A Technical Introduction to OpenVG

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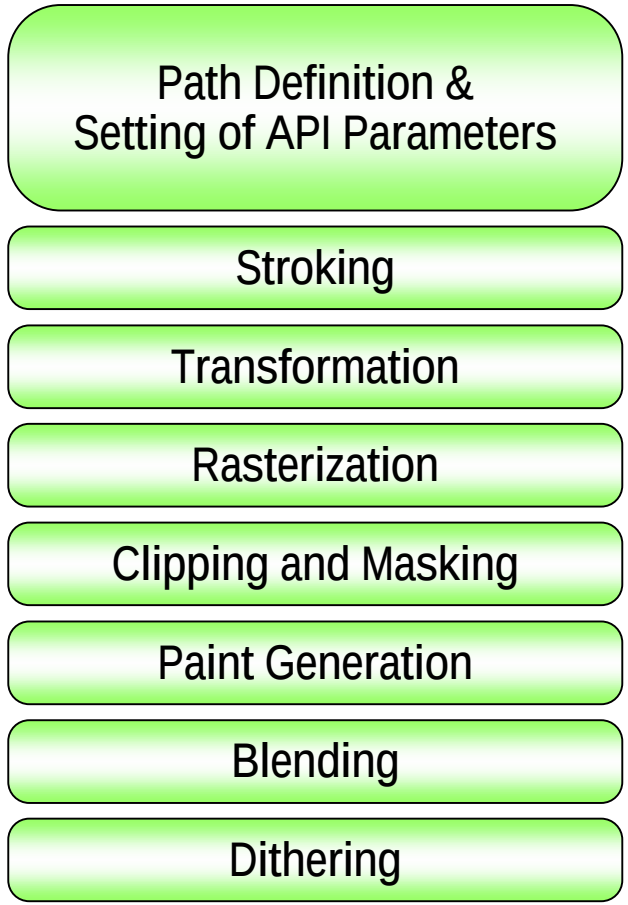
OpenVG Timeline

- OpenVG 1.0 was ratified in August, 2005
- OpenVG 1.0.1 will be ratified in the next 2 months
  - This specification contains clarifications only
- OpenVG 1.0.1 Conformance Tests will be available in August
- OpenVG 1.1 is being defined now
- Possible 1.1 Features Include:
  - Accelerated text
  - Flash-compatible rendering
  - Willing to consider other new features
- Target date for 1.1 is Q1, 2007

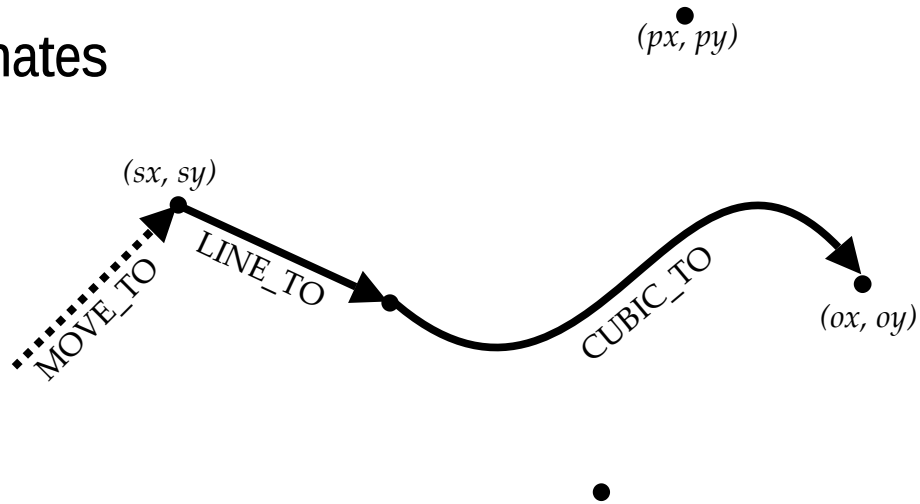
The OpenVG Pipeline

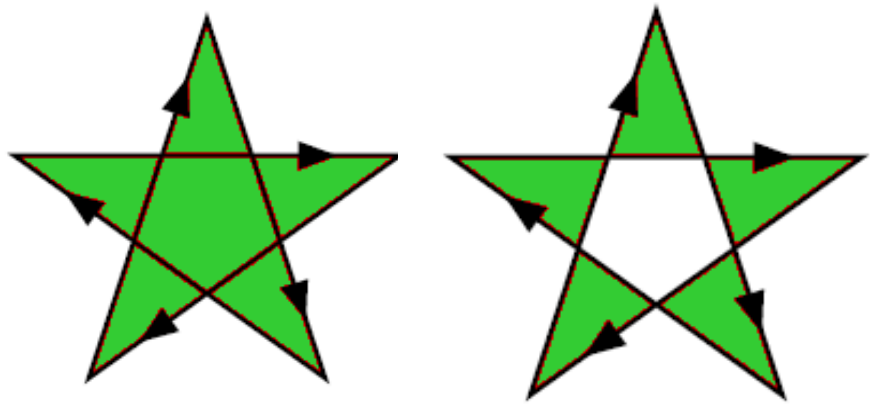
- OpenVG defines a hardware pipeline for paths and images
- Path Definition & Setting of API Parameters
- Stroking
  - Line width, joins & caps, dashing, etc.
- Transformation
  - 2x3 and 3x3 transformations
- Rasterization
- Clipping & Masking
  - Scissoring rectangles, alpha mask
- Paint Generation & Image Interpolation
  - Flat color, gradient, or pattern paint
- Blending & Antialiasing
  - Multiple blend modes
- Dithering
- OpenVG also supports Image Filters



Path Definition

- MOVE_TO, LINE_TO, QUAD_TO, CUBIC_TO, CLOSE_PATH
- Elliptical Arcs
- Absolute / Relative Coordinates
- Smooth Curves
- Path Interpolation
- Path Queries:
  - Bounding Boxes
  - Transformed Bounding Boxes
  - Point along path
  - Tangent along path
- Non-Zero and Even-Odd fill rules



