hatching

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Contents

1 COPYING

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```
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```

2 floor.c

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include <GL/glew.h>

#define PI 3.141592653589793

struct vertex { GLfloat x, y, z, nx, ny, nz, u, v; };
struct vertex vertices[361 * 361];
GLuint faces[360 * 360 * 6];

int main(int argc, char **argv)
{
  if (argc <= 1)
    return 1;
  GLfloat y = atof(argv[1]);
  for (int i = 0; i <= 360; ++i)
    for (int j = 0; j <= 360; ++j)
    {
      struct vertex *v = &vertices[361 * i + j];
      v->x = cos(2 * PI * j / 360.) * exp(log(15) - 2 * PI * i / 360.);
      v->y = y;
      v->z = sin(2 * PI * j / 360.) * exp(log(15) - 2 * PI * i / 360.);
      v->nx = 0;
      v->ny = 1;
      v->nz = 0;
      v->u = j / 360.0;
      v->v = i / 360.0;
    }
  for (int i = 0; i < 360; ++i)
    for (int j = 0; j < 360; ++j)
    {
      int i1 = i + 1;
```

```
        int j1 = j + 1;
        int k = 360 * 6 * i + 6 * j;
        faces[k + 0] = 361 * i + j;
        faces[k + 1] = 361 * i + j1;
        faces[k + 2] = 361 * i1 + j;
        faces[k + 3] = 361 * i + j1;
        faces[k + 4] = 361 * i1 + j;
        faces[k + 5] = 361 * i1 + j1;
      }
    FILE *o = fopen("floor.v", "wb");
    fwrite(vertices, sizeof(vertices), 1, o);
    fclose(o);
    o = fopen("floor.f", "wb");
    fwrite(faces, sizeof(faces), 1, o);
    fclose(o);
    return 0;
}
```

3 .gitignore

```
hatch
obj2raw
floor
wall
*.pgm
*.ppm
*.png
*.gif
*.mkv
*.obj
*.v
*.f
y.txt
```

4 hatch.c

```
#include <assert.h>
#include <complex>
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <time.h>

#include <cairo/cairo.h>
#include <fftw3.h>
#include <GL/glew.h>
#include <GLFW/glfw3.h>
#include <glm/glm.hpp>
#include <glm/gtc/matrix_transform.hpp>

#define PI 3.141592653589793
#define LEVELS 10
#define LAYERS 64
#define N (1 << LEVELS)

//#define ANAGLYPH
```

```
//#define STEREO
//#define RECORD

int cmp_float(const void *a, const void *b)
{
  const float *p = (const float *) a;
  const float *q = (const float *) b;
  float x = *p;
  float y = *q;
  return (x > y) - (x < y);
}


void debug_program(GLuint program) {
  GLint status = 0;
  glGetProgramiv(program, GL_LINK_STATUS, &status);
  GLint length = 0;
  glGetProgramiv(program, GL_INFO_LOG_LENGTH, &length);
  char *info = 0;
  if (length) {
    info = (char *) malloc(length + 1);
    info[0] = 0;
    glGetProgramInfoLog(program, length, 0, info);
    info[length] = 0;
  }
  if ((info && info[0]) || ! status) {
    fprintf(stderr, "program link info:\n%s", info ? info : "(no info log)");
  }
  if (info) {
    free(info);
  }
}


void debug_shader(GLuint shader, GLenum type, const char *source) {
  GLint status = 0;
  glGetShaderiv(shader, GL_COMPILE_STATUS, &status);
  GLint length = 0;
  glGetShaderiv(shader, GL_INFO_LOG_LENGTH, &length);
  char *info = 0;
  if (length) {
    info = (char *) malloc(length + 1);
    info[0] = 0;
    glGetShaderInfoLog(shader, length, 0, info);
    info[length] = 0;
  }
  if ((info && info[0]) || ! status) {
    const char *type_str = "unknown";
    switch (type) {
      case GL_VERTEX_SHADER: type_str = "vertex"; break;
      case GL_FRAGMENT_SHADER: type_str = "fragment"; break;
      case GL_GEOMETRY_SHADER: type_str = "geometry"; break;
    }
    fprintf(stderr, "%s shader compile info:\n%s\nshader source:\n%s", type_str,↙
        ↳ info ? info : "(no info log)", source ? source : "(no source)");
  }
  if (info) {
```

```
    free(info);
  }
}

GLuint vertex_fragment_shader(const char *vert, const char *frag) {
  GLuint program = glCreateProgram();
  {
    GLuint shader = glCreateShader(GL_VERTEX_SHADER);
    glShaderSource(shader, 1, &vert, 0);
    glCompileShader(shader);
    debug_shader(shader, GL_VERTEX_SHADER, vert);
    glAttachShader(program, shader);
    glDeleteShader(shader);
  }
  {
    GLuint shader = glCreateShader(GL_FRAGMENT_SHADER);
    glShaderSource(shader, 1, &frag, 0);
    glCompileShader(shader);
    debug_shader(shader, GL_FRAGMENT_SHADER, frag);
    glAttachShader(program, shader);
    glDeleteShader(shader);
  }
  glLinkProgram(program);
  debug_program(program);
  return program;
}

