graphgrow

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1 c/graphgrow-filter.c

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

#include <sndfile.h>
#include <GL/glew.h>
#include <GLFW/glfw3.h>

#include "graphgrow_filter_vert.glsl.c"
#include "graphgrow_filter_frag.glsl.c"
#include "shader.h"

struct filter {
  struct shader shader;
  struct { GLint u_first_pass, u_spectrum, u_bins, u_length, u_speed, u_gain, u_scaleA, u_scaleB; } uniform;
  struct { GLint u_first_pass, u_spectrum; GLfloat u_bins, u_length, u_speed, u_gain, u_scaleA, u_scaleB; } value;
  GLuint vao;
  GLuint tex[2];
  GLuint fbo[2];
  int which;
  complex float spectrum[4096];
};

void filter_init(struct filter *f) {
  shader_init(&f->shader, graphgrow_filter_vert, graphgrow_filter_frag);
  glUseProgram(f->shader.program);
  shader_uniform(f, u_first_pass);
  shader_uniform(f, u_spectrum);
  shader_uniform(f, u_bins);
  shader_uniform(f, u_length);
  shader_uniform(f, u_speed);
  shader_uniform(f, u_gain);
  shader_uniform(f, u_scaleA);
  shader_uniform(f, u_scaleB);
  f->value.u_bins = 4096;
  f->value.u_length = 1;
  f->value.u_speed = 100;
  f->value.u_gain = 0.99;
  shader_updatef(f, u_bins);
  shader_updatef(f, u_length);
  shader_updatef(f, u_speed);
  shader_updatef(f, u_gain);
  glGenVertexArrays(1, &f->vao);
  glBindVertexArray(f->vao);
  glGenTextures(2, f->tex);
  glActiveTexture(GL_TEXTURE0 + 0);
  glBindTexture(GL_TEXTURE_1D, f->tex[0]);
  glTexImage1D(GL_TEXTURE_1D, 0, GL_RGB32F, f->value.u_bins / 2, 0, GL_RGB, GL_FLOAT, 0);
  glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_LINEAR);
  glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
```

```
  glActiveTexture(GL_TEXTURE0 + 1);
  glBindTexture(GL_TEXTURE_1D, f->tex[1]);
  glTexImage1D(GL_TEXTURE_1D, 0, GL_RGB32F, f->value.u_bins / 2, 0, GL_RGB, ↙
      ↳ GL_FLOAT, 0);
  glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_LINEAR)↙
      ↳ ;
  glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
  glGenFramebuffers(2, f->fbo);
  GLenum bufs = GL_COLOR_ATTACHMENT0;
  glBindFramebuffer(GL_FRAMEBUFFER, f->fbo[0]);
  glFramebufferTexture1D(GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, GL_TEXTURE_1D, f↙
      ↳ ->tex[0], 0);
  glDrawBuffers(1, &bufs);
  glBindFramebuffer(GL_FRAMEBUFFER, f->fbo[1]);
  glFramebufferTexture1D(GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, GL_TEXTURE_1D, f↙
      ↳ ->tex[1], 0);
  glDrawBuffers(1, &bufs);
  glViewport(0, 0, f->value.u_bins / 2, 1);
}

void filter_kernel(struct filter *f, double t) {
  f->value.u_scaleA = 1.0/4.0 + t * (1.0/2.0 - 1.0/4.0);
  f->value.u_scaleB = sqrt(2) * (1.0/2.0 - f->value.u_scaleA);
  shader_updatef(f, u_scaleA);
  shader_updatef(f, u_scaleB);
  glClearColor(0, 0, 0, 0);
  glBindFramebuffer(GL_FRAMEBUFFER, f->fbo[0]);
  glClear(GL_COLOR_BUFFER_BIT);
  glBindFramebuffer(GL_FRAMEBUFFER, f->fbo[1]);
  glClear(GL_COLOR_BUFFER_BIT);
  int which = 0;
  for (int pass = 0; pass < 20; ++pass) {
    f->value.u_first_pass = pass == 0;
    shader_updatei(f, u_first_pass);
    f->value.u_spectrum = which;
    shader_updatei(f, u_spectrum);
    glActiveTexture(GL_TEXTURE0 + which);
    glGenerateMipmap(GL_TEXTURE_2D);
    glBindFramebuffer(GL_FRAMEBUFFER, f->fbo[1 - which]);
    glDrawArrays(GL_LINES, 0, 2);
    which = 1 - which;
  }
  glReadPixels(0, 0, f->value.u_bins, 1, GL_RG, GL_FLOAT, f->spectrum);
  f->spectrum[2048] = 0;
  for (int k = 1; k < 2048; ++k) {
    f->spectrum[4096 - k] = conjf(f->spectrum[k]);
  }
}

