Part 3 \o/

# 3D computer graphics with OpenGL

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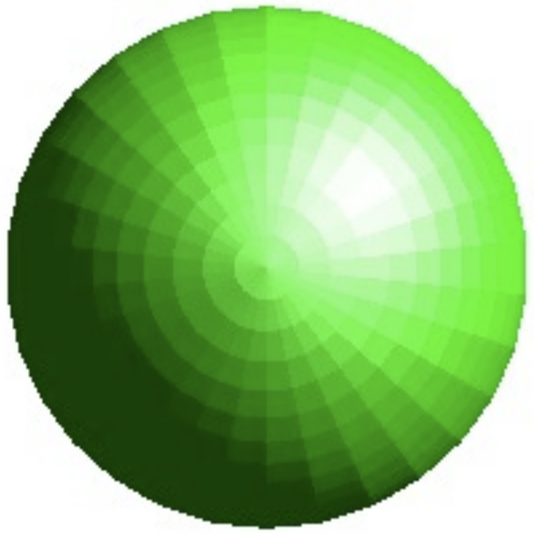
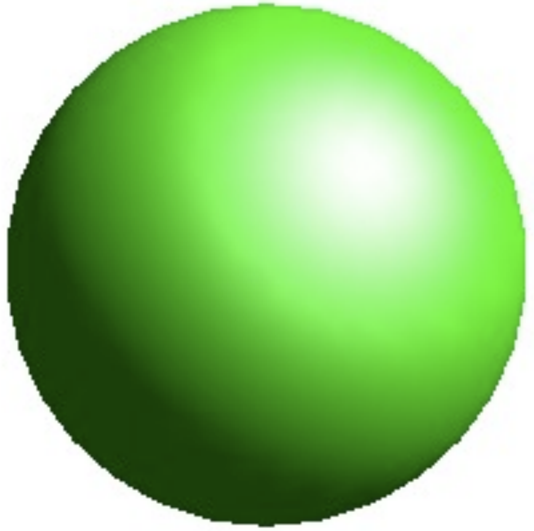
<review>

