPixelLayout` enumeration describes a number of possible geometric layouts of the red, green, and blue emissive or reflective elements within a pixel. This information may be used as a hint to the rendering engine to improve rendering quality. The supported pixel layouts are illustrated in Figure 2. The value `VG_PIXEL_LAYOUT_UNKNOWN` disables any optimizations based on pixel layout, treating the color elements of a pixel as geometrically coincident.

```
typedef enum {
  VG_PIXEL_LAYOUT_UNKNOWN        = 0x1300,
  VG_PIXEL_LAYOUT_RGB_VERTICAL   = 0x1301,
  VG_PIXEL_LAYOUT_BGR_VERTICAL   = 0x1302,
  VG_PIXEL_LAYOUT_RGB_HORIZONTAL = 0x1303,
  VG_PIXEL_LAYOUT_BGR_HORIZONTAL = 0x1304
} VGPixelLayout;
```

To provide the renderer with a pixel layout hint, use **vgSeti** with a `paramType` value of `VG_PIXEL_LAYOUT` and a value from the `VGPixelLayout` enumeration. Reading back the value with **vgGet** simply returns the value set by the application or the default value and does not necessarily reflect the properties of the drawing surface.

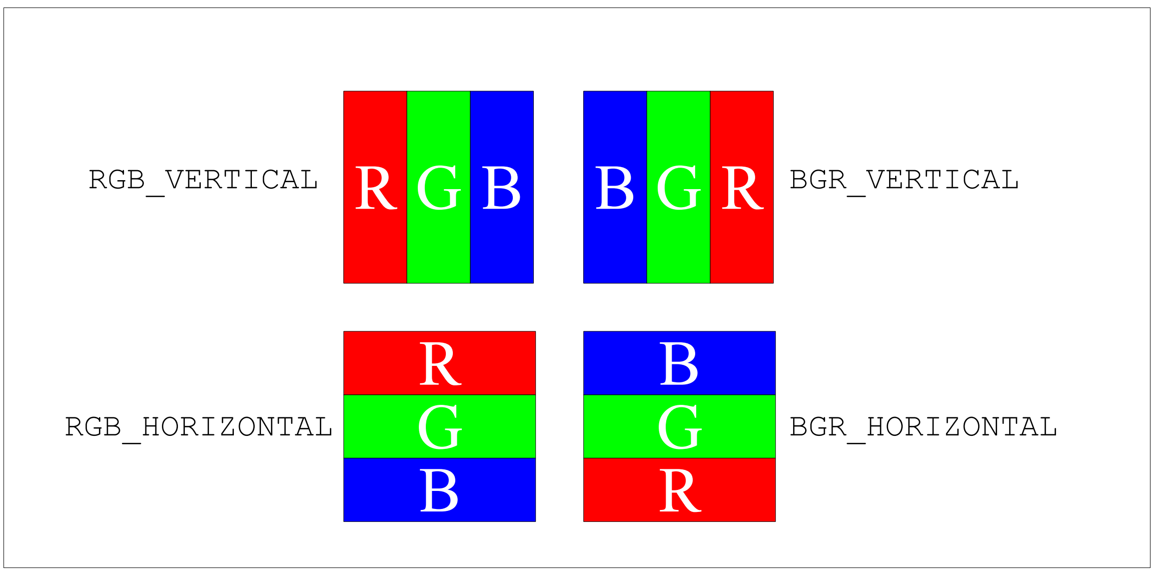


*Figure 2: `VGPixelLayout` Values*

## 6.2 Coordinate Systems and Transformations

Geometry is defined in a two-dimensional coordinate system that may or may not correspond to pixel coordinates. Drawing may be performed independently of the details of screen size, resolution, and drawing area by establishing suitable transformations between coordinate systems.

## 6.3 Coordinate Systems

Geometric coordinates are specified in the *user coordinate system*. The *path-user-to-surface* and *image-user-to-surface* transformations map between the user coordinate system and pixel coordinates on the destination drawing surface. This pixel-based coordinate system is known as the *surface coordinate system*. The relationship between the user and surface coordinate systems and the transformations that map between them is shown in Figure 3 below.

The user coordinate system is oriented such that values along the X axis increase from left to right and values along the Y axis increase from bottom to top, as in OpenGL. When the user-to-surface transformation is the identity transformation, a change of 1 unit along the X axis corresponds to moving by one pixel.

In the surface coordinate system, pixel (0, 0) is located at the lower-left corner of the drawing surface. The pixel $(x, y)$ has its center at the point $(x + ½, y + ½)$. Antialiasing filters used to evaluate the color or coverage of a pixel are centered at the pixel center. If antialiasing is disabled, the evaluation of each pixel occurs at its center.

## 6.4 Transformations

Geometry is defined in the user coordinate system, and is ultimately transformed into surface coordinates and assigned colors by means of a set of user-specified transformations that apply to geometric path data and to paint.

### 6.4.1 Homogeneous Coordinates

Homogeneous coordinates are used in order to allow translation factors to be included in the affine matrix formulation, as well as to allow perspective effects for images. In homogeneous coordinates, a two-dimensional point $(x, y)$ is represented by the three-dimensional column vector $[x, y, 1]^T$. The same point may be equivalently represented by the vector $[s*x, s*y, s]^T$ for any non-zero scale factor $s$. More detailed explanations of the use of homogeneous coordinates may be found in most standard computer graphics textbooks, for example [FvDFH95].

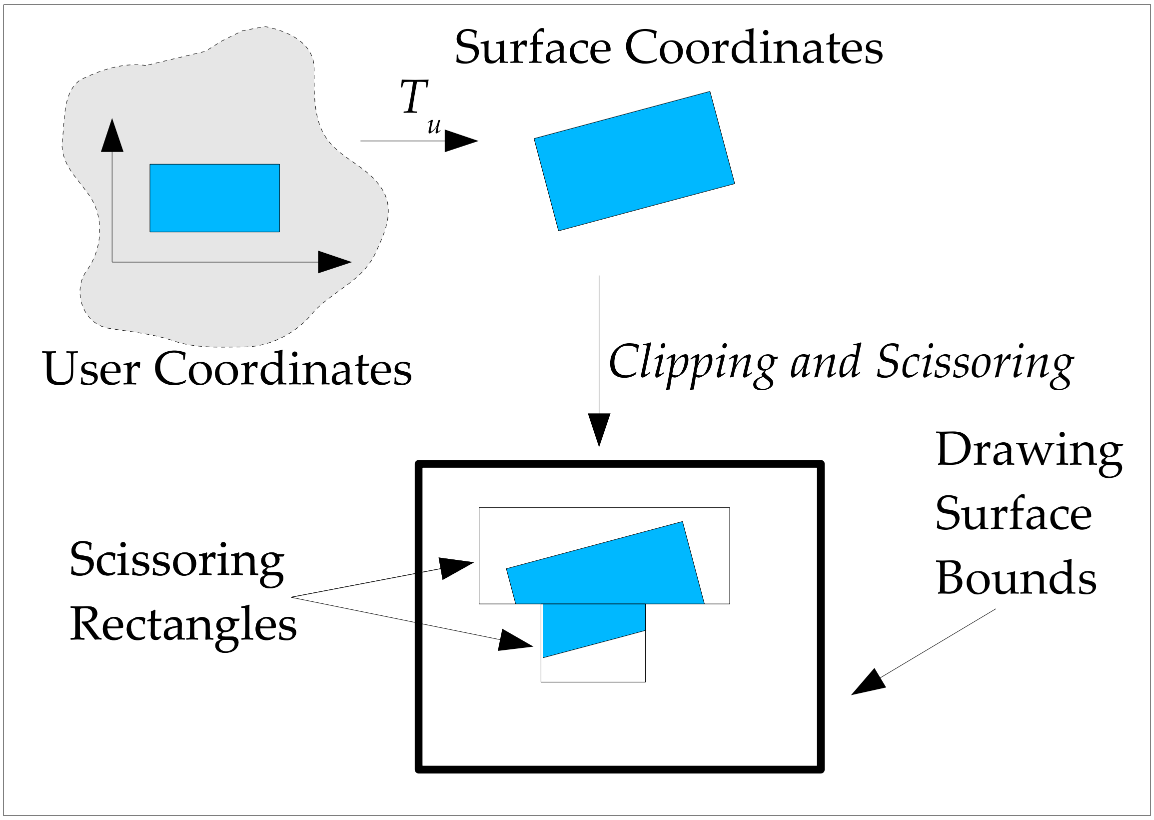


*Figure 3: Coordinates, Transformation, Clipping, and Scissoring*

### *6.4.2 Affine Transformations*

Geometric objects to be drawn are transformed from user coordinates to surface coordinates as they are drawn by means of a 3x3 *affine* transformation matrix with the following entries:

$$\begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ 0 & 0 & 1 \end{bmatrix}$$

The entries may be divided by their function:

- *sx* and *sy* define *scaling* in the *x* and *y* directions, respectively;
- *shx* and *shy* define *shearing* in the *x* and *y* directions, respectively;
- *tx* and *ty* define *translation* in the *x* and *y* directions, respectively.

An affine transformation maps a point $(x, y)$ (represented using homogeneous coordinates as the column vector $[x, y, 1]^T$) into the point $(x*sx + y*shx + tx, x*shy + y*sy + ty)$ using matrix multiplication:

$$\begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x*sx & + y*shx & + tx \\ x*shy & + y*sy & + ty \\ & 1 & \end{bmatrix}$$

Affine transformations allow any combination of scaling, rotation, shearing, and translation. The concatenation of two affine transformations is an affine transformation, whose matrix form is the product of the matrices of the original transformations.

Gradients and patterns are subject to an additional affine transformation mapping the coordinate system used to specify the gradient parameters into user coordinates. The path-user-to-surface transformation is then applied to yield surface coordinates.

OpenVG does not provide the notion of a hierarchy of transformations; applications must maintain their own matrix stacks if desired.

### 6.4.3 Projective (Perspective) Transformations

The **vgDrawImage** function uses a 3x3 *projective* (or *perspective*) transformation matrix (representing the image-user-to-surface transformation) with the following entries to transform from user coordinates to surface coordinates:

$$\begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ w_0 & w_1 & w_2 \end{bmatrix}$$

A projective transformation maps a point ($x$, $y$) into the point:

$$\left( \frac{x*sx+y*shx+tx}{x*w_0+y*w_1+w_2}, \frac{x*shy+y*sy+ty}{x*w_0+y*w_1+w_2} \right)$$

using matrix multiplication and division by the third homogeneous coordinate:

$$\begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ w_0 & w_1 & w_2 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x*sx+y*shx+tx \\ x*shy+y*sy+ty \\ x*w_0+y*w_1+w_2 \end{bmatrix} \equiv \begin{bmatrix} \dfrac{x*sx+y*shx+tx}{x*w_0+y*w_1+w_2} \\ \dfrac{x*shy+y*sy+ty}{x*w_0+y*w_1+w_2} \\ 1 \end{bmatrix}$$

The concatenation of two projective transformations is a projective transformation, whose matrix form is the product of the matrices of the original transformations.

Both affine and projective transformations map straight lines to straight lines. However, affine transformations map evenly spaced points along a source line to evenly spaced points in the destination, whereas projective transformations allow the distance between points to vary due to the effect of division by the denominator $d = (x{*}w_0 + y{*}w_1 + w_2)$. Although OpenVG does not provide support for three-dimensional coordinates, proper setting of the $w$ matrix entries can simulate the effect of placement of images in three dimensions, as well as other warping effects.

## 6.5 Matrix Manipulation

Transformation matrices are manipulated using the **vgLoadIdentity**, **vgLoadMatrix**, and **vgMultMatrix** functions. For convenience, the **vgTranslate**, **vgScale**, **vgShear**, and **vgRotate** functions may be used to concatenate common types of transformations.

The matrix conventions used by OpenVG are similar to those of OpenGL. A point to be transformed is given by a homogeneous column vector $[x, y, 1]^T$. Transformation of a point $p$ by a matrix $M$ is defined as the product $M \cdot p$. Concatenation of transformations is performed using right-multiplication of matrices.

In the following sections, the matrix being updated by each call will be represented by the symbol $M$.

### VGMatrixMode

The current matrix to be manipulated is specified by setting the matrix mode. Separate matrices are maintained for transforming paths, images, and paint (gradients and patterns). The matrix modes are defined in the `VGMatrixMode` enumeration:

```
typedef enum {
  VG_MATRIX_PATH_USER_TO_SURFACE  = 0x1400,
  VG_MATRIX_IMAGE_USER_TO_SURFACE = 0x1401,
  VG_MATRIX_FILL_PAINT_TO_USER    = 0x1402,
  VG_MATRIX_STROKE_PAINT_TO_USER  = 0x1403
} VGMatrixMode;
```

To set the matrix mode, call **vgSeti** with a type of `VG_MATRIX_MODE` and a value of `VG_MATRIX_*`. For example, to set the matrix mode to allow manipulation of the path-user-to-surface transformation, call:

```
vgSeti(VG_MATRIX_MODE, VG_MATRIX_PATH_USER_TO_SURFACE);
```

### *vgLoadIdentity*

The **vgLoadIdentity** function sets the current matrix *M* to the identity matrix:

$$M = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

```
void vgLoadIdentity(void)
```

### *vgLoadMatrix*

The **vgLoadMatrix** function loads an arbitrary set of matrix values into the current matrix. Nine matrix values are read from `m`, in the order:

$$\{ sx, shy, w_0, shx, sy, w_1, tx, ty, w_2 \}$$

defining the matrix:

$$M = \begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ w_0 & w_1 & w_2 \end{bmatrix}$$

However, if the targeted matrix is affine (*i.e.*, the matrix mode is not `VG_MATRIX_IMAGE_USER_TO_SURFACE`), the values $\{ w_0, w_1, w_2 \}$ are ignored and replaced by the values $\{ 0, 0, 1 \}$, resulting in the affine matrix:

$$M = \begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ 0 & 0 & 1 \end{bmatrix}$$

```
void vgLoadMatrix(const VGfloat * m)
```

***ERRORS***

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `m` is `NULL`

– if `m` is not properly aligned

### *vgGetMatrix*

It is possible to retrieve the value of the current transformation by calling **vgGetMatrix**. Nine values are written to `m` in the order:

$$\{ sx, shy, w_0, shx, sy, w_1, tx, ty, w_2 \}$$

For an affine matrix, $w_0$ and $w_1$ will always be 0 and $w_2$ will always be 1.

```
void vgGetMatrix(VGfloat * m)
```

***ERRORS***

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `m` is `NULL`

– if `m` is not properly aligned

### *vgMultMatrix*

The **vgMultMatrix** function right-multiplies the current matrix $M$ by a given matrix*:*

$$M = M \cdot \begin{bmatrix} sx & shx & tx \\ shy & sy & ty \\ w_0 & w_1 & w_2 \end{bmatrix}$$

```
void vgMultMatrix(const VGfloat * m)
```

***ERRORS***

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `m` is `NULL`

– if `m` is not properly aligned

Nine matrix values are read from `m` in the order:

$$\{ sx, shy, w_0, shx, sy, w_1, tx, ty, w_2 \}$$

and the current matrix is multiplied by the resulting matrix. However, if the targeted matrix is affine (*i.e.*, the matrix mode is not `VG_MATRIX_IMAGE_USER_TO_SURFACE`), the values $\{ w_0, w_1, w_2 \}$ are ignored and replaced by the values $\{ 0, 0, 1 \}$ prior to multiplication.

### *vgTranslate*

The **vgTranslate** function modifies the current transformation by appending a translation. This is equivalent to right-multiplying the current matrix *M* by a translation matrix:

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

```
void vgTranslate(VGfloat tx, VGfloat ty)
```

### *vgScale*

The **vgScale** function modifies the current transformation by appending a scale. This is equivalent to right-multiplying the current matrix *M* by a scale matrix:

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

```
void vgScale(VGfloat sx, VGfloat sy)
```

### *vgShear*

The **vgShear** function modifies the current transformation by appending a shear. This is equivalent to right-multiplying the current matrix *M* by a shear matrix:

$$M = M \cdot \begin{bmatrix} 1 & shx & 0 \\ shy & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

```
void vgShear(VGfloat shx, VGfloat shy)
```

### *vgRotate*

The **vgRotate** function modifies the current transformation by appending a counter-clockwise rotation by a given angle (expressed in degrees) about the origin. This is equivalent to multiplying the current matrix *M* by the following matrix (using the symbol *a* to represent the value of the `angle` parameter):

$$M = M \cdot \begin{bmatrix} \cos(a) & -\sin(a) & 0 \\ \sin(a) & \cos(a) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

To rotate about a center point (*cx, cy*) other than the origin, the application may perform a translation by (*-cx, -cy*), followed by the rotation, followed by a translation by (*cx, cy*).

```
void vgRotate(VGfloat angle)
```

# 7 Scissoring, Masking, and Clearing

All drawing is *clipped* (restricted) to the bounds of the drawing surface, and may be further clipped to the interior of a set of *scissoring* rectangles. If available, an alpha *mask* is applied for further clipping and to create soft edge and partial transparency effects.

Pixels outside the drawing surface bounds, or (when scissoring is enabled) not in any scissoring rectangle are not affected by any drawing operation. For any drawing operation, each pixel will receive the same value for any setting of the scissoring rectangles that contains the pixel. That is, the placement of the scissoring rectangles, and whether scissoring is enabled, affects only whether a given pixel will be written, without affecting what value it will receive.

## *7.1 Scissoring*

Drawing may be restricted to the union of a set of scissoring rectangles. Scissoring is enabled when the parameter `VG_SCISSORING` has the value `VG_TRUE`. Scissoring may be disabled by calling **vgSeti** with a `paramType` argument of `VG_SCISSORING` and a value of `VG_FALSE`.

### *VG_MAX_SCISSOR_RECTS*

The `VG_MAX_SCISSOR_RECTS` parameter contains the maximum number of scissoring rectangles that may be supplied for the `VG_SCISSOR_RECTS` parameter. All implementations must support at least 32 scissor rectangles. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti** with a `paramType` argument of `VG_MAX_SCISSOR_RECTS`:

```
VGint maxScissorRects = vgGeti(VG_MAX_SCISSOR_RECTS);
```

### *Specifying Scissoring Rectangles*

Each scissoring rectangle is specified as an integer 4-tuple of the form (*minX, minY, width, height*), where *minX* and *minY* are inclusive. A rectangle with *width* ≤ *0* or *height* ≤ *0* is ignored. The scissoring region is defined as the union of all the specified rectangles. The rectangles as specified need not be disjoint. If scissoring is enabled and no valid scissoring rectangles are present, no drawing occurs. If more than `VG_MAX_SCISSOR_RECTS` rectangles are specified, those beyond the first `VG_MAX_SCISSOR_RECTS` are discarded immediately (and will not be returned by **vgGet**).

```
#define NUM_RECTS 2
/* { Min X, Min Y, Width, Height } 4-Tuples */
VGint coords[4*NUM_RECTS] = { 20, 30, 100, 200,
                              50, 70,  80,  80 };
vgSetiv(VG_SCISSOR_RECTS, 4*NUM_RECTS, coords)
```

## 7.2 Alpha Masking

All drawing operations may be modified by an alpha mask, defining an additional alpha value at each pixel of the drawing surface that is multiplied by the coverage value computed by the rasterization stage of the pipeline. Alpha masking is enabled when an alpha mask is present for the drawing surface (*e.g.*, by specifying an `EGLConfig` with an `EGL_ALPHA_MASK_SIZE` attribute having a value greater than zero) and the `VG_MASKING` parameter has the value `VG_TRUE`. Alpha masking may be disabled by calling **vgSeti** with a parameter of `VG_MASKING` and a value of `VG_FALSE`. If an alpha mask is present, it may be manipulated by the **vgMask** function regardless of the value of `VG_MASKING` at the time of the call. If an alpha mask is not present, the behavior is the same as though there were an alpha mask having a value of 1 at every pixel; functions that manipulate the mask values have no effect.

In this section, we will describe alpha values as ranging from 0 to 1. The actual bit depth used for computation is implementation-dependent. It must be possible to obtain a mask with at least 1 bit for 1-bit black and white drawing surfaces, a 4 bit mask must be available for 16-bit color drawing surfaces, and an 8 bit mask must be available for 8-bit grayscale and 24-bit color drawing surfaces.

An alpha mask may be thought of as an alpha-only image with the same size as the current drawing surface. Initially, an alpha mask has the value of 1 at every pixel. Changes to the alpha mask outside of the current drawing surface bounds are ignored. If the drawing surface size changes, the alpha mask is resized accordingly, with new pixels being initialized to an alpha value of 1. If the context acquires a new drawing surface, the alpha mask is reset.

An alpha mask defines a stencil area through which primitives are placed before being drawn. The union, intersection, and subtraction operations on masks are defined by analogy with the corresponding operations on the stencil areas.

The mask alpha values are multiplied by the corresponding alpha values of each primitive being drawn in the clipping and masking stage (stage 5) of the rendering pipeline (see Section 2.5). The masking step is equivalent to replacing the source image with the result of the Porter-Duff operation "Src **in** Mask" (see Section 12.2).

### *VGMaskOperation*

The `VGMaskOperation` enumeration defines the set of possible operations that may be used to modify the drawing surface alpha mask, possibly making use of a new mask image. Each operation occurs within a rectangular region of interest.

The `VG_CLEAR_MASK` operation sets all mask alpha values in the region of interest to 0, ignoring the new mask image.

The `VG_FILL_MASK` operation sets all mask alpha values in the region of interest to 1, ignoring the new mask image.

The `VG_SET_MASK` operation copies alpha values in the region of interest from the new mask image, overwriting the previous alpha mask values.

The `VG_UNION_MASK` operation replaces the previous alpha mask in the region of interest by its union with the new mask image. The resulting alpha values are always greater than or equal to their previous value.

The `VG_INTERSECT_MASK` operation replaces the previous alpha mask in the region of interest by its intersection with the new mask image. The resulting mask values are always less than or equal to their previous value.

The `VG_SUBTRACT_MASK` operation subtracts the new alpha mask from the previous alpha mask and replaces the previous alpha mask in the region of interest by the resulting mask. The resulting alpha values are always less than or equal to their previous value.

Table 5 gives the equations defining the new mask alpha value for each mask operation in terms of the previous alpha value $\alpha_{prev}$ and the newly supplied mask alpha value $\alpha_{mask}$.

| ***Operation*** | ***Alpha Equation*** |
|---|---|
| `VG_CLEAR_MASK` | $\alpha_{new} = 0$ |
| `VG_FILL_MASK` | $\alpha_{new} = 1$ |
| `VG_SET_MASK` | $\alpha_{new} = \alpha_{mask}$ |
| `VG_UNION_MASK` | $\alpha_{new} = 1 - (1 - \alpha_{mask})*(1 - \alpha_{prev})$ |
| `VG_INTERSECT_MASK` | $\alpha_{new} = \alpha_{mask} * \alpha_{prev}$ |
| `VG_SUBTRACT_MASK` | $\alpha_{new} = \alpha_{prev}*(1 - \alpha_{mask})$ |

*Table 5: VGMaskOperation Equations*

```
typedef enum {
  VG_CLEAR_MASK     = 0x1500,
  VG_FILL_MASK      = 0x1501,
  VG_SET_MASK       = 0x1502,
  VG_UNION_MASK     = 0x1503,
  VG_INTERSECT_MASK = 0x1504,
  VG_SUBTRACT_MASK  = 0x1505
} VGMaskOperation;
```

### *vgMask*

The **vgMask** function modifies the alpha mask values according to a given `operation`, possibly using alpha values taken from a `mask` image. If no alpha mask is configured, **vgMask** has no effect.

The affected region is the intersection of the drawing surface bounds with the rectangle extending from pixel (*x*, *y*) of the drawing surface and having the given `width` and `height` in pixels. For operations that make use of the `mask` image parameter (*i.e.*, operations other than `VG_CLEAR_MASK` and `VG_FILL_MASK`), mask image pixels starting at (0, 0) are used, and the region is further limited to the width and height of `mask`. For the `VG_CLEAR_MASK` and `VG_FILL_MASK` operations, the `mask` parameter is ignored and does not affect the region being modified. The value `VG_INVALID_HANDLE` may be supplied in place of an actual image handle.

The `mask` image defines alpha values at each of its pixels as follows. If the image pixel format includes an alpha channel, the alpha channel is used. Otherwise, values from the red (for color image formats) or grayscale (for grayscale formats) channel are used. The value is divided by the maximum value for the channel to obtain an alpha value between 0 and 1. If the image is bi-level (black and white), black pixels receive an alpha value of 0 and white pixels receive an alpha value of 1.

```
void vgMask(VGImage mask, VGMaskOperation operation,
            VGint x, VGint y, VGint width, VGint height)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if operation is not `VG_CLEAR_MASK` or `VG_FILL_MASK`, and `mask` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `mask` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `operation` is not a valid value from the `VGMaskOperation` enumeration

– if `width` or `height` is less than or equal to 0

## *7.3 Fast Clearing*

The **vgClear** function allows a region of pixels to be set to a single color with a single call.

### *vgClear*

The **vgClear** function fills the portion of the drawing surface intersecting the rectangle extending from pixel (*x*, *y*) and having the given `width` and `height` with a constant color value, taken from the `VG_CLEAR_COLOR` parameter. The color value is expressed in non-premultiplied sRGBA (sRGB color plus alpha)format. Values outside the [0, 1] range are interpreted as the nearest endpoint of the range. The color is converted to the destination color space in the same manner as if a rectangular path were being filled. Clipping and scissoring take place in the usual fashion, but antialiasing, masking, and blending do not occur.

```
void vgClear(VGint x, VGint y, VGint width, VGint height)
```

***ERRORS***

`VG_ILLEGAL_ARGUMENT_ERROR`

– `if width` or `height` is less than or equal to 0

For example, to set the entire drawing surface with dimensions `WIDTH` and `HEIGHT` to an opaque yellow color, the following code could be used:

```
VGfloat color[4] = { 1.0f, 1.0f, 0.0f, 1.0f }; /* Opaque yellow */

vgSeti(VG_SCISSORING, VG_FALSE);
vgSetfv(VG_CLEAR_COLOR, 4, color);
vgClear(0, 0, WIDTH, HEIGHT);
```

# 8 Paths

Paths are the heart of the OpenVG API. All geometry to be drawn must be defined in terms of one or more paths. Paths are defined by a sequence of *segment commands* (or *segments*). Each segment command in the standard format may specify a move, a straight line segment, a quadratic or cubic Bézier segment, or an elliptical arc. Extensions may define other segment types.

## 8.1 Moves

A path segment may consist of a "move to" segment command that causes the path to jump directly to a given point, starting a new subpath without drawing. If a path does not begin with a move, a move to (*0, 0*) is implied.

## 8.2 Straight Line Segments

Paths may contain horizontal, vertical, or arbitrary line segment commands. A special "close path" segment command may be used to generate a straight line segment joining the current vertex of a path to the vertex that began the current portion of the path.

## 8.3 Bézier Curves

Bézier curves are polynomial curves defined using a parametric representation. That is, they are defined as the set of points of the form ($x(t)$, $y(t)$), where $x(t)$ and $y(t)$ are polynomials of $t$ and $t$ varies continuously from 0 to 1. Paths may contain quadratic or cubic Bézier segment commands.

### 8.3.1 Quadratic Bézier Curves

A quadratic Bézier segment is defined by three *control points*, ($x_0$, $y_0$), ($x_1$, $y_1$), and ($x_2$, $y_2$). The curve starts at ($x_0$, $y_0$) and ends at ($x_2$, $y_2$). The shape of the curve is influenced by the placement of the internal control point ($x_1$, $y_1$), but the curve does not usually pass through that point. The tangent of the curve at the initial point $x_0$ is aligned with and has the same direction as the vector $x_1 - x_0$; the tangent at the final point $x_2$ is aligned with and has the same direction as the vector $x_2 - x_1$. The curve is defined by the set of points ($x(t)$, $y(t)$) as $t$ varies from 0 to 1, where:

$$x(t) = x_0 * (1-t)^2 + 2 * x_1 * (1-t) * t + x_2 * t^2$$
$$y(t) = y_0 * (1-t)^2 + 2 * y_1 * (1-t) * t + y_2 * t^2$$

### 8.3.2 Cubic Bézier Curves

Cubic Bézier segments are defined by four control points ($x_0$, $y_0$), ($x_1$, $y_1$), ($x_2$, $y_2$), and ($x_3$, $y_3$). The curve starts at ($x_0$, $y_0$) and ends at ($x_3$, $y_3$). The shape of the curve is influenced by the placement of the internal control points ($x_1$, $y_1$) and ($x_2$, $y_2$), but the curve does not usually pass through those points. The tangent of the curve at the initial point $x_0$ is aligned with and has the same direction as the vector $x_1 - x_0$; the tangent at the final point $x_3$ is aligned with and has the same direction as the vector $x_3 - x_2$. The curve is defined by the set of points ($x(t)$, $y(t)$) as $t$ varies from 0 to 1, where:

$$x(t) = x_0 * (1-t)^3 + 3 * x_1 * (1-t)^2 * t + 3 * x_2 * (1-t) * t^2 + x_3 * t^3$$
$$y(t) = y_0 * (1-t)^3 + 3 * y_1 * (1-t)^2 * t + 3 * y_2 * (1-t) * t^2 + y_3 * t^3$$

### 8.3.3 $G^1$ Smooth Segments

*$G^1$ Smooth* quadratic or cubic segments implicitly define their first internal control point in such a manner as to guarantee a continuous tangent direction at the join point when they are joined to a preceding quadratic or cubic segment. Geometrically, this ensures that the two segments meet without a sharp corner. However, the length of the tangent vector may experience a discontinuity at the join point.

$G^1$ smoothness at the initial point of a quadratic or cubic segment may be guaranteed by suitable placement of the first internal control point ($x_1$, $y_1$) of the following segment. Given a previous quadratic or cubic segment with an internal control point ($px$, $py$) and final endpoint ($ox$, $oy$), we compute ($x_1$, $y_1$) as ($2*ox - px$, $2*oy - py$) (*i.e.*, the reflection of the point ($px$, $py$) about the point ($ox$, $oy$)). For segments of the same type, this will provide $C^1$ smoothness (see the next section).

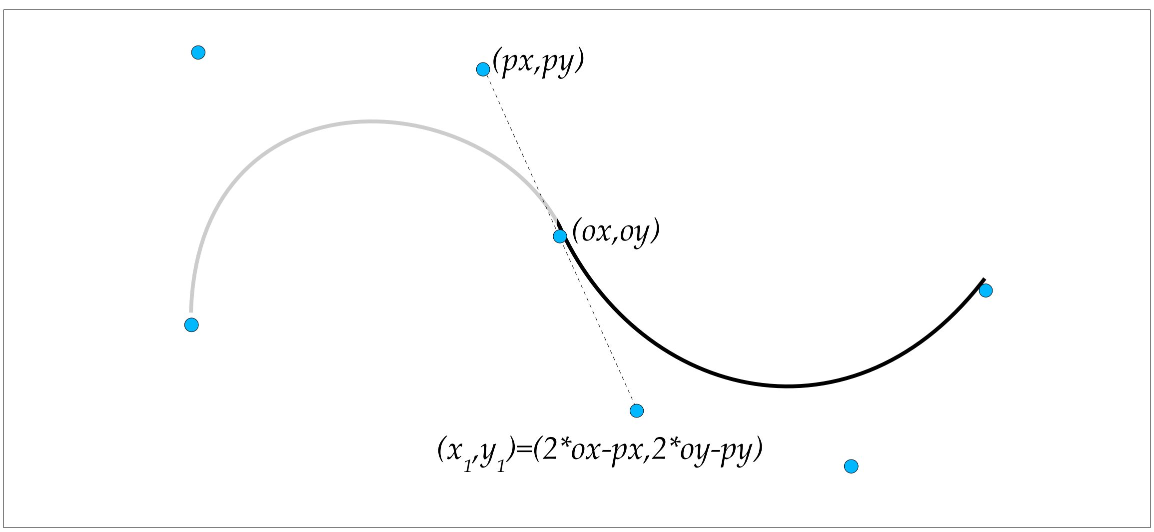


*Figure 4: Smooth Curve Construction*

### 8.3.4 $C^1$ Smooth Segments

*[ Note: this section is informative only. ]*

$C^1$ *smooth* quadratic or cubic segments define their first internal control point $(x_1, y_1)$ in such a manner as to guarantee a continuous first derivative at the join point when they are joined to a preceding quadratic or cubic segment. Geometrically, this ensures that the two segments meet with continuous parametric velocity at the join point. This is a stronger condition than $G^1$ continuity.

Given a previous quadratic or cubic segment with an internal control point $(px, py)$ and final endpoint $(ox, oy)$, $(x_1, y_1)$ is computed as follows:

- When joining a previous quadratic or cubic segment to a following segment of the same type (quadratic or cubic):

$$(x_1, y_1) = (2*ox - px,\ 2*oy - py)$$

- When joining a previous quadratic segment to a following cubic segment:

$$(x_1, y_1) = (5*ox - 2*px,\ 5*oy - 2*py)/3$$

- When joining a previous cubic segment to a following quadratic segment:

$$(x_1, y_1) = (5*ox - 3*px,\ 5*oy - 3*py)/2$$

### 8.3.5 $C^2$ Smooth Segments

*[ Note: this section is informative only. ]*

$C^2$ *smooth* cubic segments implicitly define both of their internal control points $(x_1, y_1)$ and $(x_2, y_2)$ in such a manner as to guarantee continuous first and second derivatives at the join point when they are joined to a preceding quadratic or cubic segment. Geometrically, this ensures that the two segments meet with continuous velocity and acceleration at the join point.

Given three previous control points $(qx, qy)$, $(px, py)$, and $(ox, oy)$ (for a quadratic segment, $(qx, qy)$ is the initial endpoint, $(px, py)$ is the internal control point and $(ox, oy)$ is the final endpoint; for a cubic segment, $(qx, qy)$, and $(px, py)$ are the first and second internal control points, respectively, and $(ox, oy)$ is the final endpoint), $(x_1, y_1)$ is computed as described in the preceding section, and $(x_2, y_2)$ is computed as follows.

- When joining a previous quadratic segment to a following cubic segment:

$$(x_2, y_2) = (8*ox - 6*px + qx,\ 8*oy - 6*py + qy)/3$$

- When joining a previous cubic segment to a following cubic segment:

$$(x_2, y_2) = (4*(ox - px) + qx,\ 4*(oy - py) + qy)$$

### 8.3.6 Converting Segments From Quadratic to Cubic Form

*[ Note: This section is informative only. ]*

Given a quadratic Bézier curve with control points $(x_0, y_0)$, $(x_1, y_1)$, and $(x_2, y_2)$, an identical cubic Bézier curve may be formed using the control points $(x_0, y_0)$, $(x_0 + 2*x_1, y_0 + 2*y_1)/3$, $(x_2 + 2*x_1, y_2 + 2*y_1)/3$, $(x_2, y_2)$.

## 8.4 Elliptical Arcs

Elliptical arc segments join a pair of points with a section of an ellipse with given horizontal and vertical axes and a rotation angle (in degrees). Given these parameters, there are four possible arcs distinguished by their direction around the ellipse (clockwise or counter-clockwise) and whether they take the smaller or larger path around the ellipse.

Figure 5 below shows the two possible ellipses with horizontal axis *rh*, vertical axis *rv*, and counter-clockwise rotation angle *rot* (shown as the angle between the vertical line labeled *rot* and the line labeled *rv*) passing through the points $(x_0, y_0)$ and $(x_1, y_1)$. The four arcs connecting the points are labeled L and S for large and small, and CW and CCW for clockwise and counter-clockwise.

Negative values of *rh* and *rv* are replaced with their absolute values. If *rh* or *rv* is 0, or the endpoints are coincident, a straight line segment between the endpoints is substituted for the arc. The *rot* parameter is taken modulo 360 degrees.

If no elliptical arc exists with the given parameters because the endpoints are too far apart (as detailed in the next section), the radii are scaled up uniformly by the smallest factor that permits a solution.

Some notes on the mathematics of ellipses are provided in Section 17.

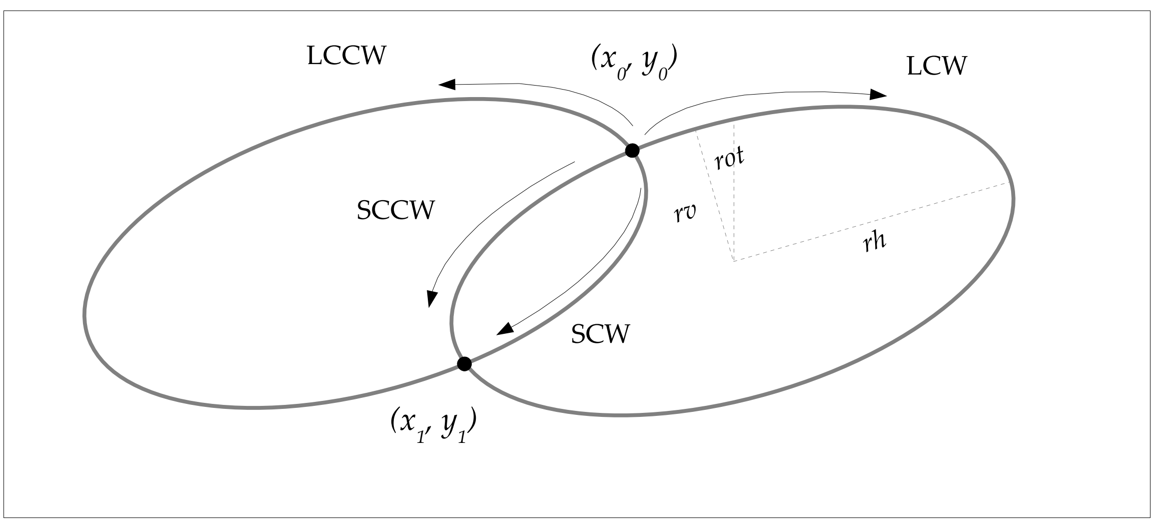


*Figure 5: Elliptical Arcs*

## 8.5 The Standard Path Format

Complex paths may be constructed in application (client-side) memory and passed into OpenVG to define a `VGPath` object. Such path data is defined by a sequence of segment commands referencing a separate sequence of geometric coordinates and parameters.

In this section, we define the standard data format for paths that may be used to define sequences of various types of path segments. Extensions may define other path data formats.

### VG_PATH_FORMAT_STANDARD

The `VG_PATH_FORMAT_STANDARD` macro defines a constant to be used as an argument to **vgAppendPathData** to indicate that path data are stored using the standard format. As this API is revised, the lower 16 bits of version number may increase. Each version of OpenVG will accept formats defined in all prior specification versions with which it is backwards-compatible.

Extensions wishing to define additional path formats may register for format identifiers that will differ in their upper 16 bits; the lower 16 bits may be used by the extension vendor for versioning purposes.