GLuint vertex_geometry_fragment_shader(const char *vert, const char *geom, const↙
    ↪ char *frag) {
  GLuint program = glCreateProgram();
  {
    GLuint shader = glCreateShader(GL_VERTEX_SHADER);
    glShaderSource(shader, 1, &vert, 0);
    glCompileShader(shader);
    debug_shader(shader, GL_VERTEX_SHADER, vert);
    glAttachShader(program, shader);
    glDeleteShader(shader);
  }
  {
    GLuint shader = glCreateShader(GL_GEOMETRY_SHADER);
    glShaderSource(shader, 1, &geom, 0);
    glCompileShader(shader);
    debug_shader(shader, GL_GEOMETRY_SHADER, frag);
    glAttachShader(program, shader);
    glDeleteShader(shader);
  }
  {
    GLuint shader = glCreateShader(GL_FRAGMENT_SHADER);
    glShaderSource(shader, 1, &frag, 0);
    glCompileShader(shader);
    debug_shader(shader, GL_FRAGMENT_SHADER, frag);
    glAttachShader(program, shader);
    glDeleteShader(shader);
  }
  glLinkProgram(program);
```

```
  debug_program(program);
  return program;
}


struct object
{
  GLuint vao;
  GLuint vbo;
  GLuint ebo;
  int count;
};


void load_object(struct object *o, const char *vname, const char *fname)
{
  FILE *vf = fopen(vname, "rb");
  fseek(vf, 0, SEEK_END);
  size_t vbytes = ftell(vf);
  rewind(vf);
  GLfloat *vertices = (GLfloat *) calloc(1, vbytes);
  fread(vertices, vbytes, 1, vf);
  fclose(vf);

  FILE *ff = fopen(fname, "rb");
  fseek(ff, 0, SEEK_END);
  size_t fbytes = ftell(ff);
  rewind(ff);
  GLuint *faces = (GLuint *) calloc(1, fbytes);
  fread(faces, fbytes, 1, ff);
  fclose(ff);

  glGenVertexArrays(1, &o->vao);
  glBindVertexArray(o->vao);

  glGenBuffers(1, &o->vbo);
  glBindBuffer(GL_ARRAY_BUFFER, o->vbo);
  glBufferData(GL_ARRAY_BUFFER, vbytes, vertices, GL_STATIC_DRAW);
  free(vertices);

  glGenBuffers(1, &o->ebo);
  glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, o->ebo);
  glBufferData(GL_ELEMENT_ARRAY_BUFFER, fbytes, faces, GL_STATIC_DRAW);
  free(faces);

  glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 8 * sizeof(GLfloat), 0);
  glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 8 * sizeof(GLfloat), ((char *)↙
      ↳  0) + 3 * sizeof(GLfloat));
  glVertexAttribPointer(2, 2, GL_FLOAT, GL_FALSE, 8 * sizeof(GLfloat), ((char *)↙
      ↳  0) + 6 * sizeof(GLfloat));
  glEnableVertexAttribArray(0);
  glEnableVertexAttribArray(1);
  glEnableVertexAttribArray(2);

  o->count = fbytes / sizeof(GLuint);
}
```

```
190 char *read_file(const char *name) {
      FILE *f = fopen(name, "r");
      fseek(f, 0, SEEK_END);
      long len = ftell(f);
      fseek(f, 0, SEEK_SET);
195   char *str = (char *) malloc(len + 1);
      fread(str, len, 1, f);
      str[len] = 0;
      fclose(f);
      return str;
200 }


    void keycb(GLFWwindow *window, int key, int scancode, int action, int mods) {
      (void) scancode;
205   (void) mods;
      if (action == GLFW_PRESS) {
        switch (key) {
          case GLFW_KEY_Q:
          case GLFW_KEY_ESCAPE:
210         glfwSetWindowShouldClose(window, GL_TRUE);
            break;
        }
      }
    }
215


    int main(int argc, char **argv)
    {
      float groundy = -1;
220   if (argc > 1)
        groundy = atof(argv[1]);

      // randomize
      srand(time(0));
225
      float fov = 60;
      int w = 1280;
      int h = 720;
      int shadowSize = 1024;
230
      // start GL
      glfwInit();
      glfwWindowHint(GLFW_CLIENT_API, GLFW_OPENGL_API);
      glfwWindowHint(GLFW_CONTEXT_VERSION_MAJOR, 3);
235   glfwWindowHint(GLFW_CONTEXT_VERSION_MINOR, 3);
      glfwWindowHint(GLFW_OPENGL_PROFILE, GLFW_OPENGL_CORE_PROFILE);
      glfwWindowHint(GLFW_OPENGL_FORWARD_COMPAT, GL_TRUE);
    #if 0
      glfwWindowHint(GLFW_DECORATED, GL_FALSE);
240 #endif
      glfwWindowHint(GLFW_RESIZABLE, GL_FALSE);
      glfwWindowHint(GLFW_SAMPLES, 16);
    #ifdef STEREO
      GLFWwindow *window = glfwCreateWindow(2 * w, h, "hatch", 0, 0);
245 #else
```

```
  GLFWwindow *window = glfwCreateWindow(w, h, "hatch", 0, 0);
#endif
  glfwMakeContextCurrent(window);
  glewExperimental = GL_TRUE;
  glewInit();
  glGetError(); // discard common error from glew

  // GL callbacks
  glfwSetKeyCallback(window, keycb);

