3D Graphics and OpenGL

First Steps
Rendering of 3D Graphics

Objects defined in (virtual/mathematical) 3D space.
Rendering of 3D Graphics

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We see surfaces of objects ⇒ define surfaces.
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Main objective: transfer (models built of) triangles from 3D space to 2D screen space. Add colors to the screen pixels covered by triangle (shading).
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Coordinate systems:
Vertices

Core data: vertices of triangles.

```c
glBegin(GL_TRIANGLES);
    glVertex3f(20.0, 20.0, 0.0);
    glVertex3f(80.0, 20.0, 0.0);
    glVertex3f(80.0, 80.0, 0.0);
    .*.
    .*.
    glEnd();
```
Other OpenGL Primitives

- **GL_POINTS**
- **GL_LINES**
- **GL_LINE_STRIP**
- **GL_LINE_LOOP**
- **GL_TRIANGLES**
- **GL_TRIANGLE_STRIP**
- **GL_TRIANGLE_FAN**
- **GL_QUADS**
- **GL_QUAD_STRIP**
- **GL_POLYGON**

Function calls:
- `glRectf(x_1, y_1, x_2, y_2)`
- `glRectf(x_1, y_1, x_2, y_2)`
OpenGL Primitives

Polygons and quads are divided into triangles by OpenGL before rendering. Must be plane and convex.
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Not planar, not convex  Planar, not convex  Planar and convex
OpenGL Primitives

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![Diagram showing examples of planar and non-planar shapes]

Not planar, not convex  Planar, not convex  Planar and convex

For efficiency, use array lists (single rendering call accessing array of many points) and display lists (precompiled and stored groups of OpenGL commands, including declarations of geometry/primitives). See sections 3.1 and 3.2.
Geometry

Core data: triangles
Geometry

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Triangle vertices and associated data:

- Position
- Color
- Normal vector
- Texture coordinate

Vertex data are interpolated across triangle at rendering time (details of interpolation and other parts of rendering later).
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OpenGL has a state

**State machine:** Long list of set variables affecting rendering. Value fixed after initialization until changed. (Alternative would be to give long list of parameters for all rendering calls).

```c
glBegin(GL_QUADS);
glColor3f(1.0, 0.0, 0.0);
   glVertex3f(20.0, 20.0, 0.0);
   glColor3f(0.0, 1.0, 0.0);
   glVertex3f(80.0, 20.0, 0.0);
   glColor3f(0.0, 0.0, 1.0);
   glVertex3f(80.0, 80.0, 0.0);
   glColor3f(1.0, 1.0, 0.0);
   glVertex3f(20.0, 80.0, 0.0);
glEnd()
```
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E.g., setting (foreground/vertex) color using `glColor`:

```c
glBegin(GL_QUADS);
    glColor3f(1.0, 0.0, 0.0);
    glVertex3f(20.0, 20.0, 0.0);
    glColor3f(0.0, 1.0, 0.0);
    glVertex3f(80.0, 20.0, 0.0);
    glColor3f(0.0, 0.0, 1.0);
    glVertex3f(80.0, 80.0, 0.0);
    glColor3f(1.0, 1.0, 0.0);
    glVertex3f(20.0, 80.0, 0.0);
    glEnd()
```
Projections

Transfer (models built of triangles built of vertex) points from 3D space to 2D screen space.
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Two types:

- Orthographic
- Perspective
Orthographic Projection
Orthographic Projection

![Orthographic Projection Diagram](image-url)
Perspective Projection

(base on the plane $z = -far$)

((far/near) left, (far/near) top, -far)
((far/near) right, (far/near) top, -far)
((far/near) left, (far/near) bottom, -far)
((far/near) right, (far/near) bottom, -far)
(left, top, -near)
(right, top, -near)
(left, bottom, -near)
(right, bottom, -near)

(0, 0, 0) = apex

viewing face (film) on the viewing plane $z = -near$

OpenGL Window

Computer Screen
Perspective Projection

Viewing frustum

(base on the plane $z = \text{-far}$)

(((far/near) left, (far/near) top, -far))

(((far/near) right, (far/near) top, -far))

((left, top, -near))

((right, top, -near))

((left, bottom, -near))

((right, bottom, -near))

viewing face (film) on the viewing plane $z = \text{-near}$

print

$(0, 0, 0) = \text{apex}$

OpenGL Window

Computer Screen

section of the viewing face

$pA$

$B$

$A$
Perspective

Helix curve:

Orthographic:
Perspective

Helix curve:

Orthographic:

Projective:
Clipping before Projection

The geometry is clipped against the viewing area planes before projection. Further clipping planes can be specified manually.
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Stretch after Projection

The projected image is stretched to the screen/window size after projection.
OpenGL Buffers

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Two important buffer types:

- **Color buffers.** Hold the color values to be shown on screen.
- **Depth buffer.** Resolves hidden surface removal.
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(Free)GLUT

- Library that abstracts away OS-specific interface/libraries between OpenGL and OS (incl. creation of framebuffer and double buffering swaps).

- Handles keyboard/mouse input, windowing management.

- Event loop.

- OpenGL programmer associates callback functions with events.

- Animation through timed callbacks (`glutTimerFunc()`) or idle time callback (`glutIdleFunc()`).

- Commands for triangles for basic models (cube, cone, sphere, torus, . . . ).

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- OpenGL programmer associates callback functions with events.
- Animation through timed callbacks (glutTimerFunc()) or idle time callback (glutIdleFunc()).
- Commands for triangles for basic models (cube, cone, sphere, torus, teapot, ...).

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