```
#define VG_PATH_FORMAT_STANDARD 0
```

### 8.5.1 Path Segment Command Side Effects

In order to define the semantics of each segment command type, we define three reference points (all are initially (0, 0)):

- (*sx*, *sy*): the beginning of the current subpath, *i.e.*, the position of the last `MOVE_TO` segment.
- (*ox*, *oy*): the last point of the previous segment.
- (*px*, *py*): the last internal control point of the previous segment, if the segment was a (regular or smooth) quadratic or cubic Bézier, or else the last point of the previous segment.

Figure 6 illustrates the locations of these points at the end of a sequence of segment commands { MOVE_TO, LINE_TO, CUBIC_TO }.

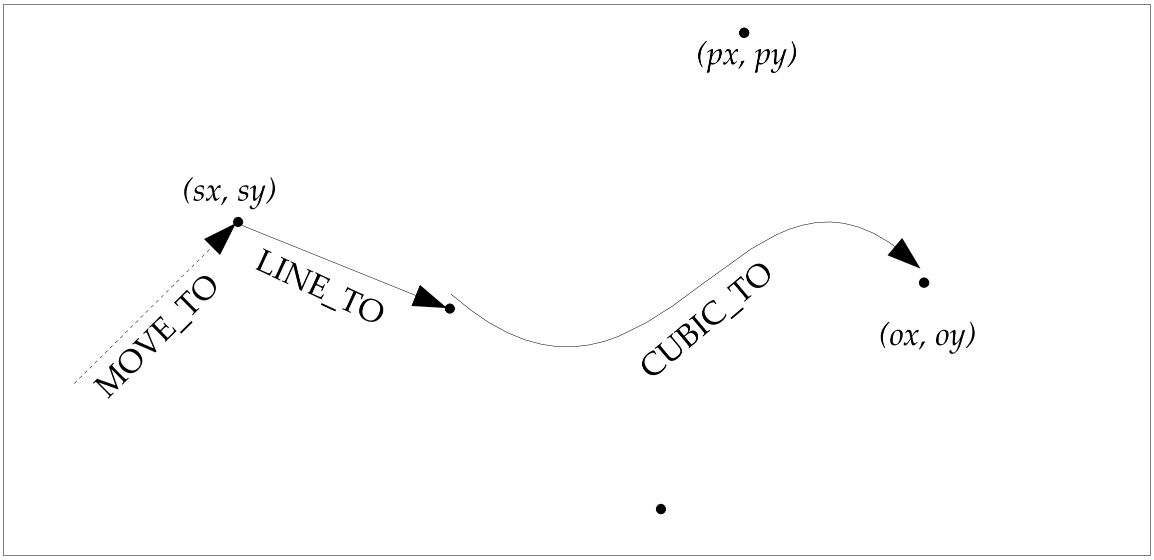


*Figure 6: Segment Reference Points*

We define points (*x0, y0*), (*x1, y1*), and (*x2, y2*) in the discussion below as absolute coordinates. For segments defined using relative coordinates, (*x0, y0*), etc., are defined as the incoming coordinate values added to (*ox, oy*). Ellipse *rx*, *ry*, and *rot* parameters are unaffected by the use of relative coordinates.

Each segment (except for `MOVE_TO` segments) begins at the point (*ox, oy*) defined by the previous segment.

A path consists of a sequence of subpaths. As path segment commands are encountered, each segment is appended to the *current subpath*. The current subpath is ended by a `MOVE_TO` or `CLOSE_PATH` segment, and a new current subpath is begun. The end of the path data also ends the current subpath.

### 8.5.2 Segment Commands

The following table describes each segment command type along with its prefix, the number of specified coordinates and parameters it requires, the numerical value of the segment command, the formulas for any implicit coordinates, and the side effects of the segment command on the points (*ox, oy*), (*sx, sy*), and (*px, py*) and on the termination of the current subpath.

| ***Type*** | ***Command*** | ***Coordinates*** | ***Value*** | ***Implicit Points*** | ***Side Effects*** |
|---|---|---|---|---|---|
| Close Path | CLOSE_PATH | *none* | 0 | | *(px,py)=(ox,oy)=(sx,sy)*<br>End current subpath |
| Move | MOVE_TO | *x0,y0* | 1 | | *(sx,sy)=(px,py)=(ox,oy) =(x0,y0)*<br>End current subpath |
| Line | LINE_TO | *x0,y0* | 2 | | *(px,py)=(ox,oy)=(x0,y0)* |
| Horizontal Line | HLINE_TO | *x0* | 3 | *y0=oy* | *(px,py)=(x0,oy)*<br>*ox=x0* |
| Vertical Line | VLINE_TO | *y0* | 4 | *x0=ox* | *(px,py)=(ox,y0)*<br>*oy=y0* |
| Quadratic | QUAD_TO | *x0,y0,x1,y1* | 5 | | *(px,py)=(x0,y0)*<br>*(ox,oy)=(x1,y1)* |
| Cubic | CUBIC_TO | *x0,y0,x1,y1, x2,y2* | 6 | | *(px,py)=(x1,y1)*<br>*(ox,oy)=(x2,y2)* |
| $G^1$ Smooth Quad | SQUAD_TO | *x1,y1* | 7 | *(x0,y0)= (2*ox-px, 2*oy-py)* | *(px,py)= (2*ox-px, 2*oy-py)*<br>*(ox,oy)=(x1,y1)* |
| $G^1$ Smooth Cubic | SCUBIC_TO | *x1,y1,x2,y2* | 8 | *(x0,y0)= (2*ox-px, 2*oy-py)* | *(px,py)=(x1,y1)*<br>*(ox,oy)=(x2,y2)* |
| Small CCW Arc | SCCWARC_TO | *rx,ry,rot,x0,y0* | 9 | | *(px,py)=(ox,oy)=(x0,y0)* |
| Small CW Arc | SCWARC_TO | *rx,ry,rot,x0,y0* | 10 | | *(px,py)=(ox,oy)=(x0,y0)* |
| Large CCW Arc | LCCWARC_TO | *rx,ry,rot,x0,y0* | 11 | | *(px,py)=(ox,oy)=(x0,y0)* |
| Large CW Arc | LCWARC_TO | *rx,ry,rot,x0,y0* | 12 | | *(px,py)=(ox,oy)=(x0,y0)* |
| Reserved | Reserved | | 13-15 | | |

*Table 6: Client-Side Path Segment Commands*

Each segment type may be defined using either absolute or relative coordinates. A relative coordinate (*x*, *y*) is added to (*ox*, *oy*) to obtain the corresponding absolute coordinate (*ox* + *x*, *oy* + *y*). Relative coordinates are converted to absolute coordinates immediately as each segment is encountered.

The `HLINE_TO` and `VLINE_TO` segment types are provided in order to avoid the need for an SVG viewing application (for example) to perform its own relative to absolute conversions when parsing path data.

In SVG, the behavior of smooth quadratic and cubic segments differs slightly from the behavior defined above. If a smooth quadratic segment follows a non-quadratic segment, or a smooth cubic segment follows a non-cubic segment, the initial control point (*x0*, *y0*) is placed at (*ox*, *oy*) instead of being computed as the reflection of (*px*, *py*). This behavior may be emulated by converting an SVG smooth segment into a regular segment with all of its control points specified when the preceding segment is of a different degree.

### 8.5.3 Coordinate Data Formats

Coordinate and parameter data (henceforth called simply coordinate data) may be expressed in the set of formats shown in Table 7 below. Multi-byte coordinate data (*i.e.*, `S_16`, `S_32` and `F` datatypes) are stored within a client-side representation using the native byte order (endianness) of the platform. Implementations may quantize incoming data in the `S_32` and `F` formats to a lesser number of bits, provided at least 16 bits of precision are maintained.

Judicious use of smooth curve segments and 8- and 16-bit datatypes can result in substantial memory savings for common path data, such as font glyphs. Using smaller datatypes also conserves bus bandwidth when transferring paths from application memory to OpenVG.

| ***Datatype*** | `VG_PATH_DATATYPE` ***Suffix*** | ***Bytes*** | ***Value*** |
|---|---|---|---|
| 8-bit signed integer | `S_8` | 1 | 0 |
| 16-bit signed integer | `S_16` | 2 | 1 |
| 32-bit signed integer | `S_32` | 4 | 2 |
| IEEE 754 floating-point | `F` | 4 | 3 |

*Table 7: Client-Side Path Coordinate Datatypes*

#### VGPathDatatype

The `VGPathDatatype` enumeration defines values describing the possible numerical datatypes for path coordinate data.

```
typedef enum {
  VG_PATH_DATATYPE_INVALID      = -1,
  VG_PATH_DATATYPE_S_8          =  0,
  VG_PATH_DATATYPE_S_16         =  1,
  VG_PATH_DATATYPE_S_32         =  2,
  VG_PATH_DATATYPE_F            =  3
} VGPathDatatype;
```

## 8.5.4 Segment Type Marker Definitions

Segment type markers are defined as 8-bit integers, with the leading 3 bits reserved for future use, the next 4 bits containing the segment command type, and the least significant bit indicating absolute vs. relative coordinates (0 for absolute, 1 for relative). The reserved bits must be set to 0.

For the `CLOSE_PATH` segment command, the value of the Abs/Rel bit is ignored.


*Figure 7: Segment Type Marker Layout*

### VGPathAbsRel

The `VGPathAbsRel` enumeration defines values indicating absolute (`VG_ABSOLUTE`) and relative (`VG_RELATIVE`) values.

```
typedef enum {
  VG_ABSOLUTE = 0,
  VG_RELATIVE = 1
} VGPathAbsRel;
```

### VGPathSegment

The `VGPathSegment` enumeration defines values for each segment command type. The values are pre-shifted by 1 bit to allow them to be combined easily with values from `VGPathAbsRel`.

```
typedef enum {
  VG_CLOSE_PATH                     = ( 0 << 1),
  VG_MOVE_TO                        = ( 1 << 1),
  VG_LINE_TO                        = ( 2 << 1),
  VG_HLINE_TO                       = ( 3 << 1),
  VG_VLINE_TO                       = ( 4 << 1),
  VG_QUAD_TO                        = ( 5 << 1),
  VG_CUBIC_TO                       = ( 6 << 1),
  VG_SQUAD_TO                       = ( 7 << 1),
  VG_SCUBIC_TO                      = ( 8 << 1),
  VG_SCCWARC_TO                     = ( 9 << 1),
  VG_SCWARC_TO                      = (10 << 1),
  VG_LCCWARC_TO                     = (11 << 1),
  VG_LCWARC_TO                      = (12 << 1)
} VGPathSegment;
```

### *VGPathCommand*

The `VGPathCommand` enumeration defines combined values for each segment command type and absolute/relative value. The values are shifted left by one bit and ORed bitwise (*i.e.,* using the C `|` operator) with the appropriate value from `VGPathAbsRel` to obtain a complete segment command value.

```
typedef enum {
  VG_MOVE_TO_ABS                      = VG_MOVE_TO    | VG_ABSOLUTE,
  VG_MOVE_TO_REL                      = VG_MOVE_TO    | VG_RELATIVE,
  VG_LINE_TO_ABS                      = VG_LINE_TO    | VG_ABSOLUTE,
  VG_LINE_TO_REL                      = VG_LINE_TO    | VG_RELATIVE,
  VG_HLINE_TO_ABS                     = VG_HLINE_TO   | VG_ABSOLUTE,
  VG_HLINE_TO_REL                     = VG_HLINE_TO   | VG_RELATIVE,
  VG_VLINE_TO_ABS                     = VG_VLINE_TO   | VG_ABSOLUTE,
  VG_VLINE_TO_REL                     = VG_VLINE_TO   | VG_RELATIVE,
  VG_QUAD_TO_ABS                      = VG_QUAD_TO    | VG_ABSOLUTE,
  VG_QUAD_TO_REL                      = VG_QUAD_TO    | VG_RELATIVE,
  VG_CUBIC_TO_ABS                     = VG_CUBIC_TO   | VG_ABSOLUTE,
  VG_CUBIC_TO_REL                     = VG_CUBIC_TO   | VG_RELATIVE,
  VG_SQUAD_TO_ABS                     = VG_SQUAD_TO   | VG_ABSOLUTE,
  VG_SQUAD_TO_REL                     = VG_SQUAD_TO   | VG_RELATIVE,
  VG_SCUBIC_TO_ABS                    = VG_SCUBIC_TO  | VG_ABSOLUTE,
  VG_SCUBIC_TO_REL                    = VG_SCUBIC_TO  | VG_RELATIVE,
  VG_SCCWARC_TO_ABS                   = VG_SCCWARC_TO | VG_ABSOLUTE,
  VG_SCCWARC_TO_REL                   = VG_SCCWARC_TO | VG_RELATIVE,
  VG_SCWARC_TO_ABS                    = VG_SCWARC_TO  | VG_ABSOLUTE,
  VG_SCWARC_TO_REL                    = VG_SCWARC_TO  | VG_RELATIVE,
  VG_LCCWARC_TO_ABS                   = VG_LCCWARC_TO | VG_ABSOLUTE,
  VG_LCCWARC_TO_REL                   = VG_LCCWARC_TO | VG_RELATIVE,
  VG_LCWARC_TO_ABS                    = VG_LCWARC_TO  | VG_ABSOLUTE,
  VG_LCWARC_TO_REL                    = VG_LCWARC_TO  | VG_RELATIVE
} VGPathCommand;
```

### 8.5.5 Client-Side Path Example

The following code example shows how to traverse a client-side path stored using the standard representation. A byte is read containing a segment command, and the segment command type and relative/absolute flag are extracted by application-defined `SEGMENT_COMMAND` and `SEGMENT_ABS_REL` macros. The number of coordinates and number of bytes per coordinate (for the given data format) are also determined using lookup tables. Finally, the relevant portion of the path data stream representing the current segment is copied into a temporary buffer and used as an argument to a user-defined **processSegment** function that may perform further processing.

```
#define PATH_MAX_COORDS  6 /* Maximum number of coordinates/command */
#define PATH_MAX_BYTES   4 /* Bytes in largest data type */
#define SEGMENT_COMMAND(command) /* Extract segment type */ \
    ((command) & 0x1e)
#define SEGMENT_ABS_REL(command) /* Extract absolute/relative bit */ \
    ((command) & 0x1)

/* Number of coordinates for each command */
static const VGint numCoords[] = {0,2,2,1,1,4,6,2,4,5,5,5,5};
/* Number of bytes for each datatype */
static const VGint numBytes[] = {1,2,4,4};

/* User-defined function to process a single segment */
extern void
processSegment(VGPathSegment command, VGPathAbsRel absRel,
               VGPathDatatype datatype,
               void * segmentData);

/* Process a path in the standard format, one segment at a time. */
void
processPath(const VGubyte * pathSegments, const void * pathData,
            int numSegments, VGPathDatatype datatype)
{
  VGubyte segmentType, segmentData[PATH_MAX_COORDS*PATH_MAX_BYTES];
  VGint segIdx = 0, dataIdx = 0;
  VGint command, absRel, numBytes;

  while (segIdx < numSegments) {
    segmentType = pathSegments[segIdx++];
    command = SEGMENT_COMMAND(segmentType);
    absRel = SEGMENT_ABS_REL(segmentType);
    numBytes = numCoords[command]*numBytes[datatype];

    /* Copy segment data for further processing */
    memcpy(segmentData, &pathData[dataIdx], numBytes);

    /* Process command */
    processSegment(command, absRel, datatype, (void *) segmentData);
    dataIdx += numBytes;
  }
}
```

## 8.6 Path Operations

In addition to filling or stroking a path, the API allows the following basic operations on paths:

- Create a path with a given set of capabilities (**vgCreatePath**)
- Remove data from a path (**vgClearPath**)
- Deallocate a path (**vgDestroyPath**)
- Query path information (using **vgGetParameter**)
- Query the set of capabilities for a path (**vgGetPathCapabilities**)
- Reduce the set of capabilities for a path (**vgRemovePathCapabilities**)
- Append data from one path onto another (**vgAppendPath**)
- Append client-side data onto a path (**vgAppendPathData**)
- Modify coordinates stored in a path (**vgModifyPathCoords**)
- Transform a path (**vgTransformPath**)
- Interpolate between two paths (**vgInterpolatePath**)
- Determine the geometrical length of a path (**vgPathLength**)
- Get position and tangent information for a point at a given geometric distance along path (**vgPointAlongPath**)
- Get an axis-aligned bounding box for a path (**vgPathBounds**, **vgTransformedPathBounds**)

Higher-level geometric primitives are defined in the optional `VGU` utility library (see Section 16):

- Append a line to a path (**vguLine**)
- Append a polyline or polygon to a path (**vguPolygon**)
- Append a rectangle to a path (**vguRect**)
- Append a round-cornered rectangle to a path (**vguRoundRect**)
- Append an ellipse to a path (**vguEllipse**)
- Append a circular arc to a path (**vguArc**)

### 8.6.1 Storage of Paths

OpenVG stores path data internally to the implementation. Paths are referenced via opaque `VGPath` handles. Applications may initialize paths using the client-side memory representation defined above or other representations defined by extensions.

It is possible for an implementation to store path data in hardware-accelerated memory. Implementations may also make use of their own internal representation of path segments. The intent is for applications to be able to define a set of paths, for example one for each glyph in the current typeface, and to be able to re-render each previously defined path with maximum efficiency.

### VGPath

`VGPath` represents an opaque handle to a path.

```
typedef VGHandle VGPath;
```

## 8.6.2 Creating and Destroying Paths

Paths are created and destroyed using the **vgCreatePath** and **vgDestroyPath** functions. During the lifetime of a path, an application may indicate which path operations it plans to perform using path capability flags defined by the `VGPathCapabilities` enumeration.

### *VGPathCapabilities*

The `VGPathCapabilities` enumeration defines a set of constants specifying which operations may be performed on a given path object. At the time a path is defined, the application specifies which operations it wishes to be able to perform on the path. Over time, the application may disable previously enabled capabilities, but it may not re-enable capabilities once they have been disabled. This feature allows OpenVG implementations to make use of internal path representations that may not support all path operations, possibly resulting in higher performance on paths where those operations will not be performed.

The capability bits and the functionality they allow are described below:

- `VG_PATH_CAPABILITY_APPEND_FROM` – use path as the `srcPath` argument to **vgAppendPath**
- `VG_PATH_CAPABILITY_APPEND_TO` - use path as the `dstPath` argument to **vgAppendPath** and **vgAppendPathData**
- `VG_PATH_CAPABILITY_MODIFY` – use path as the `dstPath` argument to **vgModifyPathCoords**
- `VG_PATH_CAPABILITY_TRANSFORM_FROM` – use path as the `srcPath` argument to **vgTransformPath**
- `VG_PATH_CAPABILITY_TRANSFORM_TO` – use path as the `dstPath` argument to **vgTransformPath**
- `VG_PATH_CAPABILITY_INTERPOLATE_FROM` – use path as the `startPath` or `endPath` argument to **vgInterpolatePath**
- `VG_PATH_CAPABILITY_INTERPOLATE_TO` – use path as the `dstPath` argument to **vgInterpolatePath**
- `VG_PATH_CAPABILITY_PATH_LENGTH` – use path as the `path` argument to **vgPathLength**
- `VG_PATH_CAPABILITY_POINT_ALONG_PATH` – use path as the `path` argument to **vgPointAlongPath**

- `VG_PATH_CAPABILITY_TANGENT_ALONG_PATH` – use path as the `path` argument to **vgPointAlongPath** with non-`NULL` `tangentX` and `tangentY` arguments
- `VG_PATH_CAPABILITY_PATH_BOUNDS` – use path as the `path` argument to **vgPathBounds**
- `VG_PATH_CAPABILITY_PATH_TRANSFORMED_BOUNDS` – use path as the `path` argument to **vgPathTransformedBounds**
- `VG_PATH_CAPABILITY_ALL` – a bitwise OR of all the defined path capabilities

```
typedef enum {
  VG_PATH_CAPABILITY_APPEND_FROM                = (1 <<  0),
  VG_PATH_CAPABILITY_APPEND_TO                  = (1 <<  1),
  VG_PATH_CAPABILITY_MODIFY                     = (1 <<  2),
  VG_PATH_CAPABILITY_TRANSFORM_FROM             = (1 <<  3),
  VG_PATH_CAPABILITY_TRANSFORM_TO               = (1 <<  4),
  VG_PATH_CAPABILITY_INTERPOLATE_FROM           = (1 <<  5),
  VG_PATH_CAPABILITY_INTERPOLATE_TO             = (1 <<  6),
  VG_PATH_CAPABILITY_PATH_LENGTH                = (1 <<  7),
  VG_PATH_CAPABILITY_POINT_ALONG_PATH           = (1 <<  8),
  VG_PATH_CAPABILITY_TANGENT_ALONG_PATH         = (1 <<  9),
  VG_PATH_CAPABILITY_PATH_BOUNDS                = (1 << 10),
  VG_PATH_CAPABILITY_PATH_TRANSFORMED_BOUNDS    = (1 << 11),
  VG_PATH_CAPABILITY_ALL                        = (1 << 12) - 1
} VGPathCapabilities;
```

It is legal to call **vgCreatePath**, **vgClearPath**, and **vgDestroyPath** regardless of the current setting of the path's capability bits, as these functions discard the existing path definition.

### *vgCreatePath*

**vgCreatePath** creates a new path that is ready to accept segment data and returns a `VGPath` handle to it. The path data will be formatted in the format given by `pathFormat`, typically `VG_PATH_FORMAT_STANDARD`. The `datatype` parameter contains a value from the `VGPathDatatype` enumeration (other than `VG_PATH_DATATYPE_INVALID`) indicating the datatype that will be used for coordinate data. The `capabilities` argument is a bitwise OR of the desired `VGPathCapabilities` values. Bits of `capabilities` that do not correspond to values from `VGPathCapabilities` have no effect. If an error occurs, `VG_INVALID_HANDLE` is returned.

The `scale` and `bias` parameters are used to interpret each coordinate of the path data; an incoming coordinate value $v$ will be interpreted as the value ($scale*v + bias$). `scale` must not equal 0. The datatype, scale, and bias together define a valid coordinate data range for the path; segment commands that attempt to place a coordinate in the path that is outside this range will overflow silently, resulting in an undefined coordinate value. Functions that query a path containing such values, such as **vgPathLength** and **vgPointAlongPath,** also return undefined results.

The `segmentCapacityHint` parameter provides a hint as to the total number of segments that will eventually be stored in the path. The `coordCapacityHint` parameter provides a hint as to the total number of specified coordinates (as defined in the "Coordinates" column of Table 6) that will eventually be stored in the path. A value less than or equal to 0 for either hint indicates that the capacity is unknown. The path storage space will in any case grow as needed, regardless of the hint values. However, supplying hints may improve performance by reducing the need to allocate additional space as the path grows. Implementations should allow applications to append segments and coordinates up to the stated capacity in small batches without degrading performance due to excessive memory reallocation.

```
VGPath vgCreatePath(VGint pathFormat,
                    VGPathDatatype datatype,
                    VGfloat scale, VGfloat bias,
                    VGint segmentCapacityHint,
                    VGint coordCapacityHint,
                    VGbitfield capabilities)
```

***ERRORS***

`VG_UNSUPPORTED_PATH_FORMAT_ERROR`

– if `pathFormat` is not a supported format

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `datatype` is not a valid value from the `VGPathDatatype` enumeration

– if `scale` is equal to 0

### *vgClearPath*

**vgClearPath** removes all segment command and coordinate data associated with a `path`. The handle continues to be valid for use in the future, and the path format and datatype retain their existing values. The `capabilities` argument is a bitwise OR of the desired `VGPathCapabilities` values. Bits of `capabilities` that do not correspond to values from `VGPathCapabilities` have no effect. Using **vgClearPath** may be more efficient than destroying and re-creating a path for short-lived paths.

```
void vgClearPath(VGPath path, VGbitfield capabilities)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

### vgDestroyPath

**vgDestroyPath** releases any resources associated with `path`, and makes the handle invalid in all contexts that shared it.

```
void vgDestroyPath(VGPath path)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

## 8.6.3 Path Queries

### VGPathParamType

Values from the `VGPathParamType` enumeration may be used as the `paramType` argument to **vgGetParameter** to query various features of a path. All of the parameters defined by `VGPathParamType` are read-only. Table 8 shows the datatypes for each parameter type.

```
typedef enum {
  VG_PATH_FORMAT       = 0x1600,
  VG_PATH_DATATYPE     = 0x1601,
  VG_PATH_SCALE        = 0x1602,
  VG_PATH_BIAS         = 0x1603,
  VG_PATH_NUM_SEGMENTS = 0x1604,
  VG_PATH_NUM_COORDS   = 0x1605
} VGPathParamType;
```

| ***Parameter*** | ***Datatype*** |
|---|---|
| `VG_PATH_FORMAT` | `VGint` |
| `VG_PATH_DATATYPE` | `VGint` |
| `VG_PATH_SCALE` | `VGfloat` |
| `VG_PATH_BIAS` | `VGfloat` |
| `VG_PATH_NUM_SEGMENTS` | `VGint` |
| `VG_PATH_NUM_COORDS` | `VGint` |

*Table 8: VGPathParamType Datatypes*

### Path Format

The command format of a path is queried as an integer value using the `VG_PATH_FORMAT` parameter:

```
VGPath path;
VGint pathFormat = vgGetParameteri(path, VG_PATH_FORMAT);
```

### *Path Datatype*

The coordinate datatype of a path is queried as an integer value using the `VG_PATH_DATATYPE` parameter. The returned integral value should be cast to the `VGPathDatatype` enumeration:

```
VGPath path;
VGPathDatatype pathDatatype =
  (VGPathDatatype)vgGetParameteri(path, VG_PATH_DATATYPE);
```

### *Path Scale*

The scale factor of the `path` is queried as a floating-point value using the `VG_PATH_SCALE` parameter:

```
VGPath path;
VGfloat pathScale = vgGetParameterf(path, VG_PATH_SCALE);
```

### *Path Bias*

The bias of the `path` is queried as a floating-point value using the `VG_PATH_BIAS` parameter:

```
VGPath path;
VGfloat pathBias = vgGetParameterf(path, VG_PATH_BIAS);
```

### *Number of Segments*

The number of segments stored in the path is queried as an integer value using the `VG_PATH_NUM_SEGMENTS` parameter:

```
VGPath path;
VGint pathNumSegments = vgGetParameteri(path, VG_PATH_NUM_SEGMENTS);
```

### *Number of Coordinates*

The total number of specified coordinates (*i.e.,* those defined in the "Coordinates" column of Table 6) stored in the path is queried as an integer value using the `VG_PATH_NUM_COORDS` parameter:

```
VGPath path;
VGint pathNumCoords = vgGetParameteri(path, VG_PATH_NUM_COORDS);
```

## 8.6.4 Querying and Modifying Path Capabilities

### vgGetPathCapabilities

The **vgGetPathCapabilities** function returns the current capabilities of the `path`, as a bitwise OR of `VGPathCapabilities` constants. If an error occurs, 0 is returned.

```
VGbitfield vgGetPathCapabilities(VGPath path)
```

*ERRORS*

`VG_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

### vgRemovePathCapabilities

The **vgRemovePathCapabilities** function requests the set of capabilities specified in the `capabilities` argument to be disabled for the given `path`. The `capabilities` argument is a bitwise OR of the `VGPathCapabilities` values whose removal is requested. Attempting to remove a capability that is already disabled has no effect. Bits of `capabilities` that do not correspond to values from `VGPathCapabilities` have no effect.

An implementation may choose to ignore the request to remove a particular capability if no significant performance improvement would result. In this case, **vgGetPathCapabilities** will continue to report the capability as enabled.

```
void vgRemovePathCapabilities(VGPath path, VGbitfield capabilities)
```

*ERRORS*

`VG_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

## 8.6.5 Copying Data Between Paths

### vgAppendPath

**vgAppendPath** appends a copy of all path segments from `srcPath` onto the end of the existing data in `dstPath`. It is legal for `srcPath` and `dstPath` to be handles to the same path object, in which case the contents of the path are duplicated. If `srcPath` and `dstPath` are handles to distinct path objects, the contents of `srcPath` will not be affected by the call.

The VG_PATH_CAPABILITY_APPEND_FROM capability must be enabled for srcPath, and the VG_PATH_CAPABILITY_APPEND_TO capability must be enabled for dstPath.

If the scale and bias of dstPath define a narrower range than that of srcPath, overflow may occur silently.

```
void vgAppendPath(VGPath dstPath, VGPath srcPath)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if either dstPath or srcPath is not a valid path handle, or is not shared with the current context

VG_PATH_CAPABILITY_ERROR

– if VG_PATH_CAPABILITY_APPEND_FROM is not enabled for srcPath

– if VG_PATH_CAPABILITY_APPEND_TO is not enabled for dstPath

### *8.6.6 Appending Client-Side Data to a Path*

#### *vgAppendPathData*

**vgAppendPathData** appends data taken from a client-side representation stored in pathData to the given path dstPath. The data are formatted using the path format of dstPath (as returned by querying the path's VG_PATH_FORMAT parameter using **vgGetParameteri**). The numSegments parameter gives the total number of entries in the pathSegments array, and must be greater than 0. The pathData pointer must be aligned on a 1-, 2-, or 4-byte boundary (as defined in the "Bytes" column of Table 7) depending on the size of the coordinate datatype (as returned by querying the path's VG_PATH_DATATYPE parameter using **vgGetParameteri**). The VG_PATH_CAPABILITY_APPEND_TO capability must be enabled for path.

Each incoming coordinate value, regardless of datatype, is transformed by the scale factor and bias of the path.

```
void vgAppendPathData(VGPath dstPath,
                      VGint numSegments,
                      const VGubyte * pathSegments,
                      const void * pathData)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if `dstPath` is not a valid path handle, or is not shared with the current context

`VG_PATH_CAPABILITY_ERROR`

– if `VG_PATH_CAPABILITY_APPEND_TO` is not enabled for `dstPath`

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `pathSegments` or `pathData` is `NULL`

– if `pathData` is not properly aligned

– if `numSegments` is less than or equal to 0

– if `pathSegments` contains an illegal command

### 8.6.7 Modifying Path Data

Coordinate data in an existing path may be modified, for example to create animation effects. Implementations should choose an internal representation for paths that have the `VG_PATH_CAPABILITY_MODIFY` capability enabled that allows for efficient modification of the coordinate data.

#### vgModifyPathCoords

**vgModifyPathCoords** modifies the coordinate data for a contiguous range of segments of `dstPath`, starting at `startIndex` (where 0 is the index of the first path segment) and having length `numSegments`. The data in `pathData` must be formatted in exactly the same manner as the original coordinate data for the given segment range. The `pathData` pointer must be aligned on a 1-, 2-, or 4-byte boundary depending on the size of the coordinate datatype (as returned by querying the path's `VG_PATH_DATATYPE` parameter using **vgGetParameteri**). The `VG_PATH_CAPABILITY_MODIFY` capability must be enabled for `path`.

Each incoming coordinate value, regardless of datatype, is transformed by the scale factor and bias of the path.

```
void vgModifyPathCoords(VGPath dstPath,
                        int startIndex, int numSegments,
                        const void * pathData)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `dstPath` is not a valid path handle, or is not shared with the current context

`VG_PATH_CAPABILITY_ERROR`

– if VG_PATH_CAPABILITY_MODIFY is not enabled for dstPath

VG_ILLEGAL_ARGUMENT_ERROR

– if pathData is NULL

– if pathData is not properly aligned

– if startIndex is less than 0

– if numSegments is less than or equal to 0

– if startIndex + numSegments is greater than the number of segments in the path

## 8.6.8 Transforming a Path

### vgTransformPath

**vgTransformPath** appends a transformed copy of srcPath to the current contents of dstPath. The appended path is equivalent to the results of applying the current path-user-to-surface transformation (VG_MATRIX_PATH_USER_TO_SURFACE) to srcPath.

It is legal for srcPath and dstPath to be handles to the same path object, in which case the the transformed path will be appended to the existing path. If srcPath and dstPath are handles to distinct path objects, the contents of srcPath will not be affected by the call.

The VG_PATH_CAPABILITY_TRANSFORM_FROM capability must be enabled for srcPath, and the VG_PATH_CAPABILITY_TRANSFORM_TO capability must be enabled for dstPath.

Overflow may occur silently if coordinates are transformed outside the datatype range of dstPath.

```
void vgTransformPath(VGPath dstPath, VGPath srcPath)
```

*ERRORS*

VG_BAD_HANDLE_ERROR

– if either dstPath or srcPath is not a valid path handle, or is not shared with the current context

VG_PATH_CAPABILITY_ERROR

– if VG_PATH_CAPABILITY_TRANSFORM_FROM is not enabled for srcPath

– if VG_PATH_CAPABILITY_TRANSFORM_TO is not enabled for dstPath

### 8.6.9 Interpolating Between Paths

Interpolation takes two compatible paths, in a sense described below, and defines a new path that interpolates between them by a parameter `amount`. When `amount` is equal to 0, the result is equivalent to the first path; when `amount` is equal to 1, the result is equivalent to the second path. Values between 0 and 1 produce paths that smoothly interpolate between the two extremes. Values outside the [0, 1] range produce extrapolated paths. Conceptually, interpolation occurs as follows. First, the two path parameters are copied and the copies are normalized by:

- Converting all coordinates to floating-point format, applying the path scale and bias parameters
- Converting all relative segments to absolute form
- Converting all LINE_TO_*, HLINE_TO_*, and VLINE_TO_* segments to LINE_TO form
- Converting all QUAD_TO_*, SQUAD_TO_*, CUBIC_TO_*, and SCUBIC_TO_* segments to CUBIC_TO form
- Retaining all *ARC_TO_* and CLOSE_PATH segments

If, following normalization, both paths have the same sequence of segment types (treating all forms of arc as the same), interpolation proceeds by linearly interpolating between each corresponding pair of segment parameters in the normalized paths. If the starting arc type differs from the final arc type, the starting arc type is used for values of `amount` less than 0.5, and the final arc type is used for values greater than or equal to 0.5. Finally, the coordinates are converted to the data type of the destination.

#### vgInterpolatePath

The **vgInterpolatePath** function appends a path, defined by interpolation (or extrapolation) between the paths `startPath` and `endPath` by the given `amount`, to the path `dstPath`. It returns `VG_TRUE` if interpolation was successful (*i.e.*, the paths had compatible segment types after normalization), and `VG_FALSE` otherwise. If interpolation is unsuccessful, `dstPath` is left unchanged.

It is legal for dst`Path` to be a handle to the same path object as either `startPath` or `endPath` or both, in which case the contents of the source path or paths referenced by `dstPath` will have the interpolated path appended. If `dstPath` is not the a handle to the same path object as either `startPath` or `endPath`, the contents of `startPath` and `endPath` will not be affected by the call.

Overflow may occur silently if the datatype of `dstPath` has insufficient range to store an interpolated coordinate value.

The `VG_PATH_CAPABILITY_INTERPOLATE_FROM` capability must be enabled for both of `startPath` and `endPath`, and the `VG_PATH_CAPABILITY_INTERPOLATE_TO` capability must be enabled for `dstPath`.

```
VGboolean vgInterpolatePath(VGPath dstPath,
                            VGPath startPath,
                            VGPath endPath,
                            VGfloat amount)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if any of `dstPath`, `startPath`, or `endPath` is not a valid path handle, or is not shared with the current context

`VG_PATH_CAPABILITY_ERROR`

– if `VG_PATH_CAPABILITY_PATH_INTERPOLATE_TO` is not enabled for `dstPath`

– if `VG_PATH_CAPABILITY_PATH_INTERPOLATE_FROM` is not enabled for `startPath` or `endPath`

### *8.6.10 Length of a Path*

An approximation to the geometric length of a portion of a path may be obtained by calling the **vgPathLength** function. `MOVE_TO` segments and implicit path closures (see Section 8.7.1) do not contribute to the path length. `CLOSE_PATH` segments have the same length as a `LINE_TO` segment with the same endpoints.

#### *vgPathLength*

The **vgPathLength** function returns the length of a given portion of a path in the user coordinate system (that is, in the path's own coordinate system, disregarding any matrix settings). Only the subpath consisting of the `numSegments` path segments beginning with `startSegment` (where the initial path segment has index 0) is used. If an error occurs, -1.0f is returned.

The `VG_PATH_CAPABILITY_PATH_LENGTH` capability must be enabled for `path`.