  // set up shaders
  char *s_vertex   = read_file("hatch.vert");
  char *s_fragment = read_file("hatch.frag");
  GLuint p = vertex_fragment_shader(s_vertex, s_fragment);
  free(s_vertex);
  free(s_fragment);
  glUseProgram(p);
  GLint u_projectionMatrix = glGetUniformLocation(p, "projectionMatrix");
  GLint u_modelMatrix = glGetUniformLocation(p, "modelMatrix");
  GLint u_normalMatrix = glGetUniformLocation(p, "normalMatrix");
  GLint u_light = glGetUniformLocation(p, "light");
  GLint u_scale = glGetUniformLocation(p, "scale");
  GLint u_eye = glGetUniformLocation(p, "eye");
  GLint u_material = glGetUniformLocation(p, "material");
  GLint u_ambient = glGetUniformLocation(p, "ambient");
  GLint u_diffuse = glGetUniformLocation(p, "diffuse");
  GLint u_specular = glGetUniformLocation(p, "specular");
  GLint u_index = glGetUniformLocation(p, "index");
  GLint u_roughness = glGetUniformLocation(p, "roughness");
  GLint u_alpha = glGetUniformLocation(p, "alpha");
  GLint u_hatch = glGetUniformLocation(p, "hatch");
  GLint u_shadow = glGetUniformLocation(p, "shadow");
  GLint u_farplane = glGetUniformLocation(p, "far_plane");
  GLint u_hue = glGetUniformLocation(p, "hue");

  float aspect = w / (float) h;
  glm::mat4 projectionMatrix(glm::perspective(float(fov * PI / 180), aspect, 1.f
      , 100.f));
  glUniformMatrix4fv(u_projectionMatrix, 1, GL_FALSE, &projectionMatrix[0][0]);
  glUniform3f(u_eye, 0, 0, 0);
  glUniform3f(u_material, 0.75, 0.75, 0.75);
  glUniform1f(u_ambient, 0.01);
  glUniform1f(u_diffuse, 0.5);
  glUniform1f(u_specular, 0.5);
  glUniform1f(u_index, 1.5);
  glUniform1f(u_roughness, 0.15 * 0.15);
  glUniform1f(u_alpha, 1);
  glUniform1f(u_scale, 1);
  glUniform1i(u_hatch, 0);
  glUniform1i(u_shadow, 1);
  glUniform1f(u_farplane, 50);

  s_vertex   = read_file("shadow.vert");
  char *s_geom=read_file("shadow.geom");
  s_fragment = read_file("shadow.frag");
  GLuint sp = vertex_geometry_fragment_shader(s_vertex, s_geom, s_fragment);
  free(s_vertex);
```

```
    free(s_geom);
    free(s_fragment);
    glUseProgram(sp);
305 GLint u_sshadowMatrix = glGetUniformLocation(sp, "shadowMatrix");
    GLint u_smodelMatrix = glGetUniformLocation(sp, "modelMatrix");
    GLint u_sfarplane = glGetUniformLocation(sp, "far_plane");
    glm::mat4 s(glm::perspective(glm::radians(90.0f), 1.0f, 0.1f, 50.0f));
    glm::mat4 shadowMatrix[6] =
310   { s * glm::lookAt(glm::vec3(0.0f), glm::vec3( 1.0, 0.0, 0.0), glm::vec3↙
        ↳ (0.0,-1.0, 0.0))
      , s * glm::lookAt(glm::vec3(0.0f), glm::vec3(-1.0, 0.0, 0.0), glm::vec3↙
        ↳ (0.0,-1.0, 0.0))
      , s * glm::lookAt(glm::vec3(0.0f), glm::vec3( 0.0, 1.0, 0.0), glm::vec3(0.0,↙
        ↳  0.0, 1.0))
      , s * glm::lookAt(glm::vec3(0.0f), glm::vec3( 0.0,-1.0, 0.0), glm::vec3(0.0,↙
        ↳  0.0,-1.0))
      , s * glm::lookAt(glm::vec3(0.0f), glm::vec3( 0.0, 0.0, 1.0), glm::vec3↙
        ↳ (0.0,-1.0, 0.0))
315   , s * glm::lookAt(glm::vec3(0.0f), glm::vec3( 0.0, 0.0,-1.0), glm::vec3↙
        ↳ (0.0,-1.0, 0.0))
      };
    glUniformMatrix4fv(u_sshadowMatrix, 6, GL_FALSE, &shadowMatrix[0][0][0]);
    glUniform1f(u_sfarplane, 50);

320

    // hatch texture
    glActiveTexture(GL_TEXTURE0 + 0);
    GLuint hatch;
    glGenTextures(1, &hatch);
325 glBindTexture(GL_TEXTURE_2D_ARRAY, hatch);
    glTexImage3D(GL_TEXTURE_2D_ARRAY, 0, GL_RGBA, N, N, LAYERS, 0, GL_RGBA, ↙
      ↳ GL_UNSIGNED_BYTE, 0);
    glGenerateMipmap(GL_TEXTURE_2D_ARRAY);
    glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_MAX_ANISOTROPY_EXT, 16);
    glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_MIN_FILTER, ↙
      ↳ GL_LINEAR_MIPMAP_LINEAR);
330 glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_WRAP_S, GL_REPEAT);
    glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_WRAP_T, GL_REPEAT);

    // shadow map
335 GLuint shadow;
    glGenTextures(1, &shadow);
    glActiveTexture(GL_TEXTURE0 + 1);
    glBindTexture(GL_TEXTURE_CUBE_MAP, shadow);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
340 glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_S, GL_CLAMP_TO_EDGE);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_T, GL_CLAMP_TO_EDGE);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_R, GL_CLAMP_TO_EDGE);
    for (int i = 0 ; i < 6 ; i++)
345   glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_X + i, 0, GL_DEPTH_COMPONENT32, ↙
        ↳ shadowSize, shadowSize, 0, GL_DEPTH_COMPONENT, GL_FLOAT, 0);

    GLuint fbo;
    glGenFramebuffers(1, &fbo);
    glBindFramebuffer(GL_FRAMEBUFFER, fbo);
```

```
350     glFramebufferTexture(GL_FRAMEBUFFER, GL_DEPTH_ATTACHMENT, shadow, 0);
        glDrawBuffer(GL_NONE);
        glReadBuffer(GL_NONE);
        glBindFramebuffer(GL_FRAMEBUFFER, 0);