const double pi = 3.141592653589793;

int main(int argc, char **argv) {
  (void) argc;
  (void) argv;

  glfwInit();
  glfwWindowHint(GLFW_CLIENT_API, GLFW_OPENGL_API);
```

```
105   glfwWindowHint(GLFW_CONTEXT_VERSION_MAJOR, 3);
      glfwWindowHint(GLFW_CONTEXT_VERSION_MINOR, 3);
      glfwWindowHint(GLFW_OPENGL_PROFILE, GLFW_OPENGL_CORE_PROFILE);
      glfwWindowHint(GLFW_OPENGL_FORWARD_COMPAT, GL_TRUE);
      GLFWwindow *window = glfwCreateWindow(512, 16, "graphgrow-filter", 0, 0);
110   glfwMakeContextCurrent(window);
      glewExperimental = GL_TRUE;
      glewInit();
      glGetError(); // discard common error from glew

115   struct filter filter;
      filter_init(&filter);

      SF_INFO sf_info = { 0, 48000, 2, SF_FORMAT_WAV | SF_FORMAT_FLOAT, 0, 0 };
      SNDFILE *sf_file = sf_open("graphgrow-filter.wav", SFM_WRITE, &sf_info);
120
      for (int frame = 0; frame < 750; ++frame) {
        filter_kernel(&filter, 0.5*(1 - cos(pi * frame/750.0)));
        sf_writef_float(sf_file, (float *) &filter.spectrum[0], filter.value.u_bins)↙
            ↳ ;
      }
125
      sf_close(sf_file);
      return 0;
    }
```

2 c/graphgrow_filter_frag.glsl

```
    #version 330 core

    const float pi = 3.141592653589793;
    const float twopi = 2.0 * pi;
  5 const float SR = 48000.0;

    uniform bool u_first_pass;
    uniform sampler1D u_spectrum;
    uniform float u_bins;
 10 uniform float u_length;
    uniform float u_speed;
    uniform float u_gain;
    uniform float u_scaleA;
    uniform float u_scaleB;
 15 uniform float u_offsetA;
    uniform float u_offsetB;

    in float i_bin;

 20 out vec3 o_response;

    vec2 cis(float t) {
      return vec2(cos(t), sin(t));
    }
 25
    vec2 cmul(vec2 a, vec2 b) {
      return vec2(a.x * b.x - a.y * b.y, a.x * b.y + a.y * b.x);
    }
```

```
vec2 cpow(vec2 a, float b) {
  return pow(length(a), b) * cis(atan(a.y, a.x) * b);
}

void main() {
  float rms = sqrt(texelFetch(u_spectrum, 0, 11).z);
  float freq = SR * i_bin / u_bins;
  float phase = freq * u_length / u_speed;
  if (u_first_pass) {
    vec2 OUTPUT = pow(u_gain, u_length) * cis(twopi * phase);
    o_response = vec3(OUTPUT, dot(OUTPUT, OUTPUT));
    return;
  }
  vec2 u = pow(u_gain, u_scaleA * u_length) * cis(twopi * u_scaleA * phase);
  vec2 v = pow(u_gain, u_scaleB * u_length) * cis(twopi * u_scaleB * phase);
  {
    float bin2 = i_bin * u_scaleA;
    vec2 u2 = cpow(texture(u_spectrum, bin2/u_bins).xy/rms, u_scaleA);
    if (! ((u2.x == 0 && u2.y == 0) || isnan(u2.x) || isnan(u2.y) || isinf(u2.x)
        ↳ || isinf(u2.y))) { u = u2; }
  }
  {
    float bin2 = i_bin * u_scaleB;
    vec2 v2 = cpow(texture(u_spectrum, bin2/u_bins).xy/rms, u_scaleB);
    if (! ((v2.x == 0 && v2.y == 0) || isnan(v2.x) || isnan(v2.y) || isinf(v2.x)
        ↳ || isinf(v2.y))) { v = v2; }
  }
  vec2 INPUT = vec2(1.0, 0.0);
  // edge losses
  vec2 a = u, b = v, c = v, d = v, e = v, f = u, g = u, h = u;
  // node values
  vec2 z = vec2(0.0, 0.0);
  vec2 A = z, B = z, C = z, D = z, E = z, F = z, G = z, H = z;
  // fixed point iteration
  for (int k = 0; k < 512; ++k) {
    // scale by degree
    A /= 1.0;
    B /= 3.0;
    C /= 3.0;
    D /= 3.0;
    E /= 3.0;
    F /= 1.0;
    G /= 1.0;
    H /= 1.0;
    // accumulate neighbours
    vec2 An = cmul(a, B) + INPUT;
    vec2 Bn = cmul(a, A) + cmul(b, C) + cmul(e, E);
    vec2 Cn = cmul(b, B) + cmul(c, D) + cmul(f, F);
    vec2 Dn = cmul(c, C) + cmul(d, E) + cmul(h, H);
    vec2 En = cmul(e, B) + cmul(d, D) + cmul(g, G);
    vec2 Fn = cmul(f, C);
    vec2 Gn = cmul(g, E);
    vec2 Hn = cmul(h, D);
    // step
    A = An;
    B = Bn;
    C = Cn;
```