## flat shading vs. Gouraud shading



`glShadeModel(GL_FLAT);`



`glShadeModel(GL_SMOOTH);`

## lighting example

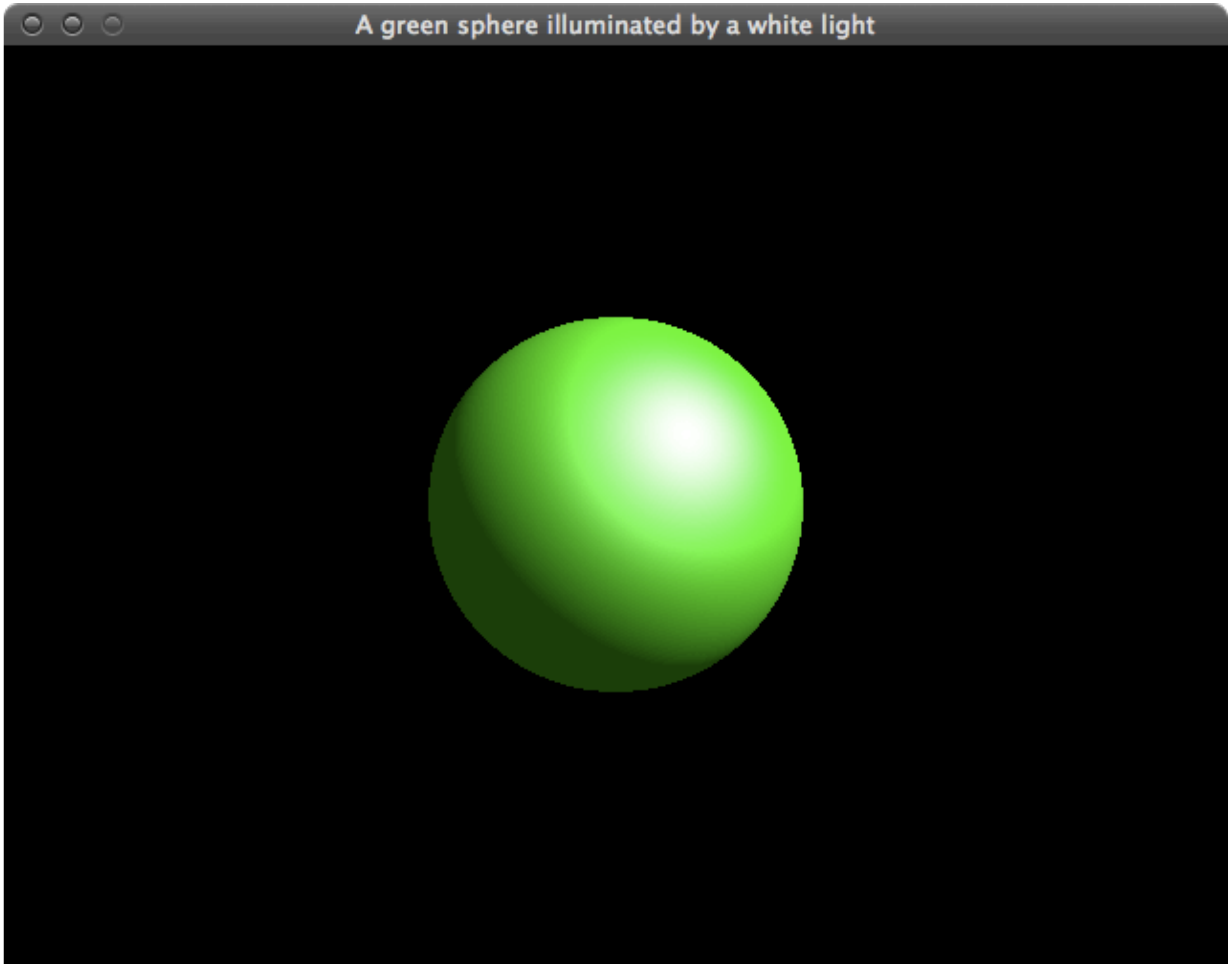
```
void myinit(int width, int height)
{
  GLfloat mat_specular[] = { 1.0, 1.0, 1.0, 1.0 };
  GLfloat mat_shininess[] = { 10.0 };
  GLfloat mat_ambient_and_diffuse[] = { 0.0, 1.0, 0.0, 1.0 };

  glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
  glMaterialfv(GL_FRONT, GL_SHININESS, mat_shininess);
  glMaterialfv(GL_FRONT, GL_AMBIENT, mat_ambient_and_diffuse);
  glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_ambient_and_diffuse);

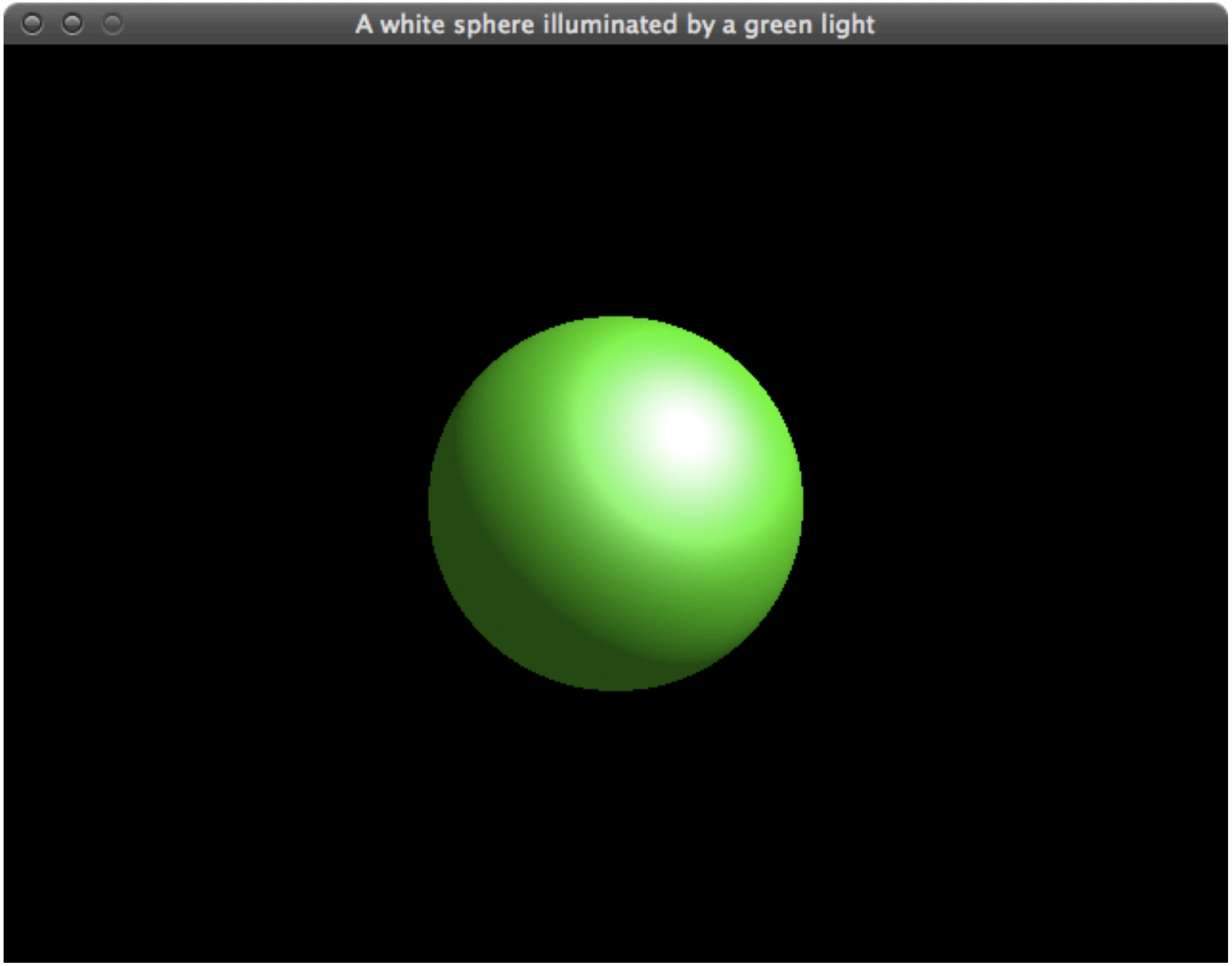
  GLfloat light_position[] = { 1.0, 1.0, 1.0, 0.0 };
  glLightfv(GL_LIGHT0, GL_POSITION, light_position);

  glEnable(GL_LIGHTING);
  glEnable(GL_LIGHT0);
  glShadeModel(GL_SMOOTH);

  // continue with initialisation code as before
  // ....
```