```
VGfloat vgPathLength(VGPath path,
                     VGint startSegment, VGint numSegments);
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

`VG_PATH_CAPABILITY_ERROR`

– if `VG_PATH_CAPABILITY_PATH_LENGTH` is not enabled for `path`

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `startSegment` is less than 0 or greater than the index of the final path segment

– if `numSegments` is less than or equal to 0

– if (`startSegment` + `numSegments` – 1) is less than 0 or greater than the index of the final path segment

## 8.6.11 Position and Tangent Along a Path

Some path operations, such as the placement and orientation of text along a path, require the computation of a set of points along a path as well as a normal (perpendicular) vector at each point. The **vgPointAlongPath** function provides these values.

### The Tangents of a Path Segment

The tangent at a given point along a path is defined as a vector pointing in the same direction as the path at that point. The tangent at any point of a line segment is parallel to the line segment; the tangent at any point along a Bézier curve or elliptical arc segment may be defined using the derivative of the parametric equations $x(t)$ and $y(t)$ that define the curve. The incoming tangent at a point is defined using the direction in which the curve is "traveling" prior to arriving at the point; the outgoing tangent is defined using the direction the curve is traveling as it leaves the point. The incoming and outgoing tangents may differ at a vertex joining different curve segments, or at a sharp "cusp" in a curve.

If a point along a path segment has no tangent defined, for example where a path segment has collapsed to a single point or a cusp has formed, the following algorithm is used to define incoming and outgoing tangents at the point. Search backwards until a segment is found with a tangent defined at its end point, or the start of the current subpath is reached; if a tangent is found, use it as the incoming tangent. Search forwards until a segment is found with a tangent defined at its starting point, or the end of the current subpath is reached; if a tangent is found, use it as the outgoing tangent. If these searches produce exactly one defined tangent, that tangent is used as both the incoming and outgoing tangent. If the searches produced no defined tangent, the incoming and outgoing tangents are both assigned the value (1, 0).

### *vgPointAlongPath*

The **vgPointAlongPath** function returns the point lying a given distance along a given portion of a path and the tangent vector at that point. Only the subpath consisting of the `numSegments` path segments beginning with `startSegment` (where the initial path segment has index 0) is used.

If `distance` is less than or equal to 0, the starting point of the path segment indexed by `startSegment` is used. If `distance` is greater than or equal to the value returned by **vgPathLength** (called with the same `startSegment` and `numSegments` parameters), the ending point of the path segment indexed by (`startSegment` + `numSegments` – 1) is used. Intermediate values return the (*x, y*) coordinates and tangent vector of the point at the given distance along the subpath.

The `VG_PATH_CAPABILITY_POINT_ALONG_PATH` capability must be enabled for `path`.

If the reference arguments `x` and `y` are both non-`NULL`, and the `VG_PATH_CAPABILITY_POINT_ALONG_PATH` capability is enabled for `path`, the point (*x, y*) is returned in `x` and `y`. Otherwise the variables referenced by `x` and `y` are not written.

If the reference arguments `tangentX` and `tangentY` are both non-`NULL`, and the `VG_PATH_CAPABILITY_TANGENT_ALONG_PATH` capability is enabled for `path`, the geometric tangent vector at the point (*x, y*) is returned in `tangentX` and `tangentY`. Otherwise the variables referenced by `tangentX` and `tangentY` are not written.

Where the incoming tangent is defined, **vgPointAlongPath** returns it. Where only the outgoing tangent is defined, the outgoing tangent is returned.

The points returned by **vgPointAlongPath** are not guaranteed to match the path as rendered; some deviation is to be expected.

```
void vgPointAlongPath(VGPath path,
                      VGint startSegment, VGint numSegments,
                      VGfloat distance,
                      VGfloat * x, VGfloat * y,
                      VGfloat * tangentX, VGfloat * tangentY)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

`VG_PATH_CAPABILITY_ERROR`

– If `x` and `y` are both non-`NULL`, and the `VG_PATH_CAPABILITY_POINT_ALONG_PATH` is not enabled for `path`

– If `tangentX` and `tangentY` are both non-`NULL`, and the `VG_PATH_CAPABILITY_TANGENT_ALONG_PATH` capability is not enabled for `path`

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `startSegment` is less than 0 or greater than the index of the final path segment

– if `numSegments` is less than or equal to 0

– if (`startSegment` + `numSegments` – 1) is less than 0 or greater than the index of the final path segment

– if `x`, `y`, `tangentX` or `tangentY` is not properly aligned

### 8.6.12 Querying the Bounding Box of a Path

To draw complex scenes efficiently, it is important to avoid drawing objects that do not appear in the region being drawn. A simple way to determine whether an object may be visible is to determine whether its *bounding box* – an axis-aligned rectangle that is guaranteed to contain the entire object – intersects the drawn region. The **vgPathBounds** and **vgPathTransformedBounds** functions provide bounding box information.

Two types of bounding boxes may be obtained for a path. The first, obtained by calling **vgPathBounds**, returns a tight axis-aligned bounding box for the area contained within the path in its own coordinate system. The second, obtained by calling **vgPathTransformedBounds**, returns an axis-aligned bounding box for the path as it will appear when drawn on the drawing surface (*i.e.*, following application of the current path-user-to-surface transform). The latter function does not guarantee to bound the shape tightly, but still may provide tighter bounds than those obtained by transforming the result of **vgPathBounds**, at a lower cost.

The bounding box of a path is defined to contain the area within the path, *i.e.*, the area that would be drawn if the path were to be filled. If the path is to be stroked, the application must adjust the bounding box to take the stroking parameters into account. Note that Miter joins in particular may extend far outside the bounding box.

#### vgPathBounds

The **vgPathBounds** function returns an axis-aligned bounding box that tightly bounds the interior of the given `path`. Stroking parameters are ignored. If `path` is empty, `minX` and `minY` are set to 0 and `width` and `height` are set to -1. If path contains a single point, minX and minY are set to the coordinates of the point and width and height are set to 0.

The VG_PATH_CAPABILITY_PATH_BOUNDS capability must be enabled for path.

```
void vgPathBounds(VGPath path,
                  VGfloat * minX, VGfloat * minY,
                  VGfloat * width, VGfloat * height)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if path is not a valid path handle, or is not shared with the current context

VG_ILLEGAL_ARGUMENT_ERROR

– if minX, minY, width, or height is NULL

– if minX, minY, width, or height is not properly aligned

VG_PATH_CAPABILITY_ERROR

– if VG_PATH_CAPABILITY_PATH_BOUNDS is not enabled for path

### *vgPathTransformedBounds*

The **vgPathTransformedBounds** function returns an axis-aligned bounding box that is guaranteed to enclose the geometry of the given path following transformation by the current path-user-to-surface transform. The returned bounding box is not guaranteed to fit tightly around the path geometry. If path is empty, minX and minY are set to 0 and width and height are set to -1. If path contains a single point, minX and minY are set to the transformed coordinates of the point and width and height are set to 0.

The VG_PATH_CAPABILITY_PATH_TRANSFORMED_BOUNDS capability must be enabled for path.

```
void vgPathTransformedBounds(VGPath path,
                             VGfloat * minX, VGfloat * minY,
                             VGfloat * width, VGfloat * height)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if path is not a valid path handle, or is not shared with the current context

VG_ILLEGAL_ARGUMENT_ERROR

– if `minX`, `minY`, `width`, or `height` is `NULL`

– if `minX`, `minY`, `width`, or `height` is not properly aligned

`VG_PATH_CAPABILITY_ERROR`

– if `VG_PATH_CAPABILITY_PATH_TRANSFORMED_BOUNDS` is not enabled for `path`

## 8.7 Interpretation of Paths

The interpretation of a path, composed of a sequence of one or more subpaths, depends on whether it is to be stroked or filled. For stroked paths, each subpath has stroking parameters applied to it separately, with the dash phase at the end of each subpath used at the beginning of the next subpath. This process results in a set of stroked shapes. The union of these shapes then defines the outline path to be filled. For filled paths, the interior of the path (as defined below) is filled.

### 8.7.1 Filling Paths

A simple, non-self-intersecting closed path divides the plane into two regions, a bounded *inside* region and an unbounded *outside* region. Note that knowing the orientation of the outermost path (*i.e.*, clockwise or counter-clockwise) is not necessary to differentiate between the inside and outside regions.

A path that self-intersects, or that has multiple overlapping subpaths, requires additional information in order to define the inside region. Two rules that provide different definitions for the area enclosed by such paths, known as the non-zero and even/odd fill rules, are supported by OpenVG. To determine whether any point in the plane is contained in the inside region, imagine drawing a line from that point out to infinity in any direction such that the line does not cross any vertex of the path. For each edge that is crossed by the line, add 1 to the counter if the edge crosses from left to right, as seen by an observer walking along the line towards infinity, and subtract 1 if the edge crosses from right to left. In this way, each region of the plane will receive an integer value.

The non-zero fill rule says that the point is inside the shape if the resulting sum is not equal to 0. The even/odd rule says that the point is inside the shape if the resulting sum is odd, regardless of sign (*e.g.*, -7 is odd, 0 is even). Consider the star-shaped path shown in Figure 8 below, indicated with solid lines. The orientation of the lines making up the path is indicated with arrows. An imaginary line to infinity starting in the central region of the star is shown as a dashed line pointing to the right. Two edges of the star cross the line to infinity going left to right, indicated by the downward-pointing arrows. The central region therefore has a count of +2. According to the even/odd rule, it is outside the path, whereas according to the non-zero rule it is inside. Implementations must be able to deal with paths having up to 255 crossings along any line. The behavior of more complex paths is undefined.

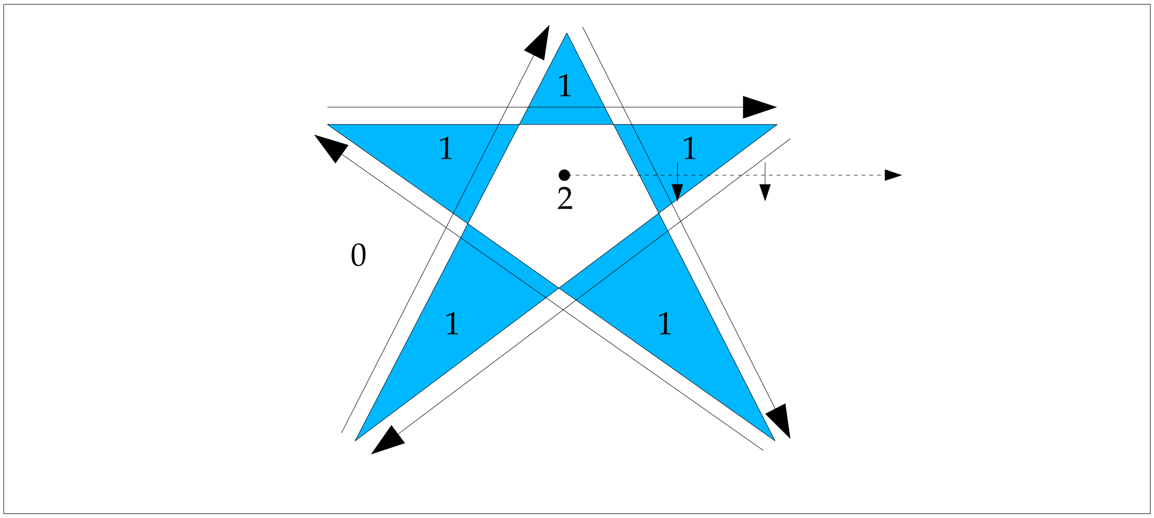


*Figure 8: Even/Odd Fill Rule*

### *Creating Holes in Paths*

The fill rule is applied with respect to all subpaths simultaneously during filling. Thus, one subpath may be used to create a hole inside an enclosing subpath by defining the two subpaths with opposing orientations (clockwise versus counter-clockwise). Note that the orientation of extremely small paths may depend on the numerical precision of the internal representation of points. Care should be taken to avoid the use of paths that have nearly collapsed to a line or a point.

The relative orientation of subpaths, along with the fill rule, determines whether overlapping subpaths will result in holes, as shown in Figure 9 below.

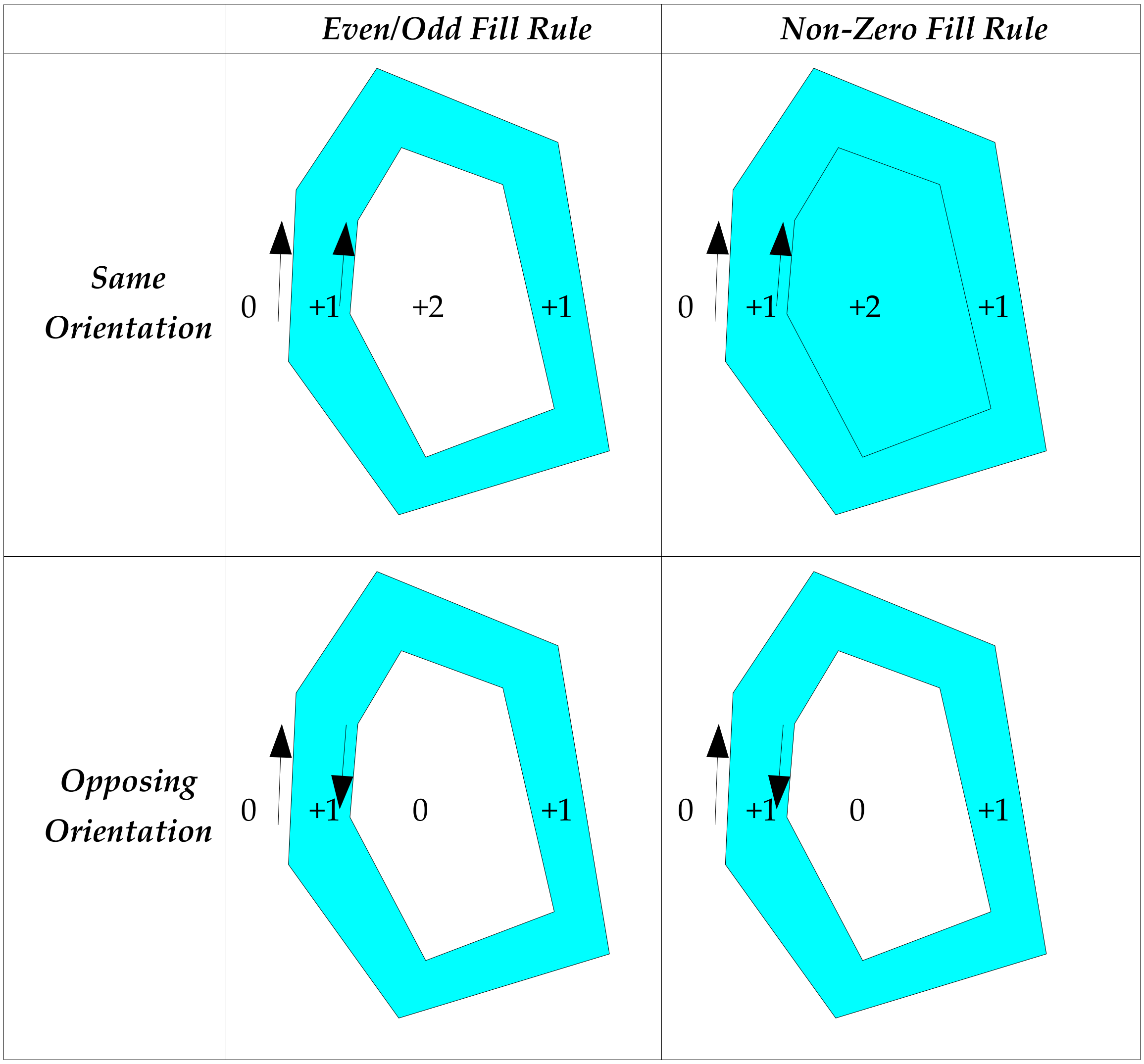


*Figure 9: Creating Holes with Subpaths*

### *Implicit Closure of Filled Subpaths*

For filled paths, any subpaths that do not end with a `CLOSE_PATH` segment command (*i.e.*, they are terminated with a `MOVE_TO_ABS` or `MOVE_TO_REL` segment command, or they contain the final segment of the path) are implicitly closed, without affecting the position of any other vertices of the path or the (*sx, sy*), (*px, py*) or (*ox, oy*) variables. For example, consider the sequence of segment commands:

```
MOVE_TO_ABS    0,  0; LINE_TO_ABS   10, 10; LINE_TO_ABS   10,  0
MOVE_TO_REL   10,  2; LINE_TO_ABS   30, 12; LINE_TO_ABS   30,  2
```

If filled, this sequence will result in one filled triangle with vertices (*0, 0*), (*10, 10*), and (*10, 0*) and another filled triangle with vertices (*20, 2*), (*30, 12*), and (*30, 2*). Note that the implicit closure of the initial subpath prior to the `MOVE_TO_REL` segment command has no effect on the starting coordinate of the second triangle; it is computed by adding the relative offset (*10, 2*) to the final coordinate of the previous segment (*10, 0*) to obtain (*20, 2*) and is not altered by the (virtual) insertion of the line connecting the first subpath's final vertex (*10, 0*) to its initial vertex (*0, 0*)). Figure 10 illustrates this process, with the resulting filled areas highlighted. When stroking a path, no implicit closure takes place, as shown in Figure 11.

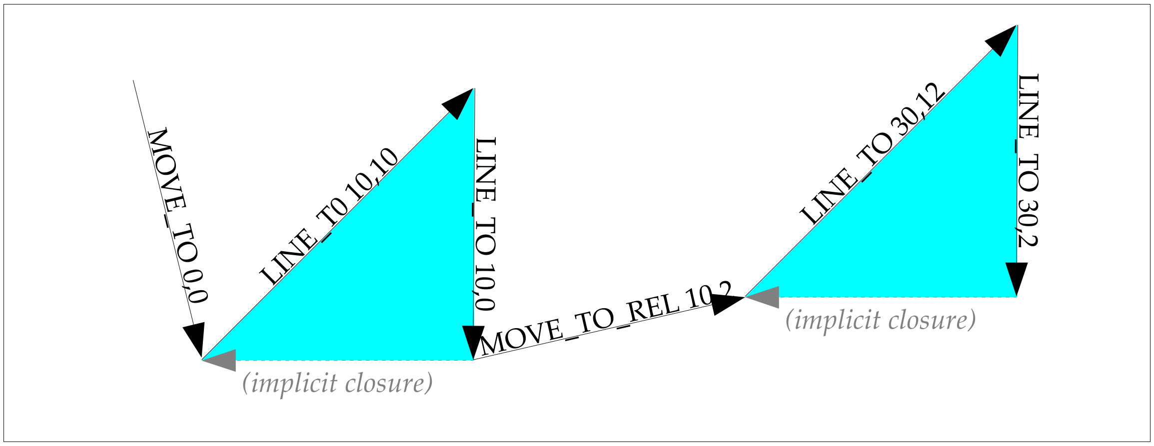


*Figure 10: Implicit Closure of Filled Paths*

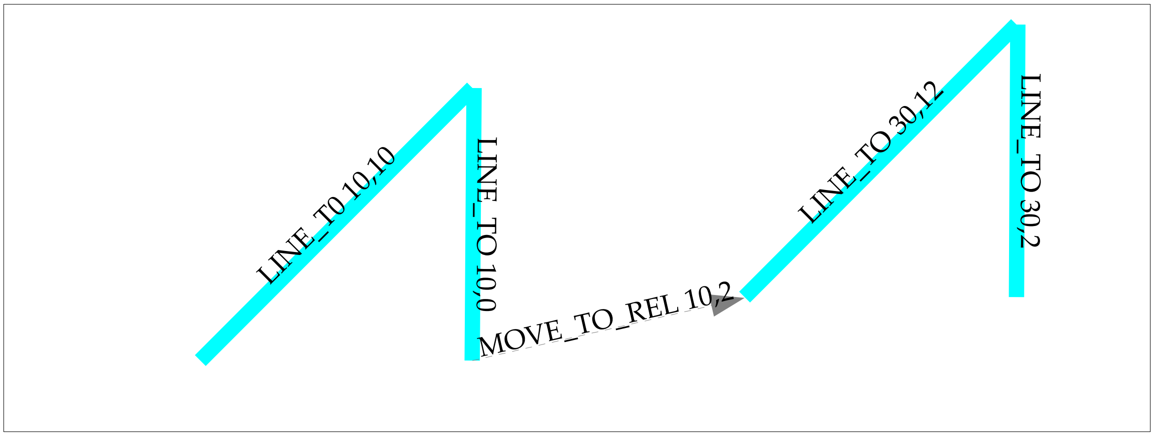


*Figure 11: Stroked Paths Have No Implicit Closure*

### 8.7.2 Stroking Paths

Stroking a path consists of "widening" the edges of the path using a straight-line pen held perpendicularly to the path. At the start and end vertices of the path, an additional end-cap style is applied. At interior vertices of the path, a line join style is applied.

Conceptually, stroking of a path is performed in two steps. First, the stroke parameters are applied in the user coordinate system to form a new shape representing the end result of dashing, widening the path, and applying the end cap and line join styles. Second, a path is created that defines the outline of this stroked shape. This path is transformed using the path-user-to-surface transformation (possibly involving shape distortions due to non-uniform scaling or shearing). Finally, the resulting path is filled with paint in exactly the same manner as when filling a user-defined path using the non-zero fill rule.

Stroking a path applies a single "layer" of paint, regardless of any intersections between portions of the thickened path. Figure 12 illustrates this principle. A single stroke (above) is drawn with a black color and an alpha value of 50%, compared with two separate strokes (below) drawn with the same color and alpha values. The single stroke produces a shape with a uniform color of 50% gray, as if a single layer of translucent paint has been applied, even where portions of the path overlap one another. By contrast, the separate strokes produce two applications of the translucent paint in the area of overlap, resulting in a darkened area.

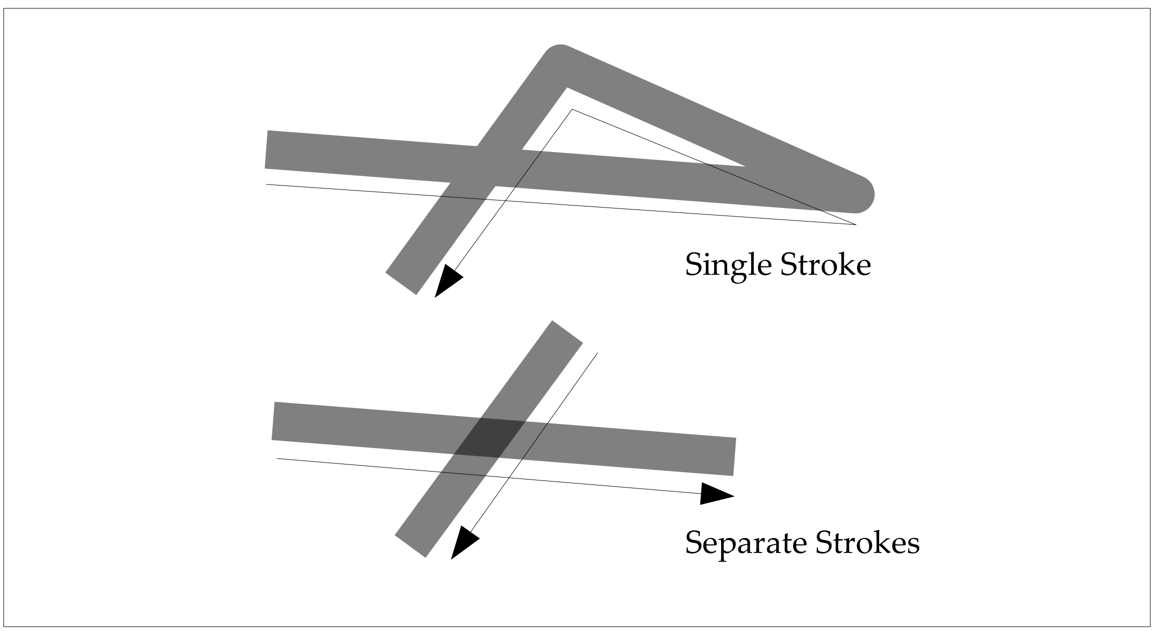


*Figure 12: Each Stroke Applies a Single Layer of Paint*

### 8.7.3 Stroke Parameters

Stroking a path involves the following parameters, set on a context:

- Line width in user coordinate system units
- End cap style – one of Butt, Round, or Square
- Line join style – one of Miter, Round, or Bevel
- Miter limit – if using Miter join style
- Dash pattern – array of dash on/off lengths in user units
- Dash phase – initial offset into the dash pattern

These parameters are set on the current context using the variants of the **vgSet** function. The values most recently set prior to calling **vgDrawPath** (see Section 8.8) are applied to generate the stroke.

#### End Cap Styles

Figure 13 illustrates the Butt (top), Round (center), and Square (bottom) end cap styles applied to a path consisting of a single line segment. Figure 14 highlights the additional geometry created by the end caps. The Butt end cap style terminates each segment with a line perpendicular to the tangent at each endpoint. The Round end cap style appends a semicircle with a diameter equal to the line width centered around each endpoint. The Square end cap style appends a rectangle with two sides of length equal to the line width perpendicular to the tangent, and two sides of length equal to half the line width parallel to the tangent, at each endpoint. The outgoing tangent is used at the left endpoint and the incoming tangent is used at the right endpoint.

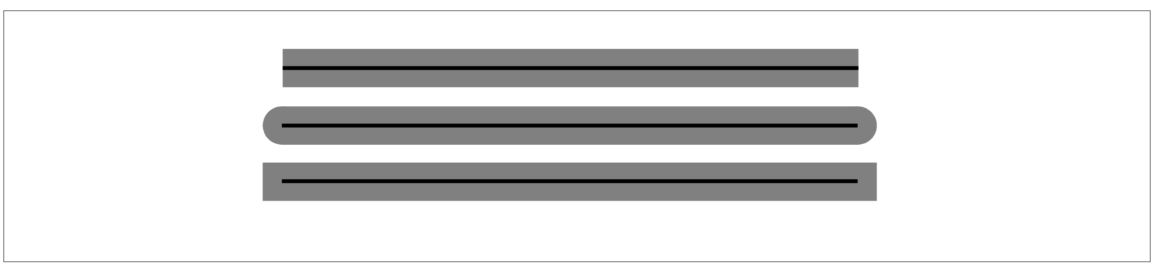

*Figure 13: End Cap Styles*

*Figure 14: End Cap Styles with Additional Geometry Highlighted*

### Line Join Styles

Figure 15 illustrates the Bevel (left), Round (center), and Miter (right) line join styles applied to a pair of line segments. Figure 16 highlights the additional geometry created by the line joins. The Bevel join style appends a triangle with two vertices at the outer endpoints of the two "fattened" lines and a third vertex at the intersection point of the two original lines. The Round join style appends a wedge-shaped portion of a circle, centered at the intersection point of the two original lines, having a radius equal to half the line width. The Miter join style appends a trapezoid with one vertex at the intersection point of the two original lines, two adjacent vertices at the outer endpoints of the two "fattened" lines and a fourth vertex at the extrapolated intersection point of the outer perimeters of the two "fattened" lines.

When stroking using the Miter join style, the *miter length* (*i.e.*, the length between the intersection of the two original lines and the extrapolated intersection point of the outer perimeters of the two "fattened" lines) is compared to the product of the user-set miter limit and the line width. If the miter length exceeds this product, the Miter join is not drawn and a Bevel join is substituted.

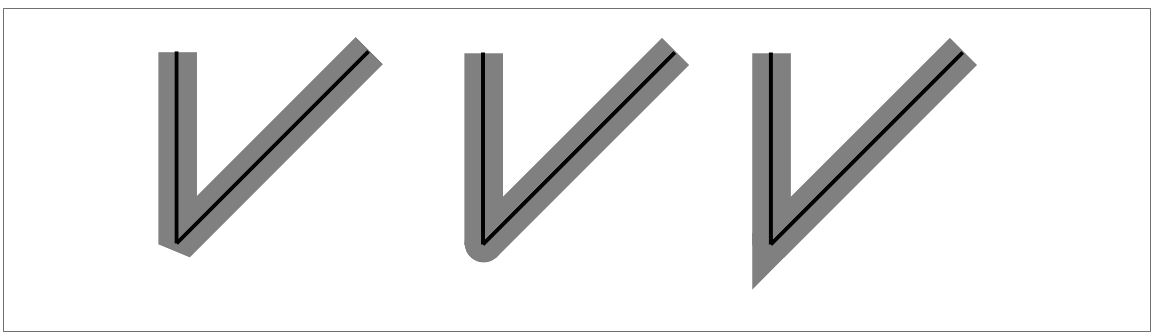

*Figure 15: Line Join Styles*

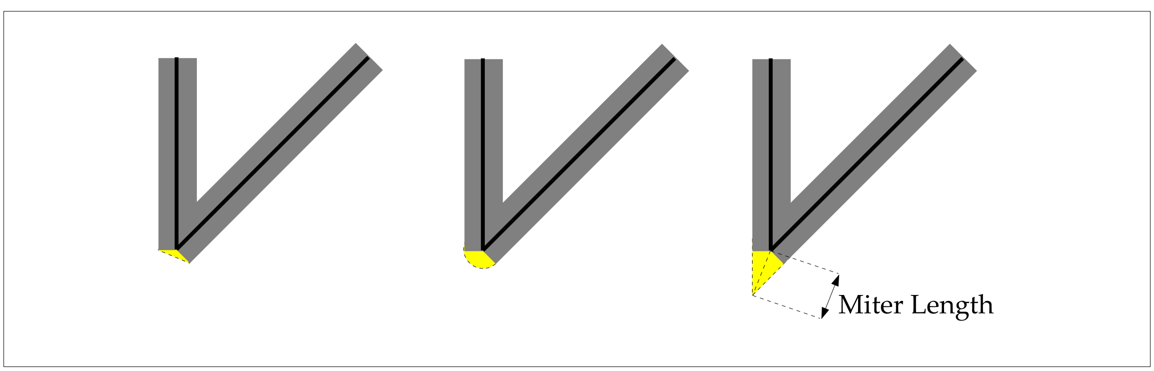


*Figure 16: Line Join Styles with Additional Geometry Highlighted*

### Miter Length

The ratio of miter length to line width may be computed directly from the angle θ between the two line segments being joined as $1/sin(\theta/2)$. A number of angles with their corresponding miter limits for a line width of 1 are shown in Table 9.

| *Angle (degrees)* | *Miter Limit* | *Angle (degrees)* | *Miter Limit* |
|---|---|---|---|
| 10 | 11.47 | 45 | 2.61 |
| 11.47 | 10 | 60 | 2 |
| 23 | 5 | 90 | 1.41 |
| 28.95 | 4 | 120 | 1.15 |
| 30 | 3.86 | 150 | 1.03 |
| 38.94 | 3 | 180 | 1 |

*Table 9: Corresponding Angles and Miter Limits*

### Dashing

The dash pattern consists of a sequence of lengths of alternating "on" and "off" dash segments. The first value of the dash array defines the length, in user coordinates, of the first "on" dash segment. The second value defines the length of the following "off" segment. Each subsequent pair of values defines one "on" and one "off" segment.

The dash phase defines the starting point in the dash pattern that is associated with the start of the first segment of the path. For example, if the dash pattern is [ 10 20 30 40 ] and the dash phase is 35, the path will be stroked with an "on" segment of length 25 (skipping the first "on" segment of length 10, the following "off" segment of length 20, and the first 5 units of the next "on" segment), followed by an "off" segment of length 40. The pattern will then repeat from the beginning, with an "on" segment of length 10, an "off" segment of length 20, an "on" segment of length 30, etc. Figure 17 illustrates this dash pattern.

Conceptually, dashing is performed by breaking the path into a set of subpaths according to the dash pattern. Each subpath is then drawn independently using the end cap, line join style, and miter limit that were set for the path as a whole.

Dashes of length 0 are drawn only if the end cap style is `VG_CAP_ROUND` or `VG_CAP_SQUARE`. The incoming and outgoing tangents are evaluated at the point, using the **vgPointAlongPath** algorithm. The end caps are drawn using the orientation of each tangent, and a join is drawn between them if the tangent directions differ. If the end cap style is `VG_CAP_BUTT`, nothing will be drawn.

A dash, or space between dashes, with length less than 0 is treated as having a length of 0.

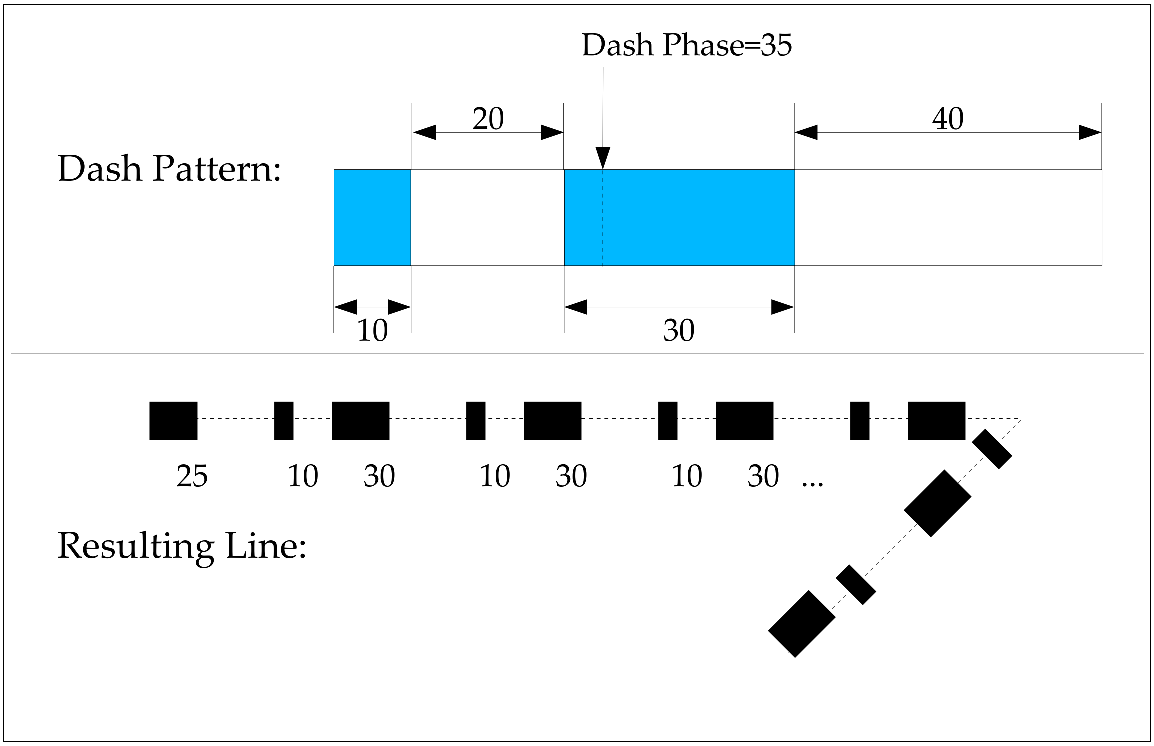


*Figure 17: Dash Pattern and Phase Example*

### 8.7.4 Stroke Generation

The algorithm for generating a stroke is as follows. The steps described in this section conceptually take place on a copy of the path being stroked in which all relative and implicit coordinates have been converted to absolute coordinates. An initial `MOVE_TO` segment is added if needed.

The path to be stroked is divided into subpaths, each ending with a `MOVE_TO` or `CLOSE_PATH` segment command or with the final path segment. Subpaths consisting of only a single `MOVE_TO` segment are discarded.

A subpath consisting of a single point (*i.e.*, a `MOVE_TO` segment followed by a sequence of `LINE_TO`, `QUAD_TO`, `CUBIC_TO`, and/or `ARC_TO` segments with all control points equal to the current point, possibly followed by a `CLOSE_PATH` segment) is collapsed to a lone vertex, which is marked as an END vertex (for later generation of end caps). A tangent vector of (1, 0) is used for Square end caps.

Subpaths that do not consist only of a single point have any zero-length segments removed.

If a subpath does not end with a `CLOSE_PATH` segment command, its first and last vertices are marked as END vertices. All the internal vertices that begin or end path segments within the subpath, as well as the initial/final vertex if the subpath ends with a `CLOSE_PATH` segment, are marked as JOIN vertices (for later generation of line joins).

Each subpath is processed in turn as described below until all subpaths have been stroked.

If dashing is enabled, the dash pattern and phase are used to break the subpath into a series of smaller subpaths representing the "on" portions of the dash pattern. New vertices are created at the endpoints of each dash subpath and marked as END vertices. The old subpath is discarded and replaced with the dash subpaths for the remainder of the stroke processing. The dash phase is advanced for each subsequent segment by the length of the previous segment (where `CLOSE_PATH` segments are treated as `LINE_TO` segments). The final dash phase at the end of the subpath is used as the initial dash phase for the next subpath.

For each END vertex, an end cap is created (if Square or Round end caps have been requested) using the orientation given by the tangent vector. The tangent vector is defined in the same manner as for the **vgPointAlongPath** function (see p. 66).

For each JOIN vertex, a line join is created using the orientations given by the tangent vectors of the two adjacent path segments. If Miter joins are being used, the length of the miter is computed and compared to the product of the line width and miter limit; if the miter would be too long, a Bevel join is substituted.

### 8.7.5 Setting Stroke Parameters

Setting the line width of a stroke is performed using **vgSetf** with a `paramType` argument of `VG_STROKE_LINE_WIDTH`**.** A line width less than or equal to 0 prevents stroking from taking place.

