Curves in OpenGL — Evaluators

OpenGL supports the drawing of curved surfaces through the use of evaluators.

Evaluators can be used to construct curves and surfaces based on the Bernstein basis polynomials. This includes Bézier curves and patches, and B-splines.

In order to draw curves and surfaces using other basis polynomials (e.g., Hermite polynomials) the user program must transform that basis to a Bernstein basis.

Consider first one-dimensional evaluators. The following steps are performed:

- Define a one-dimensional evaluator with `glMap1*()`
- Enable it with `glEnable()`

  (Both functions are usually called as part of initialization.)
- The function is evaluated at a series of points using `glEvalCoord1()` between a `glBegin()` and `glEnd()` block in the `display()` function. [This is similar to using `glVertex*()`.]

`glEvalCoord1()` is usually called within a `for` loop.

The function `glMap1()` defines a one-dimensional evaluator that evaluates the Bernstein polynomial of order $n + 1$, where n is the degree of the polynomial.

```
void glMap1fd(GLenum target, TYPE t1, TYPE t2, GLint
stride, GLint order, const TYPE *points);
```

`target` specifies what the control points represent (see the table following), `t1` and `t2` specify the range for the variable t, `stride` specifies the number of entries between the beginning of one control point and the beginning of the next one in the data structure referenced by `points`. This allows control points to be embedded in arbitrary data structures. `order` is the order of the polynomial, which is the same as the number of control points. `*points` is a pointer to the list of control points.

Parameter	Meaning
`GL_MAP1_VERTEX_3`	x, y, z vertex coordinates
`GL_MAP1_VERTEX_4`	x, y, z, w vertex coordinates
`GL_MAP1_INDEX`	color index
`GL_MAP1_COLOR_4`	R, G, B, A
`GL_MAP1_NORMAL`	normal coordinates
`GL_MAP1_TEXTURE_COORD_1`	s texture coordinates
`GL_MAP1_TEXTURE_COORD_2`	s, t texture coordinates
`GL_MAP1_TEXTURE_COORD_3`	s, t, r texture coordinates
`GL_MAP1_TEXTURE_COORD_4`	s, t, r, q texture coordinates

`void glEvalCoord1{fd}(TYPE t);`

Evaluates the enabled one-dimensional function. The argument `t` is the value of the parameter.

The following code is from the program `bezcurve.c`:

```
#define STEPS 5

GLfloat ctrlpts[4][3] = {
        { -4.0, -4.0, 0.0}, { -2.0, 4.0, 0.0},
        {2.0, -4.0, 0.0}, {4.0, 4.0, 0.0}};

void init(void)
{
   glClearColor(0.0, 0.0, 0.0, 0.0);
   glShadeModel(GL_FLAT);
   glMap1f(GL_MAP1_VERTEX_3, 0.0, 1.0,
           3, 4, &ctrlpts[0][0]);
   glEnable(GL_MAP1_VERTEX_3);
}
```

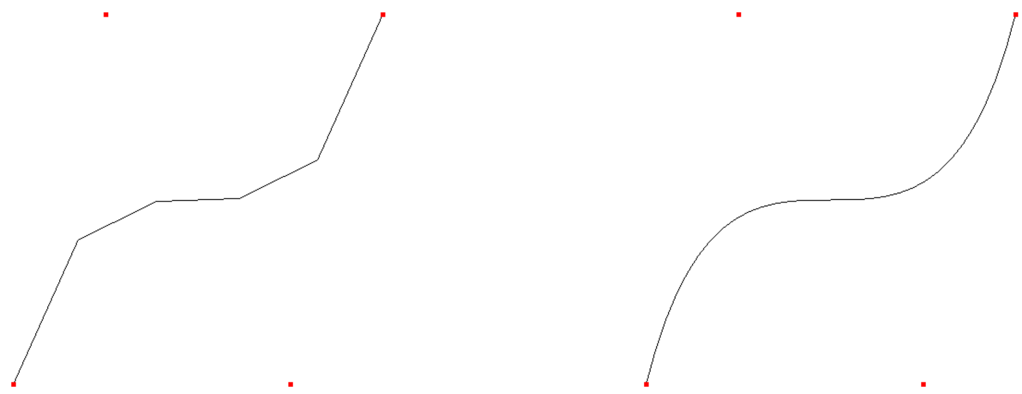
Note: the `stride` parameter is 3, while `order` is set to 4 (the degree is 3).

```
void display(void)
{
   int i;

   glClear(GL_COLOR_BUFFER_BIT);
   glColor3f(1.0, 1.0, 1.0);
   glBegin(GL_LINE_STRIP);
      for (i = 0; i <= STEPS; i++)
         glEvalCoord1f((GLfloat) i / (GLfloat) STEPS);
   glEnd();

   /* Display the control points as dots. */
   glPointSize(5.0);
   glColor3f(0.0, 0.0, 1.0);
   glBegin(GL_POINTS);
      for (i = 0; i < 4; i++)
         glVertex3fv(&ctrlpts[i][0]);
   glEnd();
   glFlush();
}
```