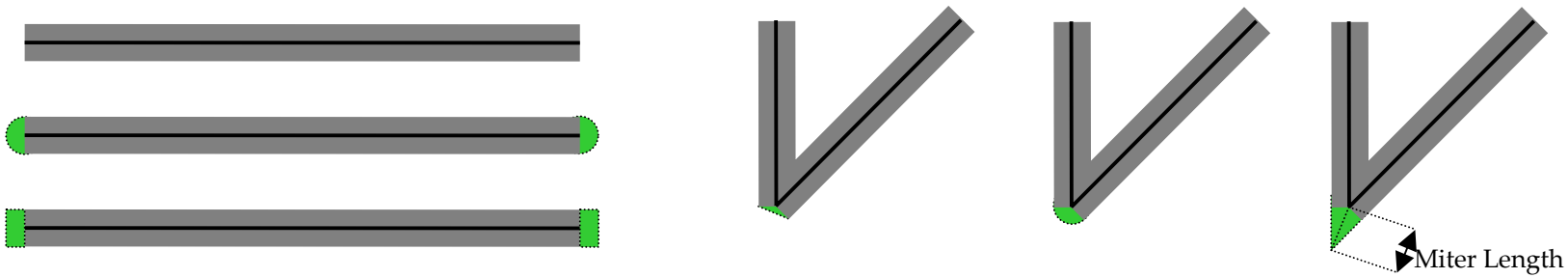


Setting API Parameters

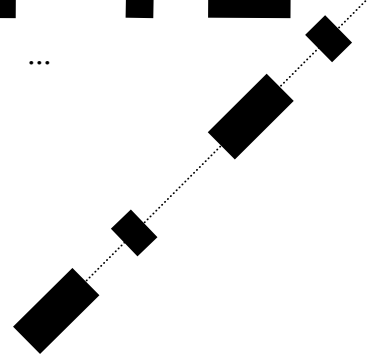
- OpenVG follows the OpenGL model:
  - vg{Get,Set}{f,i,fv,iv}
  - vg{Get,Set}Parameter{f,i,fv,iv}
- Settable parameters:
  - `VG_MATRIX_MODE, VG_FILL_RULE, VG_IMAGE_QUALITY, VG_RENDERING_QUALITY, VG_BLEND_MODE, VG_IMAGE_MODE, VG_SCISSOR_RECTS, VG_STROKE_LINE_WIDTH, VG_STROKE_CAP_STYLE, VG_STROKE_JOIN_STYLE, VG_STROKE_MITER_LIMIT, VG_STROKE_DASH_PATTERN, VG_STROKE_DASH_PHASE, VG_TILE_FILL_COLOR, VG_CLEAR_COLOR, VG_MASKING, VG_SCISSORING, VG_PIXEL_LAYOUT, VG_FILTER_FORMAT_LINEAR, VG_FILTER_FORMAT_PREMULTIPLIED, VG_FILTER_CHANNEL_MASK`
- Read-only 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, VG_MAX_FLOAT`

Stroking

- Stroking takes a path and defines an outline around it:
  - Line Width
  - End cap style (Butt, Round, or Square)
  - Line join style (Bevel, Round, or Miter)
  - Miter limit (to convert long miters to bevels)
  - Dash array and offset



Dash array = { 10, 20, 30, 40} / Dash Phase = 35



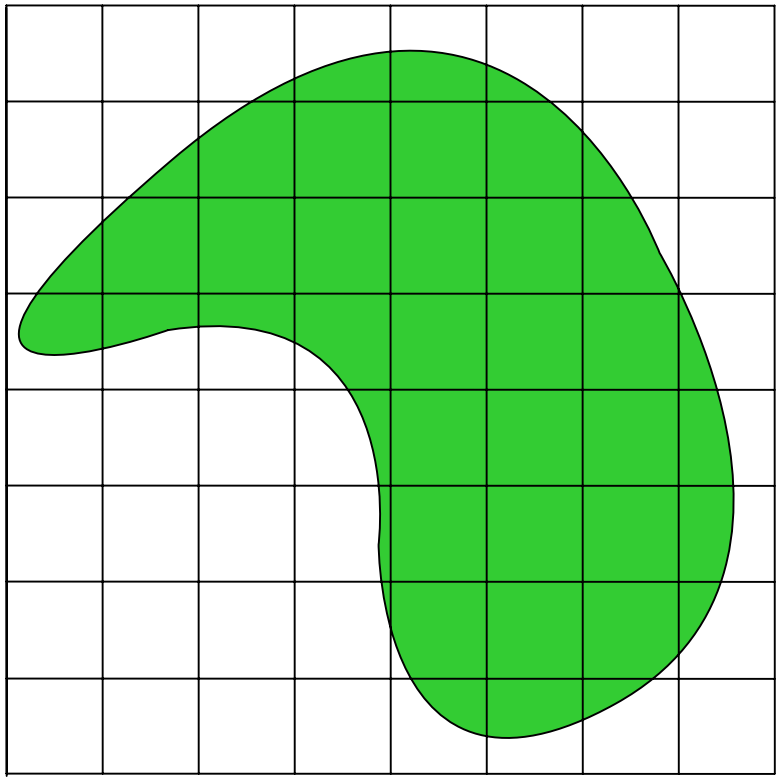
Transformations

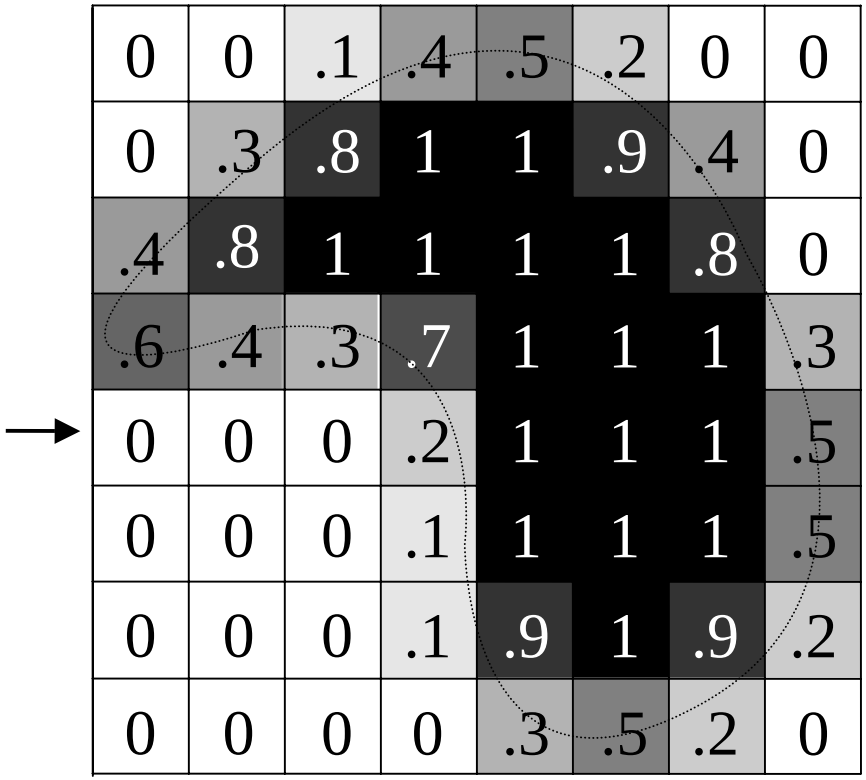
- Paths use 2x3 affine transformations
- Images use 3x3 perspective transformations
- Transformation functions are similar to OpenGL:
  - vgLoadIdentity
  - vgLoadMatrix
  - vgGetMatrix
  - vgMultMatrix
  - vgScale
  - vgRotate
  - vgTranslate
  - vgShear

$$\begin{bmatrix} 1.080 & 0.101 & 0 \\ 0.209 & 0.691 & 0 \\ 1.28\times 10^{-3} & -1.19\times 10^{-3} & 1 \end{bmatrix}$$

Rasterization (continued)

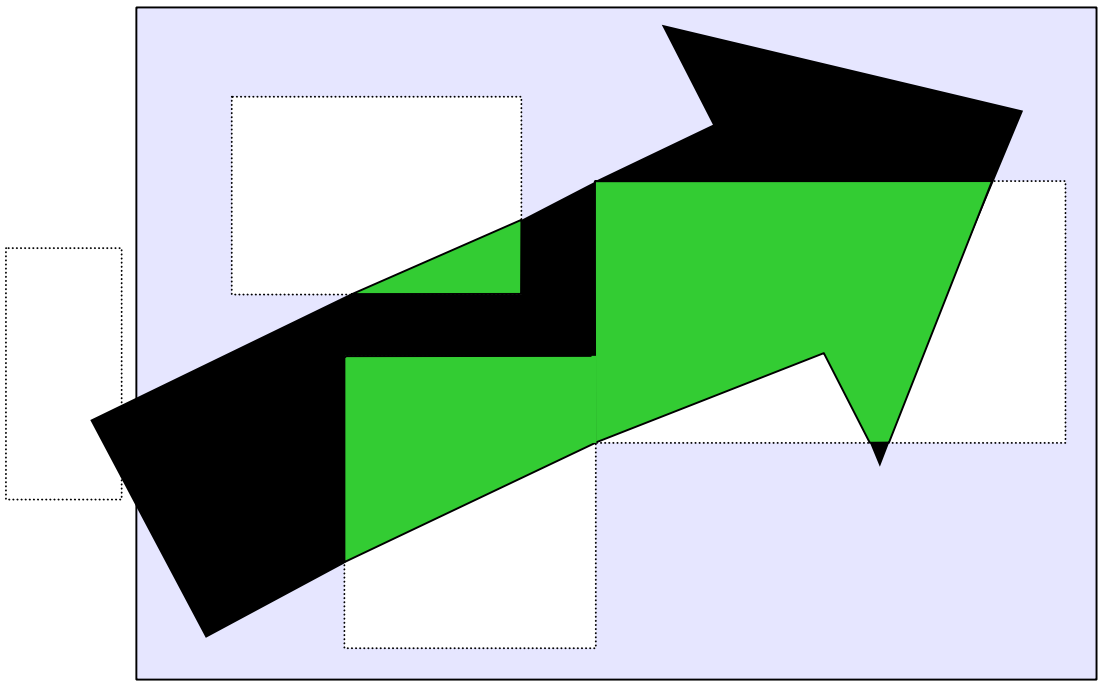
- The goal of rasterization is to determine a filtered alpha value for each pixel, based on the geometry around that pixel
- Filters may be up to 3 pixels in diameter