```
VGfloat lineWidth;
vgSetf(VG_STROKE_LINE_WIDTH, lineWidth);
```

#### VGCapStyle

The `VGCapStyle` enumeration defines constants for the Butt, Round, and Square end cap styles:

```
typedef enum {
  VG_CAP_BUTT   = 0x1700,
  VG_CAP_ROUND  = 0x1701,
  VG_CAP_SQUARE = 0x1702
} VGCapStyle;
```

Setting the end cap style is performed using **vgSeti** with a `paramType` argument of `VG_STROKE_CAP_STYLE` and a value from the `VGCapStyle` enumeration.

```
VGCapStyle capStyle;
vgSeti(VG_STROKE_CAP_STYLE, capStyle);
```

### *VGJoinStyle*

The `VGJoinStyle` enumeration defines constants for the Miter, Round, and Bevel line join styles:

```
typedef enum {
  VG_JOIN_MITER = 0x1800,
  VG_JOIN_ROUND = 0x1801,
  VG_JOIN_BEVEL = 0x1802
} VGJoinStyle;
```

Setting the line join style is performed using **vgSeti** with a `paramType` argument of `VG_STROKE_JOIN_STYLE` and a value from the `VGJoinStyle` enum.

```
VGJoinStyle joinStyle;
vgSeti(VG_STROKE_JOIN_STYLE, joinStyle);
```

Setting the miter limit is performed using **vgSetf** with a `paramType` argument of `VG_STROKE_MITER_LIMIT`:

```
VGfloat miterLimit;
vgSetf(VG_STROKE_MITER_LIMIT, miterLimit);
```

Miter limit values less than 1 are silently clamped to 1.

### *VG_MAX_DASH_COUNT*

The `VG_MAX_DASH_COUNT` parameter contains the maximum number of dash segments that may be supplied for the `VG_STROKE_DASH_PATTERN` parameter. All implementations must must support at least 16 dash segments (8 on/off pairs). If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti**:

```
VGint maxDashCount = vgGeti(VG_MAX_DASH_COUNT);
```

### *Setting the Dash Pattern*

The dash pattern is set using **vgSetfv** with a `paramType` argument of `VG_STROKE_DASH_PATTERN`:

```
VGfloat dashPattern[DASH_COUNT];
VGint count = DASH_COUNT;
vgSetfv(VG_STROKE_DASH_PATTERN, count, dashPattern);
```

Dashing may be disabled by calling **vgSetfv** with a `count` of 0:

```
vgSetfv(VG_STROKE_DASH_PATTERN, 0, NULL);
```

The dash phase is set using **vgSetf** with a `paramType` argument of `VG_STROKE_DASH_PHASE`:

```
VGfloat dashPhase;
vgSetf(VG_STROKE_DASH_PHASE, dashPhase);
```

If the dash pattern has length 0, dashing is not performed. If the dash pattern has an odd number of elements, the final element is ignored. Note that this behavior is different from that defined by SVG; the SVG behavior may be implemented by duplicating the odd-length dash pattern to obtain one with even length.

If more than `VG_MAX_DASH_COUNT` dashes are specified, those beyond the first `VG_MAX_DASH_COUNT` are discarded immediately (and will not be returned by **vgGet)**.

A negative dash phase is equivalent to the positive phase obtained by adding a suitable multiple of the dash pattern length.

### 8.7.6 Non-Scaling Strokes

In some cases, applications may wish stroked geometry to appear with a particular stroke width in the surface coordinate system, independent of the current user-to-surface transformation. For example, a stroke representing a road on a map might stay the same width as the user zooms in and out of the map, since the stroke width is intended to indicate the type of road (*e.g.*, one-way street, divided road, interstate highway or Autobahn) rather than its true width on the ground.

OpenVG does not provide direct support for this "non-scaling stroke" behavior. However, the behavior may be obtained relatively simply using a combination of features.

If the current user-to-surface transformation consists only of uniform scaling, rotation, and translation (*i.e.*, no shearing or non-uniform scaling), then the stroke width may be set to the desired stroke width in drawing surface coordinates, divided by the scaling factor introduced by the transformation. This scaling factor may be known to the application *a priori*, or else it may be computed as the square root of the absolute value of the determinant (*sx*sy – shx*shy*) of the user-to-surface transformation.

If the user-to-surface transformation includes shearing or non-uniform scaling, the geometry to be stroked must be transformed into surface coordinates prior to stroking. The paint transformation must also be set to the concatenation of the paint-to-user and user-to-surface transformations in order to allow correct painting of the stroked geometry. The following code illustrates this technique:

```
VGPath srcPath; /* Path to be drawn with non-scaling stroke */
VGPath dstPath; /* Path in drawing surface coordinates */
VGfloat strokePaintToUser[9]; /* Paint-to-user transformation */
VGfloat pathUserToSurface[9]; /* User-to-surface transformation */

/* Transform the geometry into surface coordinates. */
vgMatrixMode(VG_MATRIX_PATH_USER_TO_SURFACE);
vgLoadMatrix(pathUserToSurface);
vgTransformPath(dstPath, srcPath);

/* Use the identity matrix for drawing the stroked path. */
vgLoadIdentity();

/* Set the paint transformation to the concatenation of the
 * paint-to-user and user-to-surface transformations.
 */
vgMatrixMode(VG_MATRIX_FILL_PAINT_TO_USER);
vgLoadMatrix(pathUserToSurface);
vgMultMatrix(strokePaintToUser);

/* Stroke the transformed path. */
vgDrawPath(dstPath, VG_STROKE_PATH);
```

## 8.8 Filling or Stroking a Path

### VGFillRule

The `VGFillRule` enumeration defines constants for the even/odd and non-zero fill rules.

```
typedef enum {
  VG_EVEN_ODD = 0x1900,
  VG_NON_ZERO = 0x1901
} VGFillRule;
```

To set the rule for filling, call **vgSeti** with a `type` parameter value of `VG_FILL_RULE` and a `value` parameter defined using a value from the `VGFillRule` enumeration. When the path is filled, the most recent setting of the fill rule on the current context is used. The fill rule setting has no effect on stroking.

```
VGFillRule fillRule;
vgSeti(VG_FILL_RULE, fillRule);
```

### VGPaintMode

The `VGPaintMode` enumeration defines constants for stroking and filling paths, to be used by the **vgDrawPath**, **vgSetPaint**, and **vgGetPaint** functions.

```
typedef enum {
  VG_STROKE_PATH = (1 << 0),
  VG_FILL_PATH   = (1 << 1)
} VGPaintMode;
```

### *vgDrawPath*

Filling and stroking are performed by the **vgDrawPath** function. The `paintModes` argument is a bitwise OR of values from the `VGPaintMode` enumeration, determining whether the path is to be filled (`VG_FILL_PATH`), stroked (`VG_STROKE_PATH`), or both (`VG_FILL_PATH | VG_STROKE_PATH`). If both filling and stroking are to be performed, the path is first filled, then stroked.

```
void vgDrawPath(VGPath path, VGbitfield paintModes)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `paintModes` is not a valid bitwise OR of values from the `VGPaintMode` enumeration

### *Filling a Path*

Calling **vgDrawPath** with a `paintModes` argument of `VG_FILL_PATH` causes the given path to be filled, using the paint defined for the `VG_FILL_PATH` paint mode and the current fill rule.

The matrix currently set for the `VG_MATRIX_FILL_PAINT_TO_USER` matrix mode is applied to the paint used to fill the path outline. The matrix currently set for the `VG_MATRIX_PATH_USER_TO_SURFACE` matrix mode is used to transform the outline of the path and the paint into surface coordinates.

```
vgDrawPath(VGPath path, VG_FILL_PATH);
```

### *Stroking a Path*

Calling **vgDrawPath** with a `paintModes` argument of `VG_STROKE_PATH` causes the given path to be stroked, using the paint defined for the `VG_STROKE_PATH` paint mode and the current set of stroke parameters.

The matrix currently set for the `VG_MATRIX_STROKE_PAINT_TO_USER` matrix mode is applied to the paint used to fill the stroked path outline. The matrix currently set for the `VG_MATRIX_PATH_USER_TO_SURFACE` matrix mode is used to transform the outline of the stroked path and the paint into surface coordinates.

```
vgDrawPath(VGPath path, VG_STROKE_PATH);
```

The following code sample shows how an application might set stroke parameters using variants of **vgSet**, and stroke a path object (defined elsewhere):

```
VGPath path;

/* Set the line width to 2.5 */
vgSetf(VG_STROKE_LINE_WIDTH, 2.5f);
/* Set the miter limit to 10.5 */
vgSetf(VG_STROKE_MITER_LIMIT, 10.5f);
/* Set the cap style to CAP_SQUARE */
vgSeti(VG_STROKE_CAP_STYLE, VG_CAP_SQUARE);
/* Set the join style to JOIN_MITER */
vgSeti(VG_STROKE_JOIN_STYLE, VG_JOIN_MITER);

/* Set the dash pattern */
VGfloat dashes[] = { 1.0f, 2.0f, 2.0f, 2.0f };
vgSetfv(VG_STROKE_DASH_PATTERN, 4, dashes);

/* Set the dash phase to 0.5 */
vgSetf(VG_STROKE_DASH_PHASE, 0.5f);

/* Stroke the path */
vgDrawPath(path, VG_STROKE_PATH);
```

### *Filling and Stroking a Path*

Calling **vgDrawPath** with a `paintModes` argument of `(VG_FILL_PATH | VG_STROKE_PATH)` causes the given path to be first filled, then stroked, exactly as if **vgDrawPath** were called twice in succession, first with a `paintModes` argument of `VG_FILL_PATH` and second with a `paintModes` argument of `VG_STROKE_PATH`.

```
vgDrawPath(VGPath path, VG_FILL_PATH | VG_STROKE_PATH);
```

# 9 Paint

Paint defines a color and an alpha value for each pixel being drawn. *Color paint* defines a constant color for all pixels; *gradient paint* defines a linear or radial pattern of smoothly varying colors; and *pattern paint* defines a possibly repeating rectangular pattern of colors based on a source image. It is possible to define new types of paint as extensions.

Paint is defined in its own coordinate system, which is transformed into user coordinates by means of the fill-paint-to-user and stroke-paint-to-user transformations (set using the `VG_MATRIX_FILL_PAINT_TO_USER` and `VG_MATRIX_STROKE_PAINT_TO_USER` matrix modes) depending on whether the current geometry is being filled or stroked.

Given a (fill or stroke) paint-to-user transformation $T_p$ and path-user-to-surface transformation $T_u$, the paint color and alpha of a pixel to be drawn with surface coordinates ($x$, $y$) is defined by mapping its center point ($x + ½$, $y + ½$) through the inverse transformation $(Tu \circ Tp)^{-1}$, resulting in a sample point in the paint coordinate space. The paint value nearest that point may be used (point sampling), or paint values from multiple points surrounding the central sample point may be combined to produce an interpolated paint value. Paint color values are processed in premultiplied alpha format during interpolation.

If the inverse transformation cannot be computed due to a (near-)singularity, no drawing occurs.

## 9.1 Paint Definitions

The OpenVG context stores two paint definitions at a time, one to be applied to stroked shapes and one for filled shapes. This allows the interior of a path to be filled using one type of paint and its outline to be stroked with another kind of paint in a single **vgDrawPath** operation. Initially, default values are used.

### VGPaint

`VGPaint` represents an opaque handle to a paint object. A `VGPaint` object is *live*; changes to a `VGPaint` object (using `vgSetParameter`, or by altering an attached pattern image) attached to a context will immediately affect drawing calls on that context. If a `VGPaint` object is accessed from multiple threads, the application must ensure (using **vgFinish** along with application-level synchronization primitives) that the paint definition is not altered from one context while another context may still be using it for drawing.

```
typedef VGHandle VGPaint;
```

### 9.1.1 Creating and Destroying Paint Objects

#### vgCreatePaint

**vgCreatePaint** creates a new paint object that is initialized to a set of default values and returns a `VGPaint` handle to it. If insufficient memory is available to allocate a new object, `VG_INVALID_HANDLE` is returned.

```
VGPaint vgCreatePaint(void)
```

#### vgDestroyPaint

The resources associated with a paint object may be deallocated by calling **vgDestroyPaint**. Following the call, the `paint` handle is no longer valid in any of the contexts that shared it. If the paint object is currently active in a drawing context, the context continues to access it until it is replaced or the context is destroyed.

```
void vgDestroyPaint(VGPaint paint)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `paint` is not a valid paint handle, or is not shared with the current context

### 9.1.2 Setting the Current Paint

#### vgSetPaint

Paint definitions are set on the current context using the **vgSetPaint** function. The `paintModes` argument is a bitwise OR of values from the `VGPaintMode` enumeration, determining whether the paint object is to be used for filling (`VG_FILL_PATH`), stroking (`VG_STROKE_PATH`), or both (`VG_FILL_PATH | VG_STROKE_PATH`). The current `paint` replaces the previously set paint object, if any, for the given paint mode or modes. If `paint` is equal to `VG_INVALID_HANDLE`, the previously set paint object for the given mode (if present) is removed and the paint settings are restored to their default values.

```
void vgSetPaint(VGPaint paint, VGbitfield paintModes)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `paint` is neither a valid paint handle nor equal to `VG_INVALID_HANDLE`, or is not shared with the current context

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `paintModes` is not a valid bitwise OR of values from the `VGPaintMode` enumeration

### *vgGetPaint*

The **vgGetPaint** function returns the paint object currently set for the given `paintMode`, or `VG_INVALID_HANDLE` if an error occurs or if no paint object is set on the given context with the given `paintMode`.

```
VGPaint vgGetPaint(VGPaintMode paintMode)
```

*ERRORS*

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `paintMode` is not a valid value from the `VGPaintMode` enumeration

## 9.1.3 Setting Paint Parameters

Paint functionality is controlled by a number of paint parameters that are stored in each paint object.

### *VGPaintParamType*

Values from the `VGPaintParamType` enumeration may be used as the `paramType` argument to **vgSetParameter** and **vgGetParameter** to set and query various features of a paint object:

```
typedef enum {
  /* Color paint parameters */
  VG_PAINT_TYPE                          = 0x1A00,
  VG_PAINT_COLOR                         = 0x1A01,
  VG_PAINT_COLOR_RAMP_SPREAD_MODE        = 0x1A02,
  VG_PAINT_COLOR_RAMP_STOPS              = 0x1A03,

  /* Linear gradient paint parameters */
  VG_PAINT_LINEAR_GRADIENT               = 0x1A04,

  /* Radial gradient paint parameters */
  VG_PAINT_RADIAL_GRADIENT               = 0x1A05,

  /* Pattern paint parameters */
  VG_PAINT_PATTERN_TILING_MODE           = 0x1A06
} VGPaintParamType;
```

The default values that are used when no paint object is present (*i.e.*, in a newly-created context or following a call to **vgSetPaint** with a `paint` value of `VG_INVALID_HANDLE`) are shown in Table 10. These values are also used as the initial parameter value for a newly created paint object.

| *Parameter* | *Datatype* | *Default Value* |
|---|---|---|
| VG_PAINT_TYPE | VGPaintType | VG_PAINT_TYPE_COLOR |
| VG_PAINT_COLOR | VGfloat[4] | { 0.0f, 0.0f, 0.0f, 1.0f } |
| VG_PAINT_COLOR_RAMP_ SPREAD_MODE | VGColorRampSpreadMode | VG_COLOR_RAMP_SPREAD_PAD |
| VG_PAINT_COLOR_RAMP_ STOPS | VGfloat * | Array of Length 0 |
| VG_PAINT_LINEAR_ GRADIENT | VGfloat[4] | { 0.0f, 0.0f, 1.0f, 0.0f } |
| VG_PAINT_RADIAL_ GRADIENT | VGfloat[5] | { 0.0f, 0.0f, 0.0f, 0.0f, 1.0f } |
| VG_PAINT_PATTERN_ TILING_MODE | VGTilingMode | VG_TILE_FILL |

*Table 10: VGPaintParamType Defaults*

#### *VGPaintType*

The `VGPaintType` enumeration is used to supply values for the `VG_PAINT_TYPE` paint parameter to determine the type of paint to be applied.

```
typedef enum {
  VG_PAINT_TYPE_COLOR           = 0x1B00,
  VG_PAINT_TYPE_LINEAR_GRADIENT = 0x1B01,
  VG_PAINT_TYPE_RADIAL_GRADIENT = 0x1B02,
  VG_PAINT_TYPE_PATTERN         = 0x1B03
} VGPaintType;
```

## 9.2 Color Paint

Color paint uses a fixed color and alpha for all pixels. An alpha value of 1 produces a fully opaque color. Colors are specified in non-premultiplied sRGBA format.

### *Setting Color Paint Parameters*

To enable color paint, use **vgSetParameteri** to set the paint type to `VG_PAINT_TYPE_COLOR`.

The **vgSetParameterfv** function allows the color and alpha values to be set using the VG_PAINT_COLOR paint parameter to values between 0 and 1. Values outside this range are interpreted as the nearest endpoint of the range.

```
VGfloat fill_red, fill_green, fill_blue, fill_alpha;
VGfloat stroke_red, stroke_green, stroke_blue, stroke_alpha;
VGPaint myFillPaint, myStrokePaint;

VGfloat * fill_RGBA = {
  fill_red, fill_green, fill_blue, fill_alpha
};

VGfloat * stroke_RGBA = {
  stroke_red, stroke_green, stroke_blue, stroke_alpha
};

/* Fill with color paint */
vgSetParameteri(myFillPaint, VG_PAINT_TYPE, VG_PAINT_TYPE_COLOR);
vgSetParameterfv(myFillPaint, VG_PAINT_COLOR, 4, fill_RGBA);

/* Stroke with color paint */
vgSetParameteri(myStrokePaint, VG_PAINT_TYPE, VG_PAINT_TYPE_COLOR);
vgSetParameterfv(myStrokePaint, VG_PAINT_COLOR, 4, stroke_RGBA);
```

### *vgSetColor*

As a shorthand, the **vgSetColor** function allows the VG_PAINT_COLOR parameter of a given paint object to be set using a 32-bit non-premultiplied sRGBA_8888 representation (see Section 10.2). The rgba parameter is a VGuint with 8 bits of red starting at the most significant bit, followed by 8 bits each of green, blue, and alpha. Each color or alpha channel value is conceptually divided by 255.0f to obtain a value between 0 and 1.

```
void vgSetColor(VGPaint paint, VGuint rgba)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if paint is not a valid paint handle, or is not shared with the current context

The code:

```
VGPaint paint;
VGuint rgba;
vgSetColor(paint, rgba)
```

is equivalent to the code:

```
VGfloat rgba_f[4];
rgba_f[0] = ((rgba >> 24) & 0xff)/255.0f;
rgba_f[1] = ((rgba >> 16) & 0xff)/255.0f;
rgba_f[2] = ((rgba >>  8) & 0xff)/255.0f;
rgba_f[3] = ( rgba        & 0xff)/255.0f;
vgSetParameterfv(paint, VG_PAINT_COLOR, 4, rgba_f);
```

### *vgGetColor*

The current setting of the `VG_PAINT_COLOR` parameter on a given `paint` object may be queried as a 32-bit non-premultiplied `sRGBA_8888` value. Each color channel or alpha value is clamped to the [0, 1] range, multiplied by 255, and rounded to obtain an 8-bit integer; the resulting values are packed into a 32-bit value in the same format as for **vgSetColor**.

```
VGuint vgGetColor(VGPaint paint)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `paint` is not a valid paint handle, or is not shared with the current context

The code:

```
VGPaint paint;
VGuint rgba;
rgba = vgGetColor(paint);
```

is equivalent to the code:

```
#define CLAMP(x) ((x) < 0.0f ? 0.0f : ((x) > 1.0f ? 1.0f : (x)))

VGfloat rgba_f[4];
int red, green, blue, alpha;

vgGetParameterfv(paint, VG_PAINT_COLOR, 4, rgba_f);

/*
 * Clamp color and alpha values from vgGetParameterfv to the
 * [0, 1] range, scale to 8 bits, and round to integer.
 */
red   = (int)(CLAMP(rgba_f[0])*255.0f + 0.5f);
green = (int)(CLAMP(rgba_f[1])*255.0f + 0.5f);
blue  = (int)(CLAMP(rgba_f[2])*255.0f + 0.5f);
alpha = (int)(CLAMP(rgba_f[3])*255.0f + 0.5f);
rgba = (red << 24) | (green << 16) | (blue << 8) | alpha;
```

## 9.3 Gradient Paint

Gradients are patterns used for filling or stroking. They are defined mathematically in two parts; a scalar-valued *gradient function* defined at every point in the two-dimensional plane (in paint coordinates), followed by a *color ramp* mapping.

### 9.3.1 Linear Gradients

Linear gradients define a scalar-valued gradient function based on two points ( *x0, y0*) and (*x1, y1*) (in the paint coordinate system) with the following properties:

- It is equal to 0 at (*x0, y0*)
- It is equal to 1 at (*x1, y1*)
- It increases linearly along the line from (*x0, y0*) to (*x1, y1*)
- It is constant along lines perpendicular to the line from (*x0, y0*) to (*x1, y1*)

An expression for the gradient function is:

$$g(x, y) = \frac{\Delta x(x - x0) + \Delta y(y - y0)}{\Delta x^2 + \Delta y^2}$$

where $\Delta x = x1 - x0$ and $\Delta y = y1 - y0$. If the points (*x0, y0*) and (*x1, y1*) are coincident (and thus $\Delta x^2 + \Delta y^2 = 0$), the function is given the value 1 everywhere.

#### Setting Linear Gradient Parameters

To enable linear gradient paint, use **vgSetParameteri** to set the paint type to `VG_PAINT_TYPE_LINEAR_GRADIENT`.

The linear gradient parameters are set using **vgSetParameterfv** with a `paramType` argument of `VG_PAINT_LINEAR_GRADIENT`. The gradient values are supplied as a vector of 4 floats in the order *{ x0, y0, x1, y1 }*.

```
VGfloat fill_x0, fill_y0, fill_x1, fill_y1;
VGfloat stroke_x0, stroke_y0, stroke_x1, stroke_y1;
VGPaint myFillPaint, myStrokePaint;
VGfloat * fill_linear_gradient = {
  fill_x0, fill_y0, fill_x1, fill_y1
};
VGfloat * stroke_linear_gradient = {
  stroke_x0, stroke_y0, stroke_x1, stroke_y1
};

/* Fill with linear gradient paint */
vgSetParameteri(myFillPaint, VG_PAINT_TYPE,
                VG_PAINT_TYPE_LINEAR_GRADIENT);
vgSetParameterfv(myFillPaint, VG_PAINT_LINEAR_GRADIENT,
                 4, fill_linear_gradient);
/* Stroke with linear gradient paint */
vgSetParameteri(myStrokePaint, VG_PAINT_TYPE,
                VG_PAINT_TYPE_LINEAR_GRADIENT);
vgSetParameterfv(myStrokePaint, VG_PAINT_LINEAR_GRADIENT,
                 4, stroke_linear_gradient);
```

## 9.3.2 Radial Gradients

Radial gradients define a scalar-valued gradient function based on a *gradient circle* defined by a *center point* (*cx, cy*), a radius *r*, and a *focal point* (*fx, fy*) that is forced to lie within the circle. All parameters are given in the paint coordinate system.

The computation of the radial gradient function is illustrated in Figure 18. The function is equal to 0 at the focal point and 1 along the circumference of the gradient circle. Elsewhere, it is equal to the distance between (*x, y*) and (*fx, fy*) (shown as $d_1$) divided by the length of the line segment starting at (*fx, fy*), passing through (*x, y*), and ending on the circumference of the gradient circle (shown as $d_2$). If the radius is less than or equal to 0, the function is given the value 1 everywhere.

An expression for the gradient function may be derived by defining the line between (*fx, fy*) and (*x, y*) by the parametric expression $(fx, fy) + t*(x - fx, y - fy)$ and determining the positive value of *t* at which the line intersects the circle $(x - cx)^2 + (y - cy)^2 = r^2$. Figure 18 illustrates the construction. The gradient value $g(x, y)$ is then given by $1/t$. The resulting expression is:

$$g(x,y)=\frac{dx^2+dy^2}{\sqrt{r^2(dx^2+dy^2)-(dx\ fy'-dy\ fx')^2}-(dx\ fx'+dy\ fy')}$$

where $fx' = fx - cx$, $fy' = fy - cy$, $dx = x - fx$ and $dy = y - fy$.

This may be rearranged and simplified to obtain a formula that does not require per-pixel division:

$$g(x, y) = \frac{(dx\, fx' + dy\, fy') + \sqrt{r^2(dx^2 + dy^2) - (dx\, fy' - dy\, fx')^2}}{r^2 - (fx'^2 + fy'^2)}$$

One way to evaluate the gradient function efficiently is to rewrite it in the form:

$$g_y(x) = (A\,x + B) + \sqrt{C\,x^2 + D\,x + E}$$

and to use forward differencing of $Ax + B$ and $Cx^2 + Dx + E$ to evaluate it incrementally along a scanline with several additions and a single square root per pixel.

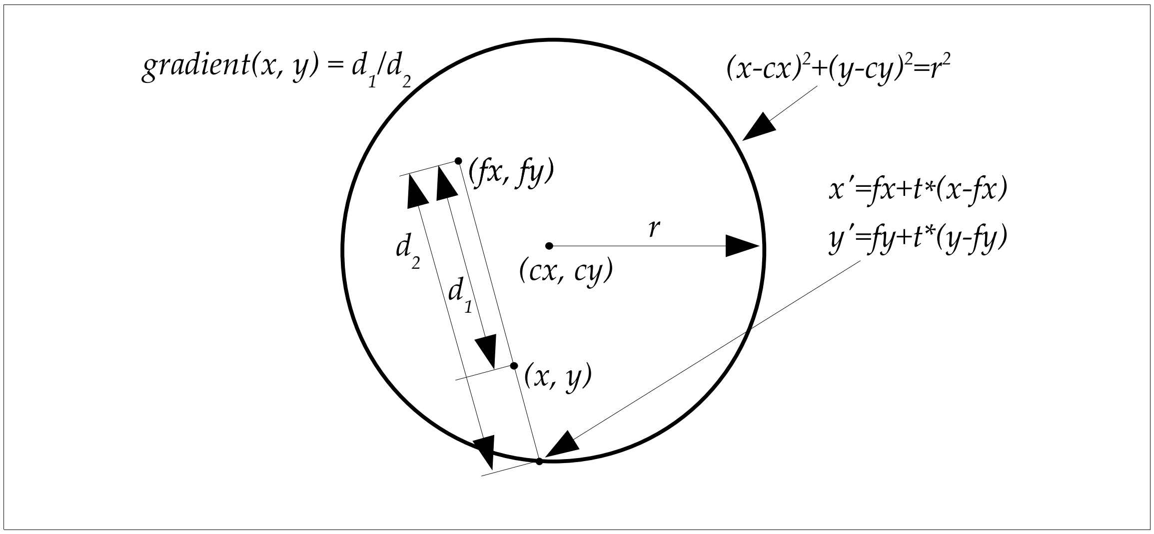


*Figure 18: Radial Gradient Function*

### *Setting Radial Gradient Parameters*

To enable radial gradient paint, use **vgSetParameteri** to set the paint type to `VG_PAINT_TYPE_RADIAL_GRADIENT`. The radial gradient parameters are set using **vgSetParameterfv** with a `paramType` argument of `VG_PAINT_RADIAL_GRADIENT`. The gradient values are supplied as a vector of 5 floats in the order *{ cx, cy, fx, fy, r }*.

If (*fx, fy*) lies outside the circumference of the circle, the intersection of the line from the center to the focal point with the circumference of the circle is used as the focal point in place of the specified point. To avoid a division by 0, the implementation may move the focal point along the line towards the center of the circle by an amount sufficient to avoid numerical instability, provided the new location lies at a distance of at least *.99r* from the circle center. The following code illustrates the setting of radial gradient parameters:

```
VGPaint myFillPaint, myStrokePaint;
VGfloat fill_cx, fill_cy, fill_fx, fill_fy, fill_r;
VGfloat stroke_cx, stroke_cy, stroke_fx, stroke_fy, stroke_r;
VGfloat * fill_radial_gradient = { fill_cx, fill_cy,
  fill_fx, fill_fy, fill_r };
VGfloat * stroke_radial_gradient = { stroke_cx, stroke_cy,
  stroke_fx, stroke_fy, stroke_r };
vgSetParameteri(myFillPaint, VG_PAINT_TYPE,      /* Fill */
                VG_PAINT_TYPE_RADIAL_GRADIENT);
vgSetParameterfv(myFillPaint, VG_PAINT_RADIAL_GRADIENT,
                 5, fill_radial_gradient);
vgSetParameteri(myStrokePaint, VG_PAINT_TYPE,    /* Stroke */
                VG_PAINT_TYPE_RADIAL_GRADIENT);
vgSetParameterfv(myStrokePaint, VG_PAINT_RADIAL_GRADIENT,
                 5, stroke_radial_gradient);
```

### 9.3.3 Color Ramps

Color ramps map the scalar values produced by gradient functions to colors. The application defines the non-premultiplied sRGBA color and alpha value associated with each of a number of values, called *stops*. A stop is defined by an *offset* between 0 and 1, inclusive, and a color value. Stops must be specified in increasing order; if they are not, the entire sequence is ignored. It is legal to have multiple stops with the same offset value, which will result in a discontinuity in the color ramp, with the first stop with a given offset value defining the right endpoint of one interval and the last stop with the same offset value defining the left endpoint of the next interval. At an offset value equal to that of a stop, the color value is that of the last stop with the given offset. Intermediate stops with the same offset value have no effect. Stops with offsets less than 0 or greater than 1 are ignored.

If no valid stops have been specified (*e.g.*, due to an empty input array, out-of-range, or out-of-order stops), a stop at 0 with ($R$, $G$, $B$, $\alpha$) color (*0.0, 0.0, 0.0, 1.0*) (opaque black) and a stop at 1 with color (*1.0, 1.0, 1.0, 1.0*) (opaque white) are implicitly defined. If at least one valid stop has been specified, but none has been defined with an offset of 0, an implicit stop is added with an offset of 0 and the same color as the first user-defined stop. If at least one valid stop has been specified, but none has been defined with an offset of 1, an implicit stop is added with an offset of 1 and the same color as the last user-defined stop.

If a color or alpha value of a given stop falls outside of the range [0, 1], the closest endpoint of the range is used instead.

Color and alpha values at offset values between the values given by stops are defined by means of linear interpolation between the values defined at the nearest stops above and below the given offset value. Interpolation is performed using the sRGB color values. Gradient color values are processed in premultiplied alpha format during interpolation.

### *VG_MAX_COLOR_RAMP_STOPS*

The `VG_MAX_COLOR_RAMP_STOPS` parameter contains the maximum number of gradient stops supported by the OpenVG implementation. All implementations must support at least 32 stops. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. Implicitly defined stops at offsets 0 and 1 are not counted against this maximum. The value may be retrieved by calling **vgGeti**:

```
VGint maxStops = vgGeti(VG_MAX_COLOR_RAMP_STOPS);
```

### *VGColorRampSpreadMode*

The application may only define stops with offsets between 0 and 1. Spread modes define how the given set of stops are repeated or extended in order to define interpolated color values for arbitrary input values outside the [0,1] range. The `VGColorRampSpreadMode` enumeration defines three modes:

- `VG_COLOR_RAMP_SPREAD_PAD` – extend stops
- `VG_COLOR_RAMP_SPREAD_REPEAT` – repeat stops
- `VG_COLOR_RAMP_SPREAD_REFLECT` – repeat stops in reflected order

```
typedef enum {
  VG_COLOR_RAMP_SPREAD_PAD     = 0x1C00,
  VG_COLOR_RAMP_SPREAD_REPEAT  = 0x1C01,
  VG_COLOR_RAMP_SPREAD_REFLECT = 0x1C02
} VGColorRampSpreadMode;
```

In pad mode, the colors defined at 0 and 1 are used for all stop values less than 0 or greater than 1, respectively.

In repeat mode, the color values defined between 0 and 1 are repeated indefinitely in both directions. Gradient values outside the [0, 1] range are shifted by an integer amount to place them into that range. For example, a gradient value of 5.6 will receive the same color as a gradient value of 0.6. A gradient value of -5.6 will receive the same color as a gradient value of 0.4 (since 0.4 = -5.6 + 6).

In reflect mode, the color values defined between 0 and 1 are repeated indefinitely in both directions, but with alternate copies of the range reversed. A gradient value of 1.2 will receive the same color as a gradient value of 0.8, since 0.8 = 1.0 – 0.2 and 1.2 = 1.0 + 0.2. A gradient value of 2.4 will receive the same color as a gradient value of 0.4.

The color ramp pad modes are illustrated schematically in Figure 19.

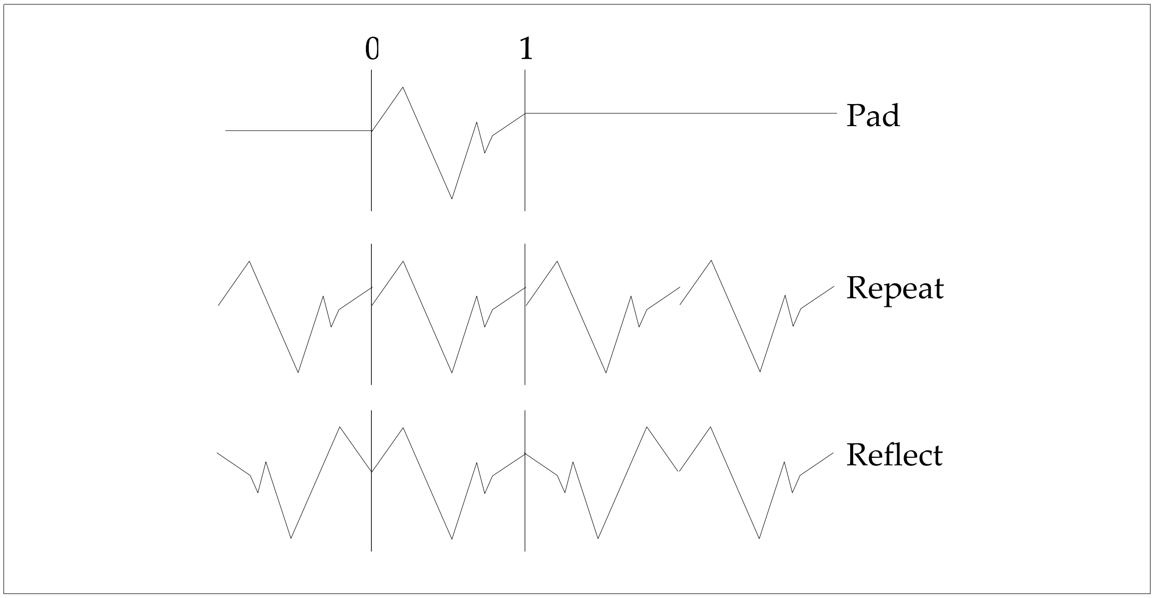


*Figure 19: Color Ramp Pad Modes*

### *Setting Color Ramp Parameters*

Color ramp parameters are set using **vgSetParameter**. The `VG_PAINT_COLOR_RAMP_SPREAD_MODE` parameter controls the spread mode using a value from the `VGColorRampSpreadMode` enumeration. The `VG_PAINT_COLOR_RAMP_STOPS` parameter takes an array of floating-point values giving the offsets and colors of the stops, in order. Each stop is defined by a floating-point offset value and four floating-point values containing the sRGBA color and alpha value associated with each stop, in the form of a non-premultiplied ($R$, $G$, $B$, $\alpha$) quad. If the number of values is not a multiple of 5, the final values beyond the last 5-tuple are ignored. Up to `VG_MAX_COLOR_RAMP_STOPS` 5-tuples may be set. If more than `VG_MAX_COLOR_RAMP_STOPS` 5-tuples are specified, those beyond the first `VG_MAX_COLOR_RAMP_STOPS` are discarded immediately (and will not be returned by **vgGetParameter)**.