355     glActiveTexture(GL_TEXTURE0 + 0);

        fftw_complex *signal = (fftw_complex *) fftw_malloc(N * N * sizeof(*signal));
        fftw_complex *spectrum = (fftw_complex *) fftw_malloc(N * N * sizeof(*spectrum
            ↳ ));
        float *image = (float *) fftw_malloc(N * N * sizeof(*image));
360     float *histogram = (float *) fftw_malloc(N * N * sizeof(*histogram));
        unsigned char *pgm = (unsigned char *) fftw_malloc(N * N);
        fftw_plan ifft = fftw_plan_dft_2d(N, N, spectrum, signal, FFTW_BACKWARD,
            ↳ FFTW_ESTIMATE);
        // blue
        for (int i = 0; i < N; ++i)
365     {
          double x = i < N/2 ? i : N - i;
          for (int j = 0; j < N; ++j)
          {
            double y = j < N/2 ? j : N - j;
370         double f2 = x * x + y * y;
            double t = 6.283185307179586 * rand() / (double) RAND_MAX;
            spectrum[N * i + j][0] = f2 * cos(t);
            spectrum[N * i + j][1] = f2 * sin(t);
          }
375     }
        fftw_execute(ifft);
        // normalize
        double mi = 1.0/0.0;
        double ma = -1.0/0.0;
380     for (int i = 0; i < N * N; ++i)
        {
          double s = signal[i][0];
          mi = s < mi ? s : mi;
          ma = s > ma ? s : ma;
385     }
        for (int i = 0; i < N * N; ++i)
        {
          double s = signal[i][0];
          double g = 255 * (s - mi) / (ma - mi);
390       image[i] = g;
        }
        // equalize
        memcpy(histogram, image, N * N * sizeof(*image));
        qsort(histogram, N * N, sizeof(*histogram), cmp_float);
395     for (int i = 0; i < N * N; ++i)
        {
          float *h = (float *) bsearch(&image[i], histogram, N * N, sizeof(*histogram)
              ↳ , cmp_float);
          assert(h);
          image[i] = h - histogram;
400       pgm[i] = 256 * image[i] / (float) (N * N);
        }
        // output
      #if 0
```

```
  FILE *out = fopen("blue.pgm", "wb");
  fprintf(out, "P5\n%d %d\n255\n", N, N);
  fwrite(pgm, N * N, 1, out);
  fclose(out);
#endif
  // generate hatching
  for (int level = 0; level <= LEVELS; ++level)
  {
    int size = 1 << level;
    double length = N / 8.0;
    cairo_surface_t *surface = cairo_image_surface_create(CAIRO_FORMAT_ARGB32, size, size);
    cairo_t *cr = cairo_create(surface);
    cairo_set_source_rgba(cr, 1, 1, 1, 1);
    cairo_paint(cr);
    cairo_set_source_rgba(cr, 0, 0, 0, 1);
    cairo_set_line_width(cr, 1);
    cairo_set_line_cap(cr, CAIRO_LINE_CAP_ROUND);
    for (int density = 0; density < LAYERS; ++density)
    {
      double lo = 8 *  density    * size / (double) LAYERS;
      double hi = 8 * (density+1) * size / (double) LAYERS;
      int dx = density < LAYERS/2;
      int dy = !dx;
      for (int i = 0; i < N; ++i)
      {
        for (int j = 0; j < N; ++j)
        {
          int t = image[N * i + j];
          if (lo <= t && t < hi)
          {
            for (int di = -N; di <= N; di += N)
            {
              for (int dj = -N; dj <= N; dj += N)
              {
                cairo_move_to(cr, size * (i + di) / (double) N, size * (j + dj) / (double) N);
                cairo_line_to(cr, size * (i + di + (dx + dy) * length) / (double) N, size * (j + dj + (dy - dx) * length) / (double) N);
              }
            }
          }
        }
      }
    }
    cairo_stroke(cr);
    cairo_surface_flush(surface);
#if 0
    char filename[100];
    snprintf(filename, 100, "%02d-%02d.png", density, level);
    cairo_surface_write_to_png(surface, filename);
#endif
    void *pixels = cairo_image_surface_get_data(surface);
    int stride = cairo_image_surface_get_stride(surface);
    glPixelStorei(GL_UNPACK_ROW_LENGTH, stride / 4);
    glTexSubImage3D(GL_TEXTURE_2D_ARRAY, LEVELS - level, 0, 0, LAYERS - density - 1, size, size, 1, GL_RGBA, GL_UNSIGNED_BYTE, pixels);
    glPixelStorei(GL_UNPACK_ROW_LENGTH, 0);
```

```
    }
    cairo_destroy(cr);
    cairo_surface_destroy(surface);
  }

  // free fftw stuff
  fftw_destroy_plan(ifft);
  fftw_free(signal);
  fftw_free(spectrum);
  fftw_free(image);
  fftw_free(histogram);
  fftw_free(pgm);

  // load objects
  struct object obunny, ofloor, owall;
  load_object(&obunny, "bunny.v", "bunny.f");
  load_object(&ofloor, "floor.v", "floor.f");
  load_object(&owall, "wall.v", "wall.f");

  // main loop
  glClearColor(1, 1, 1, 1);
  glClearDepth(1.0);
  glEnable(GL_DEPTH_TEST);
  int frame = 0;
  glfwPollEvents();
#ifdef RECORD
  unsigned char *video = (unsigned char *) malloc(2 * w * h * 3);
#endif
  while (! glfwWindowShouldClose(window)) {