Scissoring

- Only pixels inside a set of scissor rectangles are drawn
- Scissoring is disabled by default



Display

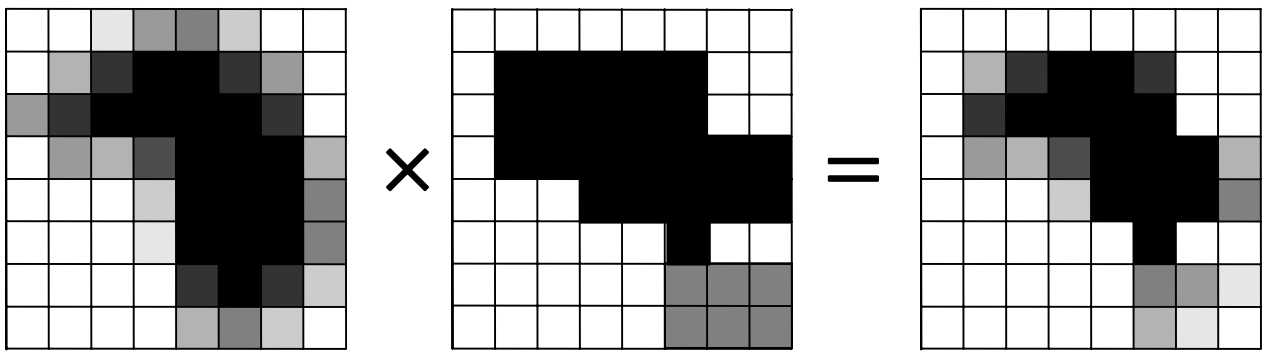
Scissor Rectangles

Pixels drawn

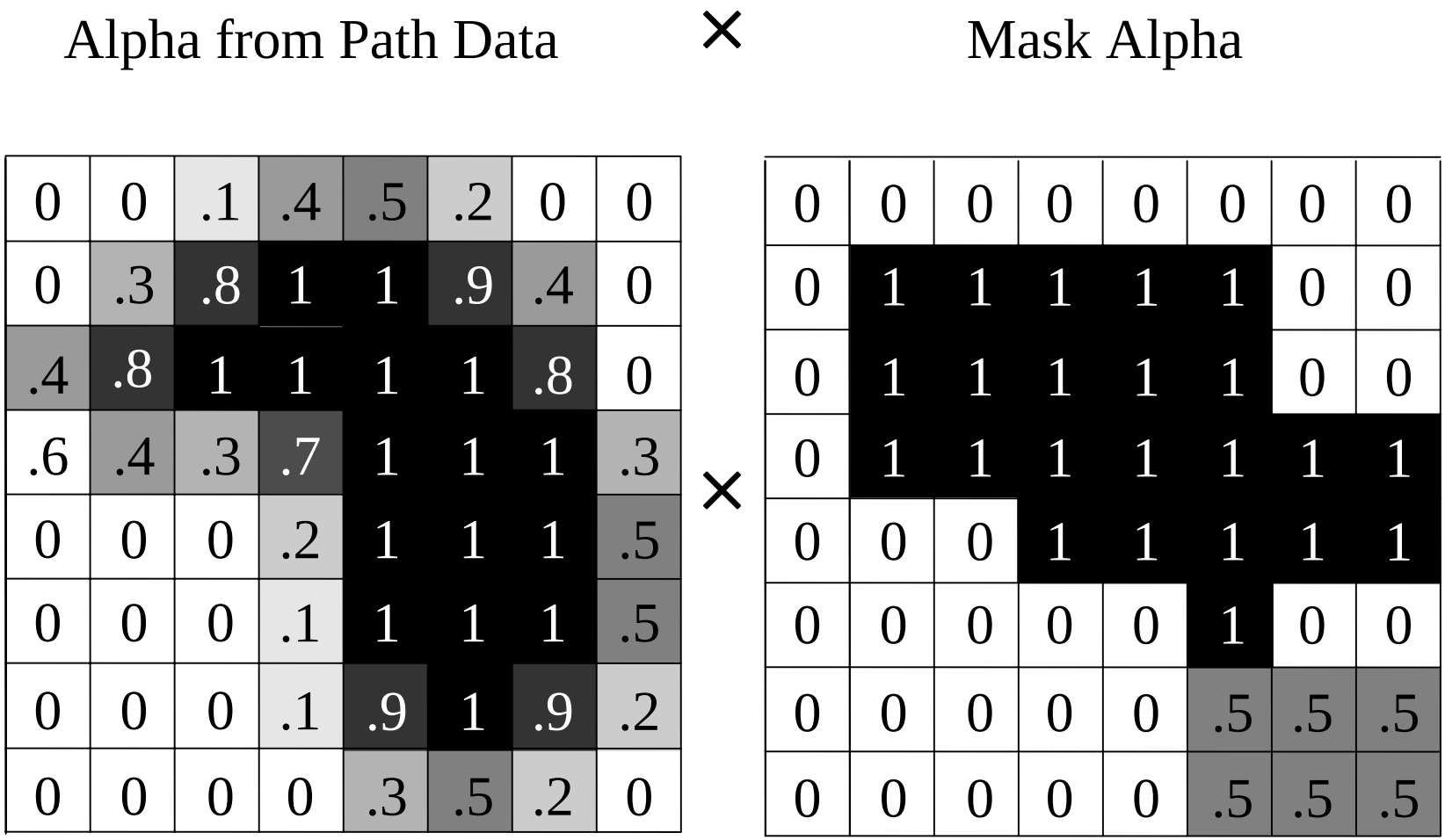
Pixels not drawn

Masking

- In addition to scissoring, a per-pixel mask may be applied
- The mask has an alpha value at each pixel that is multiplied by the alpha from the rendering stage
- May be used to “cut out” an area, create area transitions
- Mask values may be modified using image data
  - Fill, Clear, Set, Add, Subtract, Intersect



Masking (continued)



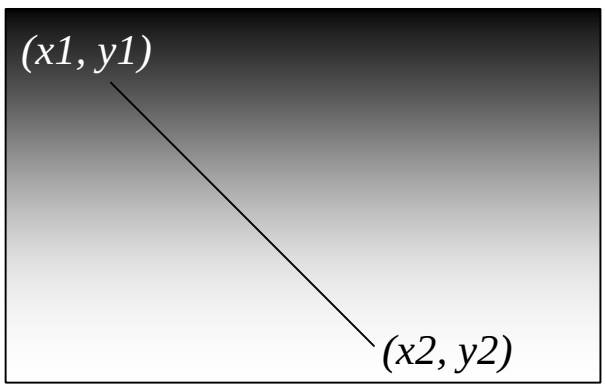
Masking (continued)