```
      D = Dn;
      E = En;
      F = Fn;
      G = Gn;
      H = Hn;
    }
    // output
    vec2 OUTPUT = H;
    o_response = vec3(OUTPUT, dot(OUTPUT, OUTPUT));
}
```

3 c/graphgrow-filter.pd

```
#N canvas 1984 133 1920 1022 10;
#X obj 101 100 bng 15 250 50 0 empty empty empty 17 7 0 10 -262144
-1 -1;
#X obj 101 122 openpanel;
#X obj 100 168 soundfiler;
#N canvas 1055 276 454 660 fft 0;
#X obj 19 17 block~ 4096 4 1;
#X obj 28 50 inlet~;
#X obj 28 72 *~;
#X obj 31 334 rfft~;
#X obj 32 368 *~;
#X obj 32 396 -~;
#X obj 62 372 *~;
#X obj 95 371 *~;
#X obj 127 371 *~;
#X obj 40 305 tabreceive~ window;
#X obj 95 399 +~;
#X obj 31 465 rifft~;
#X obj 31 487 *~;
#X obj 31 509 outlet~;
#X obj 343 23 inlet;
#X obj 343 45 / 4096;
#X obj 343 67 int;
#X obj 234 188 * 4096;
#X obj 65 171 tabreceive~ ramp;
#X floatatom 374 102 5 0 0 0 - - -, f 5;
#X obj 97 430 /~ 1;
#X obj 30 422 /~ 1;
#X obj 226 339 +~;
#X obj 185 337 +~;
#X obj 313 155 int;
#X obj 288 131 t f f;
#X obj 300 198 -;
#X obj 268 261 t b f;
#X obj 268 283 1;
#X obj 268 305 -;
#X obj 185 301 *~ 0;
#X obj 223 300 *~ 0;
#X obj 330 308 *~ 0;
#X obj 368 307 *~ 0;
#X obj 382 201 * 4096;
#X obj 249 49 inlet~;
#X obj 249 71 snapshot~;
#X obj 199 50 bang~;
```

```
45  #X obj 249 93 *;
    #X obj 316 42 bng 15 250 50 0 empty empty empty 17 7 0 10 -262144 -1
    -1;
    #X obj 378 124 + 1;
    #X obj 378 146 int;
50  #X obj 381 174 min 0;
    #X obj 419 100 - 1;
    #X obj 234 163 min 0;
    #X obj 174 213 tabread4~ re;
    #X obj 198 235 tabread4~ im;
55  #X obj 340 226 tabread4~ re;
    #X obj 350 246 tabread4~ im;
    #X connect 1 0 2 0;
    #X connect 2 0 3 0;
    #X connect 3 0 4 0;
60  #X connect 3 0 7 0;
    #X connect 3 1 6 0;
    #X connect 3 1 8 0;
    #X connect 4 0 5 0;
    #X connect 5 0 21 0;
65  #X connect 6 0 5 1;
    #X connect 7 0 10 0;
    #X connect 8 0 10 1;
    #X connect 9 0 2 1;
    #X connect 9 0 12 1;
70  #X connect 10 0 20 0;
    #X connect 11 0 12 0;
    #X connect 12 0 13 0;
    #X connect 14 0 15 0;
    #X connect 15 0 16 0;
75  #X connect 16 0 19 0;
    #X connect 16 0 38 1;
    #X connect 16 0 43 0;
    #X connect 17 0 45 1;
    #X connect 17 0 46 1;
80  #X connect 18 0 45 0;
    #X connect 18 0 46 0;
    #X connect 18 0 47 0;
    #X connect 18 0 48 0;
    #X connect 20 0 11 1;
85  #X connect 21 0 11 0;
    #X connect 22 0 7 1;
    #X connect 22 0 6 1;
    #X connect 23 0 8 1;
    #X connect 23 0 4 1;
90  #X connect 24 0 26 1;
    #X connect 24 0 44 0;
    #X connect 25 0 26 0;
    #X connect 25 1 24 0;
    #X connect 26 0 27 0;
95  #X connect 26 0 32 1;
    #X connect 26 0 33 1;
    #X connect 27 0 28 0;
    #X connect 27 1 29 1;
    #X connect 28 0 29 0;
100 #X connect 29 0 31 1;
    #X connect 29 0 30 1;
```