    // update animation
    float z = 2 * PI * frame / (float) 512;
    glm::vec3 light(1.0, groundy + 1.0f, -2.0);
    glm::mat4 rot(glm::rotate(glm::mat4(1.0f), float(z), glm::vec3(0.0f, 1.0f, ↙
        ↳ 0.0f)));
    glm::mat4 modelMatrix1(glm::translate(glm::mat4(1.0f), glm::vec3(1.0f, 0.0f,↙
        ↳  -5.0f)));
    glm::mat4 modelMatrix(modelMatrix1 * glm::scale(glm::mat4(1.0f), glm::vec3↙
        ↳ (1.5f)) * rot);
    glm::mat3 normalMatrix(glm::inverse(glm::transpose(glm::mat3(modelMatrix))))↙
        ↳ ;
    glm::mat4 lightMatrix(glm::translate(glm::mat4(1.0f), -light) * modelMatrix)↙
        ↳ ;
#ifdef STEREO
    glm::vec3 leftLight, rightLight;
    glm::mat4 leftProjectionMatrix, leftModelMatrix, rightProjectionMatrix, ↙
        ↳ rightModelMatrix;
    {
      float near = 1;
      float focus = 5;
      float far = 100;
      float eyesep = focus / 30;
      float ratio  = w / (double) h;
      float wd2 = 1 * tan(glm::radians(fov / 2.));
      float ndfl = near / focus;
      float e = eyesep / 2;
      float left  = - ratio * wd2 - 0.5 * eyesep * ndfl;
```

```
        float right =   ratio * wd2 - 0.5 * eyesep * ndfl;
        float top    =   wd2;
        float bottom = - wd2;
        glm::vec3 rightEye(-e, 0.0f, 0.0f);
        rightProjectionMatrix = glm::frustum(left,right,bottom,top,near,far);
        rightModelMatrix = glm::translate(glm::mat4(1.0f), rightEye) * modelMatrix;
        rightLight = light + rightEye;
        left  = - ratio * wd2 + 0.5 * eyesep * ndfl;
        right =   ratio * wd2 + 0.5 * eyesep * ndfl;
        glm::vec3 leftEye(e, 0.0f, 0.0f);
        leftProjectionMatrix = glm::frustum(left,right,bottom,top,near,far);
        leftModelMatrix = glm::translate(glm::mat4(1.0f), leftEye) * modelMatrix;
        leftLight = light + leftEye;
    }
#endif

    // render shadow cube map
    glViewport(0, 0, shadowSize, shadowSize);
    glCullFace(GL_FRONT);
    glUseProgram(sp);
    glUniformMatrix4fv(u_smodelMatrix, 1, GL_FALSE, &lightMatrix[0][0]);
    glBindFramebuffer(GL_FRAMEBUFFER, fbo);
    glClear(GL_DEPTH_BUFFER_BIT);
    glBindVertexArray(obunny.vao);
    glDrawElements(GL_TRIANGLES, obunny.count, GL_UNSIGNED_INT, 0);
    glBindVertexArray(ofloor.vao);
    glDrawElements(GL_TRIANGLES, ofloor.count, GL_UNSIGNED_INT, 0);
    glBindVertexArray(owall.vao);
    glDrawElements(GL_TRIANGLES, owall.count, GL_UNSIGNED_INT, 0);

    // redisplay
    glUseProgram(p);
    glCullFace(GL_BACK);
    glBindFramebuffer(GL_FRAMEBUFFER, 0);
    glUniformMatrix3fv(u_normalMatrix, 1, GL_FALSE, &normalMatrix[0][0]);
    glColorMask(GL_TRUE, GL_TRUE, GL_TRUE, GL_TRUE);
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

#if defined(ANAGLYPH) | defined(STEREO)

#ifdef ANAGLYPH
    glViewport(0, 0, w, h);
    glColorMask(GL_TRUE, GL_FALSE, GL_FALSE, GL_FALSE);
#else
    glViewport(0, 0, w, h);
#endif
    glUniform3fv(u_light, 1, &leftLight[0]);
    glUniformMatrix4fv(u_projectionMatrix, 1, GL_FALSE, &leftProjectionMatrix[0][0]);
    glUniformMatrix4fv(u_modelMatrix, 1, GL_FALSE, &leftModelMatrix[0][0]);

    glUniform3f(u_hue, 0.25, 0.0, 0.0);
    glBindVertexArray(obunny.vao);
    glDrawElements(GL_TRIANGLES, obunny.count, GL_UNSIGNED_INT, 0);
    glUniform3f(u_hue, 0.0, 0.25, 0.0);
    glBindVertexArray(ofloor.vao);
```

```
        glDrawElements(GL_TRIANGLES, ofloor.count, GL_UNSIGNED_INT, 0);
        glUniform3f(u_hue, 0.0, 0.125, 0.25);
        glBindVertexArray(owall.vao);
        glDrawElements(GL_TRIANGLES, owall.count, GL_UNSIGNED_INT, 0);
        glClear(GL_DEPTH_BUFFER_BIT);