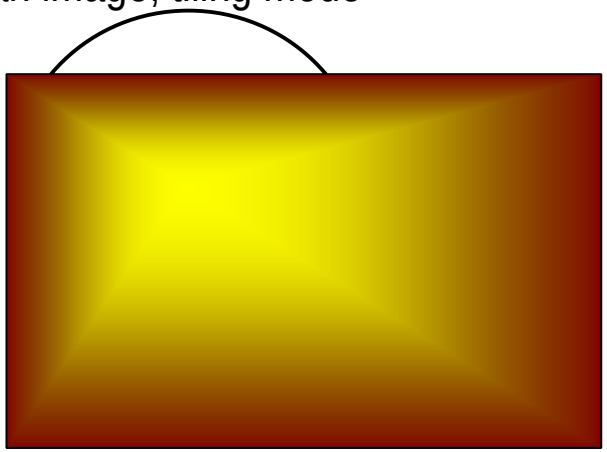
= Resulting Masked Alpha

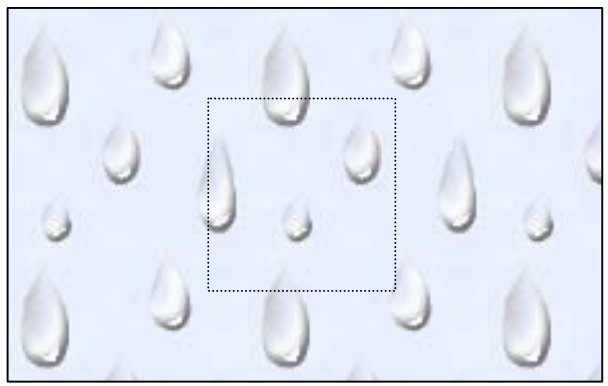
0	0	0	0	0	0	0	0
0	.3	.8	1	1	.9	0	0
0	.8	1	1	1	1	0	0
0	.4	.3	.7	1	1	1	.3
0	0	0	.2	1	1	1	.5
0	0	0	0	0	1	0	0
0	0	0	0	0	.5	.4	.1
0	0	0	0	0	.2	.1	0

Paint Generation

- Paint is generated pixel-by-pixel and applied to geometry
- The alpha from the previous stage (rendering + masking) is used to determine how much paint to apply
- Separate paint objects for stroking, filling
- Paint is transformed by an affine transform
- Four types of paint are supported:
  - Flat color paint
  - Linear gradient paint: points (x1, y1) and (x2, y2), color ramp
  - Radial gradient paint: center (x, y), focus (x, y), radius, color ramp
  - Pattern paint based on an image, tiling mode





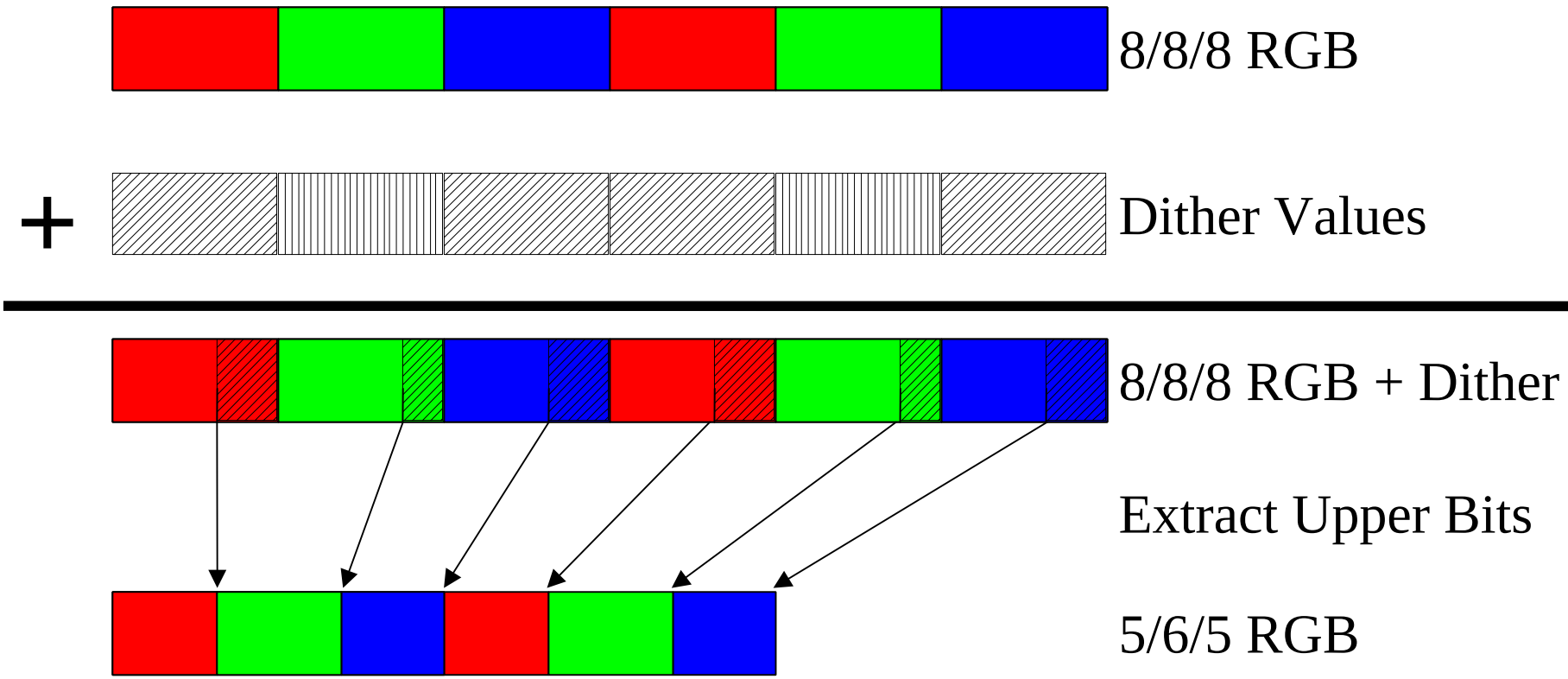


Blending

- Combine masked alpha from path with paint alpha
- Blend the result onto the drawing surface
- Blending is a function of:
  - The paint (R, G, B) color
  - The masked alpha value (path alpha × mask alpha × paint alpha)
  - The destination (R, G, B) color
  - The destination alpha value (1 if no stored alpha)
- There are 8 blending functions:
  - Porter-Duff “source” mode (copy source to destination)
  - Porter-Duff “source **over** destination”/ “destination **over** source”
  - Porter-Duff “source **in** destination”/ “destination **in** source”
  - Lighten (choose lighter of source and destination)
  - Darken (choose darker of source and destination)
  - Multiply (black source pixel forces black, white leaves unchanged)
  - “Screen”(white source pixel forces white, black leaves unchanged)
  - Additive (add pixel values, add alpha up to 1)