```
#X connect 30 0 23 0;
#X connect 31 0 22 0;
#X connect 32 0 23 1;
#X connect 33 0 22 1;
#X connect 34 0 47 1;
#X connect 34 0 48 1;
#X connect 35 0 36 0;
#X connect 36 0 38 0;
#X connect 37 0 36 0;
#X connect 38 0 25 0;
#X connect 38 0 40 0;
#X connect 39 0 16 0;
#X connect 40 0 41 0;
#X connect 41 0 42 0;
#X connect 42 0 34 0;
#X connect 43 0 42 1;
#X connect 43 0 44 1;
#X connect 44 0 17 0;
#X connect 45 0 30 0;
#X connect 46 0 31 0;
#X connect 47 0 32 0;
#X connect 48 0 33 0;
#X restore 98 232 pd fft;
#X obj 365 136 table re;
#X obj 118 350 dac~;
#X obj 267 186 table window 4096;
#X obj 267 217 loadbang;
#X msg 267 239 4096;
#X obj 267 261 until;
#X obj 267 283 f 0;
#X obj 313 284 + 1;
#X obj 313 306 mod 4096;
#X obj 269 331 expr 0.5-0.5*cos(2.0*3.141592653*$f1/4096);
#X obj 269 309 t f f;
#X obj 271 392 tabwrite window;
#X obj 96 255 *~ 0;
#X floatatom 174 227 5 0 0 0 - - -, f 5;
#X floatatom 152 398 5 0 0 0 - - -, f 5;
#X obj 172 248 / 200000;
#X obj 405 189 table ramp 4096;
#X obj 281 365 tabwrite ramp;
#X obj 365 158 table im;
#X msg 216 319 0;
#X obj 1014 41 bang~;
#X obj 1014 63 snapshot~;
#X obj 167 281 env~ 16384;
#X obj 196 377 t f f;
#X floatatom 196 399 5 0 0 0 - - -, f 5;
#X obj 197 357 max;
#X msg 697 68 0 \, destroy;
#X obj 649 164 gemhead;
#X msg 670 327 snap;
#X obj 670 300 t b a;
#X obj 639 491 separator;
#X obj 1009 492 separator;
#X obj 819 494 separator;
#X obj 737 391 scale 4;
```

```
#X obj 753 331 square 4;
#X obj 655 71 tgl 15 0 empty empty empty 17 7 0 10 -262144 -1 -1 0
1;
#X obj 670 254 t a a;
#X obj 639 600 scale;
#X obj 819 600 scale;
#X obj 1009 600 scale;
#X obj 1242 494 separator;
#X obj 1241 582 scale;
#X obj 639 663 square 1;
#X obj 825 664 square 1;
#X obj 1013 668 square 1;
#X obj 1238 658 square 1;
#X floatatom 1014 85 5 0 0 0 - - -, f 5;
#X obj 1016 108 expr 1.0/4.0+0.5*(1-cos(3.141592653*$f1))*(1.0/2.0-1.0/4.0)
;
#X obj 1012 160 expr sqrt(2.0)*(1.0/2.0-$f1);
#X floatatom 1058 133 5 0 0 0 - - -, f 5;
#X floatatom 1045 183 5 0 0 0 - - -, f 5;
#X obj 1103 131 s scaleA;
#X obj 1160 572 r scaleA;
#X obj 1006 234 s scaleB;
#X obj 1257 204 -;
#X obj 1257 160 t b f;
#X obj 1258 251 s offsetA;
#X obj 639 551 translateXYZ -0.5 0 0;
#X obj 1121 506 r offsetA;
#X obj 902 521 * -1;
#X obj 820 552 translateXYZ 0 -0.5 0;
#X obj 1011 550 translateXYZ -0.5 0 0;
#X obj 1244 552 translateXYZ 0 0.5 0;
#X obj 1257 182 1;
#X obj 1013 134 t f f;
#X obj 735 461 t a a a a a;
#X obj 631 699 separator;
#X obj 1001 700 separator;
#X obj 811 702 separator;
#X obj 634 799 scale;
#X obj 814 799 scale;
#X obj 1004 798 scale;
#X obj 1234 702 separator;
#X obj 1237 801 scale;
#X obj 631 871 square 1;
#X obj 817 872 square 1;
#X obj 1005 876 square 1;
#X obj 1230 866 square 1;
#X obj 631 759 translateXYZ -0.5 0 0;
#X obj 907 717 * -1;
#X obj 812 760 translateXYZ 0 -0.5 0;
#X obj 1003 758 translateXYZ -0.5 0 0;
#X obj 1236 760 translateXYZ 0 0.5 0;
#X obj 733 672 t a a a a a;
#X obj 1149 711 r offsetB;
#X obj 1008 187 t f f;
#X obj 1091 249 s offsetB;
#X obj 1152 780 r scaleB;
#X obj 749 284 separator;
```