Screenshots...



On the left, the constant `STEPS` is set to 5; on the right it is set to 30.

It is common for coordinate values to be evenly spaced, as they were in the previous example.

In this case, the functions `glMapGrid1()` and `glEvalMesh1()` are useful.

```
void glMapGrid1{fd}(GLint n, TYPE t1, TYPE t2);
```

Defines a grid that goes from `t1` to `t2` in `n` evenly spaced steps.

```
void glEvalMesh1(GLenum mode, GLint p1, GLint p2);
```

Applies the currently defined grid to all enabled evaluators. The `mode` can be either `GL_POINT` or `GL_LINE`, depending on whether points or a connected line is required. The call has exactly the same effect as issuing a `glEvalCoord1()` for each of the steps from `p1` to `p2`, inclusive.

The previous code could be rewritten as:

```
void init(void)
{
   glClearColor(1.0, 1.0, 1.0, 0.0);
   glShadeModel(GL_FLAT);
   glMap1f(GL_MAP1_VERTEX_3, 0.0, 1.0, 3, 4, &ctrlpts[0][0]
   glEnable(GL_MAP1_VERTEX_3);
   glMapGrid1f(STEPS, 0.0, 1.0);
}
void display(void)
{
   glClear(GL_COLOR_BUFFER_BIT);
   glColor3f(1.0, 0.0, 0.0);
   glEvalMesh1(GL_LINE, 0, STEPS);

   /* Display control points as dots. */
         .
         .
         .
   glFlush();
}
```

Two dimensional evaluators

Two-dimensional evaluators evaluate the Bernstein polynomials for two parameters, u and v. These evaluators are used as follows:

- Define the evaluator(s) with `glMap2*()`
- Enable them by passing the appropriate value to `glEnable()`
- Invoke them either by calling `glEvalCoord2()` between a `glBegin` and `glEnd` pair, or by specifying and applying a mesh with `glMapGrid2()` and `glEvalMesh2()`.

```
void glMap2{fd}(GLenum target, TYPE u1, TYPE u2, GLint
ustride, GLint uorder, TYPE v1, TYPE v2, GLint vstride,
GLint vorder, TYPE *points)
```

The `target` parameter is as shown in the earlier table, except `MAP1` is replaced by `MAP2`. `u1`, `u2`, `v1`, and `v2` are the ranges for u and v. `ustride` and `vstride` are the "distance" to the next `u` and `v` values in the array of control points. `uorder` and `vorder` are the order parameters, which also give the number of control points: `uorder` $\times$ `vorder`.

For example, you could have control points for a number of different shapes stored in a single array

```
GLfloat ctrlpts[100][100][3];
```

To select the 4×4 subset (assume `uorder` = `vorder` = 4) starting at `[20][10]`, you would specify that...

`ustride` should be 3*100 and `vstride` should be 3 (C stores arrays in row major order).

`*points` should be set to `&ctrlpts[20][10][0]`.

`void glEvalCoord2{fd} (TYPE u, TYPE v);`

Causes evaluation of the enabled two-dimensional maps. The arguments `u` and `v` are values for the domain coordinates.

If either of the vertex evaluators is enabled (`GL_MAP2_VERTEX_3` or `GL_MAP2_VERTEX_4`), then the normal to the surface is computed analytically. This normal is associated with the generated vertex if automatic normal generation has been enabled using `glEnable(GL_AUTO_NORMAL)`. If it is disabled, the corresponding enabled normal map is used. If no such map exists, the current normal is used.