Dithering

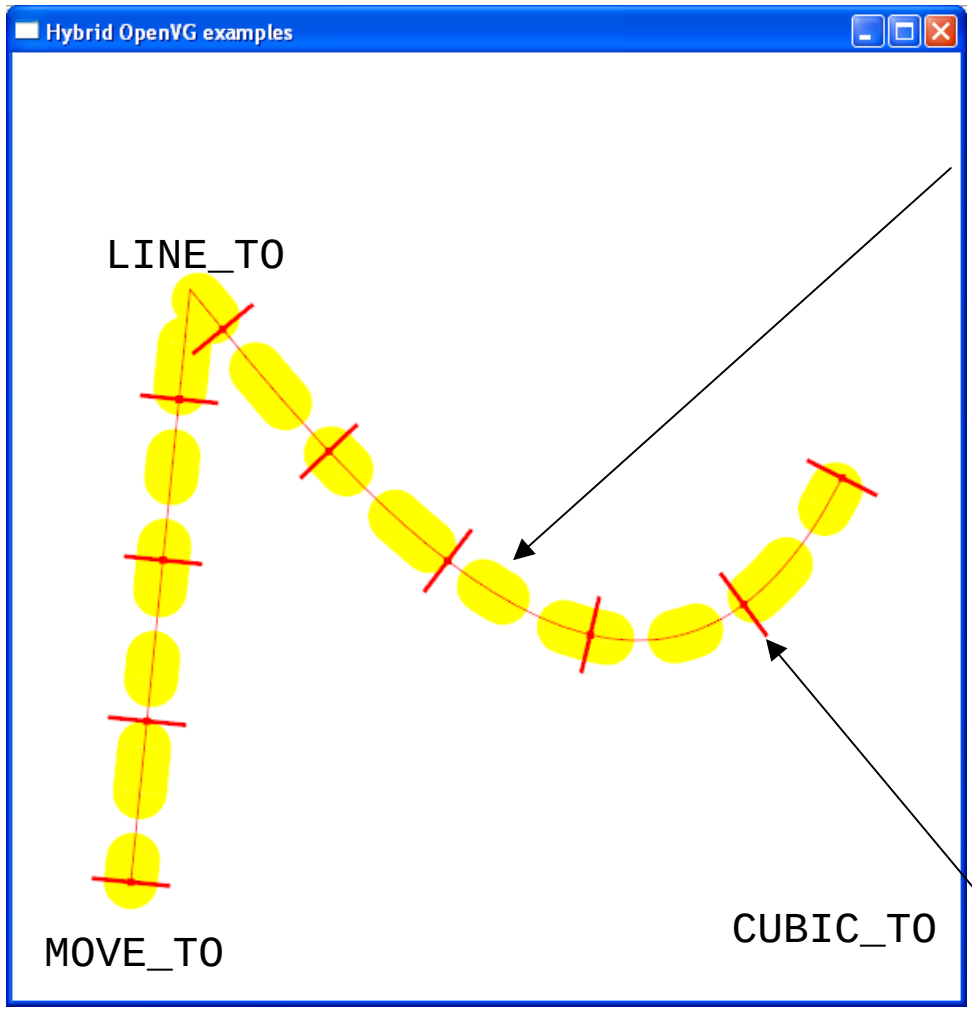
- As a final stage, the bit depth of pixels may be reduced using dithering
- The details of dithering are platform-specific



Images

- Images are defined using one of 13 pixel formats
  - Linear or non-linear (sRGB) color spaces
  - Linear or non-linear grayscale
  - Pre-multiplied or non-premultiplied alpha
  - 8/8/8, 5/6/5, 5/5/5/1, 4/4/4/4 bit depths (< 8 non-linear color only)
  - 1-bit Black & White (e.g., for Fax applications)
- Images may be stored in accelerated memory
- Image filters may be applied:
  - Color Matrix
  - Convolve, Separable Convolve, Gaussian Blur
  - Lookup, LookupSingle
- Images may be drawn in perspective
- Image may be used as a stencil to apply paint
  - Very useful for drawing anti-aliased text
- Image and paint colors may be multiplied together

Demo - Stroking




```
VGfloat d[] = { 5, 15, 10, 15 };
vgSetfv(VG_DASH_PATTERN, 4, d);
```

```
VGPath path = vgCreatePath(...);
cmd[0] = VG_MOVE_TO_ABS;
cmd[1] = VG_LINE_TO_ABS;
cmd[2] = VG_CUBIC_TO_ABS;
coord[0] = ...;
vgAppendPathData(...)
vgDrawPath(path, VG_STROKE_PATH)
```

vgPointAlongPath

Creating a Path

```
VGubyte * commands;
VGfloat * coords;
VGint numCmds, numCoords;

// 0,0 is O.K. for numCommands, numCoords
VGPath path = vgCreatePath(VG_PATH_FORMAT_STANDARD,
                           VG_PATH_DATATYPE_F,
                           1.0f, 0.0f, // scale,bias
                           numCmds, numCoords,
 VG_PATH_CAPABILITY_ALL);
commands[0] = VG_MOVE_TO_ABS;
coords[0] = ...; coords[1] = ...; /* x,y */
/* ... */
vgAppendPathData(path, numCmds, commands, coords);
```

Creating Color Paint

```
VGfloat color[] = { 1.0f, 1.0f, 0.0f, 1.0f }; /* RGBA */
VGPaint colorPaint = vgCreatePaint();

/* Paint Type */
vgSetParameteri(paint,
                VG_PAINT_TYPE, VG_PAINT_TYPE_COLOR);

/* Paint Color */
vgSetParameterfv(paint, VG_PAINT_COLOR, 4, color);
```

Setting Stroking Parameters

```
VGfloat lineWidth, miterLimit;
VGint capStyle, joinStyle;
VGfloat dashPattern[NUM_DASHES], dashPhase;

vgSetParameterf(VG_STROKE_LINE_WIDTH, lineWidth);
vgSetParameteri(VG_STROKE_CAP_STYLE, capStyle);
vgSetParameteri(VG_STROKE_JOIN_STYLE, joinStyle);
vgSetParameterf(VG_STROKE_MITER_LIMIT, miterLimit);
vgSetParameterfv(VG_STROKE_DASH_PATTERN,
                 NUM_DASHES, dashPattern);
vgSetParameterfv(VG_STROKE_DASH_PATTERN,
                 0, (VGfloat *) 0);
vgSetParameterf(VG_STROKE_DASH_PHASE, dashPhase);
```

Drawing the Path

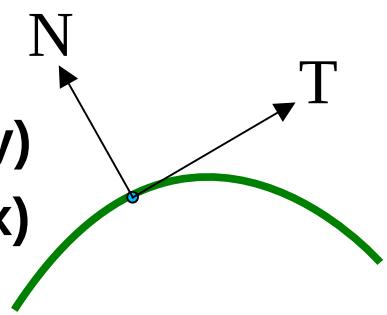
```
VGPath path;
VGPaint fillPaint, strokePaint;
VGboolean doFill, doStroke;

if (doFill) {
  vgSetPaint(fillPaint, VG_FILL_PATH);
}
if (doStroke) {
  vgSetPaint(strokePaint, VG_STROKE_PATH);
}
if (doFill || doStroke) {
  vgDrawPath(path, (doFill ? VG_FILL_PATH : 0) |
                   (doStroke ? VG_STROKE_PATH : 0));
}
```