A common set of color ramp settings are used for both linear and radial gradients defined on a given paint object.

```
VGPaint myFillPaint, myStrokePaint;
VGColorRampSpreadMode fill_spreadMode
VGfloat fill_stops[5*FILL_NUM_STOPS];
VGColorRampSpreadMode stroke_spreadMode;
VGfloat stroke_stops[5*STROKE_NUM_STOPS];

vgSetParameteri(myFillPaint, VG_PAINT_COLOR_RAMP_SPREAD_MODE,
                fill_spreadMode);
vgSetParameterfv(myFillPaint, VG_PAINT_COLOR_RAMP_STOPS,
                 5*FILL_NUM_STOPS, fill_stops);
vgSetParameteri(myStrokePaint, VG_PAINT_COLOR_RAMP_SPREAD_MODE,
                stroke_spreadMode);
vgSetParameterfv(myStrokePaint, VG_PAINT_COLOR_RAMP_STOPS,
                 5*STROKE_NUM_STOPS, stroke_stops);
```

### Formal Definition of Spread Modes

This section provides a formal definition of the color ramp spread modes.

In the following, assume that a sequence of stops $\{S_0, S_1, ..., S_{N-1}\}$ have been defined by the application, and/or by default or implicit values. The stop $S_i$ is defined to have offset $x_i$ and color $c_i$. The stops are assumed to be ordered by offset but may have duplicate offsets; that is, for all $i < j$, $x_i \le x_j$. To determine the interpolated color value at a given offset value $v$, determine the smallest $i$ such that $x_{i+1} > v$. If $x_i = v$, use the color $c_i$, otherwise perform linear interpolation between the stops $S_i$ and $S_{i+1}$ to produce the color $c_i + (c_{i+1} - c_i)(v - x_i)/(x_{i+1} - x_i)$.

In pad mode, values smaller than 0 are assigned the color $c_0$ and values greater than or equal to 1 are assigned the color $c_{N-1}$.

In repeat and reflect modes, additional stops $\{ ..., S_{-1}, S_N, ... \}$ are defined along the entire real number line in order to ensure that an $x_{i+1} > v$ exists for all values of $v$. Interpolation occurs normally on the extended set of stops.

In repeat mode, new stops $S_{kN+i}$ are defined with an offset of $(x_i + k)$ and a color $c_i$ for all integers $k \neq 0$ and $0 \le i < N$.

In reflect mode, new stops $S_{-i-1}$ are first defined for $0 \le i < N$ with offset $-x_i$ and color $c_i$. Next, new stops $S_{2kN+i}$ are defined with offset $(x_i + 2k)$ and a color $c_i$ for all integers $k \neq 0$ and $-N \le i < N$.

### 9.3.4 Gradient Examples

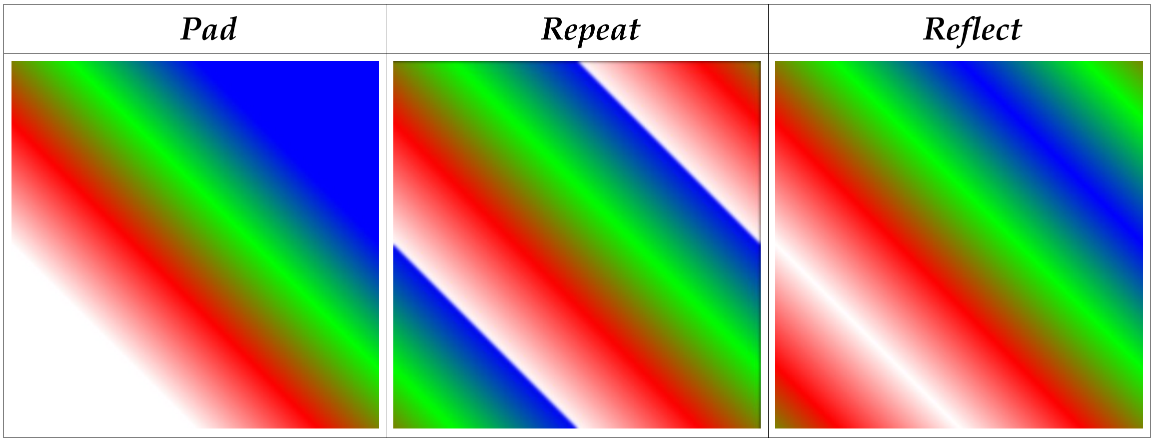


*Figure 20: Linear Gradients*

Figure 20 shows a square from (0, 0) to (400, 400) painted with a set of linear gradients with (*x0*, *y0*) = (50, 50), (*x1*, *y1*) = (350, 350).

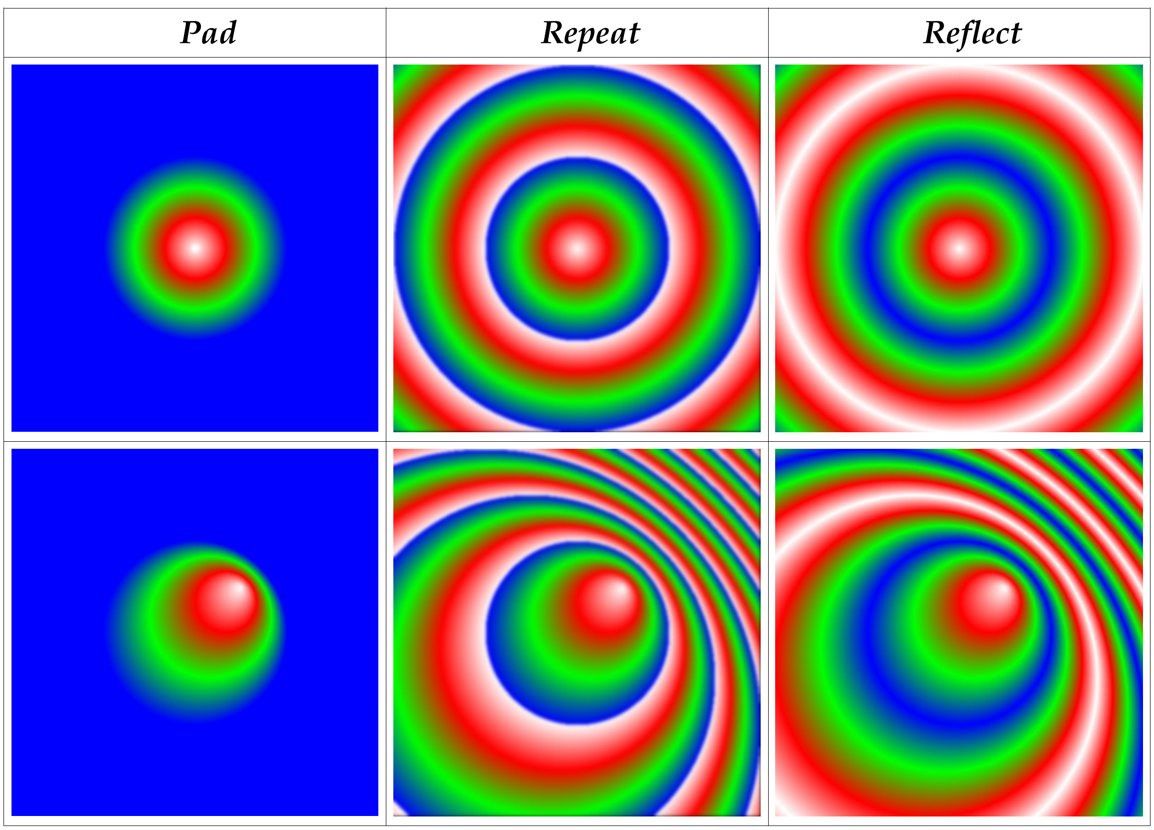


*Figure 21: Centered and Non-Centered Radial Gradients*

Figure 21 shows the same square painted with radial gradients with centered and non-centered focal points. The centered gradient, shown in the top row, has its center (*cx, cy*) and focal point (*fx, fy*) both at (200, 200). The non-centered gradient, shown in the bottom row, has its center (*cx, cy*) at (200, 200) and its focal point (*fx, fy*) at (250, 250). The radius *r* for both gradients is equal to 100.

All the gradients shown above utilize a color ramp with stops at offsets 0.0, 0.33, 0.66, and 1.0 colored white, red, green, and blue, respectively, as shown in Figure 22.

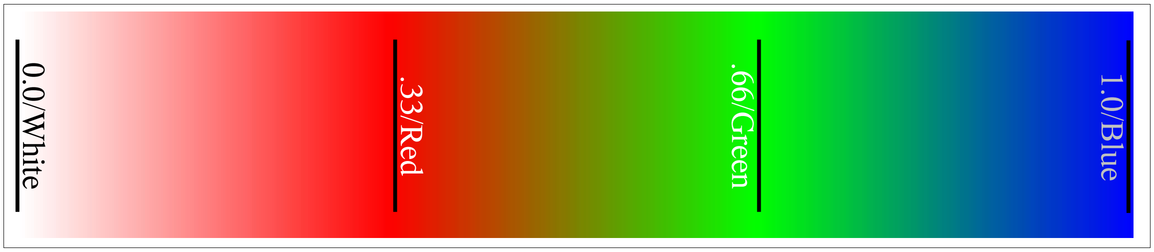


*Figure 22: Color Ramp used for Gradient Examples*

## 9.4 Pattern Paint

Pattern paint defines a rectangular pattern of colors based on the pixel values of an image. Images are described below in Section 10. Each pixel (*x, y*) of the pattern image defines a point of color at the pixel center ($x + ½$, $y + ½$).

Filtering may be used to construct an interpolated pattern value at the sample point, based on the pattern image pixel values. The pattern tiling mode is used to define values for pixel centers in the pattern space that lie outside of the bounds of the pattern.

Interpolation may be performed between multiple pixels of the pattern image to produce an antialiased pattern value. The image quality setting at the time of drawing (determined by the `VG_IMAGE_QUALITY` parameter) is used to control the quality of pattern interpolation. If the image quality is set to `VG_IMAGE_QUALITY_NONANTIALIASED`, nearest-neighbor interpolation (point sampling) is used. If the image quality is set to `VG_IMAGE_QUALITY_FASTER` or `VG_IMAGE_QUALITY_BETTER`, higher-quality interpolation will be used if available. Interpolation is done in the color space of the image using a premultiplied representation.

vgPaintPattern

The **vgPaintPattern** function replaces any previous pattern image defined on the given `paint` object for the given set of paint modes with a new pattern image. A value of `VG_INVALID_HANDLE` for the `pattern` parameter removes the current pattern image from the paint object.

If the current paint object has its `VG_PAINT_TYPE` parameter set to `VG_PAINT_TYPE_PATTERN`, but no pattern image is set, the paint object behaves as if `VG_PAINT_TYPE` were set to `VG_PAINT_TYPE_COLOR`.

While an image is set as the paint pattern for any paint object, it may not be used as a rendering target. Conversely, an image that is currently a rendering target may not be set as a paint pattern.

```
void vgPaintPattern(VGPaint paint, VGImage pattern)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `paint` is not a valid paint handle, or is not shared with the current context

– if `pattern` is neither a valid image handle nor equal to `VG_INVALID_HANDLE`, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `pattern` is currently a rendering target

### 9.4.1 Pattern Tiling

Patterns may be extended (tiled) using one of four possible tiling modes, defined by the `VGTilingMode` enumeration.

#### *VGTilingMode*

The `VGTilingMode` enumeration defines possible methods for defining colors for source pixels that lie outside the bounds of the source image.

The `VG_TILE_FILL` condition specifies that pixels outside the bounds of the source image should be taken as the color `VG_TILE_FILL_COLOR`. The color is expressed as a non-premultiplied sRGBA color and alpha value. Values outside the [0, 1] range are interpreted as the nearest endpoint of the range.

The `VG_TILE_PAD` condition specifies that pixels outside the bounds of the source image should be taken as having the same color as the closest edge pixel of the source image. That is, a pixel $(x, y)$ has the same value as the image pixel $(max(0, min(x, width - 1)), max(0, min(y, height - 1)))$.

The `VG_TILE_REPEAT` condition specifies that the source image should be repeated indefinitely in all directions. That is, a pixel $(x, y)$ has the same value as the image pixel $(x \bmod width, y \bmod height)$ where the operator '$a \bmod b$' returns a value between $0$ and $(b - 1)$ such that $a = k*b + (a \bmod b)$ for some integer $k$.

The `VG_TILE_REFLECT` condition specifies that the source image should be reflected indefinitely in all directions. That is, a pixel $(x, y)$ has the same value as the image pixel $(x', y')$ where:

$$x' = \begin{cases} x \bmod width & \text{if } floor(x/width) \text{ is even,} \\ width - 1 - (x \bmod width) & \text{otherwise.} \end{cases}$$

$$y' = \begin{cases} y \bmod height & \text{if } floor(y/height) \text{ is even,} \\ height - 1 - (y \bmod height) & \text{otherwise.} \end{cases}$$

```
typedef enum {
  VG_TILE_FILL    = 0x1D00,
  VG_TILE_PAD     = 0x1D01,
  VG_TILE_REPEAT  = 0x1D02,
  VG_TILE_REFLECT = 0x1D03,
} VGTilingMode;
```

### Setting the Pattern Tiling Mode

The pattern tiling mode is set using **vgSetParameteri** with a `paramType` argument of `VG_PAINT_PATTERN_TILING_MODE`.

```
VGPaint myFillPaint, myStrokePaint;
VGImage myFillPaintPatternImage, myStrokePaintPatternImage;

VGTilingMode fill_tilingMode, stroke_tilingMode;

vgSetParameteri(myFillPaint, VG_PAINT_TYPE,
                VG_PAINT_TYPE_PATTERN);
vgSetParameteri(myFillPaint, VG_PAINT_PATTERN_TILING_MODE,
                fill_tilingMode);
vgPaintPattern(myFillPaint, myFillPaintPatternImage);

vgSetParameteri(myStrokePaint, VG_PAINT_TYPE,
                VG_PAINT_TYPE_PATTERN);
vgSetParameteri(myStrokePaint, VG_PAINT_PATTERN_TILING_MODE,
                stroke_tilingMode);
vgPaintPattern(myStrokePaint, myStrokePaintPatternImage);
```

# 10 Images

Images are rectangular collections of pixels. Image data may be inserted or extracted in a variety of formats with varying bit depths, color spaces, and alpha channel types. The actual storage format of an image is implementation-dependent, and may be optimized for a given device. Images may be drawn to a drawing surface, used to define paint patterns, or operated on directly by image filter operations.

## 10.1 Image Coordinate Systems

An image defines a coordinate system in which pixels are indexed using integer coordinates, with each integer corresponding to a distinct pixel. The lower-left pixel has a coordinate of $(0, 0)$, the $x$ coordinate increases horizontally from left to right, and the $y$ coordinate increases vertically from bottom to top. Note that this orientation is consistent with the other coordinate systems used in the OpenVG API, but differs from the top-to-bottom orientation used by many other imaging systems.

The "energy" of a pixel is located at the pixel center; that is, the pixel with coordinate $(x, y)$ has its energy at the point $(x + ½, y + ½)$. The color at a point not located at a pixel center may be defined by applying a suitable filter to the colors defined at a set of nearby pixel centers.

## 10.2 Image Formats

### *VGImageFormat*

The VGImageFormat enumeration defines the set of supported pixel formats and color spaces for images:

```
typedef enum {
  VG_IMAGE_FORMAT_INVALID = -1,
  VG_sRGBX_8888           =  0,
  VG_sRGBA_8888           =  1,
  VG_sRGBA_8888_PRE       =  2,
  VG_sRGB_565             =  3,
  VG_sRGBA_5551           =  4,
  VG_sRGBA_4444           =  5,
  VG_sL_8                 =  6,
  VG_lRGBX_8888           =  7,
  VG_lRGBA_8888           =  8,
  VG_lRGBA_8888_PRE       =  9,
  VG_lL_8                 = 10,
  VG_A_8                  = 11,
  VG_BW_1                 = 12
} VGImageFormat;
```

The letter `A` denotes an alpha ($\alpha$) channel , `R` denotes red, `G` denotes green, and `B` denotes blue. `X` denotes a padding byte that is ignored. `L` denotes grayscale, and `BW` denotes (linear) bi-level grayscale (black-and-white), with 0 representing black and 1 representing white in either case. A lower-case letter `s` represents a non-linear, perceptually-uniform color space, as in sRGB and sL; a lower-case letter `l` represents a linear color space using the sRGB primaries. Formats with a suffix of `_PRE` store pixel values in premultiplied format.

The `VG_A_8` format is treated as though it were `VG_lRGBA_8888`, with R=G=B=1. Color information is discarded when placing an RGBA value into a `VG_A_8` pixel.

Abbreviated names such as `lL` or `sRGBA_PRE` are used in this document where the exact number of bits per channel is not relevant, such as when pixel values are considered to have been remapped to a [0, 1] range. Such abbreviated names are not an official part of the API.

The bits for each color channel are stored within a machine word representing a single pixel from left to right (MSB to LSB) in the order indicated by the pixel format name. For example, in a pixel with a format of `VG_sRGB_565`, the bits representing the red channel may be obtained by shifting right by 11 bits (to remove 6 bits of green and 5 bits of blue) and masking with the 5-bit wide mask value 0x1f. Note that this definition is independent of the endianness of the underlying platform as sub-word memory addresses are not involved.

Table 11 summarizes the symbols used in image format names.

Table 12 lists the size of a single pixel for each image format, in terms of bytes and bits. Note that all formats other than VG_BW_1 use a whole number of bytes per pixel.

Formats having linear-light coding (`VG_lRGBX_8888`, `VG_lRGBA_8888`, `VG_lRGBA_8888_PRE`, and `VG_lL8`) are liable to exhibit banding (or contouring) artifacts when viewed with a contrast ratio greater than about 10:1 [POYN03] and are intended mainly for inputting existing linearly-coded imagery. For high-quality imaging, consider using one of the non-linear, perceptually uniform image formats such as `VG_sRGBX_8888`, `VG_sRGBA_8888`, `VG_sRGBA_8888_PRE`, and `VG_sL_8`.

| Symbol | Interpretation |
| --- | --- |
| A | Alpha channel |
| R | Red color channel |
| G | Green color channel |
| B | Blue color channel |
| X | Uninterpreted padding byte |
| L | Grayscale |
| BW | 1-bit Black and White |
| l | Linear color space |
| s | Non-linear (sRGB) color space |
| PRE | Alpha values are premultiplied |

*Table 11: Symbols Used in Image Format Names*

| Format | Bytes Per Pixel | Bits Per Pixel |
| --- | --- | --- |
| VG_sRGBX_8888 | 4 | 32 |
| VG_sRGBA_8888 | 4 | 32 |
| VG_sRGBA_8888_PRE | 4 | 32 |
| VG_sRGB_565 | 2 | 16 |
| VG_sRGBA_5551 | 2 | 16 |
| VG_sRGBA_4444 | 2 | 16 |
| VG_sL_8 | 1 | 8 |
| VG_lRGBX_8888 | 4 | 32 |
| VG_lRGBA_8888 | 4 | 32 |
| VG_lRGBA_8888_PRE | 4 | 32 |
| VG_lL_8 | 1 | 8 |
| VG_A_8 | 1 | 8 |
| VG_BW_1 | n/a | 1 |

*Table 12: Image Format Pixel Sizes*

## 10.3 Creating and Destroying Images

### VGImage

Images are accessed using opaque handles of type `VGImage`.

```
typedef VGHandle VGImage;
```

### VGImageQuality

The `VGImageQuality` enumeration defines varying levels of resampling quality to be used when drawing images.

The `VG_IMAGE_QUALITY_NONANTIALIASED` setting disables resampling; images are drawn using point sampling (also known as nearest-neighbor interpolation) only. `VG_IMAGE_QUALITY_FASTER` enables low-to-medium quality resampling that does not require extensive additional resource allocation. `VG_IMAGE_QUALITY_BETTER` enables high-quality resampling that may allocate additional memory for pre-filtering, tables, and the like. Implementations are not required to provide three distinct resampling algorithms, but the non-antialiased (point sampling) mode must be supported.

```
typedef enum {
  VG_IMAGE_QUALITY_NONANTIALIASED  = (1 << 0),
  VG_IMAGE_QUALITY_FASTER          = (1 << 1),
  VG_IMAGE_QUALITY_BETTER          = (1 << 2)
} VGImageQuality;
```

Use **vgSeti** with a parameter type of `VG_IMAGE_QUALITY` to set the filter type to be used for image drawing:

```
VGImageQuality quality;
vgSeti(VG_IMAGE_QUALITY, quality);
```

### VG_MAX_IMAGE_WIDTH

The `VG_MAX_IMAGE_WIDTH` read-only parameter contains the largest legal value of the `width` parameter to the **vgCreateImage** function. All implementations must define `VG_MAX_IMAGE_WIDTH` to be an integer no smaller than 256. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti**:

```
VGint imageMaxWidth = vgGeti(VG_MAX_IMAGE_WIDTH);
```

### VG_MAX_IMAGE_HEIGHT

The `VG_MAX_IMAGE_HEIGHT` read-only parameter contains the largest legal value of the `height` parameter to the **vgCreateImage** function. All implementations must define `VG_MAX_IMAGE_HEIGHT` to be an integer no smaller than 256. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti**:

```
VGint imageMaxHeight = vgGeti(VG_MAX_IMAGE_HEIGHT);
```

### VG_MAX_IMAGE_PIXELS

The `VG_MAX_IMAGE_PIXELS` read-only parameter contains the largest legal value of the product of the `width` and `height` parameters to the **vgCreateImage** function. All implementations must define `VG_MAX_IMAGE_PIXELS` to be an integer no smaller than 65536. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti**:

```
VGint imageMaxPixels = vgGeti(VG_MAX_IMAGE_PIXELS);
```

### VG_MAX_IMAGE_BYTES

The `VG_MAX_IMAGE_BYTES` read-only parameter contains the largest number of bytes that may make up the image data passed to the **vgCreateImage** function. All implementations must define `VG_MAX_IMAGE_BYTES` to be an integer no smaller than 65536. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti**:

```
VGint imageMaxBytes = vgGeti(VG_MAX_IMAGE_BYTES);
```

### vgCreateImage

**vgCreateImage** creates an image with the given `width`, `height`, and pixel `format` and returns a `VGImage` handle to it. If an error occurs, `VG_INVALID_HANDLE` is returned. All color and alpha channel values are initially set to zero. The `format` parameter must contain a value from the `VGImageFormat` enumeration other than `VG_IMAGE_FORMAT_INVALID`.

The `allowedQuality` parameter is a bitwise OR of values from the `VGImageQuality` enumeration, indicating which levels of resampling quality may be used to draw the image. It is always possible to draw an image using the `VG_IMAGE_QUALITY_NONANTIALIASED` quality setting even if it is not explicitly specified.

```
VGImage vgCreateImage(VGImageFormat format,
                      VGint width, VGint height,
                      VGbitfield allowedQuality)
```

***ERRORS***

`VG_UNSUPPORTED_IMAGE_FORMAT_ERROR`

– if format is not a valid value from the `VGImageFormat` enumeration

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` are less than or equal to 0

– if `width` is greater than `VG_MAX_IMAGE_WIDTH`

– if `height` is greater than `VG_MAX_IMAGE_HEIGHT`

– if `width*height` is greater than `VG_MAX_IMAGE_PIXELS`

– if `width*height*`(pixel size of `format`) is greater than `VG_MAX_IMAGE_BYTES`

– if `allowedQuality` is not a bitwise OR of values from the `VGImageQuality` enumeration

### *vgDestroyImage*

The resources associated with an image may be deallocated by calling **vgDestroyImage.** Following the call, the `image` handle is no longer valid in any context that shared it. If the image is currently in use as a rendering target, is the ancestor of another image (see **vgChildImage**), or is set as a paint pattern image on a `VGPaint` object, its definition remains available to those consumers as long as they remain valid, but the handle may no longer be used. When those uses cease, the image's resources will automatically be deallocated.

```
void vgDestroyImage(VGImage image);
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `image` is not a valid image handle, or is not shared with the current context

## *10.4 Querying Images*

### *VGImageParamType*

Values from the `VGImageParamType` enumeration may be used as the `paramType` argument to **vgGetParameter** to query various features of an image. All of the parameters defined by `VGImageParamType` have integer values and are read-only.

```
typedef enum {
  VG_IMAGE_FORMAT = 0x1E00,
  VG_IMAGE_WIDTH  = 0x1E01,
  VG_IMAGE_HEIGHT = 0x1E02
} VGImageParamType;
```

### Image Format

The value of the `format` parameter that was used to define the image may be queried using the `VG_IMAGE_FORMAT` parameter. The returned integral value should be cast to the `VGImageFormat` enumeration:

```
VGImage image;
VGImageFormat imageFormat =
  (VGImageFormat)vgGetParameteri(image, VG_IMAGE_FORMAT);
```

### Image Width

The value of the `width` parameter that was used to define the image may be queried using the `VG_IMAGE_WIDTH` parameter:

```
VGImage image;
VGint imageWidth = vgGetParameteri(image, VG_IMAGE_WIDTH);
```

### Image Height

The value of the `height` parameter that was used to define the image may be queried using the `VG_IMAGE_HEIGHT` parameter:

```
VGImage image;
VGint imageHeight = vgGetParameteri(image, VG_IMAGE_HEIGHT);
```

## 10.5 Reading and Writing Image Pixels

### vgClearImage

The **vgClearImage** function fills a given rectangle of an image with the color specified by the `VG_CLEAR_COLOR` parameter. The rectangle to be cleared is given by `x`, `y`, `width`, and `height`, which must define a positive region. The rectangle is clipped to the bounds of the image.

```
void vgClearImage(VGImage image,
                  VGint x, VGint y, VGint width, VGint height)
```

*ERRORS*

`VG_BAD_HANDLE_ERROR`

– if `image` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `image` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0

### vgImageSubData

The **vgImageSubData** function reads pixel values from memory, performs format conversion if necessary, and stores the resulting pixels into a rectangular portion of an `image`.

Pixel values are read starting at the address given by the pointer `data`; adjacent scanlines are separated by `dataStride` bytes. Negative or zero values of `dataStride` are allowed. The region to be written is given by `x`, `y`, `width`, and `height`, which must define a positive region. Pixels that fall outside the bounds of the image are ignored.

Pixel values in memory are formatted according to the `dataFormat` parameter, which must contain a value from the `VGImageFormat` enumeration other than `VG_IMAGE_FORMAT_INVALID`. The `data` pointer must be aligned according to the number of bytes of the pixel format specified by `dataFormat`, unless `dataFormat` is equal to `VG_BW_1`, in which case 1 byte alignment is sufficient. Each pixel is converted into the format of the destination image as it is written.

If `dataFormat` is not equal to `VG_BW_1`, the destination image pixel (`x` + *i*, `y` + *j*) for $0 \le i <$ `width` and $0 \le j <$ `height` is taken from the *N* bytes of memory starting at *data + j*dataStride + i*N*, where *N* is the number of bytes per pixel given in Table 12. For multi-byte pixels, the bits are arranged in the same order used to store native multi-byte primitive datatypes. For example, a 16-bit pixel would be written to memory in the same format as when writing through a pointer with a native 16-bit integral datatype.

If `dataFormat` is equal to `VG_BW_1`, pixel (`x` + *i*, `y` + *j*) of the destination image is taken from the bit at position (*i % 8*) within the byte at *data + j*dataStride + floor*(*i/8*) where the least significant bit (LSB) of a byte is considered to be at position 0 and the most significant bit (MSB) is at position 7. Each scanline must be padded to a multiple of 8 bits. Note that `dataStride` is always given in terms of bytes, not bits.

```
void vgImageSubData(VGImage image,
                    const void * data, VGint dataStride,
                    VGImageFormat dataFormat,
                    VGint x, VGint y, VGint width, VGint height)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if image is not a valid image handle, or is not shared with the current context

VG_IMAGE_IN_USE_ERROR

– if image is currently a rendering target

VG_UNSUPPORTED_IMAGE_FORMAT_ERROR

– if dataFormat is not a valid value from the VGImageFormat enumeration

VG_ILLEGAL_ARGUMENT_ERROR

– if width or height is less than or equal to 0

– if data is NULL

– if data is not properly aligned

### *vgGetImageSubData*

The **vgGetImageSubData** function reads pixel values from a rectangular portion of an image, performs format conversion if necessary, and stores the resulting pixels into memory.

Pixel values are written starting at the address given by the pointer data; adjacent scanlines are separated by dataStride bytes. Negative or zero values of dataStride are allowed. The region to be read is given by x, y, width, and height, which must define a positive region. Pixels that fall outside the bounds of the image are ignored.

Pixel values in memory are formatted according to the dataFormat parameter, which must contain a value from the VGImageFormat enumeration other than VG_IMAGE_FORMAT_INVALID. The data pointer must be aligned according to the number of bytes of the pixel format specified by dataFormat, unless dataFormat is equal to VG_BW_1, in which case 1 byte alignment is sufficient. Each pixel is converted from the format of the source image as it is read.

The pixel layout in memory is identical to that of **vgImageSubData**.

```
void vgGetImageSubData(VGImage image,
                       void * data, VGint dataStride,
                       VGImageFormat dataFormat,
                       VGint x, VGint y, VGint width, VGint height)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if `image` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `image` is currently a rendering target

`VG_UNSUPPORTED_IMAGE_FORMAT_ERROR`

– if `dataFormat` is not a valid value from the `VGImageFormat` enumeration

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0

– if `data` is `NULL`

– if `data` is not properly aligned

## 10.6 Child Images

A *child image* is an image that shares physical storage with a portion of an existing image, known as its *parent*. An image may have any number of children, but each image has only one parent (that may be itself). An *ancestor* of an image is defined as the image itself, its parent, its parent's parent, etc. Thus a pair of images share storage if and only if they have a common ancestor. Changes to an image are immediately reflected in all other images that share storage with it.

A child image remains valid even following a call to **vgDestroyImage** on one of its ancestors (other than itself). When the last image of a set of images that share pixel storage is destroyed, the storage will be reclaimed. Implementations may use a reference count to determine when image storage may be reclaimed.

An image that shares storage with any other image may not be used as a rendering target until all the images with which it shares storage have been destroyed.

### vgChildImage

The **vgChildImage** function returns a new `VGImage` handle that refers to a portion of the `parent` image. The region is given by the intersection of the bounds of the parent image with the rectangle beginning at pixel (`x`, `y`) with dimensions `width` and `height`, which must define a positive region contained entirely within `parent`.

```
VGImage vgChildImage(VGImage parent,
                     VGint x, VGint y, VGint width, VGint height)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `parent` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `parent` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `x` is less than 0 or greater than or equal to the parent width

– if `y` is less than 0 or greater than or equal to the parent height

– if `width` or `height` is less than or equal to 0

– if `x + width` is greater than the parent width

– if `y + height` is greater than the parent height

### *vgGetParent*

The **vgGetParent** function returns the parent of the given `image`. If `image` has no parent, `image` is returned.

```
VGImage vgGetParent(VGImage image)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `image` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `image` is currently a rendering target

## *10.7 Copying Pixels Between Images*

### *vgCopyImage*

Pixels may be copied between images using the **vgCopyImage** function. The source image pixel (`sx` + *i*, `sy` + *j*) is copied to the destination image pixel (`dx` + *i*, `dy` + *j*), for $0 \le i <$ `width` and $0 \le j <$ `height`. Pixels whose source or destination lie outside of the bounds of the respective image are ignored. Pixel format conversion is applied as needed.

If the `dither` flag is equal to `VG_TRUE`, an implementation-dependent dithering algorithm may be applied. This may be useful when copying into a destination image with a smaller color bit depth than that of the source image. Implementations should choose an algorithm that will provide good results when the output images are displayed as successive frames in an animation.

If `src` and `dst` are the same image, or have a common ancestor and thus share storage, the copy will occur in a consistent fashion as though the source pixels were first copied into a temporary buffer and then copied from the temporary buffer to the destination.

```
void vgCopyImage(VGImage dst, VGint dx, VGint dy,
                 VGImage src, VGint sx, VGint sy,
                 VGint width, VGint height,
                 VGboolean dither)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if either `dst` or `src` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if either `dst` or `src` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0

## 10.8 Drawing Images to the Drawing Surface

Images may be drawn onto a drawing surface. An affine or projective transformation may be applied while drawing. The current image and blending modes are used to control how image pixels are combined with the current paint and blended into the destination. Conversion between the image and destination pixel formats is applied automatically.

### VGImageMode

The `VGImageMode` enumeration is used to select between several styles of image drawing, described in the **vgDrawImage** section below.

```
typedef enum {
  VG_DRAW_IMAGE_NORMAL   = 0x1F00,
  VG_DRAW_IMAGE_MULTIPLY = 0x1F01,
  VG_DRAW_IMAGE_STENCIL  = 0x1F02
} VGImageMode;
```

To set the image drawing mode, use **vgSeti** with a `paramType` value of `VG_IMAGE_MODE`:

```
VGImageMode drawImageMode;
vgSeti(VG_IMAGE_MODE, drawImageMode);
```

### *vgDrawImage*

An image may be drawn to the current drawing surface using the **vgDrawImage** function. The current image-user-to-surface transformation $T_i$ is applied to the image, so that the image pixel centered at ($px$ + ½, $py$ + ½) is mapped to the point ($T_i$)($px$ + ½, $py$ + ½). In practice, backwards mapping may be used. That is, a sample located at ($x$, $y$) in the surface coordinate system is colored according to an interpolated image pixel value at the point $(T_i)^{-1}(x, y)$ in the image coordinate system. If $T_i$ is non-invertible (or nearly so, within the limits of numerical accuracy), no drawing occurs.

Interpolation is done in the color space of the image. Image color values are processed in premultiplied alpha format during interpolation.

When a projective transformation is used (*i.e.*, the bottom row of the image-user-to-surface transformation contains values [ $w_0$ $w_1$ $w_2$ ] different from [ 0 0 1 ]), each corner point ($x$, $y$) of the image must result in a positive value of $d = (x*w_0 + y*w_1 + w_2)$, or else nothing is drawn. This rule prevents degeneracies due to transformed image points passing through infinity, which occurs when $d$ passes through 0. By requiring $d$ to be positive at the corners, it is guaranteed to be positive at all interior points as well.

The set of pixels affected consists of the quadrilateral with vertices ($T_i$)(0, 0), ($T_i$)($w$, 0), ($T_i$)($w$, $h$), and ($T_i$)(0, $h$) (where $w$ and $h$ are respectively the width and height of the image), plus a boundary of up to 1½ pixels for filtering purposes.

Clipping, masking, and scissoring are applied in the same manner as with **vgDrawPath**.

To limit drawing to a subregion of the image, create a child image using **vgChildImage**.

The image quality will be the maximum quality allowed by the image (as determined by the `allowedQuality` parameter to **vgCreateImage**) that is not higher than the current setting of `VG_IMAGE_QUALITY`.

```
void vgDrawImage(VGImage image)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `image` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `image` is currently a rendering target

The effects of **vgDrawImage** depend on the current setting of the `VG_IMAGE_MODE` parameter:

### VG_DRAW_IMAGE_NORMAL

When the `VG_IMAGE_MODE` parameter is set to `VG_DRAW_IMAGE_NORMAL`, the image is drawn opaquely, and no paint generation takes place.

### VG_DRAW_IMAGE_MULTIPLY

When the `VG_IMAGE_MODE` parameter is set to `VG_DRAW_IMAGE_MULTIPLY`, the image being drawn is multiplied by the paint color and alpha values. This allows the image to be drawn translucently (by setting the paint color to R=G=B=1 and A=opacity), or to be modulated in other ways. For example, a gradient paint could be used to create a fading effect, or a pattern paint could be used to vary the opacity on a pixel-by-pixel basis. If the paint color is opaque white (R=G=B=A=1) everywhere, the results are equivalent to those of `VG_DRAW_IMAGE_NORMAL`.

Paint generation (using the `VGPaint` object defined for the `VG_FILL_PATH` paint mode) occurs at each pixel, and the interpolated image and paint color and alpha values are multiplied channel-by-channel. The result (considered to be in the same color space as the image) is used as the input to the current blend function and normal blending takes place.

### VG_DRAW_IMAGE_STENCIL

When the `VG_IMAGE_MODE` parameter is set to `VG_DRAW_IMAGE_STENCIL`, the image being drawn acts as a stencil through which the current paint is applied. This allows an image to take the place of a geometric path definition in some cases, such as drawing text glyphs. A special set of blending equations allows the red, green, and blue channels to be blended using distinct alpha values taken from the image. This feature allows stencils to take advantage of sub-pixel effects on LCD displays.

Paint generation (using the `VGPaint` object defined for the `VG_FILL_PATH` paint mode) occurs at each pixel. The interpolated image and paint color and alpha values are combined at each pixel as follows. Each image color channel value is multiplied by its corresponding alpha value (if the image has an alpha channel) and by the paint alpha value to produce an alpha value associated with that color channel. The result is considered to be in the same color space as the paint (*i.e.*, sRGB for all forms of paint except pattern paint with a linear pattern image). The current blending equation (see Section 12) is applied separately for each destination color channel, using the alpha value computed above as the source alpha value for the blend, and the paint color value as the source color value.