materialcolour.cpp



lightcolour.cpp

## what you need

- a light source
- glMaterial instead of glColor
- normal vectors
    - faces must be defined in counter-clockwise order
    - to test: glEnable(GL_CULL_FACE);
      glFrontFace(GL_CCW);
    - normals should be unit length
        - either do normalisation yourself (recommended)
        - or let OpenGL do it for you:
          glEnable(GL_NORMALIZE);

</review>

## needful things for your toolbox

- fullscreen mode
- repeating key events
- animation using timers
- Mac OS X specific:
  - synchronizing SDL_GL_SwapBuffers() with the vertical refresh

*see source code examples...*

## fullscreen mode

- simply add SDL_FULLSCREEN in SDL_SetVideoMode()

tricolour_fullscreen.cpp

## repeating key events

- interaction through key events so far:
  - increase translation/rotation value on key-down
- new and improved interaction through key events:
  - set movement flag on key-down
  - clear movement flag on key-up
  - update animation if movement flag is set

don't do this:

```
int spin = 0;

void mydisplay()
{
  glPushMatrix();
  glRotatef ((float) spin, 0.0, 1.0, 0.0);
  // draw scene here
  glPopMatrix();
}

// in event processing loop

  if (event.type == SDL_KEYDOWN) {
    switch(event.key.keysym.sym) {
      case SDLK_RIGHT:
        spin = (spin + 5) % 360;
        break;
      }
    }
  }
```

movinglight.cpp

do this instead!

```
int spin = 0;
bool spinning = false;

void mydisplay()
{
  if (spinning) spin = (spin + 1) % 360;
  glPushMatrix();
  glRotatef ((float) spin, 0.0, 1.0, 0.0);
  // draw scene here
  glPopMatrix();
}

// in event processing loop

 if (event.type == SDL_KEYDOWN) {
    switch(event.key.keysym.sym) {
      case SDLK_RIGHT:
        spinning =true;
        break;
      }
    }
  } else if (event.type == SDL_KEYUP) {
    switch(event.key.keysym.sym){
    case SDLK_RIGHT:
      spinning = false;
      break;
    }
  }
```

keyrepeat.cpp

## animation using timers

- create and add a timer

```
SDL_TimerID SDL_AddTimer(Uint32 interval,
                         SDL_NewTimerCallback callback,
                         void *param);
```