Finding Points Along the Path

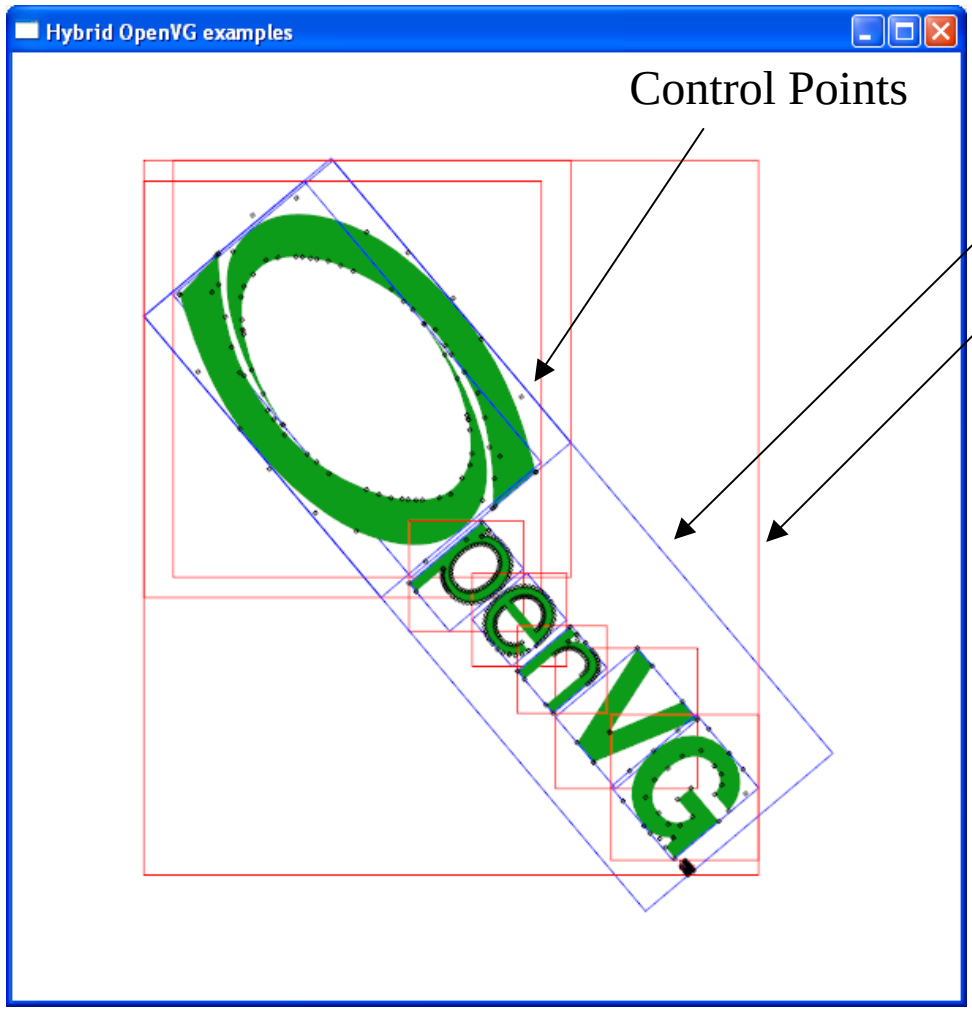
```
/* Determine # of path segments and path length */
VGint numSegments = vgGetParameteri(path,
                                    VG_PATH_NUM_SEGMENTS);
VGfloat length = vgPathLength(path, 0, numSegments);

/* Get equally-spaced points and tangents */
for (i = 0; i < numTicks; i++) {
  VGfloat x, y, tx, ty;
  vgPointAlongPath(path, 0, numSegments,
                   i*length/numTicks,
                   &x, &y, &tx, &ty);
}
```

Tangent: draw line from (x, y) to (x + tx, y + ty)

Normal: draw line from (x, y) to (x + ty, y – tx)

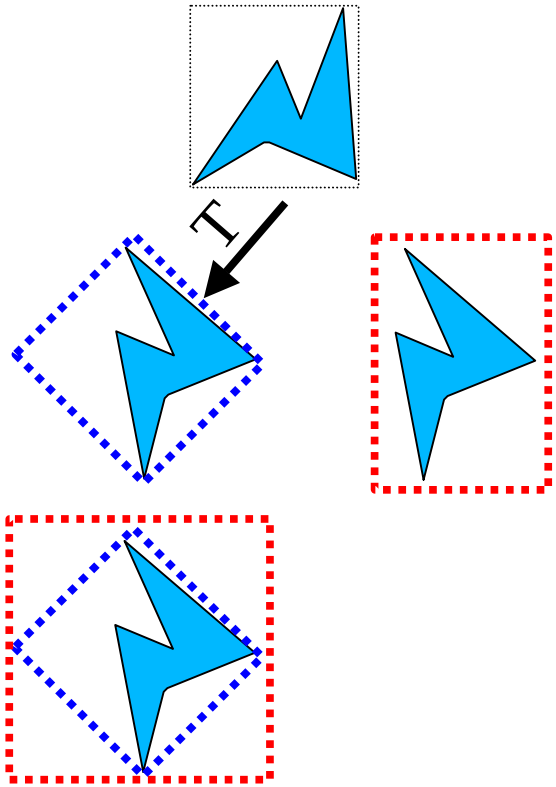


Demo – Bounding Boxes



`vgGetBounds(path)`

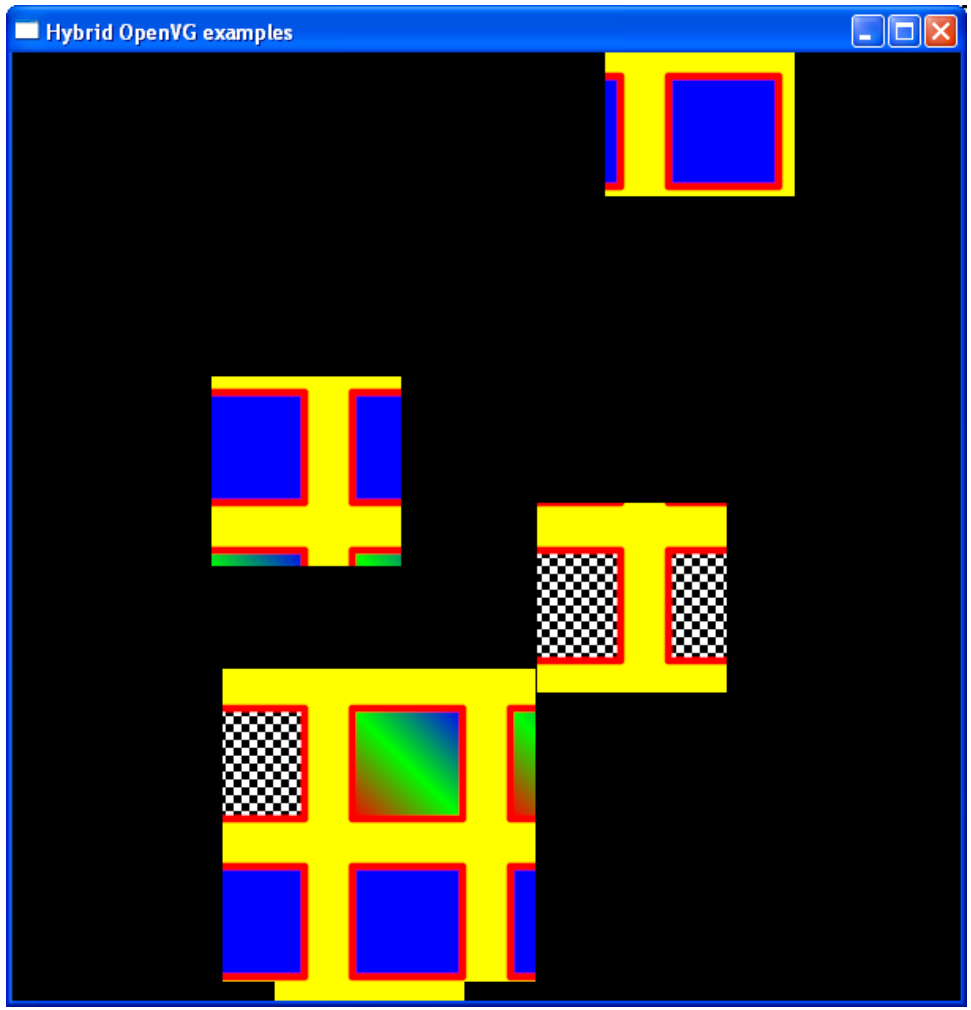
`vgGetTransformedBounds(path)`



Bounding Boxes

```
VGPath path, bounds, t_bounds;
VGfloat x, y, width, height;

vgLoadMatrix(...); /* User transformation */

vgPathBounds(path, &x, &y, &width, &height);
vguRect(bounds, x, y, width, height); // bounds <- rect
vgDrawPath(path, VG_STROKE_PATH);
vgDrawPath(bounds, VG_STROKE_PATH);

vgPathTransformedBounds(path, &x, &y, &width, &height);
vguRect(t_bounds, x, y, width, height);
vgLoadIdentity(); // Draw bounds in device coordinates
vgDrawPath(t_bounds, VG_STROKE_PATH);
```