The following code is from the example **bezsurf2.c**. Nine curved lines are drawn in each direction, with each one composed of 30 segments. The red lines vary in u, the blue ones vary in v. (The parameter `maxJ` is controlled by the user to illustrate the drawing order).

```
GLfloat ctrlpoints[4][4][3] = {
   {{-1.5, -1.5, 4.0}, {-0.5, -1.5, 2.0},
    {0.5, -1.5, -1.0}, {1.5, -1.5, 2.0}},
   {{-1.5, -0.5, 1.0}, {-0.5, -0.5, 3.0},
    {0.5, -0.5, 0.0}, {1.5, -0.5, -1.0}},
   {{-1.5, 0.5, 4.0}, {-0.5, 0.5, 0.0},
    {0.5, 0.5, 3.0}, {1.5, 0.5, 4.0}},
   {{-1.5, 1.5, -2.0}, {-0.5, 1.5, -2.0},
    {0.5, 1.5, 0.0}, {1.5, 1.5, -1.0}}
};
```

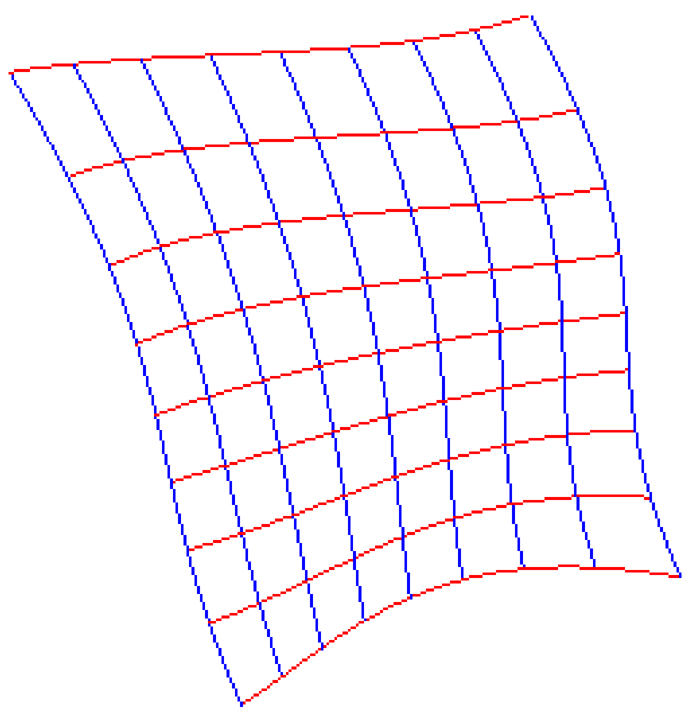
```
void display(void)
{
   int i, j;

   glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
   glPushMatrix ();
   glRotatef(15.0, 1.0, 1.0, 1.0);
   for (j = 0; j <= maxJ; j++) {
      glColor3f(1.0, 0.0, 0.0);
      glBegin(GL_LINE_STRIP);
      for (i = 0; i <= 30; i++)
         glEvalCoord2f((GLfloat)i/30.0, (GLfloat)j/8.0);
      glEnd();

      glColor3f(0.0, 0.0, 1.0);
      glBegin(GL_LINE_STRIP);
      for (i = 0; i <= 30; i++)
         glEvalCoord2f((GLfloat)j/8.0, (GLfloat)i/30.0);
      glEnd();
   }
   glPopMatrix ();
   glFlush();
}
```

```
void init(void)
{
   glClearColor (0.0, 0.0, 0.0, 0.0);
   glMap2f(GL_MAP2_VERTEX_3, 0, 1, 3, 4,
           0, 1, 12, 4, &ctrlpoints[0][0][0]);
   glEnable(GL_MAP2_VERTEX_3);
   glEnable(GL_DEPTH_TEST);
   glShadeModel(GL_FLAT);
}
```

Screenshot...



For evenly spaced coordinate values, use the following functions:

```
void glMapGrid2{fd}(GLint nu, TYPE u1, TYPE u2,
GLint nv, TYPE v1, TYPE v2);
```

Defines a two-dimensional map grid that goes from `u1` to `u2`, and from `v1` to `v2` in `nu` and `nt` evenly-spaced steps.

```
void glEvalMesh2(GLenum mode, GLint i1, GLint i2,
GLint j1, GLint j2);
```

...applies this grid to all enabled evaluators, From step `i1` to `i2` in u, and from `j1` to `j2` in v. The `mode` parameter can beset to `GL_FILL`, `GL_POINT` or `GL_LINE`. `GL_FILL` generates filled polygons.

The example `bezmesh.c` illustrates these commands.