- define timer callback function

```
typedef Uint32 (*SDL_NewTimerCallback)(Uint32 interval, void *param);
```

- in that callback function, create and send a user event

```
SDL_Event event;
event.type = SDL_USEREVENT;
event.user.code = RUN_GAME_LOOP;
SDL_PushEvent(&event);
```

- in your event processing loop, catch this event and call your display function

```
if (event.type == SDL_USEREVENT)
  if (event.user.code == RUN_GAME_LOOP) {
    mydisplay();
  }
}
```

# animation using timers

```
int main(int argc, char ** argv)
{
  // SDL and OpenGL setup code as usual

  SDL_TimerID timer;
  timer = SDL_AddTimer(20, GameLoopTimer, NULL);

  bool done = false;
  while (!done) {
    SDL_Event event;
    while (SDL_PollEvent(&event)) {
      if (event.type == SDL_USEREVENT) {
        if (event.user.code == RUN_GAME_LOOP) {
          mydisplay();
        }
      } else if (event.type == SDL_QUIT) {
        done = true;
     }
  }

  SDL_RemoveTimer(timer);
  SDL_Quit();
  return 0;
}
```

## animation using timers

```
int main(int argc, char ** argv)
{
  // SDL and OpenGL setup code as usual

  SDL_TimerID timer;
  timer = SDL_AddTimer(20, GameLoopTimer, NULL);

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        if (event.user.code == RUN_GAME_LOOP) {
          mydisplay();
        }
      } else if (event.type == SDL_QUIT) {
        done = true;
     }
  }

  SDL_RemoveTimer(timer);
  SDL_Quit();
  return 0;
}
```

## animation using timers

```
const int RUN_GAME_LOOP = 1;

Uint32 GameLoopTimer(Uint32 interval, void* param)
{
  // Create a user event to call the game loop.
  SDL_Event event;

  event.type = SDL_USEREVENT;
  event.user.code = RUN_GAME_LOOP;
  event.user.data1 = 0;
  event.user.data2 = 0;

  SDL_PushEvent(&event);
  return interval;
}
```

## animation using timers

```
const int RUN_GAME_LOOP = 1;

Uint32 GameLoopTimer(Uint32 interval, void* param)
{
  // Create a user event to call the game loop.
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  event.type = SDL_USEREVENT;
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  SDL_PushEvent(&event);
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  event.type = SDL_USEREVENT;
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  event.user.data1 = 0;
  event.user.data2 = 0;

  SDL_PushEvent(&event);
  return interval;
}
```

## animation using timers

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int main(int argc, char ** argv)
{
  // SDL and OpenGL setup code as usual

  SDL_TimerID timer;
  timer = SDL_AddTimer(20, GameLoopTimer, NULL);

  bool done = false;
  while (!done) {
    SDL_Event event;
    while (SDL_PollEvent(&event)) {
      if (event.type == SDL_USEREVENT) {
        if (event.user.code == RUN_GAME_LOOP) {
          mydisplay();
        }
      } else if (event.type == SDL_QUIT) {
        done = true;
     }
  }

  SDL_RemoveTimer(timer);
  SDL_Quit();
  return 0;
}
```

## animation using timers

```
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{
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  SDL_TimerID timer;
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  bool done = false;
  while (!done) {
    SDL_Event event;
    while (SDL_PollEvent(&event)) {
      if (event.type == SDL_USEREVENT) {
        if (event.user.code == RUN_GAME_LOOP) {
          mydisplay();
        }
      } else if (event.type == SDL_QUIT) {
        done = true;
     }
  }