```
#X obj 737 414 rotateXYZ 0 0 45;
#X obj 639 622 rotateXYZ 0 0 45;
#X obj 820 620 rotateXYZ 0 0 45;
#X obj 1010 630 rotateXYZ 0 0 45;
#X obj 1239 602 rotateXYZ 0 0 45;
#X obj 1091 227 expr $f1;
#X obj 1257 226 expr $f1*sqrt(2.0);
#X obj 737 372 pix_texture;
#X msg 629 388 quality 2;
#X obj 630 363 loadbang;
#X obj 752 309 colorRGB 1 1 1;
#X obj 15 112 *~ 2;
#X obj 15 134 -~ 1;
#X obj 15 156 abs~;
#X obj 642 119 gemwin 25;
#X obj 13 208 noise~;
#N canvas 163 366 454 660 fft 0;
#X obj 19 17 block~ 4096 4 1;
#X obj 28 50 inlet~;
#X obj 28 72 *~;
#X obj 31 334 rfft~;
#X obj 32 368 *~;
#X obj 32 396 -~;
#X obj 62 372 *~;
#X obj 95 371 *~;
#X obj 127 371 *~;
#X obj 40 305 tabreceive~ window;
#X obj 95 399 +~;
#X obj 31 465 rifft~;
#X obj 31 487 *~;
#X obj 31 509 outlet~;
#X obj 343 23 inlet;
#X obj 343 45 / 4096;
#X obj 343 67 int;
#X obj 234 188 * 4096;
#X obj 65 171 tabreceive~ ramp;
#X floatatom 374 102 5 0 0 0 - - -, f 5;
#X obj 97 430 /~ 1;
#X obj 30 422 /~ 1;
#X obj 226 339 +~;
#X obj 185 337 +~;
#X obj 313 155 int;
#X obj 288 131 t f f;
#X obj 300 198 -;
#X obj 268 261 t b f;
#X obj 268 283 1;
#X obj 268 305 -;
#X obj 185 301 *~ 0;
#X obj 223 300 *~ 0;
#X obj 330 308 *~ 0;
#X obj 368 307 *~ 0;
#X obj 382 201 * 4096;
#X obj 249 49 inlet~;
#X obj 249 71 snapshot~;
#X obj 199 50 bang~;
#X obj 249 93 *;
#X obj 316 42 bng 15 250 50 0 empty empty empty 17 7 0 10 -262144 -1
```

```
-1;
#X obj 378 124 + 1;
#X obj 378 146 int;
#X obj 381 174 min 0;
#X obj 419 100 - 1;
#X obj 234 163 min 0;
#X obj 174 213 tabread4~ re;
#X obj 198 235 tabread4~ im;
#X obj 340 226 tabread4~ re;
#X obj 350 246 tabread4~ im;
#X connect 1 0 2 0;
#X connect 2 0 3 0;
#X connect 3 0 4 0;
#X connect 3 0 7 0;
#X connect 3 1 6 0;
#X connect 3 1 8 0;
#X connect 4 0 5 0;
#X connect 5 0 21 0;
#X connect 6 0 5 1;
#X connect 7 0 10 0;
#X connect 8 0 10 1;
#X connect 9 0 2 1;
#X connect 9 0 12 1;
#X connect 10 0 20 0;
#X connect 11 0 12 0;
#X connect 12 0 13 0;
#X connect 14 0 15 0;
#X connect 15 0 16 0;
#X connect 16 0 19 0;
#X connect 16 0 38 1;
#X connect 16 0 43 0;
#X connect 17 0 45 1;
#X connect 17 0 46 1;
#X connect 18 0 45 0;
#X connect 18 0 46 0;
#X connect 18 0 47 0;
#X connect 18 0 48 0;
#X connect 20 0 11 1;
#X connect 21 0 11 0;
#X connect 22 0 7 1;
#X connect 22 0 6 1;
#X connect 23 0 8 1;
#X connect 23 0 4 1;
#X connect 24 0 26 1;
#X connect 24 0 44 0;
#X connect 25 0 26 0;
#X connect 25 1 24 0;
#X connect 26 0 27 0;
#X connect 26 0 32 1;
#X connect 26 0 33 1;
#X connect 27 0 28 0;
#X connect 27 1 29 1;
#X connect 28 0 29 0;
#X connect 29 0 31 1;
#X connect 29 0 30 1;
#X connect 30 0 23 0;
#X connect 31 0 22 0;
```