    #ifdef ANAGLYPH
        glViewport(0, 0, w, h);
        glColorMask(GL_FALSE, GL_TRUE, GL_TRUE, GL_FALSE);
    #else
        glViewport(w, 0, w, h);
    #endif
        glUniform3fv(u_light, 1, &rightLight[0]);
        glUniformMatrix4fv(u_projectionMatrix, 1, GL_FALSE, &rightProjectionMatrix
            ↪ [0][0]);
        glUniformMatrix4fv(u_modelMatrix, 1, GL_FALSE, &rightModelMatrix[0][0]);
        glUniform3f(u_hue, 0.25, 0.0, 0.0);
        glBindVertexArray(obunny.vao);
        glDrawElements(GL_TRIANGLES, obunny.count, GL_UNSIGNED_INT, 0);
        glUniform3f(u_hue, 0.0, 0.25, 0.0);
        glBindVertexArray(ofloor.vao);
        glDrawElements(GL_TRIANGLES, ofloor.count, GL_UNSIGNED_INT, 0);
        glUniform3f(u_hue, 0.0, 0.125, 0.25);
        glBindVertexArray(owall.vao);
        glDrawElements(GL_TRIANGLES, owall.count, GL_UNSIGNED_INT, 0);

    #else

        glViewport(0, 0, w, h);
        glUniform3fv(u_light, 1, &light[0]);
        glUniformMatrix4fv(u_projectionMatrix, 1, GL_FALSE, &projectionMatrix[0][0])
            ↪ ;
        glUniformMatrix4fv(u_modelMatrix, 1, GL_FALSE, &modelMatrix[0][0]);
        glUniform3f(u_hue, 0.25, 0.0, 0.0);
        glBindVertexArray(obunny.vao);
        glDrawElements(GL_TRIANGLES, obunny.count, GL_UNSIGNED_INT, 0);
        glUniform3f(u_hue, 0.0, 0.25, 0.0);
        glBindVertexArray(ofloor.vao);
        glDrawElements(GL_TRIANGLES, ofloor.count, GL_UNSIGNED_INT, 0);
        glUniform3f(u_hue, 0.0, 0.125, 0.25);
        glBindVertexArray(owall.vao);
        glDrawElements(GL_TRIANGLES, owall.count, GL_UNSIGNED_INT, 0);

    #endif

        // download output frame
    #ifdef RECORD
        if (frame == 2048)
          break;
    #ifdef STEREO
        glReadPixels(0, 0, 2 * w, h, GL_RGB, GL_UNSIGNED_BYTE, video);
        printf("P6\n%d %d\n255\n", 2 * w, h);
        for (int j = h - 1; j >= 0; --j)
          fwrite(video + j * 2 * w * 3, 2 * w * 3, 1, stdout);
    #else
        glReadPixels(0, 0, w, h, GL_RGB, GL_UNSIGNED_BYTE, video);
        printf("P6\n%d %d\n255\n", w, h);
```

```
      for (int j = h - 1; j >= 0; --j)
        fwrite(video + j * w * 3, w * 3, 1, stdout);
#endif
#endif
      glfwSwapBuffers(window);
      glfwPollEvents();
      ++frame;
    }

    // cleanup
    glfwDestroyWindow(window);
    glfwTerminate();

    return 0;
}
```

5 hatch.frag

```
#version 330 core

const float pi = 3.141592653589793;
const float layers = 64.0;

uniform vec3 light;
uniform vec3 eye;
uniform vec3 material;
uniform float ambient;
uniform float diffuse;
uniform float specular;
uniform float index;
uniform float roughness;
uniform float alpha;
uniform float scale;
uniform sampler2DArray hatch;
uniform samplerCube shadow;
uniform float far_plane;
uniform vec3 hue;

in vec3 position;
in vec3 normal;
in vec2 texcoord;

out vec4 colour;

void main(void) {
  vec3 V = normalize(eye - position);
  vec3 N = normalize(normal);
  float diff = ambient;
  float spec = 0.0;
  float q = 1.0;
  float vn = dot(V, N);
  if (vn < 0.0) {
    discard;
  } else {
    vec3 L = normalize(light - position);
    vec3 H = normalize(L + V);
    float k = 0.0;
```

```
40      float ln = max(0.0, dot(L, N));
        float s = texture(shadow, -L).x * far_plane + 0.1;
        float dist = length(light - position);
        if (ln > 0.0) {
          if (s > dist) {
45          float vh = max(0.0, dot(V, H));
            float hn = max(0.0, dot(H, N));
            float d = hn * hn;
            float D = exp((d - 1.0) / (d * roughness)) / (pi * roughness * d * d);
            float F;
50          {
              float c = vh;
              float g = sqrt(index * index + c * c - 1.0);
              float a0 = g - c;
              float a1 = g + c;
55            float a2 = a1 * c - 1.0; a2 *= a2;
              float a3 = a0 * c - 1.0; a3 *= a3;
              float a4 = 1.0 + a2 / a3;
              a0 *= a0;
              a1 *= a1;
60            F = 0.5 * a0 / a1 * a4;
            }
            float g = 2.0 * hn / vh;
            float G = min(1.0, min(g * vn, g * ln));
            k = D * F * G / (4.0 * vn * ln);
65          diff += diffuse * ln;
            spec += specular * k;
          }
        }
        vec3 rgb = clamp(q * 2.0 * material * diff + 2.0 * vec3(spec), vec3(0.0), ↙
            ↳ vec3(1.0));
70      float y = dot(vec3(0.2126, 0.7152, 0.0722), rgb);
        y = sqrt(y);
        y *= layers;
        vec2 texc = texcoord;
        y = texture(hatch, vec3(4.0 * texc, y)).y;
75      colour = vec4(mix(hue, vec3(1.0), vec3(y)), alpha);
      }
    }
```

6 hatch.vert

```
#version 330 core

uniform mat4 projectionMatrix;
uniform mat4 modelMatrix;
5 uniform mat3 normalMatrix;

layout(location = 0) in vec3 vpos;
layout(location = 1) in vec3 vnormal;
layout(location = 2) in vec2 vtexcoord;
10
out vec3 position;
out vec3 normal;
out vec2 texcoord;