  SDL_RemoveTimer(timer);
  SDL_Quit();
  return 0;
}
```

timer.cpp

## on a related note...

- so far, we used SDL_PollEvent() to check for events
  - non-blocking: will return 0 if there are no events
  - "busy waiting"
- alternative: SDL_WaitEvent()
  - blocking: does not return until an event occurs
  - better since it doesn't hog all your CPU time
  - suggested approach when using timers

timer-waitevent.cpp

  - not what want when you are not using timers, since mydisplay() would only be called when an event occurs!

## synchronised swapping

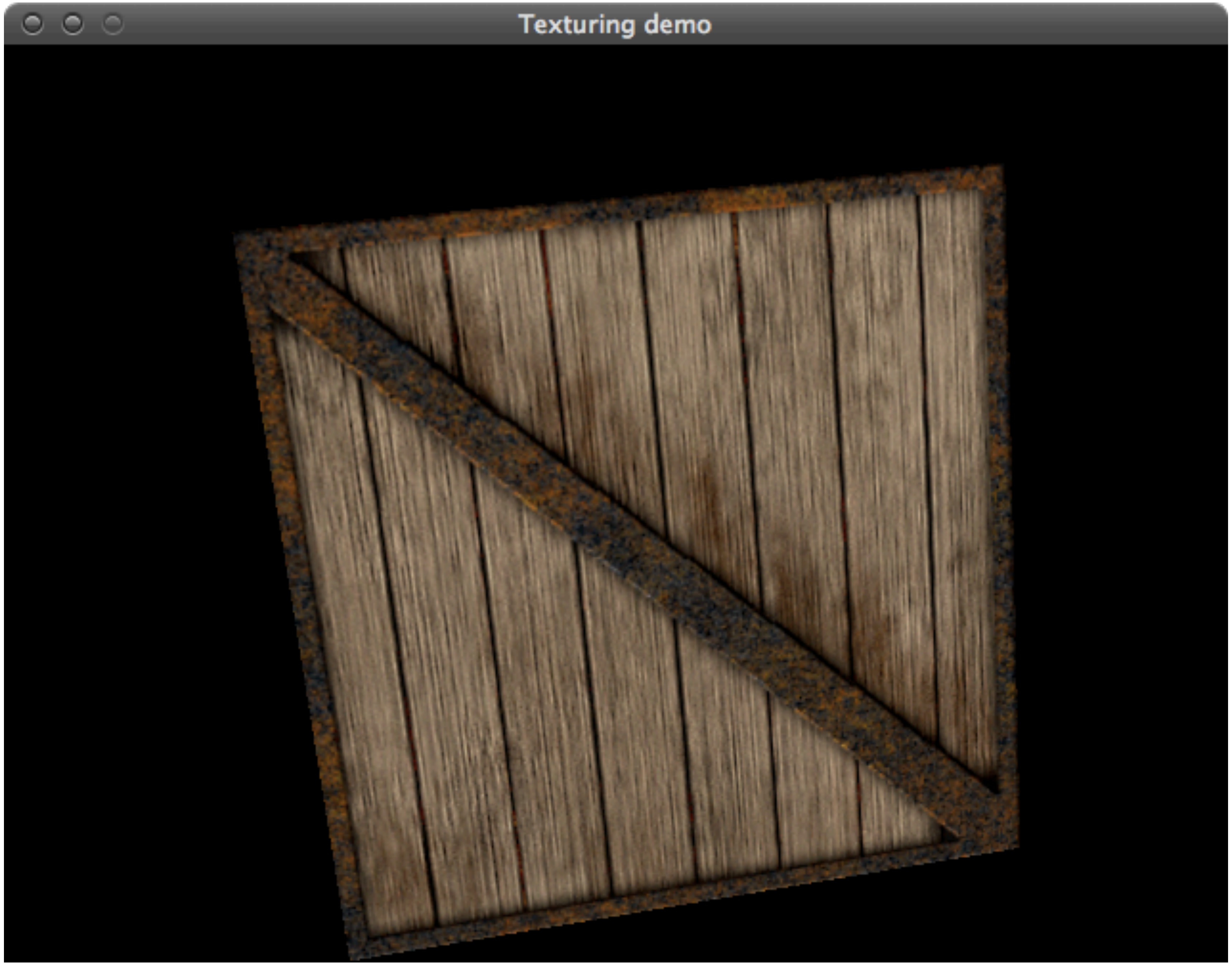
```
// Sync the SDL_GL_SwapBuffers() call with the vertical blank
// (This is for Mac OS X only!)