In terms of the blending functions $\alpha(\alpha_{src}, \alpha_{dst})$ and $c(c_{src}, c_{dst}, \alpha_{src}, \alpha_{dst})$ defined in Section 12.1, the stenciled output color and alpha values are:

$$\alpha_{tmp} = \alpha(\alpha_{image}*\alpha_{paint}, \alpha_{dst})$$
$$R_{dst} \leftarrow c(R_{paint}, R_{dst}, R_{image}*\alpha_{image}*\alpha_{paint}, \alpha_{dst}) / \alpha_{tmp}$$
$$G_{dst} \leftarrow c(G_{paint}, G_{dst}, G_{image}*\alpha_{image}*\alpha_{paint}, \alpha_{dst}) / \alpha_{tmp}$$
$$B_{dst} \leftarrow c(B_{paint}, B_{dst}, B_{image}*\alpha_{image}*\alpha_{paint}, \alpha_{dst}) / \alpha_{tmp}$$
$$\alpha_{dst} \leftarrow \alpha_{tmp}$$

For example, if Porter-Duff “Src **over** Dst” blending is enabled (see Section 12.2), the destination alpha and color values are computed as:

$$\alpha_{tmp} = (\alpha_{image}*\alpha_{paint} + \alpha_{dst}*(1 - \alpha_{image}*\alpha_{paint}))$$
$$R_{dst} \leftarrow (\alpha_{image}*\alpha_{paint}*R_{image}*R_{paint} + \alpha_{dst}*R_{dst}*(1 - \alpha_{image}*\alpha_{paint}*R_{image})) / \alpha_{tmp}$$
$$G_{dst} \leftarrow (\alpha_{image}*\alpha_{paint}*G_{image}*G_{paint} + \alpha_{dst}*G_{dst}*(1 - \alpha_{image}*\alpha_{paint}*G_{image})) / \alpha_{tmp}$$
$$B_{dst} \leftarrow (\alpha_{image}*\alpha_{paint}*B_{image}*B_{paint} + \alpha_{dst}*B_{dst}*(1 - \alpha_{image}*\alpha_{paint}*B_{image})) / \alpha_{tmp}$$
$$\alpha_{dst} \leftarrow \alpha_{tmp}$$

## 10.9 Reading and Writing Drawing Surface Pixels

Several functions are provided to read and write pixels on the drawing surface directly, without applying transformations, masking, or blending.

### 10.9.1 Writing Drawing Surface Pixels

#### vgSetPixels

The **vgSetPixels** function copies pixel data from the image `src` onto the drawing surface. The image pixel (`sx` + *i*, `sy` + *j*) is copied to the drawing surface pixel (`dx` + *i*, `dy` + *j*), for $0 \le i <$ `width` and $0 \le j <$ `height`. Pixels whose source lies outside of the bounds of `src` or whose destination lies outside the bounds of the drawing surface are ignored. Pixel format conversion is applied as needed. Scissoring takes place normally. Transformations, masking, and blending are not applied.

```
void vgSetPixels(VGint dx, VGint dy,
                 VGImage src, VGint sx, VGint sy,
                 VGint width, VGint height)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if `src` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if `src` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0

### *vgWritePixels*

The **vgWritePixels** function allows pixel data to be copied to the drawing surface without the creation of a `VGImage` object. The pixel values to be drawn are taken from the data pointer at the time of the **vgWritePixels** call, so future changes to the data have no effect. The effects of changes to the data by another thread at the time of the call to **vgWritePixels** are undefined.

The `dataFormat` parameter must contain a value from the `VGImageFormat` enumeration other than `VG_IMAGE_FORMAT_INVALID`. If `dataFormat` is not equal to `VG_BW_1`, `data` must be aligned according to the number of bytes of `dataFormat`, and the pixel at memory location *data + j*dataStride + i*(bytes per pixel of dataFormat)* is written to the drawing surface pixel (`dx` + *i*, `dy` + *j*), for $0 \le i <$ `width` and $0 \le j <$ `height`. If `dataFormat` is equal to `VG_BW_1`, data must only be 1-byte aligned, and pixel (`dx` + *i*, `dy` + *j*) of the destination image is taken from the bit at position (*i % 8*) within the byte at *data + j*dataStride + floor(i/8)* where the least significant bit (LSB) of a byte is considered to be at position 0 and the most significant bit (MSB) is at position 7.

Pixels whose destination coordinate lies outside the bounds of the drawing surface are ignored. Pixel format conversion is applied as needed. Scissoring takes place normally. Transformations, masking, and blending are not applied.

```
void vgWritePixels(const void * data, VGint dataStride,
                   VGImageFormat dataFormat,
                   VGint dx, VGint dy,
                   VGint width, VGint height)
```

***ERRORS***

`VG_UNSUPPORTED_IMAGE_FORMAT_ERROR`

– if `dataFormat` is not a valid value from the `VGImageFormat` enumeration

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0

– if `data` is `NULL`

– if data is not properly aligned

The code:

```
void * data;
VGImageFormat dataFormat;
VGint dataStride;
VGint dx, dy, width, height;

vgWritePixels(data, dataStride, dataFormat, dx, dy, width, height);
```

is equivalent to the code:

```
VGImage image;
void * data;
VGImageFormat dataFormat;
VGint dataStride;
VGint dx, dy, width, height;

image = vgCreateImage(dataFormat, width, height, 0);
vgImageSubData(image, data, dataStride, dataFormat,
               0, 0, width, height);
vgSetPixels(dx, dy, image, width, height);
vgDestroyImage(image);
```

### 10.9.2 Reading Drawing Surface Pixels

#### vgGetPixels

The **vgGetPixels** function retrieves pixel data from the drawing surface into the image dst. The drawing surface pixel (sx + $i$, sy + $j$) is copied to pixel (dx + $i$, dy + $j$) of the image dst, for $0 \le i <$ width and $0 \le j <$ height. Pixels whose source lies outside of the bounds of the drawing surface or whose destination lies outside the bounds of dst are ignored. Pixel format conversion is applied as needed. The scissoring region does not affect the reading of pixels.

```
void vgGetPixels(VGImage dst, VGint dx, VGint dy,
                 VGint sx, VGint sy,
                 VGint width, VGint height)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if dst is not a valid image handle, or is not shared with the current context

VG_IMAGE_IN_USE_ERROR

– if dst is currently a rendering target

VG_ILLEGAL_ARGUMENT_ERROR

– if width or height is less than or equal to 0

### vgReadPixels

The **vgReadPixels** function allows pixel data to be copied from the drawing surface without the creation of a VGImage object.

The dataFormat parameter must contain a value from the VGImageFormat enumeration other than VG_IMAGE_FORMAT_INVALID. If dataFormat is not equal to VG_BW_1, data must be aligned according to the number of bytes of dataFormat, and the drawing surface pixel (sx + *i*, sy + *j*) is written to the memory location *data + j*dataStride + i*(bytes per pixel of dataFormat)*, for $0 \le i <$ width *and* $0 \le j <$ height. If dataFormat is equal to VG_BW_1, data must only be 1-byte aligned, and the drawing surface pixel (sx + *i*, sy + *j*) is written to the bit at position (*i % 8*) within the byte at *data + j*dataStride + floor(i/8)* where the least significant bit (LSB) of a byte is considered to be at position 0 and the most significant bit (MSB) is at position 7.

Pixels whose source lies outside of the bounds of the drawing surface are ignored. Pixel format conversion is applied as needed. The scissoring region does not affect the reading of pixels.

```
void vgReadPixels(void * data, VGint dataStride,
                  VGImageFormat dataFormat,
                  VGint sx, VGint sy,
                  VGint width, VGint height)
```

***ERRORS***

VG_UNSUPPORTED_IMAGE_FORMAT_ERROR

– if dataFormat is not a valid value from the VGImageFormat enumeration

VG_ILLEGAL_ARGUMENT_ERROR

– if width or height is less than or equal to 0

– if data is NULL

– if data is not properly aligned

The code:

```
void * data;
VGImageFormat dataFormat;
VGint dataStride;
VGint sx, sy, width, height;

vgReadPixels(data, dataStride, dataFormat, sx, sy, width, height);
```

is equivalent to the code:

```
VGImage image;
void * data;
VGint dataStride;
VGImageFormat dataFormat;
VGint sx, sy, width, height;

image = vgCreateImage(dataFormat, width, height, 0);
vgGetPixels(image, 0, 0, sx, sy, width, height);
vgGetImageSubData(image, data, dataStride, dataFormat, width, height);
vgDestroyImage(image);
```

## 10.10 Copying Portions of the Drawing Surface

### vgCopyPixels

The **vgCopyPixels** function copies pixels from one region of the drawing surface to another. Copies between overlapping regions are allowed and always produce consistent results identical to copying the entire source region to a scratch buffer followed by copying the scratch buffer into the destination region.

The drawing surface pixel (`sx` + *i*, `sy` + *j*) is copied to pixel (`dx` + *i*, `dy` + *j*) for $0 \le i <$ `width` and $0 \le j <$ `height`. Pixels whose source or destination lies outside of the bounds of the drawing surface are ignored. Transformations, masking, and blending are not applied. Scissoring is applied to the destination, but does not affect the reading of pixels.

```
void vgCopyPixels(VGint dx, VGint dy,
                  VGint sx, VGint sy,
                  VGint width, VGint height)
```

*ERRORS*

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0

# 11 Image Filters

Image filters allow images to be modified and/or combined using a variety of imaging operations. Operations are carried out using a bit depth greater than or equal to the largest bit depth of the supplied images. The lower-left corners of all source and destination images are aligned. The destination area to be written is the intersection of the source and destination image areas. The source and destination images involved in the filter operation must not overlap (*i.e.*, have any pixels in common within any common ancestor image). Source and destination images may have a common ancestor as long as they occupy disjoint areas within that area.

## *11.1 Format Normalization*

A series of steps are carried out on application-supplied source images in order to produce normalized source images for filtering. In practice, these normalizations may be combined with the filter operations themselves for efficiency.

The source pixels are converted to one of `sRGBA`, `sRGBA_PRE`, `lRGBA`, or `lRGBA_PRE` formats, as determined by the current values of the `VG_FILTER_FORMAT_PREMULTIPLIED` and `VG_FILTER_FORMAT_LINEAR` parameters. The conversions take place in the following order (equivalent to the conversion rules defined in Section 3.4):

1) Source color and alpha values are scaled linearly to lie in a [0, 1] range. The exact precision of the internal representation is implementation-dependent.
2) If the source image has premultiplied alpha, the alpha values are divided out of each source color channel, and stored for later use. If the source image has no alpha channel, an alpha value of 1 is added to each pixel.
3) If the source pixel is in a grayscale format (`lL` or `sL`), it is converted to an RGB format (`lRGB` or `sRGB`, respectively) by replication.
4) If the `VG_FILTER_FORMAT_LINEAR` parameter is set to `VG_TRUE`, and the source pixel is in non-linear format, it is converted into the corresponding linear format (`sRGBA`→`lRGBA`). If the `VG_FILTER_FORMAT_LINEAR` parameter is set to `VG_FALSE`, and the source pixel is in linear format, it is converted into the corresponding non-linear format (`lRGBA`→`sRGBA`).
5) If the `VG_FILTER_FORMAT_PREMULTIPLIED` parameter is equal to `VG_TRUE`, each source color channel is multiplied by the corresponding alpha value. Otherwise, the color channels are left undisturbed.

An implementation may collapse steps algebraically; for example, if no conversion is to take place in step 4, the division and multiplication by alpha in steps 2 and 5 may be implemented as a no-op.

The resulting pixel will be in `sRGBA`, `sRGBA_PRE`, `lRGBA`, or `lRGBA_PRE` format. The image filter then processes each of the four source channels in an identical manner, resulting in a set of filtered pixels in the same pixel format as the incoming pixels.

Finally, the filtered pixels are converted into the destination format using the normal pixel format conversion rules, as described in section 3.4. Premultiplied alpha values are divided out prior to color-space conversion, and restored afterwards if necessary. The destination channels specified by `the` `VG_FILTER_CHANNEL_MASK` parameter (see below) are written into the destination image.

## 11.2 Channel Masks

### VGImageChannel

All image filter functions make use of the `VG_FILTER_CHANNEL_MASK` parameter that specifies which destination channels are to be written. The parameter is supplied as a bitwise OR of values from the `VGImageChannel` enumeration. If the destination pixel format is one of `VG_sL_8`, `VG_lL_8` or `VG_BW_1` pixel format, the parameter is ignored. If the destination pixel format does not contain an alpha channel, the `VG_ALPHA` bit is ignored. Bits other than those defined by the `VGImageChannel` enumeration are ignored.

```
typedef enum {
  VG_RED   = (1 << 3),
  VG_GREEN = (1 << 2),
  VG_BLUE  = (1 << 1),
  VG_ALPHA = (1 << 0)
} VGImageChannel;
```

## 11.3 Color Combination

Color channel values may be combined using the **vgColorMatrix** function, which computes output colors as linear combinations of input colors.

### vgColorMatrix

The **vgColorMatrix** function computes a linear combination of color and alpha values ($R_{src}$, $G_{src}$, $B_{src}$, $\alpha_{src}$) from the normalized source image `src` at each pixel:

$$\begin{bmatrix} R_{dst} \\ G_{dst} \\ B_{dst} \\ \alpha_{dst} \end{bmatrix} = \begin{bmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{bmatrix} \cdot \begin{bmatrix} R_{src} \\ G_{src} \\ B_{src} \\ \alpha_{src} \end{bmatrix} + \begin{bmatrix} m_{04} \\ m_{14} \\ m_{24} \\ m_{34} \end{bmatrix}$$

or:

$$\begin{aligned} R_{dst} &= m_{00} R_{src} + m_{01} G_{src} + m_{02} B_{src} + m_{03} \alpha_{src} + m_{04} \\ G_{dst} &= m_{10} R_{src} + m_{11} G_{src} + m_{12} B_{src} + m_{13} \alpha_{src} + m_{14} \\ B_{dst} &= m_{20} R_{src} + m_{21} G_{src} + m_{22} B_{src} + m_{23} \alpha_{src} + m_{24} \\ \alpha_{dst} &= m_{30} R_{src} + m_{31} G_{src} + m_{32} B_{src} + m_{33} \alpha_{src} + m_{34} \end{aligned}$$

The matrix entries are supplied in the `matrix` argument in the order $\{ m_{00}, m_{10}, m_{20}, m_{30}, m_{01}, m_{11}, m_{21}, m_{31}, m_{02}, m_{12}, m_{22}, m_{32}, m_{03}, m_{13}, m_{23}, m_{33}, m_{04}, m_{14}, m_{24}, m_{34} \}$.

```
void vgColorMatrix(VGImage dst, VGImage src,
                   const VGfloat * matrix)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if either `dst` or `src` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if either `dst` or `src` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `src` and `dst` overlap

– if `matrix` is `NULL`

– if `matrix` is not properly aligned

## *11.4 Convolution*

The **vgConvolve, vgSeparableConvolve**, and **vgGaussianBlur** functions define destination pixels based on a weighted average of neighboring source pixels, a process known as *convolution*. The set of weights, along with their relative locations, is known as the *convolution kernel*. In the discussion below, *width* and *height* refer to the dimensions of the source image.

### *VG_MAX_KERNEL_SIZE*

The `VG_MAX_KERNEL_SIZE` parameter contains the largest legal value of the `width` and `height` parameters to the **vgConvolve** function. All implementations must define `VG_MAX_KERNEL_SIZE` to be an integer no smaller than 7. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti**:

```
VGint kernelMaxSize = vgGeti(VG_MAX_KERNEL_SIZE);
```

### *VG_MAX_SEPARABLE_KERNEL_SIZE*

The `VG_MAX_SEPARABLE_KERNEL_SIZE` parameter contains the largest legal value of the `size` parameter to the **vgSeparableConvolve** function. All implementations must define `VG_MAX_SEPARABLE_KERNEL_SIZE` to be an integer no smaller than 15. If there is no implementation-defined limit, a value of `VG_MAXINT` may be returned. The value may be retrieved by calling **vgGeti**:

```
VGint separableKernelMaxSize = vgGeti(VG_MAX_SEPARABLE_KERNEL_SIZE);
```

### *vgConvolve*

The **vgConvolve** function applies a user-supplied convolution kernel to a normalized source image `src`. The dimensions of the kernel are given by `kernelWidth` and `kernelHeight`; the kernel values are specified as `kernelWidth`*`kernelHeight` `VGshort`s in column-major order. That is, the kernel entry (*i, j*) is located at position *i*kernelHeight + j* in the input sequence. The `shiftX` and `shiftY` parameters specify a translation between the source and destination images. The result of the convolution is multiplied by a `scale` factor, and a `bias` is added.

The output pixel (*x, y*) is defined as:

$$s\left(\sum_{0\le i<w}\sum_{0\le j<h} k_{(w-i-1),(h-j-1)}\, p(x+i-shiftX\,,\, y+j-shiftY)\right)+b\,,$$

where $w$ = `kernelWidth`, $h$ = `kernelHeight`, $k_{i,j}$ is the kernel element at position (*i, j*), *s* is the `scale`, *b* is the bias, and *p*(*x, y*) is the source pixel at (*x, y*), or the result of source edge extension defined by `tilingMode`, which takes a value from the `VGTilingMode` enumeration (see Section 9.4.1). Note that the use of the kernel index (*w–i–1, h–j–1*) implies that the kernel is rotated 180 degrees relative to the source image in order to conform to the mathematical definition of convolution. Figure 23 depicts the flipping of the kernel relative to the image pixels for a 3x3 kernel.

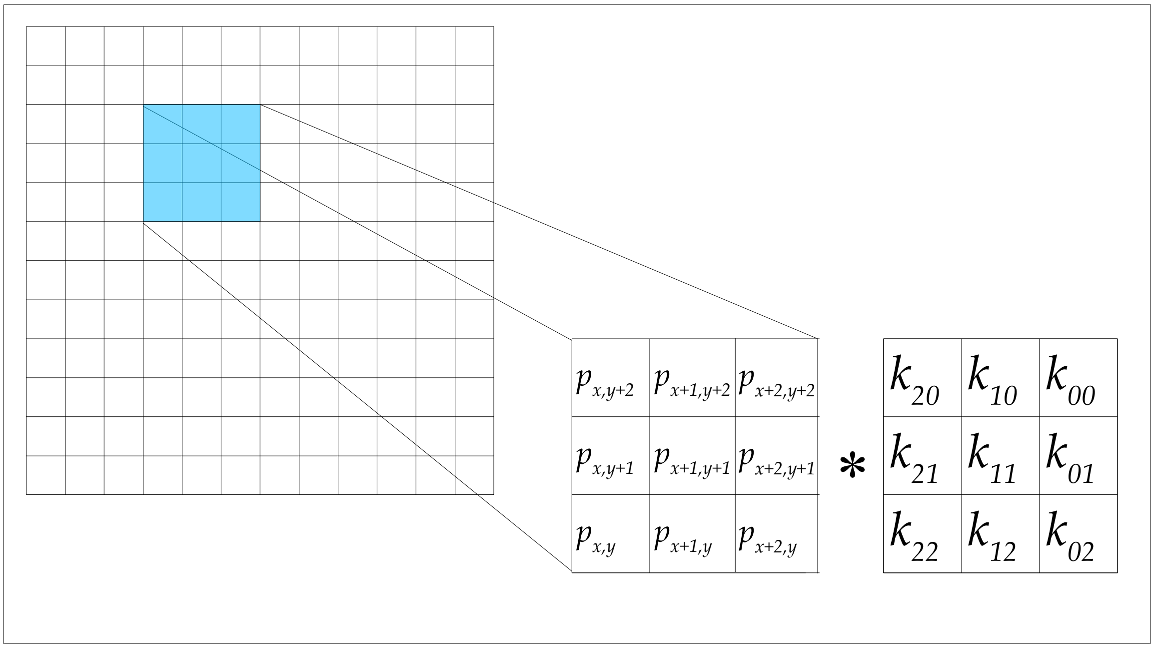


*Figure 23: Convolution With a Flipped Kernel*

The operation is applied to all channels (color and alpha) independently. If the `VG_FILTER_CHANNEL_MASK` parameter has its `VG_ALPHA` bit enabled, the convolved alpha value is used; otherwise, the original alpha value of each source pixel is used in the final destination premultiplication step.

```
void vgConvolve(VGImage dst, VGImage src,
                VGint kernelWidth, VGint kernelHeight,
                VGint shiftX, VGint shiftY,
                const VGshort * kernel,
                VGfloat scale,
                VGfloat bias,
                VGTilingMode tilingMode)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if either `dst` or `src` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if either `dst` or `src` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `src` and `dst` overlap

– if `kernelWidth` or `kernelHeight` is less than or equal to 0 or greater than `VG_MAX_KERNEL_SIZE`

– if `kernel` is `NULL`

– if `kernel` is not properly aligned

– if `tilingMode` is not one of the values from the `VGTilingMode` enumeration

### *vgSeparableConvolve*

The **vgSeparableConvolve** function applies a user-supplied separable convolution kernel to a normalized source image `src`. A separable kernel is a two-dimensional kernel in which each entry $k_{ij}$ is equal to a product $kx_i * ky_j$ of elements from two one-dimensional kernels, one horizontal and one vertical.

The lengths of the one-dimensional arrays `kernelX` and `kernelY` are given by `kernelWidth` and `kernelHeight`, respectively; the kernel values are specified as arrays of `VGfloat`s. The `shiftX` and `shiftY` parameters specifies a translation between the source and destination images. The result of the convolution is multiplied by a `scale` factor, and a `bias` is added.

The output pixel (*x, y*) is defined as:

$$s\left(\sum_{0\le i<w}\sum_{0\le j<h} kx_{(w-i-1)} ky_{(h-j-i)} \, p(x+i-shiftX\,,\, y+j-shiftY)\right)+b\,,$$

where $w$ = `kernelWidth`, $h$ = `kernelHeight`, $kx_i$ is the one-dimensional horizontal kernel element at position *i*, $ky_j$ is the one-dimensional vertical kernel element at position j, *s* is the `scale`, *b* is the bias, and *p*(*x, y*) is the source pixel at (*x, y*), or the result of source edge extension defined by `tilingMode`, which takes a value from the `VGTilingMode` enumeration (see Section 9.4.1). Note that the use of the kernel indices (*w–i–1*) and (*h–j–1*) implies that the kernel is rotated 180 degrees relative to the source image in order to conform to the mathematical definition of convolution.

The operation is applied to all channels (color and alpha) independently. If the `VG_FILTER_CHANNEL_MASK` parameter has its `VG_ALPHA` bit enabled, the convolved alpha value is used; otherwise, the original alpha value of each source pixel is used in the final destination premultiplication step.

```
void vgSeparableConvolve(VGImage dst, VGImage src,
                         VGint kernelWidth, VGint kernelHeight,
                         VGint shiftX, VGint shiftY,
                         const VGshort * kernelX,
                         const VGshort * kernelY,
                         VGfloat scale,
                         VGfloat bias,
                         VGTilingMode tilingMode)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if either dst or src is not a valid image handle, or is not shared with the current context

VG_IMAGE_IN_USE_ERROR

– if either dst or src is currently a rendering target

VG_ILLEGAL_ARGUMENT_ERROR

– if src and dst overlap

– if kernelWidth or kernelHeight is less than or equal to 0 or greater than VG_MAX_SEPARABLE_KERNEL_SIZE

– if kernelX or kernelY is NULL

– if kernelX or kernelY is not properly aligned

– if tilingMode is not one of the values from the VGTilingMode enumeration

### *vgGaussianBlur*

The **vgGaussianBlur** function computes the convolution of a normalized source image src with a separable kernel defined in each dimension by the Gaussian function *G*(*x, s*):

$$G(x, s) = \frac{1}{\sqrt{2\pi s^2}} e^{-\frac{x^2}{2s^2}}$$

where *s* is the *standard deviation*.

The two-dimensional kernel is defined by multiplying together two one-dimensional kernels, one for each axis:

$$k(x, y) = G(x, s_x) * G(y, s_y) = \frac{1}{2\pi s_x s_y} e^{-\left(\frac{x^2}{2{s_x}^2} + \frac{y^2}{2{s_y}^2}\right)}$$

where $s_x$ and $s_y$ are the (positive) standard deviations in the horizontal and vertical directions, given by the stdDeviationX and stdDeviationY parameters respectively. This kernel has special properties that allow for very efficient implementation; for example, the implementation may use multiple passes with simple kernels to obtain the same overall result with higher performance than direct convolution. If stdDeviationX and stdDeviationY are equal, the kernel is rotationally symmetric.

Source pixels outside the source image bounds are defined by `tilingMode`, which takes a value from the `VGTilingMode` enumeration (see Section 9.4.1)

The operation is applied to all channels (color and alpha) independently. If the `VG_FILTER_CHANNEL_MASK` parameter has its `VG_ALPHA` bit enabled, the convolved alpha value is used; otherwise, the original alpha value of each source pixel is used in the final destination premultiplication step.

```
void vgGaussianBlur(VGImage dst, VGImage src,
                    VGfloat stdDeviationX,
                    VGfloat stdDeviationY,
                    VGTilingMode tilingMode)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if either `dst` or `src` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if either `dst` or `src` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `src` and `dst` overlap

– if `stdDeviationX` or `stdDeviationY` is less than or equal to 0

– if `tilingMode` is not one of the values from the `VGTilingMode` enumeration

## 11.5 Lookup Tables

### vgLookup

The **vgLookup** function passes each image channel of the normalized source image `src` through a separate lookup table.

Each channel of the normalized source pixel is used as an index into the lookup table for that channel by multiplying the normalized value by 255 and rounding to obtain an 8-bit integral value. Each `LUT` parameter should contain 256 `VGubyte` entries. The outputs of the lookup tables are concatenated to form an `RGBA_8888` pixel value, which is interpreted as `lRGBA_8888`, `lRGBA_8888_PRE`, `sRGBA_8888`, or `sRGBA_8888_PRE`, depending on the values of `outputLinear` and `outputPremultiplied`.

The resulting pixels are converted into the destination format using the normal pixel format conversion rules.

```
void vgLookup(VGImage dst, VGImage src,
              const VGubyte * redLUT,
              const VGubyte * greenLUT,
              const VGubyte * blueLUT,
              const VGubyte * alphaLUT,
              VGboolean outputLinear,
              VGboolean outputPremultiplied)
```

***ERRORS***

VG_BAD_HANDLE_ERROR

– if either dst or src is not a valid image handle, or is not shared with the current context

VG_IMAGE_IN_USE_ERROR

– if either dst or src is currently a rendering target

VG_ILLEGAL_ARGUMENT_ERROR

– if src and dst overlap

– if any pointer parameter is NULL

### *vgLookupSingle*

The **vgLookupSingle** function passes a single image channel of the normalized source image src, selected by the sourceChannel parameter, through a combined lookup table that produces whole pixel values. Each normalized source channel value is multiplied by 255 and rounded to obtain an 8 bit integral value.

The specified sourceChannel of the normalized source pixel is used as an index into the lookup table. If the source image is in a single-channel grayscale (VG_lL_8, VG_sL_8, or VG_BW_1) or alpha-only (VG_A_8) format, the sourceChannel parameter is ignored and the single channel is used. The lookupTable parameter should contain 256 4-byte aligned entries in an RGBA_8888 pixel value, which is interpreted as lRGBA_8888, lRGBA_8888_PRE, sRGBA_8888, or sRGBA_8888_PRE, depending on the values of outputLinear and outputPremultiplied.

The resulting pixels are converted into the destination format using the normal pixel format conversion rules.

```
void vgLookupSingle(VGImage dst, VGImage src,
                    const VGuint * lookupTable,
                    VGImageChannel sourceChannel,
                    VGboolean outputLinear,
                    VGboolean outputPremultiplied)
```

***ERRORS***

`VG_BAD_HANDLE_ERROR`

– if either `dst` or `src` is not a valid image handle, or is not shared with the current context

`VG_IMAGE_IN_USE_ERROR`

– if either `dst` or `src` is currently a rendering target

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `src` and `dst` overlap

– if `src` is in an RGB pixel format and `sourceChannel` is not one of `VG_RED`, `VG_GREEN`, `VG_BLUE` or `VG_ALPHA` from the `VGImageChannel` enumeration

– if `lookupTable` is `NULL`

– if `lookupTable` is not properly aligned

# 12 Blending

As drawing takes place, the painted pixels that result from the paint generation (stage 6) or image interpolation (stage 7) stages of the rendering pipeline are blended into the existing pixels of the drawing surface. Blending is performed using a subset of the standard Porter-Duff blending rules [PORT84] along with several additional rules.

The source pixels are converted into the destination color space prior to blending.

## 12.1 Blending Equations

A blending mode defines an alpha blending function $\alpha(\alpha_{src}, \alpha_{dst})$ and a color blending function $c(c_{src}, c_{dst}, \alpha_{src}, \alpha_{dst})$. Given a source alpha and color tuple $(R_{src}, G_{src}, B_{src}, \alpha_{src})$ and a destination alpha and color tuple $(R_{dst}, G_{dst}, B_{dst}, \alpha_{dst})$, blending replaces the destination with the blended tuple $(c(R_{src}, R_{dst}, \alpha_{src}, \alpha_{dst}), c(G_{src}, G_{dst}, \alpha_{src}, \alpha_{dst}), c(B_{src}, B_{dst}, \alpha_{src}, \alpha_{dst}), \alpha(\alpha_{src}, \alpha_{dst}))$.

If either the source or destination is stored in a premultiplied format (*i.e.*, pixels are stored as tuples of the form $(\alpha*R, \alpha*G, \alpha*B, \alpha)$), the alpha value is conceptually divided out prior to applying the blending equations described above. If the destination is premultiplied, the destination alpha value is multiplied into each color channel prior to storage. If the destination format does not store alpha values, an alpha value of 1 is used in place of $\alpha_{dst}$.

## 12.2 Porter-Duff Blending

Porter-Duff blending defines an alpha value $\alpha(\alpha_{src}, \alpha_{dst}) = \alpha_{src}*F_{src} + \alpha_{dst}*F_{dst}$ and color $c'(c'_{src}, c'_{dst}, \alpha_{src}, \alpha_{dst}) = c'_{src}*F_{src} + c'_{dst}*F_{dst}$, where $F_{src}$ and $F_{dst}$ are defined by the blend mode and the source and destination alpha values according to Table 13 below and $c' = \alpha*c$ is a premultiplied color value. For non-premultiplied colors, we define the equivalent formula $c(c_{src}, c_{dst}, \alpha_{src}, \alpha_{dst}) = (\alpha_{src}*c_{src}*F_{src} + \alpha_{dst}*c_{dst}*F_{dst})/\alpha(\alpha_{src}, \alpha_{dst})$ (taking the value to be 0 where division by 0 would occur).

Porter-Duff blending modes are derived from the assumption that each additional primitive being drawn is uncorrelated with previous ones. That is, if a previously drawn primitive $p$ occupies a fraction $f_p$ of a pixel, and a new primitive $q$ occupies a fraction $f_q$, Porter-Duff blending assumes that a fraction $f_p*f_q$ of the pixel will be occupied by both primitives, a fraction $f_p - f_p*f_q = f_p\ (1 - f_q)$ will be occupied by $p$ only, and a fraction $f_q - f_p*f_q = f_q\ (1 - f_p)$ will be occupied by $q$ only. A total fraction of $f_p + f_q - f_p*f_q$ of the pixel is occupied by the union of the primitives.

| ***Blend Mode*** | $F_{src}$ | $F_{dst}$ |
|---|---|---|
| Src | 1 | $0$ |
| Src **over** Dst | 1 | $1 - \alpha_{src}$ |
| Dst **over** Src | $1 - \alpha_{dst}$ | 1 |
| Src **in** Dst | $\alpha_{dst}$ | 0 |
| Dst **in** Src | 0 | $\alpha_{src}$ |

*Table 13: Porter-Duff Blending Modes*

## 12.3 Additional Blending Modes

A number of additional blending modes are available. These modes are a subset of the SVG image blending modes. Note that the SVG "Normal" blending mode is equivalent to the Porter-Duff "Src **over** Dst" mode described above. The additional blend modes have the following effects:

- `VG_BLEND_MULTIPLY` – Multiply the source and destination colors together, producing the effect of placing a transparent filter over a background. A black source pixel forces the destination to black, while a white source pixel leaves the destination unchanged. If all alpha values are 1, this reduces to multiplying the source and destination color values.
- `VG_BLEND_SCREEN` – The opposite of multiplication, producing the effect of projecting a slide over a background. A black source pixel leaves the destination unchanged, while a white source pixel forces the destination to white. If all alpha values are 1, this reduces to adding the source and destination color values, and subtracting their product.
- `VG_BLEND_DARKEN` – Compute (Src **over** Dst) and (Dst **over** Src) and take the smaller (darker) value for each channel. If all alpha values are 1, this reduces to choosing the smaller value for each color channel.
- `VG_BLEND_LIGHTEN` – Compute (Src **over** Dst) and (Dst **over** Src) and take the larger (lighter) value for each channel. If all alpha values are 1, this reduces to choosing the larger value for each color channel.

The new destination alpha value for the blending modes defined in this section is always equal to $\alpha(\alpha_{src}, \alpha_{dst}) = \alpha_{src} + \alpha_{dst}*(1 - \alpha_{src})$, as for Porter-Duff "Src **over** Dst" blending. The formulas for each additional blending mode are shown in Table 14. The value shown in the right-hand column is the product of the new color value $c(c_{src}, c_{dst}, \alpha_{src}, \alpha_{dst})$ and alpha value $\alpha(\alpha_{src}, \alpha_{dst})$.

| Blend Type | $c'(c_{src}, c_{dst}, \alpha_{src}, \alpha_{dst})$ |
|---|---|
| VG_BLEND_MULTIPLY | $\alpha_{src}*c_{src}*(1-\alpha_{dst}) + \alpha_{dst}*c_{dst}*(1-\alpha_{src}) + \alpha_{src}*c_{src}*\alpha_{dst}*c_{dst}$ |
| VG_BLEND_SCREEN | $\alpha_{src}*c_{src} + \alpha_{dst}*c_{dst} - \alpha_{src}*c_{src}*\alpha_{dst}*c_{dst}$ |
| VG_BLEND_DARKEN | $min(\alpha_{src}*c_{src} + \alpha_{dst}*c_{dst}*(1-\alpha_{src}), \alpha_{dst}*c_{dst} + \alpha_{src}*c_{src}*(1-\alpha_{dst}))$ |
| VG_BLEND_LIGHTEN | $max(\alpha_{src}*c_{src} + \alpha_{dst}*c_{dst}*(1-\alpha_{src}), \alpha_{dst}*c_{dst} + \alpha_{src}*c_{src}*(1-\alpha_{dst}))$ |

*Table 14: Additional Blending Equations*

## 12.4 Additive Blending

The Porter-Duff assumption of uncorrelated alpha described above does not hold for primitives that are known to be disjoint (for example, a set of triangles with shared vertices and edges forming a mesh, or a series of text glyphs that have been spaced according to known metrics). In these cases, we expect no portion of the pixel to be occupied by both primitives and a total fraction of $f_p + f_q$ to be occupied by the union of the primitives. The *additive* blending rule may be used in this case. It sets the final alpha value of the blended pixel to the clamped sum $\alpha(\alpha_{src}, \alpha_{dst}) = min(\alpha_{src}+\alpha_{dst}, 1)$ and the color to $c(c_{src}, c_{dst}) = (\alpha_{src}*c_{src} + \alpha_{dst}*c_{dst})/min(\alpha_{src} + \alpha_{dst}, 1)$. If all alpha values are 1, this reduces to adding the values of each source color channel.

## 12.5 Setting the Blend Mode

### VGBlendMode

The `VGBlendMode` enumeration defines the possible blending modes:

```
typedef enum {
  VG_BLEND_SRC        = 0x2000,
  VG_BLEND_SRC_OVER   = 0x2001,
  VG_BLEND_DST_OVER   = 0x2002,
  VG_BLEND_SRC_IN     = 0x2003,
  VG_BLEND_DST_IN     = 0x2004,
  VG_BLEND_MULTIPLY   = 0x2005,
  VG_BLEND_SCREEN     = 0x2006,
  VG_BLEND_DARKEN     = 0x2007,
  VG_BLEND_LIGHTEN    = 0x2008,
  VG_BLEND_ADDITIVE   = 0x2009
} VGBlendMode;
```

Use **vgSeti** with a parameter type of `VG_BLEND_MODE` to set the blend mode:

```
VGBlendMode mode;
vgSeti(VG_BLEND_MODE, mode);
```

# 13 Querying Hardware Capabilities

OpenVG implementations may vary considerably in their performance characteristics. A simple hardware query mechanism is provided to allow applications to make informed choices regarding data representations, in order to maximize their chances of obtaining hardware-accelerated performance. Currently, OpenVG provides hardware queries for image formats and path datatypes.

### *VGHardwareQueryType*

The `VGHardwareQueryType` enumeration defines the set of possible hardware queries. Currently these are restricted to queries regarding image formats and path datatypes.

```
typedef enum {
  VG_IMAGE_FORMAT_QUERY  = 0x2100,
  VG_PATH_DATATYPE_QUERY = 0x2101
} VGHardwareQueryType;
```

### *VGHardwareQueryResult*

The `VGHardwareQueryResult` enumeration defines the return values from a hardware query, indicating whether or not the item being queried is hardware accelerated.

```
typedef enum {
  VG_HARDWARE_ACCELERATED   = 0x2200,
  VG_HARDWARE_UNACCELERATED = 0x2201
} VGHardwareQueryResult;
```

### *vgHardwareQuery*

The **vgHardwareQuery** function returns a value indicating whether a given `setting` of a property of a type given by `key` is generally accelerated in hardware on the currently running OpenVG implementation.