```
#X connect 32 0 23 1;
#X connect 33 0 22 1;
#X connect 34 0 47 1;
#X connect 34 0 48 1;
#X connect 35 0 36 0;
#X connect 36 0 38 0;
#X connect 37 0 36 0;
#X connect 38 0 25 0;
#X connect 38 0 40 0;
#X connect 39 0 16 0;
#X connect 40 0 41 0;
#X connect 41 0 42 0;
#X connect 42 0 34 0;
#X connect 43 0 42 1;
#X connect 43 0 44 1;
#X connect 44 0 17 0;
#X connect 45 0 30 0;
#X connect 46 0 31 0;
#X connect 47 0 32 0;
#X connect 48 0 33 0;
#X restore 99 288 pd fft;
#X obj 97 311 *~ 0;
#X obj 14 264 noise~;
#X msg 176 207 20;
#X obj 734 437 colorRGB 0.7 0.7 0.7;
#X obj 649 193 t a a;
#X obj 434 625 loadbang;
#X msg 434 654 file out 0 \, auto 1;
#X obj 407 590 spigot;
#X obj 3 34 bng 15 250 50 0 empty empty empty 17 7 0 10 -262144 -1
-1;
#X obj 13 90 vline~;
#X obj 61 475 writesf~ 2;
#X msg 8 412 stop;
#X msg 57 428 open -bytes 4 out.wav \, start;
#X msg 453 539 1;
#X msg 441 563 0;
#X obj 186 185 loadbang;
#X msg 101 144 read -maxsize 1e+09 -resize \$1 re im;
#X msg 13 66 0 \, 1 600000, f 13;
#X obj 8 390 delay 600000;
#X msg 642 44 dimen 512 512 \, create \, 1;
#X obj 737 350 pix_snap2tex 0 0 512 512;
#X obj 415 692 pix_write 0 0 512 512;
#X connect 0 0 1 0;
#X connect 1 0 126 0;
#X connect 2 0 3 2;
#X connect 2 0 109 2;
#X connect 3 0 16 0;
#X connect 7 0 8 0;
#X connect 8 0 9 0;
#X connect 9 0 10 0;
#X connect 10 0 11 0;
#X connect 10 0 14 0;
#X connect 11 0 12 0;
#X connect 12 0 10 1;
#X connect 13 0 15 0;
```

```
#X connect 14 0 13 0;
#X connect 14 0 21 0;
#X connect 14 1 15 1;
#X connect 14 1 21 1;
#X connect 16 0 26 0;
#X connect 16 0 5 0;
#X connect 16 0 120 0;
#X connect 17 0 19 0;
#X connect 19 0 16 1;
#X connect 19 0 110 1;
#X connect 23 0 29 1;
#X connect 24 0 25 0;
#X connect 25 0 50 0;
#X connect 26 0 18 0;
#X connect 26 0 29 0;
#X connect 27 0 28 0;
#X connect 27 1 29 1;
#X connect 29 0 27 0;
#X connect 30 0 107 0;
#X connect 31 0 114 0;
#X connect 32 0 130 0;
#X connect 33 0 32 0;
#X connect 33 1 130 0;
#X connect 34 0 61 0;
#X connect 35 0 65 0;
#X connect 36 0 64 0;
#X connect 37 0 93 0;
#X connect 39 0 107 0;
#X connect 40 0 33 0;
#X connect 40 1 92 0;
#X connect 41 0 94 0;
#X connect 42 0 95 0;
#X connect 43 0 96 0;
#X connect 44 0 66 0;
#X connect 45 0 97 0;
#X connect 50 0 51 0;
#X connect 51 0 53 0;
#X connect 51 0 55 0;
#X connect 51 0 68 0;
#X connect 52 0 54 0;
#X connect 52 0 89 0;
#X connect 56 0 43 1;
#X connect 56 0 42 1;
#X connect 56 0 41 1;
#X connect 56 0 45 1;
#X connect 58 0 99 0;
#X connect 59 0 67 0;
#X connect 59 1 58 1;
#X connect 61 0 41 0;
#X connect 62 0 63 0;
#X connect 62 0 65 1;
#X connect 62 0 66 2;
#X connect 63 0 64 2;
#X connect 63 0 61 1;
#X connect 64 0 42 0;
#X connect 65 0 43 0;
#X connect 66 0 45 0;
```