GLint swap = 1;
CGLSetParameter(CGLGetCurrentContext(), kCGLCPSwapInterval, &swap);
```

textures

## textures

- What is a texture?
- A texture is an “image” that is mapped to a polygon.
- Textures are rectangular arrays of data.
    - for example color data (or alpha values or...)
    - does not need to be 2D
- Individual values in a texture array: “texels”.



texturing.cpp

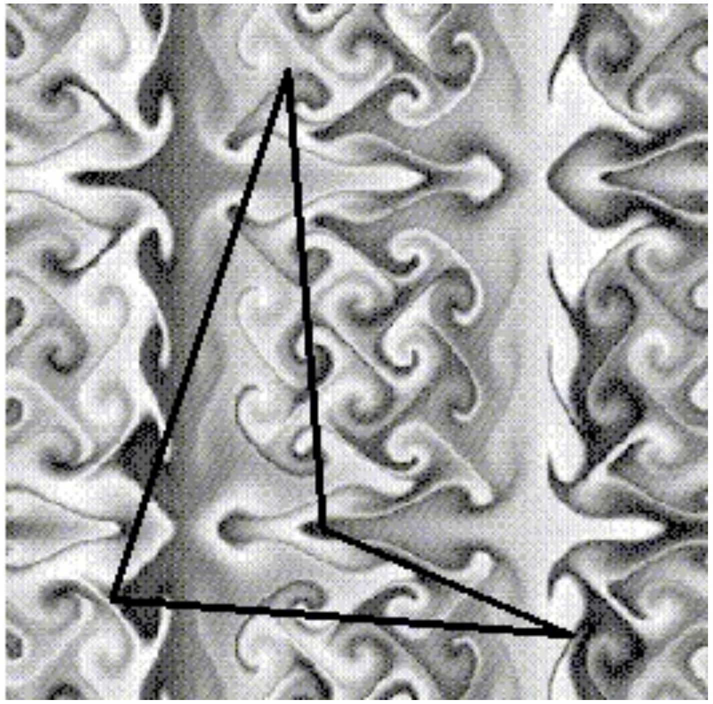
## why use textures?

- greater realism
    - real objects are not smooth and regular
- save resources
    - imaging rendering a brick wall
    - draw every single brick? that's a lot of polygons!
    - instead glue an image of a brick wall to one large polygon and draw this

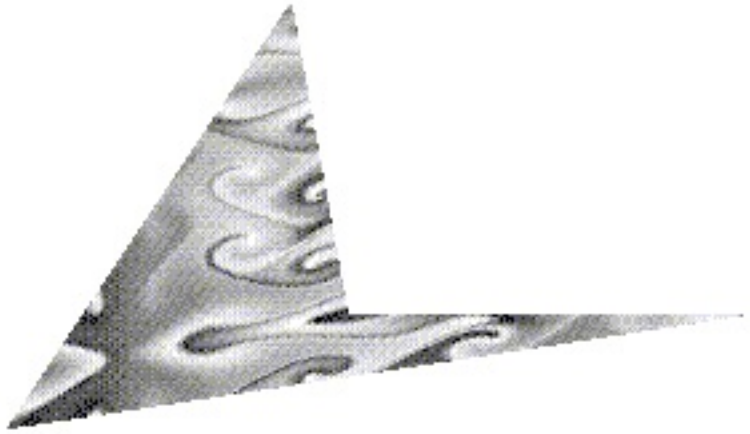
## texture mapping

- How to apply a texture to a polygon?
  - Texels must somehow be matched to pixels.
  - Polygons can be transformed... what do to with the texture in that case?
- Mapping a rectangular texture to a quad?
- Mapping a rectangular texture to a non-rectangular region?
- Texturing is actually a quite complicated process...

# texture mapping



Entire texture. Black outline shows quadrilateral and how the texture is mapped to it.



Polygon displayed on the screen. Distorted because of applied transformations. Texture is stretched in the x direction and compressed in the y direction to match this distortion.

## texturing in OpenGL

(this is a bit involved)

(so please don't get scared)

## texturing in OpenGL: setup

```
Image image("crate.tga");

glGenTextures(1, &texture);
glPixelStorei(GL_UNPACK_ALIGNMENT, 1);
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## texturing in OpenGL: usage

```
// in mydisplay()

glEnable(GL_TEXTURE_2D);
glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_DECAL);
glBindTexture(GL_TEXTURE_2D, texture);

glBegin(GL_QUADS);

// front face
glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f,  1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);

// etc.

glEnd(GL_QUADS);
```

let's do this step by step

## texturing in OpenGL: setup

```
Image image("crate.tga");

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glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## texturing in OpenGL: setup