Demo - Scissoring



Enabling Scissoring

```
VGfloat rects[4*NUM_RECTS];

vgSeti(VG_SCISSORING, VG_TRUE);
rects[0] = x0;
rects[1] = y0;
rects[2] = width0;
rects[3] = height0;
...
vgSetiv(VG_SCISSOR_RECTS, 4*NUM_RECTS, rects);
```

Creating Linear Gradient Paint

```
VGfloat lgParams[4]; /* x0, y0, x1, y1 */
VGfloat stops[5*NUM_STOPS];

VGPaint lPaint = vgCreatePaint();
/* Paint Type */
vgSetParameteri(lPaint, VG_PAINT_TYPE,
                VG_PAINT_TYPE_LINEAR_GRADIENT);
/* Gradient Parameters */
vgSetParameterfv(lPaint, VG_PAINT_LINEAR_GRADIENT,
                 4, lgParams);
/* Color Ramp */
vgSetParameterfv(lPaint, VG_PAINT_COLOR_RAMP_STOPS,
                 5*NUM_STOPS, stops);
vgSetParameteri(lPaint, VG_PAINT_COLOR_RAMP_SPREAD_MODE,
                VG_SPREAD_MODE_PAD);
```

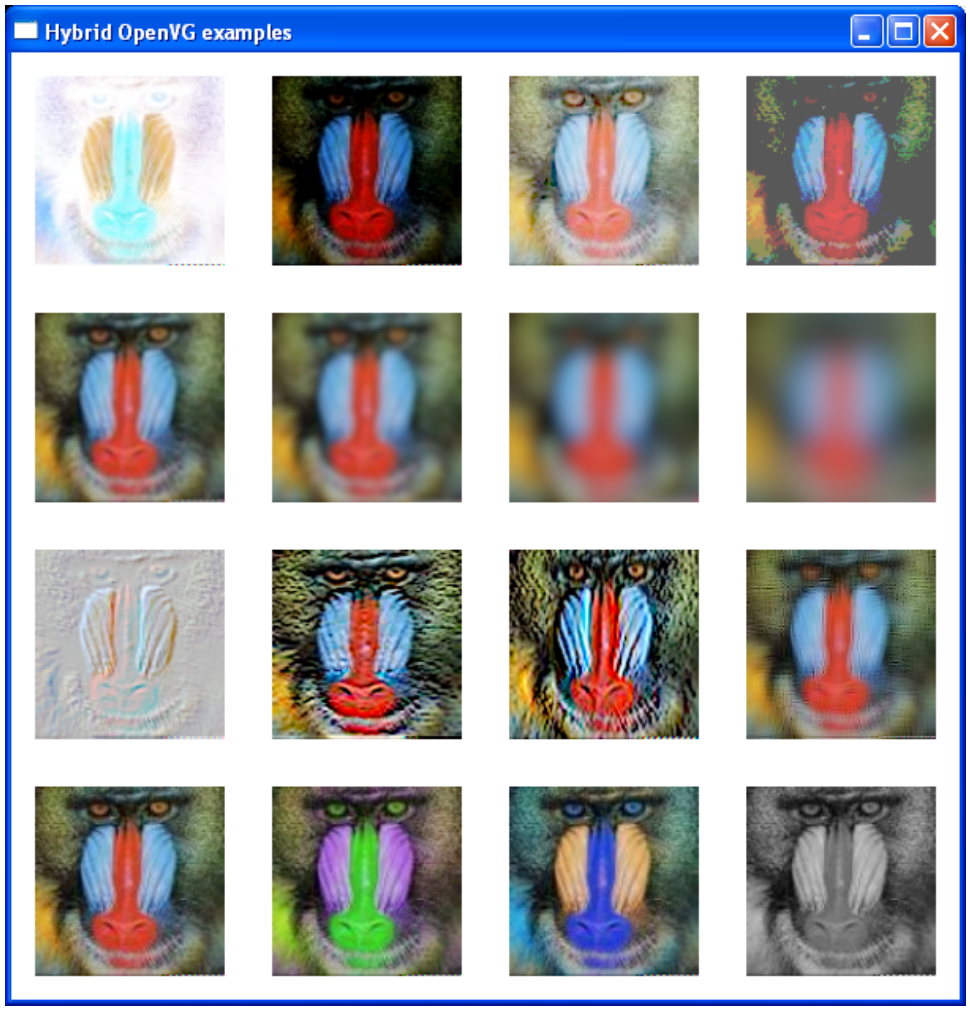
Creating Radial Gradient Paint

```
VGfloat rgParams[4]; /* cx, cy, fx, fy, r */
VGfloat stops[5*NUM_STOPS];

VGPaint rPaint = vgCreatePaint();

/* Paint Type */
vgSetParameteri(rPaint, VG_PAINT_TYPE,
                VG_PAINT_TYPE_RADIAL_GRADIENT);
/* Gradient Parameters */
vgSetParameterfv(rPaint, VG_PAINT_RADIAL_GRADIENT,
                 4, rgParams);

/* Color Ramp is the same as for linear gradient */
```

Creating Pattern Paint

```
/* Create and fill pattern image */
VGint * data;
VGint w, h;
VGImage pattern = vgCreateImage(VG_sRGBX_8888, w, h,
                                VG_IMAGE_QUALITY_FASTER);
vgImageSubData(pattern, data, 4*w, /* stride */
               VG_sRGBX_8888, 0, 0, w, h);

VGPaint pPaint = vgCreatePaint();
vgSetParameteri(pPaint, VG_PAINT_TYPE,
                VG_PAINT_TYPE_PATTERN);
vgSetParameteri(pPaint, VG_PAINT_PATTERN_TILING_MODE,
                VG_TILE_REPEAT);
vgPaintPattern(pPaint, pattern);
```

Demo – Image Filters



vgLookup: Invert, Darken, Lighten, “Posterize”

vgGaussianBlur: 1, 2, 5, 10

vgConvolve: Emboss, Edges, ?