```
#X connect 67 0 58 0;
#X connect 68 0 52 0;
#X connect 68 1 59 0;
#X connect 69 0 34 0;
#X connect 69 1 36 0;
#X connect 69 2 35 0;
#X connect 69 3 44 0;
#X connect 69 4 87 0;
#X connect 70 0 82 0;
#X connect 71 0 85 0;
#X connect 72 0 84 0;
#X connect 73 0 78 0;
#X connect 74 0 79 0;
#X connect 75 0 80 0;
#X connect 76 0 86 0;
#X connect 77 0 81 0;
#X connect 82 0 73 0;
#X connect 83 0 84 2;
#X connect 83 0 82 1;
#X connect 83 0 85 2;
#X connect 83 0 84 1;
#X connect 84 0 74 0;
#X connect 85 0 75 0;
#X connect 86 0 77 0;
#X connect 87 0 70 0;
#X connect 87 1 72 0;
#X connect 87 2 71 0;
#X connect 87 3 76 0;
#X connect 88 0 83 0;
#X connect 88 0 85 1;
#X connect 88 0 86 2;
#X connect 88 0 86 1;
#X connect 88 0 82 2;
#X connect 89 0 57 0;
#X connect 89 1 98 0;
#X connect 91 0 75 1;
#X connect 91 0 74 1;
#X connect 91 0 73 1;
#X connect 91 0 77 1;
#X connect 92 0 103 0;
#X connect 93 0 113 0;
#X connect 94 0 46 0;
#X connect 95 0 47 0;
#X connect 96 0 48 0;
#X connect 97 0 49 0;
#X connect 98 0 90 0;
#X connect 99 0 60 0;
#X connect 100 0 37 0;
#X connect 101 0 100 0;
#X connect 102 0 101 0;
#X connect 103 0 38 0;
#X connect 104 0 105 0;
#X connect 105 0 106 0;
#X connect 106 0 3 1;
#X connect 106 0 25 0;
#X connect 106 0 109 1;
#X connect 108 0 3 0;
```

```
#X connect 109 0 110 0;
#X connect 110 0 5 1;
#X connect 110 0 120 1;
#X connect 111 0 109 0;
#X connect 112 0 17 0;
#X connect 113 0 69 0;
#X connect 114 0 117 0;
#X connect 114 1 40 0;
#X connect 115 0 116 0;
#X connect 116 0 131 0;
#X connect 117 0 131 0;
#X connect 118 0 127 0;
#X connect 118 0 122 0;
#X connect 118 0 123 0;
#X connect 118 0 128 0;
#X connect 119 0 104 0;
#X connect 121 0 120 0;
#X connect 122 0 120 0;
#X connect 123 0 117 1;
#X connect 124 0 117 1;
#X connect 125 0 112 0;
#X connect 126 0 2 0;
#X connect 127 0 119 0;
#X connect 128 0 121 0;
#X connect 128 0 124 0;
#X connect 129 0 107 0;
#X connect 130 0 100 0;
#X connect 130 1 100 1;
```

4 c/graphgrow_filter_vert.glsl

```
#version 330 core

uniform float u_bins;

out float i_bin;

void main() {
  switch (gl_VertexID) {
    default:
    case 0:
      gl_Position = vec4(-1.0, 0.0, 0.0, 1.0);
      i_bin = 0.0;
      break;
    case 1:
      gl_Position = vec4( 1.0, 0.0, 0.0, 1.0);
      i_bin = u_bins / 2.0;
      break;
  }
}
```

5 c/Makefile

```
graphgrow-filter: graphgrow-filter.c graphgrow_filter_frag.glsl.c ↙
    ↳ graphgrow_filter_vert.glsl.c shader.c shader.h
        gcc -std=c99 -Wall -Wextra -pedantic -O3 -fopenmp -o graphgrow-filter ↙
            ↳ graphgrow-filter.c shader.c -lm -lsndfile -lGL -lGLEW -lglfw
```

```
graphgrow_filter_frag.glsl.c: graphgrow_filter_frag.glsl s2c.sh
	./s2c.sh graphgrow_filter_frag < graphgrow_filter_frag.glsl > ↙
	    ↳ graphgrow_filter_frag.glsl.c

graphgrow_filter_vert.glsl.c: graphgrow_filter_vert.glsl s2c.sh
	./s2c.sh graphgrow_filter_vert < graphgrow_filter_vert.glsl > ↙
	    ↳ graphgrow_filter_vert.glsl.c

.SUFFIXES:
```

6 c/s2c.sh

```
#!/bin/bash
echo "/* machine-generated file, do not edit */"
echo "static const char $1[] ="
sed 's|//.*||' |
sed 's|^|"|' |
sed 's|$|\\n"|'
echo ";"
```

7 c/shader.c