```
Image image("crate.tga");

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glBindTexture(GL_TEXTURE_2D, texture);
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glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## texturing in OpenGL: setup

```
Image image("crate.tga");

glGenTextures(1, &texture);
glPixelStorei(GL_UNPACK_ALIGNMENT, 1);
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## Pixel Storage

- Image data is usually stored in rectangular two-dimensional arrays.
  - some machines have optimized architecture for data that is aligned on two-byte, four-byte, or eight-byte boundaries
  - some machines have different byte order
- **`GL_UNPACK_ALIGNMENT`** describes how the bitmap data is stored in computer memory
  - 1 means just use next available byte
  - this is what you probably want unless you're working on a more exotic architecture
- **`GL_UNPACK_SWAP_BYTES`** specifies that endianness must be swapped

## texturing in OpenGL: setup

```
Image image("crate.tga");

glGenTextures(1, &texture);
glPixelStorei(GL_UNPACK_ALIGNMENT, 1);
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## texturing in OpenGL: setup

```
Image image("crate.tga");

glGenTextures(1, &texture);
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glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## Repeating Textures

- You can assign texture coordinates outside the range [0; 1]
- What happens?
  - either repeat the texture (**`GL_REPEAT`**)
    - integer part of the texture coordinates is ignored
  - or clamp (**`GL_CLAMP`**)
    - values > 1.0 are set to 1.0
    - values < 0.0 are set to 0.0

## texturing in OpenGL: setup

```
Image image("crate.tga");

glGenTextures(1, &texture);
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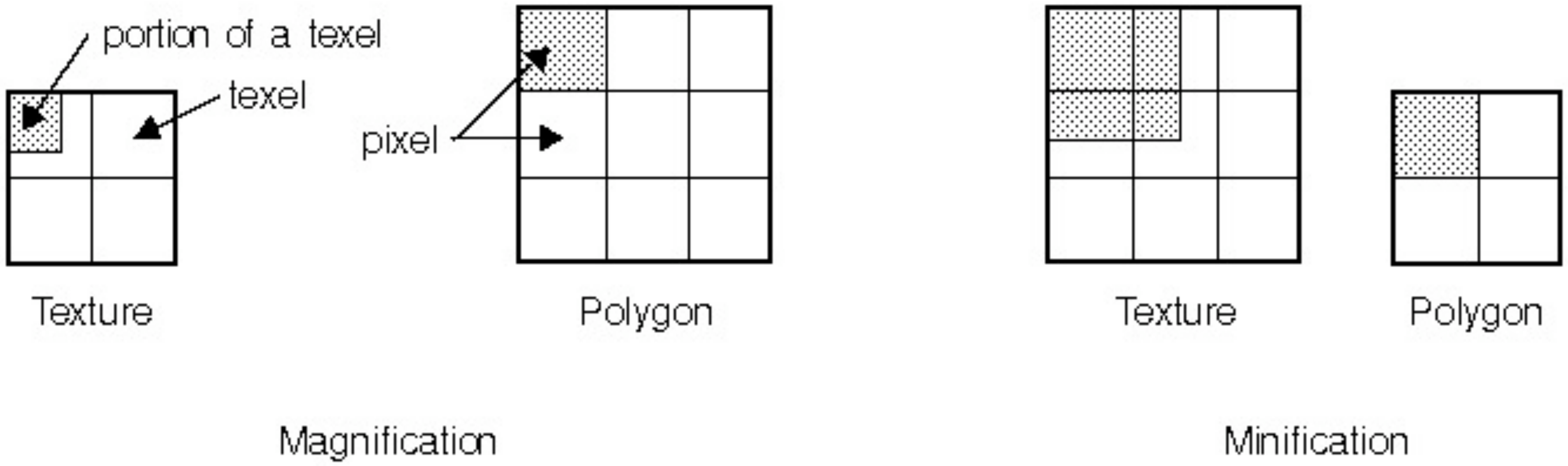
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

# Filtering



How to map individual texels of a texture to individual pixels on the final screen image?
The texel values must be interpolated/averaged - trade-off between speed and quality

Nearest neighbour interpolation or calculate average by linear interplation?
**`GL_NEAREST`** vs. **`GL_LINEAR`**