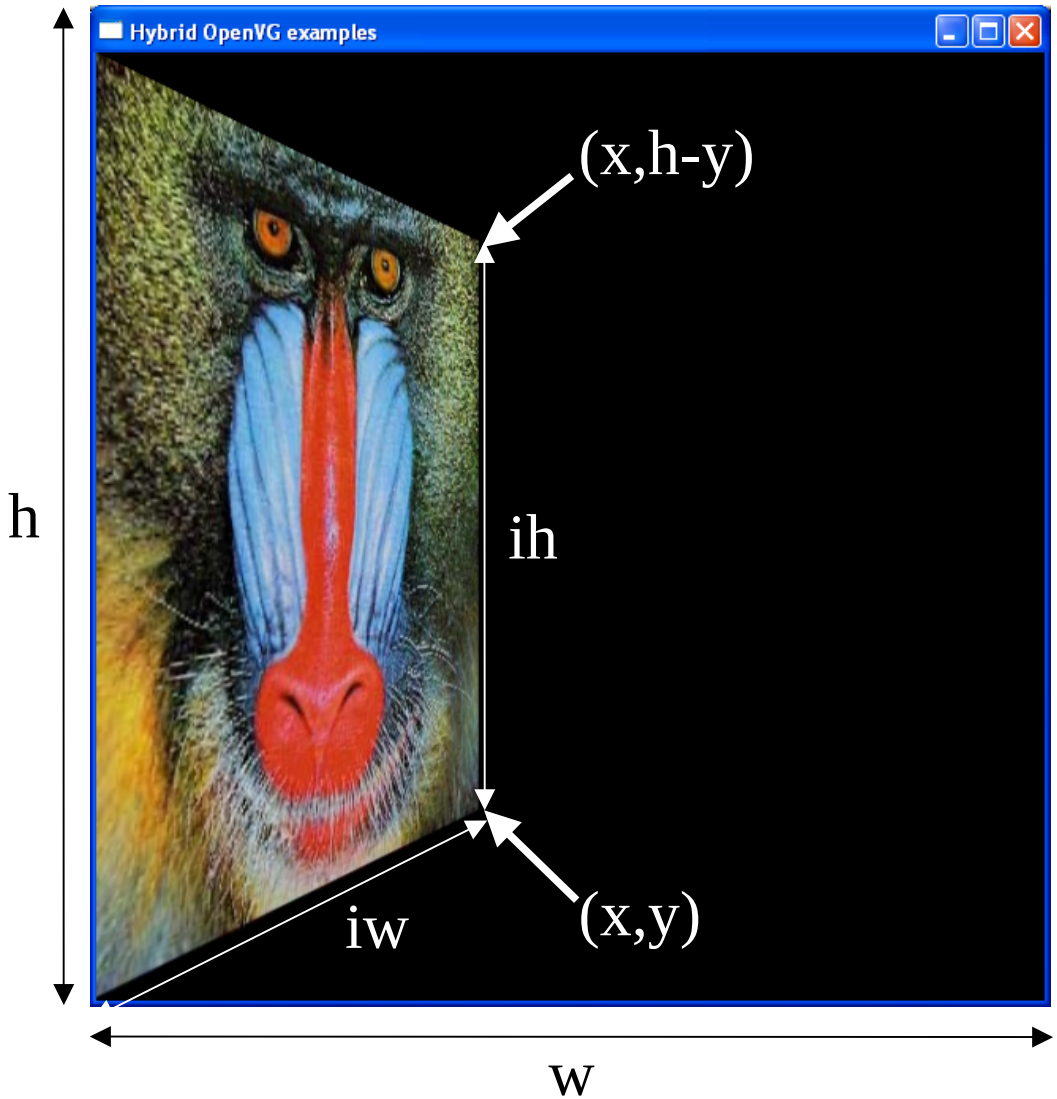
vgColorMatrix: Original, Swap RG, Swap RB, Gray

Using Image Filters

```
/* Lookup */
VGubyte r[256], g[256], b[256], a[256];
vgLookup(dst, src, r, g, b, a, VG_TRUE, VG_FALSE);

/* Gaussian Blur */
vgGaussianBlur(dst, src, radius, radius, VG_TILE_PAD);

/* Convolve */
VGshort kernel[9] = {  1, 1, 1, 1, 1, 1, 1, 1, 1 };
vgConvolve(dst, src, 3, 3, 1, 1,
           kernel, 1.0f/9.0f, 0.0f, VG_TILE_PAD);

/* Color Matrix */
VGfloat cmatrix[20]; // r' = ?r + ?g + ?b + ?a + ?
vgColorMatrix(dst, src, cmatrix);
```

OpenVG

Demo – Image Warping



Define matrix such that:

$(0,0) \rightarrow (0,0)$

$(0,h) \rightarrow (0, h)$

$(iw, 0) \rightarrow (x, y)$

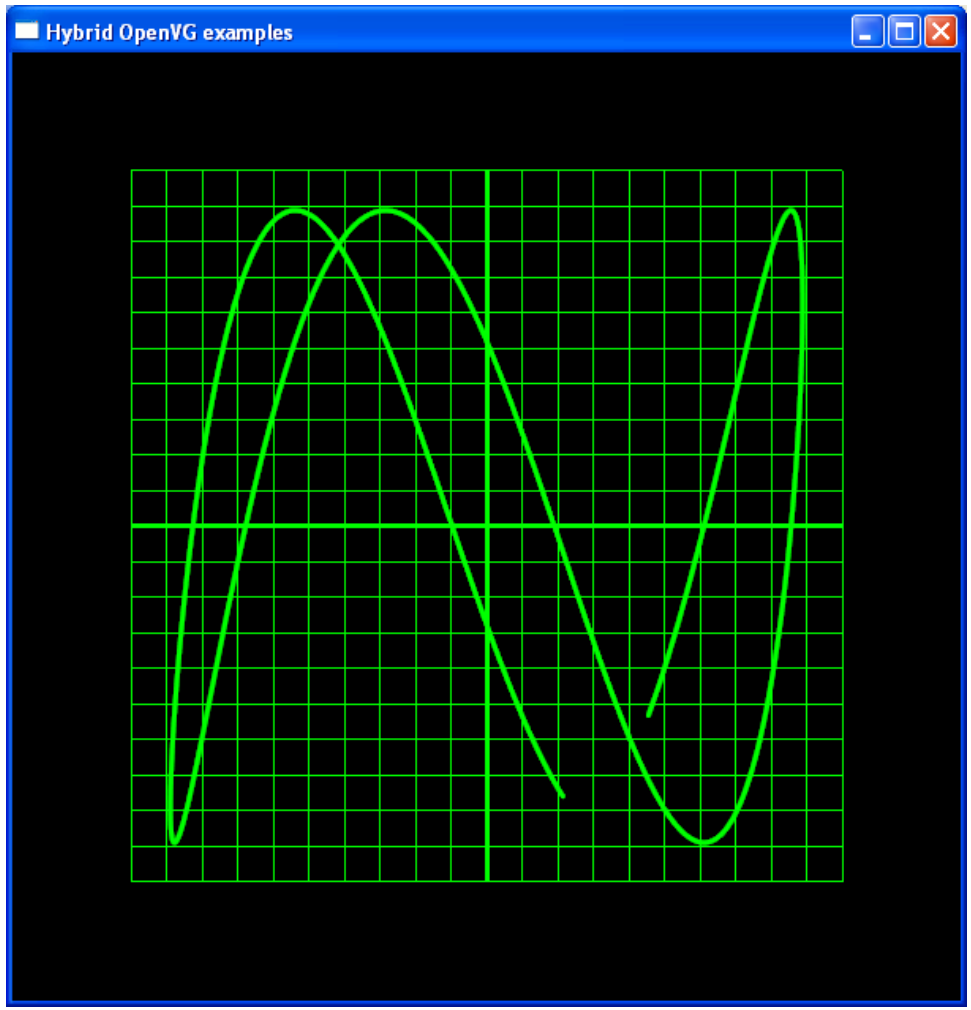
$(iw, ih) \rightarrow (x, h - y)$

Don’t forget to restore the matrix mode!

Warping Images

```
VGImage image;
VGfloat x, y, imW, imH, h;
VGfloat matrix[9];
// Derive projective matrix from corner points
vguWarpQuadToQuad(0, 0, imW, 0, imW, imH, 0, imH,
                  0, 0, x, y, x, h – y, 0, h,
                  matrix);
vgSeti(VG_MATRIX_MODE, VG_MATRIX_IMAGE_USER_TO_SURFACE);
vgLoadMatrix(matrix);
vgDrawImage(image);

/* Restore matrix mode */
vgSeti(VG_MATRIX_MODE, VG_MATRIX_PATH_USER_TO_SURFACE);
```

Demo – Oscilloscope



Draw background grid

Generate path from (cos(a*t), sin(b*t))

Stroke path

Modify a, b interactively

Any Questions?