15 void main(void) {
```

```
  vec4 p = modelMatrix * vec4(vpos, 1.0);
  vec3 n = normalMatrix * vnormal;
  position = p.xyz / p.w;
  normal = n;
  texcoord = vtexcoord;
  gl_Position = projectionMatrix * p;
}
```

7 Makefile

```
all: hatch bunny.v floor.v wall.v

clean:
	-rm -f hatch bunny.v bunny.f obj2raw wall.v wall.f wall floor.v floor.f ↙
	    ↳ floor y.txt

hatch: hatch.c
	gcc -xc++ -std=c++11 -Wall -Wextra -pedantic -O3 -o hatch hatch.c -↙
	    ↳ lfftw3 -lcairo -lGL -lGLEW -lglfw -lm

obj2raw: obj2raw.c
	gcc -std=c99 -Wall -Wextra -pedantic -o obj2raw obj2raw.c -lm

wall: wall.c
	gcc -std=c99 -Wall -Wextra -pedantic -o wall wall.c -lm

floor: floor.c
	gcc -std=c99 -Wall -Wextra -pedantic -o floor floor.c -lm

wall.v: wall y.txt
	./wall `cat y.txt`

floor.v: floor y.txt
	./floor `cat y.txt`

bunny.v: bunny.obj obj2raw
	./obj2raw bunny.obj bunny.v bunny.f > y.txt

bunny.obj:
	wget -c "http://www.d.umn.edu/~ddunham/cs5721f07/schedule/resources/↙
	    ↳ models/bunny.obj"
```

8 obj2raw.c

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>

struct vertex
{
  float x, y, z;
  float nx, ny, nz;
  float u, v;
};

struct face
{
```

```
  int a, b, c;
};

int main(int argc, char **argv)
{
  if (argc < 4)
    return 1;
  FILE *obj = fopen(argv[1], "rb");
  FILE *vs = fopen(argv[2], "wb");
  FILE *fs = fopen(argv[3], "wb");
  // count vertices and faces
  int nvs = 0;
  int nfs = 0;
  while (! feof(obj))
  {
    int c = fgetc(obj);
    if (c == 'v') nvs++;
    if (c == 'f') nfs++;
  }
  rewind(obj);
  // read vertices
  struct vertex *v = calloc(1, (nvs + nfs) * sizeof(*v));
  for (int i = 0; i < nvs; ++i)
    fscanf(obj, "v %f %f %f\n", &v[i].x, &v[i].y, &v[i].z);
  // read faces and accumulate per-face normals
  struct face *f = calloc(1, nfs * sizeof(*f));
  for (int i = 0; i < nfs; ++i)
  {
    fscanf(obj, "f %d %d %d\n", &f[i].a, &f[i].b, &f[i].c);
    f[i].a -= 1;
    f[i].b -= 1;
    f[i].c -= 1;
    float bx = v[f[i].b].x - v[f[i].a].x;
    float by = v[f[i].b].y - v[f[i].a].y;
    float bz = v[f[i].b].z - v[f[i].a].z;
    float cx = v[f[i].c].x - v[f[i].a].x;
    float cy = v[f[i].c].y - v[f[i].a].y;
    float cz = v[f[i].c].z - v[f[i].a].z;
    float nx = by * cz - bz * cy;
    float ny = bz * cx - bx * cz;
    float nz = bx * cy - by * cx;
    float n = sqrt(nx * nx + ny * ny + nz * nz);
    nx /= n;
    ny /= n;
    nz /= n;
    v[f[i].a].nx += nx;
    v[f[i].a].ny += ny;
    v[f[i].a].nz += nz;
    v[f[i].b].nx += nx;
    v[f[i].b].ny += ny;
    v[f[i].b].nz += nz;
    v[f[i].c].nx += nx;
    v[f[i].c].ny += ny;
    v[f[i].c].nz += nz;
  }
  // normalize normals, plus spherical projection for UVs
  double miny = 1.0 / 0.0;
```

```
  for (int i = 0; i < nvs; ++i)
  {
    float nx = v[i].nx;
    float ny = v[i].ny;
    float nz = v[i].nz;
    float n = sqrt(nx * nx + ny * ny + nz * nz);
    nx /= n;
    ny /= n;
    nz /= n;
    v[i].nx = nx;
    v[i].ny = ny;
    v[i].nz = nz;
    float x = v[i].x;
    float y = v[i].y;
    float z = v[i].z;
    v[i].u = atan2f(y, hypotf(x, z)) / 6.283185307179586f + 0.5f;
    v[i].v = atan2f(z, x) / 6.283185307179586f + 0.5f;
    miny = y < miny ? y : miny;
  }
  // de-seam large jumps in UVs by duplicating the farthest vertex
  int k = nvs;
  for (int i = 0; i < nfs; ++i)
  {
    float u0 = v[f[i].a].u;
    float v0 = v[f[i].a].v;
    float u1 = v[f[i].b].u;
    float v1 = v[f[i].b].v;
    float u2 = v[f[i].c].u;
    float v2 = v[f[i].c].v;
    float d01 = hypot(u0 - u1, v0 - v1);
    float d12 = hypot(u1 - u2, v1 - v2);
    float d20 = hypot(u2 - u0, v2 - v0);
    float mind = fminf(fminf(d01, d12), d20);
    float maxd = fmaxf(fmaxf(d01, d12), d20);
    if (maxd > 0.5)
    {
      if (mind == d01)
      {
        float du = u2 - u0;
        float dv = v2 - v0;
        du -= roundf(du);
        dv -= roundf(dv);
        u2 = u0 + du;
        v2 = v0 + dv;
        v[k].x  = v[f[i].c].x;
        v[k].y  = v[f[i].c].y;
        v[k].z  = v[f[i].c].z;
        v[k].nx = v[f[i].c].nx;
        v[k].ny = v[f[i].c].ny;
        v[k].nz = v[f[i].c].nz;
        v[k].u = u2;
        v[k].v = v2;
        f[i].c = k;
        k++;
      }
      if (mind == d12)
      {
```

```
            float du = u0 - u1;
            float dv = v0 - v1;
            du -= roundf(du);
            dv -= roundf(dv);
            u0 = u1 + du;
            v0 = v1 + dv;
            v[k].x  = v[f[i].a].x;
            v[k].y  = v[f[i].a].y;
            v[k].z  = v[f[i].a].z;
            v[k].nx = v[f[i].a].nx;
            v[k].ny = v[f[i].a].ny;
            v[k].nz = v[f[i].a].nz;
            v[k].u = u0;
            v[k].v = v0;
            f[i].a = k;
            k++;
          }
          if (mind == d20)
          {
            float du = u1 - u2;
            float dv = v1 - v2;
            du -= roundf(du);
            dv -= roundf(dv);
            u1 = u2 + du;
            v1 = v2 + dv;
            v[k].x  = v[f[i].b].x;
            v[k].y  = v[f[i].b].y;
            v[k].z  = v[f[i].b].z;
            v[k].nx = v[f[i].b].nx;
            v[k].ny = v[f[i].b].ny;
            v[k].nz = v[f[i].b].nz;
            v[k].u = u1;
            v[k].v = v1;
            f[i].b = k;
            k++;
          }
        }
    }
    fwrite(v, k * sizeof(*v), 1, vs);
    fwrite(f, nfs * sizeof(*f), 1, fs);
    fclose(obj);
    fclose(vs);
    fclose(fs);
    printf("%f\n", miny);
    return 0;
}
```