The return value will be one of the values `VG_HARDWARE_ACCELERATED` or `VG_HARDWARE_UNACCELERATED`, taken from the `VGHardwareQueryResult` enumeration. The legal values for the setting parameter depend on the value of the `key` parameter, as indicated by Table 15.

| ***Value of*** `key` | ***Allowable values for*** `setting` |
|---|---|
| `VG_IMAGE_FORMAT_QUERY` | `VGImageFormat` (p. ) |
| `VG_PATH_DATATYPE_QUERY` | `VGPathDatatype` (p. 50) |

*Table 15: Query Key Enumeration Types*

```
VGHardwareQueryResult vgHardwareQuery(VGHardwareQueryType key,
                                      VGint setting)
```

***ERRORS***

`VG_ILLEGAL_ARGUMENT_ERROR`

– if `key` is not one of the values from the `VGHardwareQueryType` enumeration

– if `setting` is not one of the values from the enumeration associated with `key`

# 14 Extending the API

OpenVG is designed to be extended using an extension mechanism modeled after that of OpenGL and OpenGL ES. An extension may define new state elements, new datatypes, new values for existing parameter types, and new functions. Use of these features may alter the operation of the rendering pipeline. However, an extension must have no effect on programs that do not enable any of its features.

## 14.1 Extension Naming Conventions

An OpenVG extension is named by a string of the form `OVG_`*type_name*, where *type* is either the string `EXT` or a vendor-specific string and *name* is a name assigned by the extension author. A letter `X` added to the end of *type* indicates that the extension is experimental.

Values (*e.g.*, enumerated values or preprocessor `#define`s) defined by an extension carry the suffix *_type*. Functions and datatypes carry the suffix *type* without a separating underscore.

The `openvg.h` header file will define a preprocessor macro with the name `OVG_`*type_name* and a value of 1 for each supported extension.

## 14.2 The Extension Registry

Khronos, or its designee, will maintain a publicly-accessible registry of extensions. This registry will contain, for each extension, at least the following information:

- The name of the extension in the form `OVG_`*type_name*
- An email address of a contact person
- A list of dependencies on other extensions
- A statement on the IP status of the extension
- An overview of the scope and semantics of the extension
- New functions defined by the extension
- New datatypes defined by the extension
- New values to be added to existing enumerated datatypes
- Additions and changes to the OpenVG specification
- New errors generated by functions affected by the extension
- New state defined by the extension
- Authorship information and revision history

## 14.3 Using Extensions

Extensions may be detected statically, by means of preprocessor symbols, or dynamically, by means of the **vgGetString** function. Extension functions may be included in application code statically by placing appropriate "#ifdef" directives around functions that require the presence of a particular extension, and may also be accessed dynamically through function pointers returned by **eglGetProcAddress** or by other platform-specific means.

### 14.3.1 Accessing Extensions Statically

The extensions defined by a given platform are defined in the `openvg.h` header file, or in header files automatically included by `openvg.h`. In order to write applications that run on platforms with and without a given extension, conditional compilation based on the presence of the extension's preprocessor macro may be used:

```
#ifdef OVG_EXT_my_extension
  vgMyExtensionFuncEXT(...);
#endif
```

### 14.3.2 Accessing Extensions Dynamically

OpenVG contains a mechanism for applications to access information about the runtime platform, and to access extensions that may not have been present when the application was compiled.

#### VGStringID

```
typedef enum {
  VG_VENDOR     = 0x2300,
  VG_RENDERER   = 0x2301,
  VG_VERSION    = 0x2302,
  VG_EXTENSIONS = 0x2303
} VGStringID;
```

#### vgGetString

The **vgGetString** function returns information about the OpenVG implementation, including extension information. The combination of `VG_VENDOR` and `VG_RENDERER` may be used together as a platform identifier by applications that wish to recognize a particular platform and adjust their algorithms based on prior knowledge of platform performance characteristics.

If `name` is `VG_VENDOR`, the name of company responsible for this OpenVG implementation is returned. This name does not change from release to release.

If `name` is `VG_RENDERER`, the name of the renderer is returned. This name is typically specific to a particular configuration of a hardware platform, and does not change from release to release.

If `name` is `VG_VERSION`, the version number of the renderer is returned as a string in the form *major_number.minor_number*.

If `name` is `VG_EXTENSIONS`, a space-separated list of supported extensions to OpenVG is returned.

For other values of `name`, `NULL` is returned.

```
const VGubyte * vgGetString(VGStringID name)
```

### *eglGetProcAddress*

Functions defined by an extension may be accessed by means of a function pointer obtained from the EGL function `eglGetProcAddress`. If EGL is not present, the platform may define an alternate method of obtaining extension function pointers.

## *14.4 Creating Extensions*

Any vendor may define a vendor-specific extension. Each vendor should apply to Khronos to obtain a vendor string and any numerical token values required by the extension.

An OpenVG extension may be deemed a shared extension if two or more vendors agree in good faith to ship an extension, or the Khronos OpenVG working group determines that it is in the best interest of its members that the extension be shared. A shared extension may be adopted (with appropriate naming changes) into a subsequent release of the OpenVG specification.

# 15 API Conformance

All OpenVG implementations are required to pass a conformance test suite. The exact details of the conformance testing process are available in a separate document. This chapter outlines the OpenVG conformance test philosophy and provides information that may be useful in order to ensure conformant implementations.

## 15.1 Conformance Test Principles

The OpenVG specification attempts to strike a balance between the needs of implementers and application developers. While application developers desire a stable platform that delivers predictable results, they also wish to avoid reduced performance due to an excessively strict API definition. By allowing some flexibility in how the API is implemented, implementations may be optimized for a wide variety of platforms with varying price, performance, and power characteristics. The purpose of conformance testing is to ensure that implementations with different internal approaches produce similar results.

### 15.1.1 Window System Independence

Because OpenVG does not mandate a specific window system or display management API, the conformance test suite will isolate all display dependencies in a module that may be customized for each platform. An EGL-based implementation of this module will be provided, but implementers are free to replace this implementation with one that is specific to their platform.

### 15.1.2 Antialiasing Algorithm Independence

It is anticipated that a wide variety of antialiasing approaches will be used in the marketplace. Low-cost antialiasing remains a research topic, and new algorithms continue to emerge. The conformance suite must allow for this variation, while not allowing differences in antialiasing to cover up inadequacies in other portions of the implementation such as matrix transformation or curve subdivision.

### 15.1.3 On-Device and Off-Device Testing

Certain conformance tests require only a small memory footprint, and may be run directly on the target device. Other tests operate by generating an image, which must be copied off-device. A desktop tool is used to compare the generated images against a set of reference images.

## 15.2 Types of Conformance Tests

Conformance tests fall into several classes, outlined below.

### 15.2.1 Pipeline Tests

A set of tests will be provided that attempt to isolate each pipeline stage by means of suitable parameter settings. These tests will provide assurance that each stage is functioning correctly.

### 15.2.2 Self-Consistency Tests

Certain portions of the API are required to produce exact results. For example, setting and retrieving API state, image, paint, and path parameters, setting and retrieving matrix values; error generation; and pixel copies are defined to have exact results. The conformance suite will provide strict checking for these behaviors.

### 15.2.3 Matrix Tests

The conformance suite will exercise various matrix operations and compare the results against double-precision values. The comparison threshold will be set to exclude implementations with insufficient internal precision.

### 15.2.4 Interior/Exterior Tests

Although antialiasing may have varying effects on shape boundaries, the portions of the interior and exterior of shapes that are more than 1 ½ pixels from a geometric boundary should not be affected by that boundary. If a shape is drawn using color paint, a set of known interior and exterior pixels may be tested for equality with the paint color.

### 15.2.5 Positional Invariance

Drawing should not depend on absolute screen coordinates, except for minor differences due to spatially-variant sampling and dither patterns when copying to the screen. The conformance suite will include tests that verify the positional independence of drawing.

### 15.2.6 Image Comparison Tests

To allow for controlled variation, the conformance suite will provide a set of rendering code fragments, along with reference images that have been generated using a high-quality implementation. Implementation-generated images will be compared to these reference images using a fuzzy comparison system. This approach is intended to allow for small differences in the accuracy of geometry and color processing and antialiasing, while rejecting larger differences that are considered visually unacceptable. The comparison threshold will be determined by generating images with a variety of acceptable and unacceptable differences and comparing them against the reference image.

# 16 The VGU Utility Library

For convenience, OpenVG provides an optional utility library known as VGU. Applications may choose whether to link to VGU at compile time; the library is not guaranteed to be present on the run-time platform. VGU is designed so it may be implemented in a portable manner using only the public functionality provided by the OpenVG library. VGU functions may alter the error state of the OpenVG context in which they run (*i.e.*, the value returned by **vgGetError**), but do not otherwise alter the OpenVG state when they complete without generating a `VGU_OUT_OF_MEMORY_ERROR`. VGU functions are defined in a `vgu.h` header file.

### *VGU_VERSION_1_0*

Each version of the VGU library will define constants indicating the set of supported library versions. For the current version, the constant `VGU_VERSION_1_0` is defined. Future versions will continue to define the constants for all previous versions with which they are backward compatible.

```
#define VGU_VERSION_1_0 1
```

### *VGUErrorCode*

The `VGUErrorCode` enumeration contains constants specifying possible errors generated by VGU functions. Any VGU function may return `VGU_OUT_OF_MEMORY_ERROR`, in which case the function may have caused changes to the state of OpenVG or to drawing surface pixels prior to failure.

```
typedef enum {
  VGU_NO_ERROR                          = 0,
  VGU_BAD_HANDLE_ERROR                  = 0xF000,
  VGU_ILLEGAL_ARGUMENT_ERROR            = 0xF001,
  VGU_OUT_OF_MEMORY_ERROR               = 0xF002,
  VGU_PATH_CAPABILITY_ERROR             = 0xF003,
  VGU_BAD_WARP_ERROR                    = 0xF004
} VGUErrorCode;
```

## *16.1 Higher-level Geometric Primitives*

The `VGU` library contains functions that allow applications to specify a number of higher-level geometric primitives to be appended to a path. Each primitive is immediately reduced to a series of line segments, Bézier curves, and arcs. Coordinates may overflow silently if they fall outside the range defined by the path datatype, scale, and bias.

### 16.1.1 Lines

#### vguLine

**vguLine** appends a line segment to a path. This is equivalent to the following pseudo-code:

```
LINE(x0, y0, x1, y1):

MOVE_TO_ABS x0, y0
LINE_TO_ABS x1, y1
```

```
VGUErrorCode vguLine(VGPath path,
                     VGfloat x0, VGfloat y0,
                     VGfloat x1, VGfloat y1)
```

***ERRORS***

`VGU_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

`VGU_PATH_CAPABILITY_ERROR`

– if `VG_PATH_CAPABILITY_APPEND_TO` is not enabled for `path`

### 16.1.2 Polylines and Polygons

#### vguPolygon

**vguPolygon** appends a polyline or polygon to a path. This is equivalent to the following pseudo-code:

```
POLYGON(points, count):

MOVE_TO_ABS points[0], points[1]
for (i = 1; i < count; i++) {
     LINE_TO_ABS points[2*i], points[2*i + 1]
}
if (closed) CLOSE_PATH
```

There are `2*count` coordinates in `points`.

```
VGUErrorCode vguPolygon(VGPath path,
                        const VGfloat * points, VGint count,
                        VGboolean closed)
```

***ERRORS***

VGU_BAD_HANDLE_ERROR

– if path is not a valid path handle, or is not shared with the current context

VGU_PATH_CAPABILITY_ERROR

– if VG_PATH_CAPABILITY_APPEND_TO is not enabled for path

VGU_ILLEGAL_ARGUMENT_ERROR

– if points is NULL

– if points is not properly aligned

– if count is less than or equal to 0

## 16.1.3 Rectangles

### vguRect

The **vguRect** function appends an axis-aligned rectangle with its lower-left corner at (x, y) and a given width and height to a path. This is equivalent to the following pseudo-code:

```
RECT(x, y, width, height):

MOVE_TO_ABS    x, y
HLINE_TO_REL   width
VLINE_TO_REL   height
HLINE_TO_REL  -width
CLOSE_PATH
```

```
VGUErrorCode vguRect(VGPath path,
                     VGfloat x, VGfloat y,
                     VGfloat width, VGfloat height)
```

***ERRORS***

VGU_BAD_HANDLE_ERROR

– if path is not a valid path handle, or is not shared with the current context

VGU_PATH_CAPABILITY_ERROR

– if VG_PATH_CAPABILITY_APPEND_TO is not enabled for path

VGU_ILLEGAL_ARGUMENT_ERROR

– if width or height are less than or equal to 0

## 16.1.4 Round-Cornered Rectangles

### vguRoundRect

The **vguRoundRect** function appends an axis-aligned round-cornered rectangle with the lower-left corner of its rectangular bounding box at (x, y) and a given width, height, arcWidth, and arcHeight to a path. This is equivalent to the following pseudo-code:

```
ROUNDRECT(x, y, w, h, arcWidth, arcHeight):

MOVE_TO_ABS      (x + arcWidth/2), y
HLINE_TO_REL    width – arcWidth
SCCWARC_TO_REL  arcWidth/2, arcHeight/2, 0,  arcWidth/2,  arcHeight/2
VLINE_TO_REL    height – arcHeight
SCCWARC_TO_REL  arcWidth/2, arcHeight/2, 0, -arcWidth/2,  arcHeight/2
HLINE_TO_REL    -(width – arcWidth)
SCCWARC_TO_REL  arcWidth/2, arcHeight/2, 0, -arcWidth/2, -arcHeight/2
VLINE_TO_REL    -(height – arcHeight)
SCCWARC_TO_REL  arcWidth/2, arcHeight/2, 0,  arcWidth/2, -arcHeight/2
CLOSE_PATH
```

If arcWidth is less than 0, it is clamped to 0. If arcWidth is greater than width, its value is clamped to that of width. Similarly, arcHeight is clamped to a value between 0 and height. The arcs are included even when arcWidth and/or arcHeight is 0.

```
VGUErrorCode vguRoundRect(VGPath path,
                          VGfloat x, VGfloat y,
                          VGfloat width, VGfloat height,
                          VGfloat arcWidth, VGfloat arcHeight)
```

***ERRORS***

VGU_BAD_HANDLE_ERROR

– if path is not a valid path handle, or is not shared with the current context

VGU_PATH_CAPABILITY_ERROR

– if VG_PATH_CAPABILITY_APPEND_TO is not enabled for path

VGU_ILLEGAL_ARGUMENT_ERROR

– if width or height is less than or equal to 0

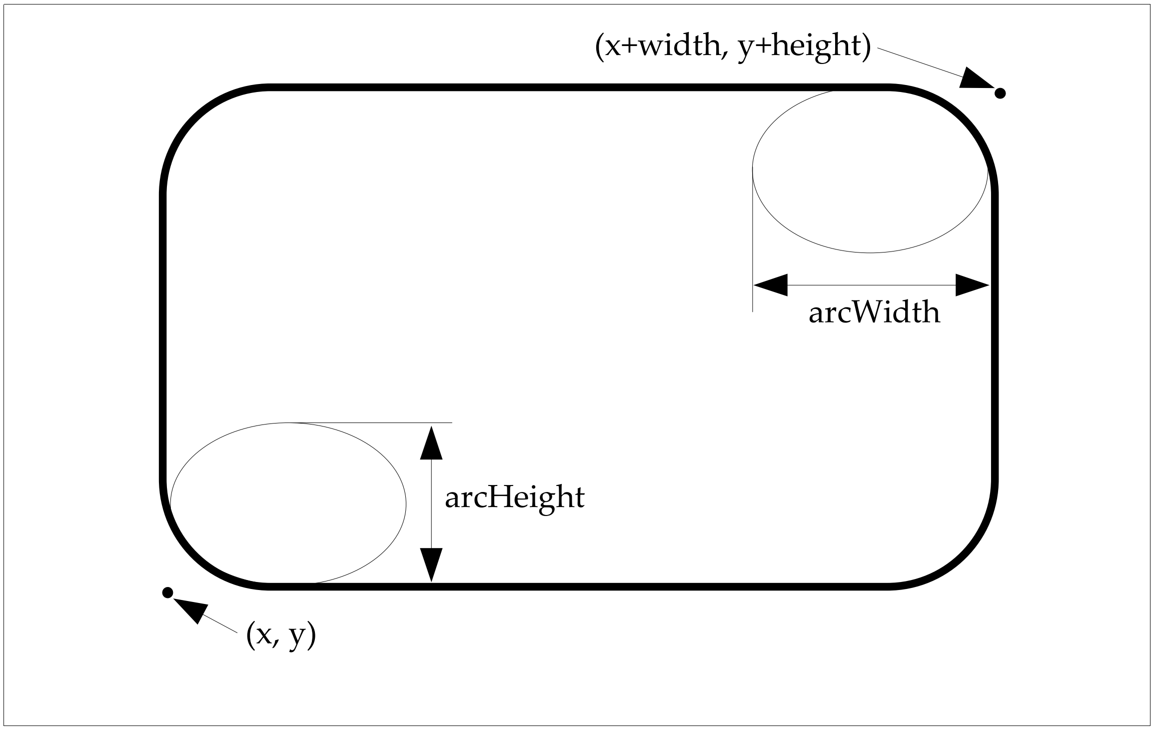


*Figure 24: Round Rectangle Parameters*

### 16.1.5 Ellipses

#### vguEllipse

**vguEllipse** appends an axis-aligned ellipse to a path. The center of the ellipse is given by (`cx, cy`) and the dimensions of the axis-aligned rectangle enclosing the ellipse are given by `width` and `height`. The ellipse begins at (*cx + width/2, cy*) and is stroked as two equal counter-clockwise arcs. This is equivalent to the following pseudo-code:

```
ELLIPSE(cx, cy, width, height):

MOVE_TO_ABS     cx + width/2, cy
SCCWARC_TO_REL  width/2, height/2, 0, -width, 0
SCCWARC_TO_REL  width/2, height/2, 0,  width, 0
CLOSE_PATH
```

```
VGUErrorCode vguEllipse(VGPath path,
                        VGfloat cx, VGfloat cy,
                        VGfloat width, VGfloat height)
```

***ERRORS***

`VGU_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

`VGU_PATH_CAPABILITY_ERROR`

– if `VG_PATH_CAPABILITY_APPEND_TO` is not enabled for `path`

`VGU_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0

### 16.1.6 Arcs

#### VGUArcType

The `VGUArcType` enumeration defines three values to control the style of arcs drawn by the **vguArc** function:

`VGU_ARC_OPEN` – arc segment only
`VGU_ARC_CHORD` – arc, plus line between arc endpoints
`VGU_ARC_PIE` – arc, plus lines from each endpoint to the ellipse center.

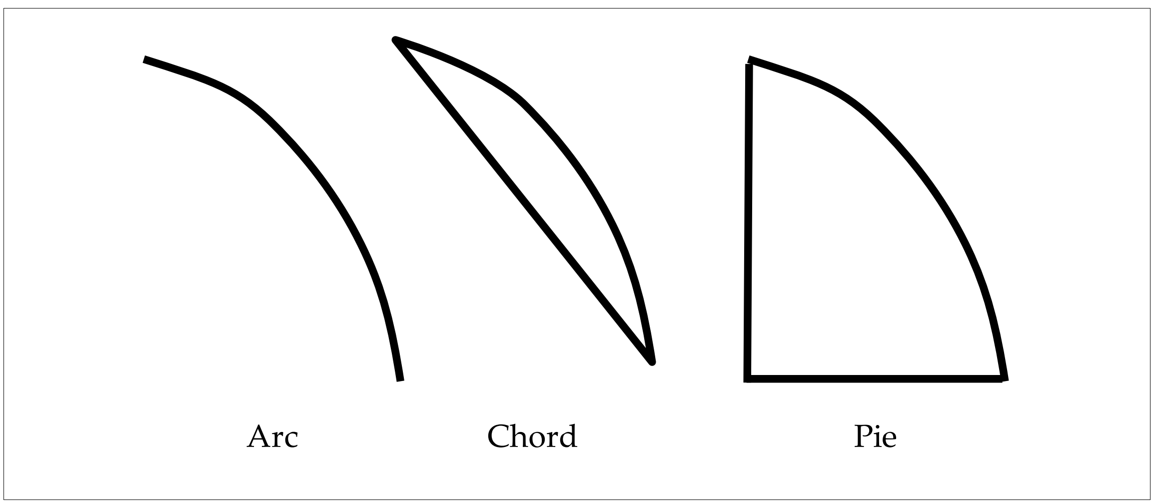


*Figure 25: `VGUArcType` Values*

#### vguArc

**vguArc** appends an elliptical arc to a path, possibly along with one or two line segments, according to the `arcType` parameter. The `startAngle` and `angleExtent` parameters are given in degrees, proceeding counter-clockwise from the positive X axis. The arc is defined on the unit circle, then scaled by the width and height of the ellipse; thus, the starting point of the arc has coordinates (*x* + *cos*(*startAngle*)**w*/2, *y* + *sin*(*startAngle*)**h*/2) and the ending point has coordinates (*x* + *cos*(*startAngle* + *angleExtent*)**w*/2, *y* + *sin*(*startAngle* + *angleExtent*)**h*/2).

If `angleExtent` is negative, the arc will proceed clockwise; it if is larger than 360 or smaller than -360, the arc will wrap around itself. The following pseudo-code illustrates the arc path generation:

```
ARC(x, y, w, h, startAngle, angleExtent, arcType):

last = startAngle + angleExtent
MOVE_TO_ABS  x+cos(startAngle)*w/2, y+sin(startAngle)*h/2
if (angleExtent > 0) {
  angle = startAngle + 180
  while (angle < last) {
    SCCW_ARC_TO_ABS w/2, h/2, 0, x+cos(angle)*w/2, y+sin(angle)*h/2
    angle += 180
  }
  SCCW_ARC_TO_ABS w/2, h/2, 0, x+cos(last)*w/2, y+sin(last)*h/2
} else {
  angle = startAngle - 180
  while (angle > last) {
    SCW_ARC_TO_ABS w/2, h/2, 0, x+cos(angle)*w/2, y+sin(angle)*h/2
    angle -= 180
  }
  SCW_ARC_TO_ABS w/2, h/2, 0, x+cos(last)*w/2, y+sin(last)*h/2
}

if arcType == VG_ARC_PIE
  MOVE_TO_ABS x, y
if arcType == VG_ARC_PIE || arcType == VG_ARC_CHORD
  CLOSE_PATH
```

```
VGUErrorCode vguArc(VGPath path,
                    VGfloat x, VGfloat y,
                    VGfloat width, VGfloat height,
                    VGfloat startAngle, VGfloat angleExtent,
                    VGUArcType arcType)
```

***ERRORS***

`VGU_BAD_HANDLE_ERROR`

– if `path` is not a valid path handle, or is not shared with the current context

`VGU_PATH_CAPABILITY_ERROR`

– if `VG_PATH_CAPABILITY_APPEND_TO` is not enabled for `path`

`VGU_ILLEGAL_ARGUMENT_ERROR`

– if `width` or `height` is less than or equal to 0
– if `arcType` is not one of the values from the `VGUArcType` enumeration

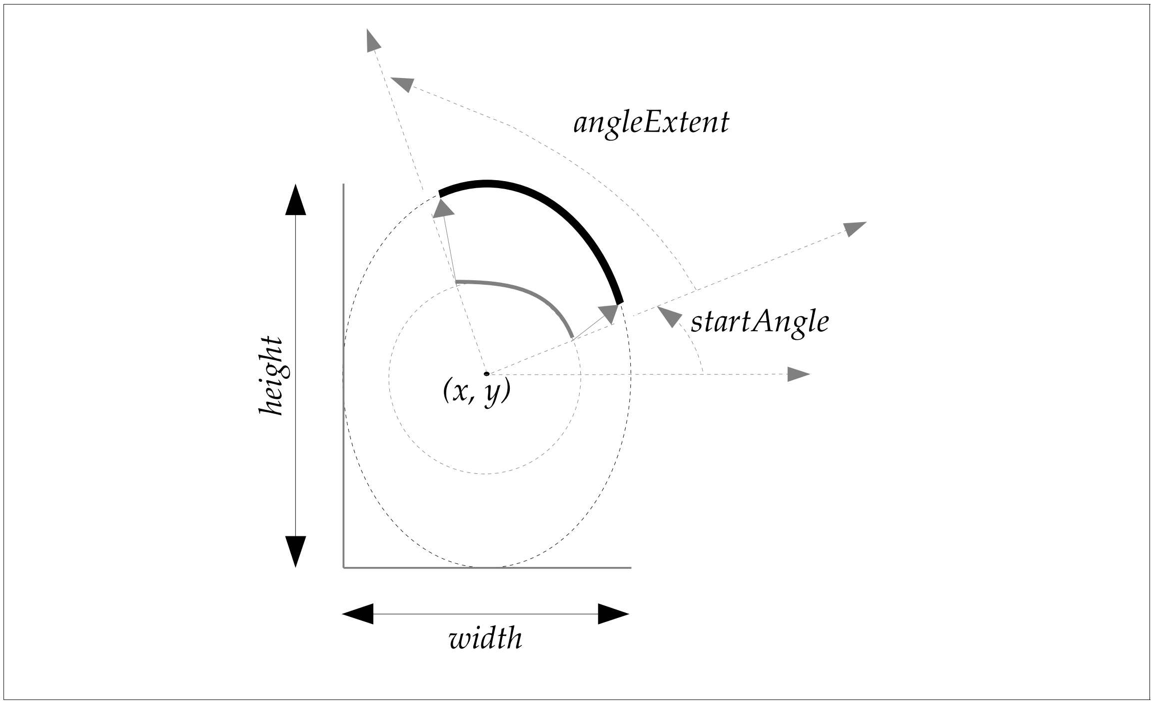


*Figure 26:* **vguArc** *Parameters*

## 16.2 Image Warping

VGU provides three utility functions to compute 3x3 projective transform matrices. The first two compute the transformation from an arbitrary quadrilateral onto the unit square, and vice versa. The third computes the transformation from an arbitrary quadrilateral to an arbitrary quadrilateral. The output transformation is stored into `matrix` as 9 elements in the order *{ sx, shy,* $w_0$*, shx, sy,* $w_1$*, tx, ty,* $w_2$ *}* (using the nomenclature of Section 6.2).

If there is no projective mapping that satisfies the given constraints due to a degeneracy, `VGU_BAD_WARP_ERROR` is returned and `matrix` is unchanged.

Formulas for computing projective warps may be found in [HECK89] and [WOLB90].

### vguComputeWarpQuadToSquare

The **vguComputeWarpQuadToSquare** function sets the entries of matrix to a projective transformation that maps the point (*sx0, sy0*) to (*0, 0*); (*sx1, sy1*) to (*1, 0*); (*sx2, sy2*) to (*0, 1*); and (*sx3, sy3*) to (*1, 1*). If a degeneracy is encountered, `VGU_BAD_WARP_ERROR` is returned and `matrix` is unchanged.

```
VGUErrorCode vguComputeWarpQuadToSquare(VGfloat sx0, VGfloat sy0,
                                        VGfloat sx1, VGfloat sy1,
                                        VGfloat sx2, VGfloat sy2,
                                        VGfloat sx3, VGfloat sy3,
                                        VGfloat * matrix)
```

***ERRORS***

VGU_ILLEGAL_ARGUMENT_ERROR

– if matrix is NULL

– if matrix is not properly aligned

VGU_BAD_WARP_ERROR

– if no non-degenerate transformation satisfies the constraints

### *vguComputeWarpSquareToQuad*

The **vguComputeWarpSquareToQuad** function sets the entries of matrix to a projective transformation that maps the point (*0, 0*) to (*dx0, dy0*); (*1, 0*) to (*dx1, dy1*); (*0, 1*) to (*dx2, dy2*); and (*1, 1*) to (*dx3, dy3*). If a degeneracy is encountered, VGU_BAD_WARP_ERROR is returned and matrix is unchanged.

```
VGUErrorCode vguComputeWarpSquareToQuad(VGfloat dx0, VGfloat dy0,
                                        VGfloat dx1, VGfloat dy1,
                                        VGfloat dx2, VGfloat dy2,
                                        VGfloat dx3, VGfloat dy3,
                                        VGfloat * matrix)
```

***ERRORS***

VGU_ILLEGAL_ARGUMENT_ERROR

– if matrix is NULL

– if matrix is not properly aligned

VGU_BAD_WARP_ERROR

– if no non-degenerate transformation satisfies the constraints

### *vguComputeWarpQuadToQuad*

The **vguComputeWarpQuadToQuad** function sets the entries of matrix to a projective transformation that maps the point (*sx0, sy0*) to (*dx0, dy0*); (*sx1, sy1*) to (*dx1, dy1*); (*sx2, sy2*) to (*dx2, dy2*); and (*sx3, sy3*) to (*dx3, dy3*). If a degeneracy is encountered, VGU_BAD_WARP_ERROR is returned and matrix is unchanged.

```
VGUErrorCode vguComputeWarpQuadToQuad(VGfloat dx0, VGfloat dy0,
                                      VGfloat dx1, VGfloat dy1,
                                      VGfloat dx2, VGfloat dy2,
                                      VGfloat dx3, VGfloat dy3,
                                      VGfloat sx0, VGfloat sy0,
                                      VGfloat sx1, VGfloat sy1,
                                      VGfloat sx2, VGfloat sy2,
                                      VGfloat sx3, VGfloat sy3,
                                      VGfloat * matrix)
```

***ERRORS***

`VGU_ILLEGAL_ARGUMENT_ERROR`

– if `matrix` is `NULL`

– if `matrix` is not properly aligned

`VGU_BAD_WARP_ERROR`

– if no non-degenerate transformation satisfies the constraints

# 17 Appendix A: Mathematics of Ellipses

The following sections are informative only. It contains mathematics pertaining to the representation of ellipses that may be of use to implementers. Some of the material is adapted from [SVGF04].

## *17.1 The Center Parameterization*

A common parameterization of an ellipse is in terms of the ellipse center point (*cx, cy*), horizontal and vertical radii *rh* and *rv*, rotation angle $\varphi$, and starting and ending angles $\theta 1$ and $\theta 2$ between 0 and 360 degrees. The parameters are listed in Table 16.

The elliptical arc may be evaluated in terms of an angular parameter $\theta$ that ranges from $\theta 1$ to $\theta 2$:

$$f(cx, cy, rh, rv, \phi, \theta) = \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix} \cdot \begin{bmatrix} rh\cos\theta \\ rv\sin\theta \end{bmatrix} + \begin{bmatrix} cx \\ cy \end{bmatrix}$$

An ellipse in the center parameterization may be viewed as a unit circle, parameterized as $(x, y) = (cos(\theta), sin(\theta))$ that has been placed through an affine transformation consisting of a rotation and a non-uniform scale:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} rh\cos(\phi) & -rv\sin(\phi) & cx \\ rh\sin(\phi) & rv\cos(\phi) & cy \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\theta) \\ \sin(\theta) \\ 1 \end{bmatrix}$$

| | |
|---|---|
| (*cx, cy*) | The center point of the ellipse |
| *rh, rv* | The radii of the unrotated ellipse |
| $\varphi$ | The counter-clockwise angle of the ellipse relative to the x axis, measured prior to scaling by (*rh, rv*) |
| $\theta 1$ | Angle of initial point (as measured on the unscaled circle) |
| $\theta 2$ | Angle of final point (as measured on the unscaled circle) |

*Table 16: Center Ellipse Parameters*

## 17.2 The Endpoint Parameterization

OpenVG paths use the endpoint parameterization of elliptical arcs as defined in SVG. An elliptical arc segment is defined in terms of its endpoints (*x0, y0*), (*x1, y1*), radii *rh* and *rv*, rotation angle *φ*, large arc flag *fA*, and sweep flag *fS*. These parameters are listed in Table 17.

| | |
|---|---|
| (*x0, y0*) | The initial endpoint of the arc |
| (*x1, y1*) | The final endpoint of the arc |
| *rh*, *rv* | The radii of the unrotated ellipse |
| *rot* | The counter-clockwise angle of the ellipse relative to the x axis, measured prior to scaling by (*rh, rv*) |
| *fA* | Large arc flag: 1 if more than 180 degrees of the arc is to be traversed (as measured on the unscaled circle), 0 otherwise |
| *fS* | Sweep flag: 1 if the arc is to be traversed in the counter-clockwise direction, 0 otherwise |

*Table 17: Endpoint Ellipse Parameters*

## 17.3 Converting from Center to Endpoint Parameterization

Conversion from a center parameterization to an endpoint parameterization simply requires evaluation the initial and final endpoints of the arc, and determining the values of the large arc and sweep flags:

$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = f(cx, cy, rh, rv, \phi, \theta_1)$$

$$\begin{bmatrix} x_2 \\ y_2 \end{bmatrix} = f(cx, cy, rh, rv, \phi, \theta_2)$$

$$f_A = \begin{cases} 1 & if\,|\theta_2 - \theta_1| > 180\,degrees \\ 0 & otherwise \end{cases}$$

$$f_S = \begin{cases} 1 & if\,\theta_2 - \theta_1 > 0 \\ 0 & otherwise \end{cases}$$

## 17.4 Converting from Endpoint to Center Parameterization

Given an endpoint representation of an ellipse as the set of parameters $(x0, y0)$, $(x1, y1)$, $rh$, $rv$, $\varphi$, $f_S$, and $f_A$, we wish to determine the center point $(cx, cy)$ and the initial and final angles $\theta 1$ and $\theta 2$.

An ellipse with center point $(cx, cy)$, radii $rh$ and $rv$, and rotation angle $rot$ satisfies the implicit equation $(x')^2 + (y')^2 = 1$, where $x' = ((x - cx)*cos(rot) + (y - cy)*sin(rot))/rh$ and $y' = (-(x - cx)*sin(rot) + (y - cy)*cos(rot))/rv$. The transformation from $(x, y)$ to $(x', y')$ simply maps the desired ellipse into a unit circle centered at the origin.

To determine the center points of the pair of ellipses with common radii and rotation angle that pass through the two given points $(x_0, y_0)$ and $(x_1, y_1)$, the plane is first transformed into a suitably scaled and rotated coordinate system such that the equation of each ellipse becomes $(x' - cx')^2 + (y' - cy')^2 = 1$. Then the problem is reduced to finding the centers $(cx_0', cy_0')$ and $(cx_1', cy_1')$ of the two unit circles whose circumferences pass through two given points. Finally, the center points are placed through an inverse transformation to obtain solutions in the original coordinate system.

The center points of the two unit circles that pass through points $(x_0, y_0)$ and $(x_1, y_1)$ are given by $(x_m \pm \Delta y*d, y_m \mp \Delta x*d)$, where $x_m = (x_0 + x_1)/2$, $y_m = (y_0 + y_1)/2$, $\Delta x = (x_0 - x_1)$ , $\Delta y = (y_0 - y_1)$, and $d = \sqrt{(1/(\Delta x^2 + \Delta y^2) - ¼)}$. If $d$ is infinite or imaginary, no solution exists due to the input points being coincident or too far apart, respectively.

The angles $\theta 1$ and $\theta 2$ may be found by finding the slope of the endpoints on the circle and computing arctangents.