# texturing in OpenGL: setup

```
Image image("crate.tga");

glGenTextures(1, &texture);
glPixelStorei(GL_UNPACK_ALIGNMENT, 1);
glBindTexture(GL_TEXTURE_2D, texture);
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glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## specifying the texture

- You need some way to get a texture image.
  - either loaded from file or procedurally generated
  - SDL_Image is your friend
- Textures are usually thought of as 2-dimensional.
  - But they can also be 1-dimensional or 3-dimensional.
- The data describing a texture can consist of one, two, three, or four elements per texel.
  - 3 or 4 elements usually represent RGB or RGBA
  - 1 element often represents e.g. a modulation constant

## specifying the texture

-
  ```
  void glTexImage2D(GLenum target, GLint level,
                    GLint components, GLsizei width,
                    GLsizei height, GLint border,
                    GLenum format, GLenum type,
                    const GLvoid *pixels);
  ```
  - **`target`** must be **`GL_TEXTURE_2D`**
  - **`level`** should be 0 (needed for MIP-mapping)
  - **`components`** specified which of RGBA are selected for use in modulating/blending
  - **`width/height`** specify texture image dimensions
  - **`border`** specifies the width of the border (usually 0)

## specifying the texture

-
  ```
  void glTexImage2D(GLenum target, GLint level,
                    GLint components, GLsizei width,
                    GLsizei height, GLint border,
                    GLenum format, GLenum type,
                    const GLvoid *pixels);
  ```
  - **`format`** specifies the format
    - **`GL_COLOR_INDEX, GL_RGB, GL_RGBA`** etc.
  - **`type`** specifies the type
    - **`GL_BYTE, GL_UNSIGNED_BYTE, GL_SHORT, GL_UNSIGNED_SHORT, GL_INT`** etc.
  - **`pixels`** contains the texture-image data

## texturing in OpenGL: usage

```
// in mydisplay()

glEnable(GL_TEXTURE_2D);
glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_DECAL);
glBindTexture(GL_TEXTURE_2D, texture);

glBegin(GL_QUADS);

// front face
glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);
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// etc.
glEnd(GL_QUADS);
```

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glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);

// etc.
glEnd(GL_QUADS);
```

## How to apply the texture?

- How should the final color be computed from the fragment color and the texture-image color?
- 3 modes:
  - just use texture color (GL_DECAL)
  - use texture to modulate fragment color - useful to combine texturing with lighting (GL_MODULATE)
  - blend a constant color with the fragment color based on the texture value (GL_BLEND)

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glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f,  1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);

// etc.
glEnd(GL_QUADS);
```

## texturing in OpenGL: usage

```
// in mydisplay()

glEnable(GL_TEXTURE_2D);
glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_DECAL);
glBindTexture(GL_TEXTURE_2D, texture);

glBegin(GL_QUADS);

// front face
glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);
glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f,  1.0f);
glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);

// etc.
glEnd(GL_QUADS);
```

## drawing the scene

- Specify both geometric coordinates and texture coordinates for the objects that should be textured.
  - For a 2D texture, texture coordinates are in the range [0; 1].
  - The object's geometric coordinates can be anything.
  - So we need to indicate how the texture should be aligned.
- For example to map a rectangular image onto a quad:
  - Use texture coordinates (0, 0), (1, 0), (1, 1), and (0, 1) for the four corners (vertices) of the polygon.

do you remember the first law of computer graphics?

where there is a will
there is a workaround

## the second law of computer graphics

was ich nicht seh, tut mir nicht weh

## write yourself a texture abstraction class

```
Image image("crate.tga");

glGenTextures(1, &texture);
glPixelStorei(GL_UNPACK_ALIGNMENT, 1);
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

glTexImage2D(GL_TEXTURE_2D, 0, image.internalFormat(),
             image.w(), image.h(), 0, image.format(),
             GL_UNSIGNED_BYTE, image.pixels());
```

## write yourself a texture abstraction class

```
// texture loading
Texture * texture = new Texture("crate.tga");
texture->load();

// texture usage
glBindTexture(GL_TEXTURE_2D, texture->id);
```

Feel free to use the one I've provided, but be aware that this is not at all production quality software. If it breaks, you get to keep both halves.

So long and thanks for all the fish...