9 palette.txt

```
#000000
#ffffff
#ff0000
#00ffff
```

10 README.md

```
hatching
```

```
    ========

    * https://mathr.co.uk/blog/2017-06-28_hatching.html

    features
    --------

    * blue noise generation via IFFT
    * tonal art map (hatching texture array with mipmaps) generated from blue noise
    * bunny converted to raw data with smooth normals and deseamed spherical UVs
    * shadows by using cubemap depth texture, with geometry shader to render layers
    * stereo option (either side-by-side or red/cyan anaglyph)

    legal
    -----

    hatching -- non-photorealistic rendering with OpenGL
    Copyright (C) 2017  Claude Heiland-Allen

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    along with this program.  If not, see <http://www.gnu.org/licenses/>.
```

11 shadow.frag

```
#version 330 core

in vec4 FragPos;

uniform float far_plane;

void main()
{
    // get distance between fragment and light source
    float lightDistance = length(FragPos.xyz / FragPos.w);

    // map to [0;1] range by dividing by far_plane
    lightDistance = lightDistance / far_plane;

    // write this as modified depth
    gl_FragDepth = lightDistance;
}
```

12 shadow.geom

```
#version 330 core
```

```
layout (triangles) in;
layout (triangle_strip, max_vertices=18) out;

uniform mat4 shadowMatrix[6];

out vec4 FragPos; // FragPos from GS (output per emitvertex)

void main()
{
    for(int face = 0; face < 6; ++face)
    {
        gl_Layer = face; // built-in variable that specifies to which face we ↙
            ↳ render.
        for(int i = 0; i < 3; ++i) // for each triangle's vertices
        {
            FragPos = gl_in[i].gl_Position;
            gl_Position = shadowMatrix[face] * FragPos;
            EmitVertex();
        }
        EndPrimitive();
    }
}
```

13 shadow.vert

```
#version 330 core

uniform mat4 modelMatrix;

layout(location = 0) in vec3 vpos;

out vec3 position;

void main(void) {
  gl_Position = modelMatrix * vec4(vpos, 1.0);
}
```

14 wall.c

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include <GL/glew.h>

#define PI 3.141592653589793

struct vertex { GLfloat x, y, z, nx, ny, nz, u, v; };
struct vertex vertices[37 * 37];
GLuint faces[36 * 36 * 6];

int main(int argc, char **argv)
{
  if (argc <= 1)
    return 1;
  GLfloat y = atof(argv[1]);
  for (int i = 0; i <= 36; ++i)
```

```
    for (int j = 0; j <= 36; ++j)
    {
      struct vertex *v = &vertices[37 * i + j];
      GLfloat c = cos(2 * PI * i / 36.);
      GLfloat s = sin(2 * PI * i / 36.);
      v->x = c * 15;
      v->y = y + 24 * j / 36.0;
      v->z = s * 15;
      v->nx = -c;
      v->ny = 0;
      v->nz = -s;
      v->u = j / 36.0;
      v->v = 3 * i / 36.0;
    }
  for (int i = 0; i < 36; ++i)
    for (int j = 0; j < 36; ++j)
    {
      int i1 = i + 1;
      int j1 = j + 1;
      int k = 36 * 6 * i + 6 * j;
      faces[k + 0] = 37 * i + j;
      faces[k + 1] = 37 * i + j1;
      faces[k + 2] = 37 * i1 + j;
      faces[k + 3] = 37 * i + j1;
      faces[k + 4] = 37 * i1 + j;
      faces[k + 5] = 37 * i1 + j1;
    }
  FILE *o = fopen("wall.v", "wb");
  fwrite(vertices, sizeof(vertices), 1, o);
  fclose(o);
  o = fopen("wall.f", "wb");
  fwrite(faces, sizeof(faces), 1, o);
  fclose(o);
  return 0;
}
```