The following code illustrates the process of computing the ellipse centers. The findUnitCircles function is called by findEllipses following inverse transformation of the original ellipse parameters.

```
#include <math.h>

#ifndef M_PI
#define M_PI 3.14159265358979323846
#endif

/*  Given: Points (x0, y0) and (x1, y1)
 * Return: TRUE if a solution exists, FALSE otherwise
 *         Circle centers are written to (cx0, cy0) and (cx1, cy1)
 */
static VGboolean
findUnitCircles(double x0, double y0, double x1, double y1,
                double *cx0, double *cy0,
                double *cx1, double *cy1)
{
  /* Compute differences and averages */
  double dx = x0 - x1;
  double dy = y0 - y1;
  double xm = (x0 + x1)/2;
  double ym = (y0 + y1)/2;
  double dsq, disc, s, sdx, sdy;

  /* Solve for intersecting unit circles */
  dsq = dx*dx + dy*dy;
  if (dsq == 0.0) return VG_FALSE; /* Points are coincident */
  disc = 1.0/dsq - 1.0/4.0;
  if (disc < 0.0) return VG_FALSE; /* Points are too far apart */
  s = sqrt(disc);
  sdx = s*dx;
  sdy = s*dy;

  *cx0 = xm + sdy;
  *cy0 = ym - sdx;
  *cx1 = xm - sdy;
  *cy1 = ym + sdx;
  return VG_TRUE;
}
```

```
/*  Given: Ellipse parameters rh, rv, rot (in degrees),
 *         endpoints (x0, y0) and (x1, y1)
 * Return: TRUE if a solution exists, FALSE otherwise
 *         Ellipse centers are written to (cx0, cy0) and (cx1, cy1)
 */

VGboolean
findEllipses(double rh, double rv, double rot,
             double x0, double y0, double x1, double y1,
             double *cx0, double *cy0, double *cx1, double *cy1)
{
  double COS, SIN, x0p, y0p, x1p, y1p;

  /* Convert rotation angle from degrees to radians */
  rot *= M_PI/180.0;

  /* Pre-compute rotation matrix entries */
  COS = cos(rot); SIN = sin(rot);

  /* Transform (x0, y0) and (x1, y1) into unit space */
  /* using (inverse) rotate, followed by (inverse) scale   */

  x0p = (x0*COS + y0*SIN)/rh;
  y0p = (-x0*SIN + y0*COS)/rv;
  x1p = (x1*COS + y1*SIN)/rh;
  y1p = (-x1*SIN + y1*COS)/rv;

  if (!findUnitCircles(x0p, y0p, x1p, y1p,
                       &pcx0, &pcy0, &pcx1, &pcy1)) {
    return VG_FALSE;
  }

  /* Transform back to original coordinate space  */
  /* using (forward) scale followed by (forward) rotate */

  pcx0 *= rh; pcy0 *= rv;
  pcx1 *= rh; pcy1 *= rv;

  *cx0 = pcx0*COS - pcy0*SIN;
  *cy0 = pcx0*SIN + pcy0*COS;
  *cx1 = pcx1*COS - pcy1*SIN;
  *cy1 = pcx1*SIN + pcy1*COS;

  return VG_TRUE;
}
```

## 17.5 Implicit Representation of an Ellipse

An ellipse (or any conic section) may be written in the implicit form:

$$A x^2 + B x y + C y^2 + D x + E y + F = 0$$

This equation describes an ellipse (or circle) if $B^2 - 4\ A\ C < 0$ (and certain other degeneracies do not occur). The center of the ellipse is located at:

$$(cx, cy) = \frac{1}{B^2 - 4 A C}(2 C D - B E, 2 A E - B D)$$

The ellipse may be re-centered about $(0, 0)$ by substituting $x \leftarrow x + cx$, $y \leftarrow y + cy$ to obtain an implicit equation with $D = E = 0$:

$$A x^2 + B x y + C y^2 + \left( \frac{A E^2 + C D^2 - B D E}{B^2 - 4 A C} + F \right) = 0$$

For a centered ellipse, the constant term must be equal to -1 since the entire formula has the form of $(x')^2 + (y')^2 - 1$ where $x'$ and $y'$ contain no constant terms. Thus in order to determine the radius and axes of a centered ellipse we only need to be concerned with equations of the form:

$$A x^2 + B x y + C y^2 - 1 = 0$$

The angle of rotation is given by:

$$\theta = \begin{cases} 0, & \text{if } B = 0 \\ \dfrac{\pi}{4}, & \text{if } B \neq 0 \text{ and } A = C \\ \dfrac{1}{2}\tan^{-1}\left(\dfrac{B}{A - C}\right), & \text{otherwise} \end{cases}$$

Applying an inverse rotation by substituting $x \leftarrow x\ cos(-\theta) + y\ sin(-\theta)$ and $y \leftarrow y\ cos(-\theta) - x\ sin(-\theta)$, we obtain a further simplification to an unrotated form:

$$A' x^2 + C' y^2 - 1 = 0$$

where:

$$A' = \begin{cases} A, & \text{if } B = 0 \\ A + \dfrac{B}{2}, & \text{if } B \neq 0 \text{ and } A = C \\ \dfrac{1}{2}\left(A + C + K(A - C)\right), & \text{otherwise} \end{cases}$$

$$C' = \begin{cases} C, & \text{if } B = 0 \\ A - \dfrac{B}{2}, & \text{if } B \neq 0 \text{ and } A = C \\ \dfrac{1}{2}\left(A + C - K(A - C)\right), & \text{otherwise} \end{cases}$$

$$\text{where } K = \sqrt{1 + \frac{B^2}{(A - C)^2}}$$

The radii of the centered, unrotated ellipse are given by:

$$rh = \frac{1}{\sqrt{A'}} \qquad rv = \frac{1}{\sqrt{C'}}$$

## 17.6 Transformation of Ellipses

As previously noted, an ellipse may be viewed as the result of a scale, rotation, and translation applied to the unit circle:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} rh\cos(\phi) & -rv\sin(\phi) & cx \\ rh\sin(\phi) & rv\cos(\phi) & cy \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\theta) \\ \sin(\theta) \\ 1 \end{bmatrix}$$

The resulting ellipse satisfies an implicit equation generated by placing each point on the ellipse through an affine transformation $M$ that is the inverse of the transformation above. The resulting points lie on the unit circle, and therefore satisfy the implicit equation $x^2 + y^2 = 1$.

If $M$ is defined as:

$$M = \begin{bmatrix} m_{00} & m_{01} & m_{02} \\ m_{10} & m_{11} & m_{12} \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} rh\cos(\phi) & -rv\sin(\phi) & cx \\ rh\sin(\phi) & rv\cos(\phi) & cy \\ 0 & 0 & 1 \end{bmatrix}^{-1}$$

then the implicit equation for the ellipse is:

$$(m_{00}x+m_{01}y+m_{02})^2+(m_{10}x+m_{11}y+m_{12})^2-1=0$$

which may be written in standard form as:

$$Ax^2+Bxy+Cy^2+Dx+Ey+F=0$$

where:

$$\begin{aligned}
&A=m_{00}^2+m_{10}^2\\
&B=2(m_{00}m_{01}+m_{10}m_{11})\\
&C=m_{01}^2+m_{11}^2\\
&D=2(m_{00}m_{02}+m_{10}m_{12})\\
&E=2(m_{01}m_{02}+m_{11}m_{12})\\
&F=m_{02}^2+m_{12}^2-1
\end{aligned}$$

The center, rotation angle, and radii of the ellipse may be determined using the formulas from the previous section.

In practice, it may be simpler to represent a transformed ellipse as the affine transformation mapping an arc of the unit circle into it. The ellipse may be rendered by concatenating its transform with the current transform and rendering the circular arc. It may be transformed by simply concatenating the transforms.

# 18 Appendix B: Header Files

This section defines minimal C language header files for the type definitions and functions of OpenVG and the VGU utility library. The actual header files provided by a platform vendor may differ from those shown here.

### *openvg.h*

```
/*********************************************************************
 *                                                                   *
 * Sample implementation of openvg.h, version 1.0                    *
 *                                                                   *
 * Copyright © 2005 The Khronos Group                                *
 *                                                                   *
 *********************************************************************/

#ifndef _OPENVG_H
#define _OPENVG_H

#ifdef __cplusplus
extern "C" {
#endif

#include <khronos_types.h>

#define OPENVG_VERSION_1_0 1

typedef khronos_float    VGfloat;
typedef khronos_int8_t   VGbyte;
typedef khronos_uint8_t  VGubyte;
typedef khronos_int16_t  VGshort;
typedef khronos_int32_t  VGint;
typedef khronos_uint32_t VGuint;
typedef khronos_uint32_t VGbitfield;

typedef enum {
  VG_FALSE = 0,
  VG_TRUE  = 1
} VGboolean;

#define VG_MAXSHORT ((VGshort)((~((unsigned)0)) >> 1))
#define VG_MAXINT ((VGint)((~((unsigned)0)) >> 1))

typedef VGuint VGHandle;

#define VG_INVALID_HANDLE ((VGHandle)0)

typedef enum {
  VG_NO_ERROR                                = 0,
  VG_BAD_HANDLE_ERROR                        = 0x1000,
  VG_ILLEGAL_ARGUMENT_ERROR                  = 0x1001,
  VG_OUT_OF_MEMORY_ERROR                     = 0x1002,
  VG_PATH_CAPABILITY_ERROR                   = 0x1003,
  VG_UNSUPPORTED_IMAGE_FORMAT_ERROR          = 0x1004,
  VG_UNSUPPORTED_PATH_FORMAT_ERROR           = 0x1005,
  VG_IMAGE_IN_USE_ERROR                      = 0x1006
} VGErrorCode;
```

```
typedef enum {
  /* Mode settings */
  VG_MATRIX_MODE                               = 0x1100,
  VG_FILL_RULE                                 = 0x1101,
  VG_IMAGE_QUALITY                             = 0x1102,
  VG_RENDERING_QUALITY                         = 0x1103,
  VG_BLEND_MODE                                = 0x1104,
  VG_IMAGE_MODE                                = 0x1105,

  /* Scissoring rectangles */
  VG_SCISSOR_RECTS                             = 0x1106,

  /* Stroke parameters */
  VG_STROKE_LINE_WIDTH                         = 0x1110,
  VG_STROKE_CAP_STYLE                          = 0x1111,
  VG_STROKE_JOIN_STYLE                         = 0x1112,
  VG_STROKE_MITER_LIMIT                        = 0x1113,
  VG_STROKE_DASH_PATTERN                       = 0x1114,
  VG_STROKE_DASH_PHASE                         = 0x1115,

  /* Edge fill color for VG_TILE_FILL tiling mode */
  VG_TILE_FILL_COLOR                           = 0x1120,

  /* Color for vgClear */
  VG_CLEAR_COLOR                               = 0x1121,

  /* Enable/disable alpha masking and scissoring */
  VG_MASKING                                   = 0x1130,
  VG_SCISSORING                                = 0x1131,

  /* Pixel layout hint information */
  VG_PIXEL_LAYOUT                              = 0x1140,

  /* Source format selection for image filters */
  VG_FILTER_FORMAT_LINEAR                      = 0x1150,
  VG_FILTER_FORMAT_PREMULTIPLIED               = 0x1151,

  /* Destination write enable mask for image filters */
  VG_FILTER_CHANNEL_MASK                       = 0x1152,

  /* Implementation limits (read-only) */
  VG_MAX_SCISSOR_RECTS                         = 0x1160,
  VG_MAX_DASH_COUNT                            = 0x1161,
  VG_MAX_KERNEL_SIZE                           = 0x1162,
  VG_MAX_SEPARABLE_KERNEL_SIZE                 = 0x1163,
  VG_MAX_COLOR_RAMP_STOPS                      = 0x1164,
  VG_MAX_IMAGE_WIDTH                           = 0x1165,
  VG_MAX_IMAGE_HEIGHT                          = 0x1166,
  VG_MAX_IMAGE_PIXELS                          = 0x1167,
  VG_MAX_IMAGE_BYTES                           = 0x1168,
  VG_MAX_FLOAT                                 = 0x1169
} VGParamType;

typedef enum {
  VG_RENDERING_QUALITY_NONANTIALIASED          = 0x1200,
  VG_RENDERING_QUALITY_FASTER                  = 0x1201,
  VG_RENDERING_QUALITY_BETTER                  = 0x1202  /* Default */
} VGRenderingQuality;

typedef enum {
```

```
  VG_PIXEL_LAYOUT_UNKNOWN                    = 0x1300,
  VG_PIXEL_LAYOUT_RGB_VERTICAL               = 0x1301,
  VG_PIXEL_LAYOUT_BGR_VERTICAL               = 0x1302,
  VG_PIXEL_LAYOUT_RGB_HORIZONTAL             = 0x1303,
  VG_PIXEL_LAYOUT_BGR_HORIZONTAL             = 0x1304
} VGPixelLayout;

typedef enum {
  VG_MATRIX_PATH_USER_TO_SURFACE             = 0x1400,
  VG_MATRIX_IMAGE_USER_TO_SURFACE            = 0x1401,
  VG_MATRIX_FILL_PAINT_TO_USER               = 0x1402,
  VG_MATRIX_STROKE_PAINT_TO_USER             = 0x1403
} VGMatrixMode;

typedef enum {
  VG_CLEAR_MASK                              = 0x1500,
  VG_FILL_MASK                               = 0x1501,
  VG_SET_MASK                                = 0x1502,
  VG_UNION_MASK                              = 0x1503,
  VG_INTERSECT_MASK                          = 0x1504,
  VG_SUBTRACT_MASK                           = 0x1505
} VGMaskOperation;

#define VG_PATH_FORMAT_STANDARD 0

typedef enum {
  VG_PATH_DATATYPE_INVALID                   = -1,
  VG_PATH_DATATYPE_S_8                       =  0,
  VG_PATH_DATATYPE_S_16                      =  1,
  VG_PATH_DATATYPE_S_32                      =  2,
  VG_PATH_DATATYPE_F                         =  3
} VGPathDatatype;

typedef enum {
  VG_ABSOLUTE                                = 0,
  VG_RELATIVE                                = 1
} VGPathAbsRel;

typedef enum {
  VG_CLOSE_PATH                              = ( 0 << 1),
  VG_MOVE_TO                                 = ( 1 << 1),
  VG_LINE_TO                                 = ( 2 << 1),
  VG_HLINE_TO                                = ( 3 << 1),
  VG_VLINE_TO                                = ( 4 << 1),
  VG_QUAD_TO                                 = ( 5 << 1),
  VG_CUBIC_TO                                = ( 6 << 1),
  VG_SQUAD_TO                                = ( 7 << 1),
  VG_SCUBIC_TO                               = ( 8 << 1),
  VG_SCCWARC_TO                              = ( 9 << 1),
  VG_SCWARC_TO                               = (10 << 1),
  VG_LCCWARC_TO                              = (11 << 1),
  VG_LCWARC_TO                               = (12 << 1)
} VGPathSegment;

typedef enum {
  VG_MOVE_TO_ABS                             = VG_MOVE_TO    | VG_ABSOLUTE,
  VG_MOVE_TO_REL                             = VG_MOVE_TO    | VG_RELATIVE,
  VG_LINE_TO_ABS                             = VG_LINE_TO    | VG_ABSOLUTE,
  VG_LINE_TO_REL                             = VG_LINE_TO    | VG_RELATIVE,
  VG_HLINE_TO_ABS                            = VG_HLINE_TO   | VG_ABSOLUTE,
```

```
  VG_HLINE_TO_REL                              = VG_HLINE_TO   | VG_RELATIVE,
  VG_VLINE_TO_ABS                              = VG_VLINE_TO   | VG_ABSOLUTE,
  VG_VLINE_TO_REL                              = VG_VLINE_TO   | VG_RELATIVE,
  VG_QUAD_TO_ABS                               = VG_QUAD_TO    | VG_ABSOLUTE,
  VG_QUAD_TO_REL                               = VG_QUAD_TO    | VG_RELATIVE,
  VG_CUBIC_TO_ABS                              = VG_CUBIC_TO   | VG_ABSOLUTE,
  VG_CUBIC_TO_REL                              = VG_CUBIC_TO   | VG_RELATIVE,
  VG_SQUAD_TO_ABS                              = VG_SQUAD_TO   | VG_ABSOLUTE,
  VG_SQUAD_TO_REL                              = VG_SQUAD_TO   | VG_RELATIVE,
  VG_SCUBIC_TO_ABS                             = VG_SCUBIC_TO  | VG_ABSOLUTE,
  VG_SCUBIC_TO_REL                             = VG_SCUBIC_TO  | VG_RELATIVE,
  VG_SCCWARC_TO_ABS                            = VG_SCCWARC_TO | VG_ABSOLUTE,
  VG_SCCWARC_TO_REL                            = VG_SCCWARC_TO | VG_RELATIVE,
  VG_SCWARC_TO_ABS                             = VG_SCWARC_TO  | VG_ABSOLUTE,
  VG_SCWARC_TO_REL                             = VG_SCWARC_TO  | VG_RELATIVE,
  VG_LCCWARC_TO_ABS                            = VG_LCCWARC_TO | VG_ABSOLUTE,
  VG_LCCWARC_TO_REL                            = VG_LCCWARC_TO | VG_RELATIVE,
  VG_LCWARC_TO_ABS                             = VG_LCWARC_TO  | VG_ABSOLUTE,
  VG_LCWARC_TO_REL                             = VG_LCWARC_TO  | VG_RELATIVE
} VGPathCommand;

typedef VGHandle VGPath;

typedef enum {
  VG_PATH_CAPABILITY_APPEND_FROM               = (1 <<  0),
  VG_PATH_CAPABILITY_APPEND_TO                 = (1 <<  1),
  VG_PATH_CAPABILITY_MODIFY                    = (1 <<  2),
  VG_PATH_CAPABILITY_TRANSFORM_FROM            = (1 <<  3),
  VG_PATH_CAPABILITY_TRANSFORM_TO              = (1 <<  4),
  VG_PATH_CAPABILITY_INTERPOLATE_FROM          = (1 <<  5),
  VG_PATH_CAPABILITY_INTERPOLATE_TO            = (1 <<  6),
  VG_PATH_CAPABILITY_PATH_LENGTH               = (1 <<  7),
  VG_PATH_CAPABILITY_POINT_ALONG_PATH          = (1 <<  8),
  VG_PATH_CAPABILITY_TANGENT_ALONG_PATH        = (1 <<  9),
  VG_PATH_CAPABILITY_PATH_BOUNDS               = (1 << 10),
  VG_PATH_CAPABILITY_PATH_TRANSFORMED_BOUNDS   = (1 << 11),
  VG_PATH_CAPABILITY_ALL                       = (1 << 12) - 1
} VGPathCapabilities;

typedef enum {
  VG_PATH_FORMAT                               = 0x1600,
  VG_PATH_DATATYPE                             = 0x1601,
  VG_PATH_SCALE                                = 0x1602,
  VG_PATH_BIAS                                 = 0x1603,
  VG_PATH_NUM_SEGMENTS                         = 0x1604,
  VG_PATH_NUM_COORDS                           = 0x1605
} VGPathParamType;

typedef enum {
  VG_CAP_BUTT                                  = 0x1700,
  VG_CAP_ROUND                                 = 0x1701,
  VG_CAP_SQUARE                                = 0x1702
} VGCapStyle;

typedef enum {
  VG_JOIN_MITER                                = 0x1800,
  VG_JOIN_ROUND                                = 0x1801,
  VG_JOIN_BEVEL                                = 0x1802
} VGJoinStyle;
```

```
typedef enum {
  VG_EVEN_ODD                                  = 0x1900,
  VG_NON_ZERO                                  = 0x1901
} VGFillRule;

typedef enum {
  VG_STROKE_PATH                               = (1 << 0),
  VG_FILL_PATH                                 = (1 << 1)
} VGPaintMode;

typedef VGHandle VGPaint;

typedef enum {
  /* Color paint parameters */
  VG_PAINT_TYPE                                = 0x1A00,
  VG_PAINT_COLOR                               = 0x1A01,
  VG_PAINT_COLOR_RAMP_SPREAD_MODE              = 0x1A02,
  VG_PAINT_COLOR_RAMP_STOPS                    = 0x1A03,

  /* Linear gradient paint parameters */
  VG_PAINT_LINEAR_GRADIENT                     = 0x1A04,

  /* Radial gradient paint parameters */
  VG_PAINT_RADIAL_GRADIENT                     = 0x1A05,

  /* Pattern paint parameters */
  VG_PAINT_PATTERN_TILING_MODE                 = 0x1A06
} VGPaintParamType;

typedef enum {
  VG_PAINT_TYPE_COLOR                          = 0x1B00,
  VG_PAINT_TYPE_LINEAR_GRADIENT                = 0x1B01,
  VG_PAINT_TYPE_RADIAL_GRADIENT                = 0x1B02,
  VG_PAINT_TYPE_PATTERN                        = 0x1B03
} VGPaintType;

typedef enum {
  VG_COLOR_RAMP_SPREAD_PAD                     = 0x1C00,
  VG_COLOR_RAMP_SPREAD_REPEAT                  = 0x1C01,
  VG_COLOR_RAMP_SPREAD_REFLECT                 = 0x1C02
} VGColorRampSpreadMode;

typedef enum {
  VG_TILE_FILL                                 = 0x1D00,
  VG_TILE_PAD                                  = 0x1D01,
  VG_TILE_REPEAT                               = 0x1D02,
  VG_TILE_REFLECT                              = 0x1D03
} VGTilingMode;

typedef enum {
  VG_IMAGE_FORMAT_INVALID                      = -1,
  VG_sRGBX_8888                                =  0,
  VG_sRGBA_8888                                =  1,
  VG_sRGBA_8888_PRE                            =  2,
  VG_sRGB_565                                  =  3,
  VG_sRGBA_5551                                =  4,
  VG_sRGBA_4444                                =  5,
  VG_sL_8                                      =  6,
  VG_lRGBX_8888                                =  7,
  VG_lRGBA_8888                                =  8,
```

```
  VG_lRGBA_8888_PRE                              =  9,
  VG_lL_8                                        = 10,
  VG_A_8                                         = 11,
  VG_BW_1                                        = 12
} VGImageFormat;

typedef VGHandle VGImage;

typedef enum {
  VG_IMAGE_QUALITY_NONANTIALIASED                = (1 << 0),
  VG_IMAGE_QUALITY_FASTER                        = (1 << 1),
  VG_IMAGE_QUALITY_BETTER                        = (1 << 2)
} VGImageQuality;

typedef enum {
  VG_IMAGE_FORMAT                                = 0x1E00,
  VG_IMAGE_WIDTH                                 = 0x1E01,
  VG_IMAGE_HEIGHT                                = 0x1E02
} VGImageParamType;

typedef enum {
  VG_DRAW_IMAGE_NORMAL                           = 0x1F00,
  VG_DRAW_IMAGE_MULTIPLY                         = 0x1F01,
  VG_DRAW_IMAGE_STENCIL                          = 0x1F02
} VGImageMode;

typedef enum {
  VG_RED                                         = (1 << 3),
  VG_GREEN                                       = (1 << 2),
  VG_BLUE                                        = (1 << 1),
  VG_ALPHA                                       = (1 << 0)
} VGImageChannel;

typedef enum {
  VG_BLEND_SRC                                   = 0x2000,
  VG_BLEND_SRC_OVER                              = 0x2001,
  VG_BLEND_DST_OVER                              = 0x2002,
  VG_BLEND_SRC_IN                                = 0x2003,
  VG_BLEND_DST_IN                                = 0x2004,
  VG_BLEND_MULTIPLY                              = 0x2005,
  VG_BLEND_SCREEN                                = 0x2006,
  VG_BLEND_DARKEN                                = 0x2007,
  VG_BLEND_LIGHTEN                               = 0x2008,
  VG_BLEND_ADDITIVE                              = 0x2009
} VGBlendMode;

typedef enum {
  VG_IMAGE_FORMAT_QUERY                          = 0x2100,
  VG_PATH_DATATYPE_QUERY                         = 0x2101
} VGHardwareQueryType;

typedef enum {
  VG_HARDWARE_ACCELERATED                        = 0x2200,
  VG_HARDWARE_UNACCELERATED                      = 0x2201
} VGHardwareQueryResult;

typedef enum {
  VG_VENDOR                                      = 0x2300,
  VG_RENDERER                                    = 0x2301,
  VG_VERSION                                     = 0x2302,
```

```
  VG_EXTENSIONS                                   = 0x2303
} VGStringID;

/* Function Prototypes */

#ifndef VG_API_CALL
#define VG_API_CALL extern
#endif

VG_API_CALL VGErrorCode vgGetError(void);

VG_API_CALL void vgFlush(void);
VG_API_CALL void vgFinish(void);

/* Getters and Setters */
VG_API_CALL void vgSetf (VGParamType type, VGfloat value);
VG_API_CALL void vgSeti (VGParamType type, VGint value);
VG_API_CALL void vgSetfv(VGParamType type, VGint count,
                         const VGfloat * values);
VG_API_CALL void vgSetiv(VGParamType type, VGint count,
                         const VGint * values);

VG_API_CALL VGfloat vgGetf(VGParamType type);
VG_API_CALL VGint   vgGeti(VGParamType type);
VG_API_CALL VGint   vgGetVectorSize(VGParamType type);
VG_API_CALL void    vgGetfv(VGParamType type, VGint count, VGfloat * values);
VG_API_CALL void    vgGetiv(VGParamType type, VGint count, VGint * values);

VG_API_CALL void vgSetParameterf(VGHandle object,
                                 VGint paramType,
                                 VGfloat value);
VG_API_CALL void vgSetParameteri(VGHandle object,
                                 VGint paramType,
                                 VGint value);
VG_API_CALL void vgSetParameterfv(VGHandle object,
                                  VGint paramType,
                                  VGint count, const VGfloat * values);
VG_API_CALL void vgSetParameteriv(VGHandle object,
                                  VGint paramType,
                                  VGint count, const VGint * values);

VG_API_CALL VGfloat vgGetParameterf(VGHandle object,
                                    VGint paramType);
VG_API_CALL VGint vgGetParameteri(VGHandle object,
                                  VGint paramType);
VG_API_CALL VGint vgGetParameterVectorSize(VGHandle object,
                                           VGint paramType);
VG_API_CALL void vgGetParameterfv(VGHandle object,
                                  VGint paramType,
                                  VGint count, VGfloat * values);
VG_API_CALL void vgGetParameteriv(VGHandle object,
                                  VGint paramType,
                                  VGint count, VGint * values);

/* Matrix Manipulation */
VG_API_CALL void vgLoadIdentity(void);
VG_API_CALL void vgLoadMatrix(const VGfloat * m);
VG_API_CALL void vgGetMatrix(VGfloat * m);
VG_API_CALL void vgMultMatrix(const VGfloat * m);
VG_API_CALL void vgTranslate(VGfloat tx, VGfloat ty);
```

```
VG_API_CALL void vgScale(VGfloat sx, VGfloat sy);
VG_API_CALL void vgShear(VGfloat shx, VGfloat shy);
VG_API_CALL void vgRotate(VGfloat angle);

/* Masking and Clearing */
VG_API_CALL void vgMask(VGImage mask, VGMaskOperation operation,
                        VGint x, VGint y, VGint width, VGint height);
VG_API_CALL void vgClear(VGint x, VGint y, VGint width, VGint height);

/* Paths */
VG_API_CALL VGPath vgCreatePath(VGint pathFormat,
                                VGPathDatatype datatype,
                                VGfloat scale, VGfloat bias,
                                VGint segmentCapacityHint,
                                VGint coordCapacityHint,
                                VGbitfield capabilities);
VG_API_CALL void vgClearPath(VGPath path, VGbitfield capabilities);
VG_API_CALL void vgDestroyPath(VGPath path);
VG_API_CALL void vgRemovePathCapabilities(VGPath path,
                                          VGbitfield capabilities);
VG_API_CALL VGbitfield vgGetPathCapabilities(VGPath path);
VG_API_CALL void vgAppendPath(VGPath dstPath, VGPath srcPath);
VG_API_CALL void vgAppendPathData(VGPath dstPath,
                                  VGint numSegments,
                                  const VGubyte * pathSegments,
                                  const void * pathData);
VG_API_CALL void vgModifyPathCoords(VGPath dstPath, VGint startIndex,
                                    VGint numSegments,
                                    const void * pathData);
VG_API_CALL void vgTransformPath(VGPath dstPath, VGPath srcPath);
VG_API_CALL VGboolean vgInterpolatePath(VGPath dstPath,
                                        VGPath startPath,
                                        VGPath endPath,
                                        VGfloat amount);
VG_API_CALL VGfloat vgPathLength(VGPath path,
                                 VGint startSegment, VGint numSegments);
VG_API_CALL void vgPointAlongPath(VGPath path,
                                  VGint startSegment, VGint numSegments,
                                  VGfloat distance,
                                  VGfloat * x, VGfloat * y,
                                  VGfloat * tangentX, VGfloat * tangentY);
VG_API_CALL void vgPathBounds(VGPath path,
                              VGfloat * minX, VGfloat * minY,
                              VGfloat * width, VGfloat * height);
VG_API_CALL void vgPathTransformedBounds(VGPath path,
                                         VGfloat * minX, VGfloat * minY,
                                         VGfloat * width, VGfloat * height);
VG_API_CALL void vgDrawPath(VGPath path, VGbitfield paintModes);

/* Paint */
VG_API_CALL VGPaint vgCreatePaint(void);
VG_API_CALL void vgDestroyPaint(VGPaint paint);
VG_API_CALL void vgSetPaint(VGPaint paint, VGbitfield paintModes);
VG_API_CALL VGPaint vgGetPaint(VGPaintMode paintMode);
VG_API_CALL void vgSetColor(VGPaint paint, VGuint rgba);
VG_API_CALL VGuint vgGetColor(VGPaint paint);
VG_API_CALL void vgPaintPattern(VGPaint paint, VGImage pattern);

/* Images */
VG_API_CALL VGImage vgCreateImage(VGImageFormat format,
```

```
                                  VGint width, VGint height,
                                  VGbitfield allowedQuality);
VG_API_CALL void vgDestroyImage(VGImage image);
VG_API_CALL void vgClearImage(VGImage image,
                              VGint x, VGint y, VGint width, VGint height);
VG_API_CALL void vgImageSubData(VGImage image,
                                const void * data, VGint dataStride,
                                VGImageFormat dataFormat,
                                VGint x, VGint y, VGint width, VGint height);
VG_API_CALL void vgGetImageSubData(VGImage image,
                                   void * data, VGint dataStride,
                                   VGImageFormat dataFormat,
                                   VGint x, VGint y,
                                   VGint width, VGint height);
VG_API_CALL VGImage vgChildImage(VGImage parent,
                                 VGint x, VGint y, VGint width, VGint height);
VG_API_CALL VGImage vgGetParent(VGImage image);
VG_API_CALL void vgCopyImage(VGImage dst, VGint dx, VGint dy,
                             VGImage src, VGint sx, VGint sy,
                             VGint width, VGint height,
                             VGboolean dither);
VG_API_CALL void vgDrawImage(VGImage image);
VG_API_CALL void vgSetPixels(VGint dx, VGint dy,
                             VGImage src, VGint sx, VGint sy,
                             VGint width, VGint height);
VG_API_CALL void vgWritePixels(const void * data, VGint dataStride,
                               VGImageFormat dataFormat,
                               VGint dx, VGint dy,
                               VGint width, VGint height);
VG_API_CALL void vgGetPixels(VGImage dst, VGint dx, VGint dy,
                             VGint sx, VGint sy,
                             VGint width, VGint height);
VG_API_CALL void vgReadPixels(void * data, VGint dataStride,
                              VGImageFormat dataFormat,
                              VGint sx, VGint sy,
                              VGint width, VGint height);
VG_API_CALL void vgCopyPixels(VGint dx, VGint dy,
                              VGint sx, VGint sy,
                              VGint width, VGint height);

/* Image Filters */
VG_API_CALL void vgColorMatrix(VGImage dst, VGImage src,
                               const VGfloat * matrix);
VG_API_CALL void vgConvolve(VGImage dst, VGImage src,
                            VGint kernelWidth, VGint kernelHeight,
                            VGint shiftX, VGint shiftY,
                            const VGshort * kernel,
                            VGfloat scale,
                            VGfloat bias,
                            VGTilingMode tilingMode);
VG_API_CALL void vgSeparableConvolve(VGImage dst, VGImage src,
                                     VGint kernelWidth,
                                     VGint kernelHeight,
                                     VGint shiftX, VGint shiftY,
                                     const VGshort * kernelX,
                                     const VGshort * kernelY,
                                     VGfloat scale,
                                     VGfloat bias,
                                     VGTilingMode tilingMode);
VG_API_CALL void vgGaussianBlur(VGImage dst, VGImage src,
```

```
                                VGfloat stdDeviationX,
                                VGfloat stdDeviationY,
                                VGTilingMode tilingMode);
VG_API_CALL void vgLookup(VGImage dst, VGImage src,
                          const VGubyte * redLUT,
                          const VGubyte * greenLUT,
                          const VGubyte * blueLUT,
                          const VGubyte * alphaLUT,
                          VGboolean outputLinear,
                          VGboolean outputPremultiplied);
VG_API_CALL void vgLookupSingle(VGImage dst, VGImage src,
                                const VGuint * lookupTable,
                                VGImageChannel sourceChannel,
                                VGboolean outputLinear,
                                VGboolean outputPremultiplied);

/* Hardware Queries */
VG_API_CALL VGHardwareQueryResult vgHardwareQuery(VGHardwareQueryType key,
                                                  VGint setting);

/* Renderer and Extension Information */
VG_API_CALL const VGubyte * vgGetString(VGStringID name);

#ifdef __cplusplus
} /* extern "C" */
#endif

#endif /* _OPENVG_H */
```

### vgu.h

```
/*********************************************************************
 *                                                                   *
 * Sample implementation of vgu.h, version 1.0                       *
 *                                                                   *
 * Copyright © 2005 The Khronos Group                                *
 *                                                                   *
 **********************************************************************/

#ifndef _VGU_H
#define _VGU_H

#ifdef __cplusplus
extern "C" {
#endif

#include <vg/openvg.h>

#define VGU_VERSION_1_0 1

#ifndef VGU_API_CALL
#define VGU_API_CALL extern
#endif

typedef enum {
  VGU_NO_ERROR                                   = 0,
  VGU_BAD_HANDLE_ERROR                           = 0xF000,
  VGU_ILLEGAL_ARGUMENT_ERROR                     = 0xF001,
  VGU_OUT_OF_MEMORY_ERROR                        = 0xF002,
  VGU_PATH_CAPABILITY_ERROR                      = 0xF003,
  VGU_BAD_WARP_ERROR                             = 0xF004
} VGUErrorCode;

typedef enum {
  VGU_ARC_OPEN                                   = 0xF100,
  VGU_ARC_CHORD                                  = 0xF101,
  VGU_ARC_PIE                                    = 0xF102
} VGUArcType;

VGU_API_CALL VGUErrorCode vguLine(VGPath path,
                                  VGfloat x0, VGfloat y0,
                                  VGfloat x1, VGfloat y1);

VGU_API_CALL VGUErrorCode vguPolygon(VGPath path,
                                     const VGfloat * points, VGint count,
                                     VGboolean closed);

VGU_API_CALL VGUErrorCode vguRect(VGPath path,
                                  VGfloat x, VGfloat y,
                                  VGfloat width, VGfloat height);

VGU_API_CALL VGUErrorCode vguRoundRect(VGPath path,
                                       VGfloat x, VGfloat y,
                                       VGfloat width, VGfloat height,
                                       VGfloat arcWidth, VGfloat arcHeight);

VGU_API_CALL VGUErrorCode vguEllipse(VGPath path,
                                     VGfloat cx, VGfloat cy,
                                     VGfloat width, VGfloat height);
```

```
VGU_API_CALL VGUErrorCode vguArc(VGPath path,
                                 VGfloat x, VGfloat y,
                                 VGfloat width, VGfloat height,
                                 VGfloat startAngle, VGfloat angleExtent,
                                 VGUArcType arcType);

VGU_API_CALL VGUErrorCode vguComputeWarpQuadToSquare(VGfloat sx0, VGfloat sy0,
                                                     VGfloat sx1, VGfloat sy1,
                                                     VGfloat sx2, VGfloat sy2,
                                                     VGfloat sx3, VGfloat sy3,
                                                     VGfloat * matrix);

VGU_API_CALL VGUErrorCode vguComputeWarpSquareToQuad(VGfloat dx0, VGfloat dy0,
                                                     VGfloat dx1, VGfloat dy1,
                                                     VGfloat dx2, VGfloat dy2,
                                                     VGfloat dx3, VGfloat dy3,
                                                     VGfloat * matrix);

VGU_API_CALL VGUErrorCode vguComputeWarpQuadToQuad(VGfloat dx0, VGfloat dy0,
                                                   VGfloat dx1, VGfloat dy1,
                                                   VGfloat dx2, VGfloat dy2,
                                                   VGfloat dx3, VGfloat dy3,
                                                   VGfloat sx0, VGfloat sy0,
                                                   VGfloat sx1, VGfloat sy1,
                                                   VGfloat sx2, VGfloat sy2,
                                                   VGfloat sx3, VGfloat sy3,
                                                   VGfloat * matrix);

#ifdef __cplusplus
} /* extern "C" */
#endif

#endif /* #ifndef _VGU_H */
```

# 19 Bibliography

**ADOB99** Adobe Systems Incorporated: *PostScript Language Reference Manual* (*third edition*), Addison-Wesley, Reading, MA, 1999.

**ADOB03** Adobe Systems Incorporated: *PDF Reference* (*fourth edition*): http://partners.adobe.com/asn/acrobat/sdk/public/docs/PDFReference15_v5.pdf

**FvDFH95** Foley J., A. van Dam, S. Feiner and J. Hughes, *Computer Graphics: Principles and Practice* (*second edition*), Addison-Wesley, Reading, MA, 1995.

**HECK89** Heckbert, Paul, *Fundamentals of Texture Mapping and Image Warping*, Master's thesis, UCB/CSD 89/516, CS Division, U.C. Berkeley, June 1989.

**ITU90** Recommendation ITU-R BT.709, *Basic Parameter Values for the HDTV Standard for the Studio and for International Programme Exchange* (1990), ITU, Geneva, Switzerland.

**MACR04** Macromedia, Inc., Macromedia Flash Developer Center: http://www.macromedia.com/devnet/mx/flash

**PORT84** Porter, T. and T. Duff, "Compositing Digital Images," *Computer Graphics* 18(3):253-259 (proc. SIGGRAPH 1984), July 1984.

**POYN03** Poynton, Charles, *Digital Video and HDTV Algorithms and Interfaces*, Morgan Kaufmann, San Francisco, 2003.

**sRGB99** IEC 61966-2-1, *Multimedia systems and equipment — Colour measurement and management — Part 2-1: Default RGB colour space — sRGB: http://www.w3.org/Graphics/Color/sRGB.html*

**SUN04** Sun Microsystems, Inc., Java 2 Standard Edition Java 2D API Home Page: http://java.sun.com/products/java-media/2D

**SVGF04** W3C Recommendation, Scalable Vector Graphics (SVG) Full 1.2 Specification: http://www.w3.org/TR/SVG12

**SVGT05** W3C Recommendation, Scalable Vector Graphics (SVG) Tiny 1.2 Specification: http://www.w3.org/TR/SVGMobile12

**WOLB90** Wolberg, G., *Digital Image Warping*, IEEE Computer Society Press, Washington, D.C., 1990.

**WYSZ00** Wyszecki, G. and W. S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, Wiley-Interscience, New York, 2000.

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# 21 Indices

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