```
/* ============================================================================
pool-party -- water simulation
Copyright (C) 2016  Claude Heiland-Allen <claude@mathr.co.uk>
----------------------------------------------------------------------------
based on:
rdex -- reaction-diffusion explorer
Copyright (C) 2008  Claude Heiland-Allen <claude@mathr.co.uk>
----------------------------------------------------------------------------
Generic Shader
============================================================================ */

#include <stdio.h>
#include <stdlib.h>
#include "shader.h"

//============================================================================
// print a shader object's debug log
void shader_debug(GLuint obj) {
//  return; // FIXME: only dump logs when shader compile/link failed
  int infologLength = 0;
  int maxLength;
  if (glIsShader(obj)) {
    glGetShaderiv(obj, GL_INFO_LOG_LENGTH, &maxLength);
  } else {
    glGetProgramiv(obj, GL_INFO_LOG_LENGTH, &maxLength);
  }
  char *infoLog = malloc(maxLength);
  if (!infoLog) {
    return;
  }
  if (glIsShader(obj)) {
    glGetShaderInfoLog(obj, maxLength, &infologLength, infoLog);
  } else {
```

```
    glGetProgramInfoLog(obj, maxLength, &infologLength, infoLog);
  }
  if (infologLength > 0) {
    fprintf(stderr, "%s\n", infoLog);
  }
  free(infoLog);
}

//============================================================
// generic shader initialization
struct shader *shader_init(
  struct shader *shader, const char *vert, const char *frag
) {
  if (! shader) { return 0; }
  shader->linkStatus     = 0;
  shader->vertexSource   = vert;
  shader->fragmentSource = frag;
  if (shader->vertexSource || shader->fragmentSource) {
    shader->program = glCreateProgram();
    if (shader->vertexSource) {
      shader->vertex =
        glCreateShader(GL_VERTEX_SHADER);
      glShaderSource(shader->vertex,
        1, &shader->vertexSource, 0
      );
      glCompileShader(shader->vertex);
      shader_debug(shader->vertex);
      glAttachShader(shader->program, shader->vertex);
    }
    if (shader->fragmentSource) {
      shader->fragment =
        glCreateShader(GL_FRAGMENT_SHADER);
      glShaderSource(shader->fragment,
        1, &shader->fragmentSource, 0
      );
      glCompileShader(shader->fragment);
      shader_debug(shader->fragment);
      glAttachShader(shader->program, shader->fragment);
    }
    glLinkProgram(shader->program);
    shader_debug(shader->program);
    glGetProgramiv(shader->program,
      GL_LINK_STATUS, &shader->linkStatus
    );
    if (! shader->linkStatus) { return 0; }
  } else { return 0; }
  return shader;
}

// EOF
```

8 c/shader.h

```
/* ============================================================
pool-party -- water simulation
Copyright (C) 2016  Claude Heiland-Allen <claude@mathr.co.uk>
------------------------------------------------------------
```

```
based on:
rdex -- reaction-diffusion explorer
Copyright (C) 2008  Claude Heiland-Allen <claude@mathr.co.uk>
-------------------------------------------------------------------------
Generic Shader
=========================================================================*/

#ifndef SHADER_H
#define SHADER_H 1

#include <GL/glew.h>

//=========================================================================
// generic shader data
struct shader {
  GLint linkStatus;
  GLuint program;
  GLuint fragment;
  GLuint vertex;
  const char *fragmentSource;
  const char *vertexSource;
};

//=========================================================================
// generic shader uniform location access macro
#define shader_uniform(self,name) \
  (self)->uniform.name = \
    glGetUniformLocation((self)->shader.program, #name)

//=========================================================================
// generic shader uniform update access macro (integer)
#define shader_updatei(self,name) \
  glUniform1i((self)->uniform.name, (self)->value.name)

//=========================================================================
// generic shader uniform update access macro (integer vector)
#define shader_update2i(self,name) \
  glUniform2iv((self)->uniform.name, 1, (self)->value.name)

//=========================================================================
// generic shader uniform update access macro (float)
#define shader_updatef(self,name) \
  glUniform1f((self)->uniform.name, (self)->value.name)

//=========================================================================
// generic shader initialization
struct shader *shader_init(
  struct shader *shader, const char *vert, const char *frag
);

#endif
```

9 extra/mk.hs

```
import Control.Monad (forM_)
import Control.Monad.ST (ST, runST)
import Data.STRef
```

```
import Data.Array.Unboxed as A
import Data.Array.ST (STUArray, newArray, readArray, writeArray)
import Data.Array.Unsafe (unsafeFreeze)

import Data.ByteString as Strict
import Data.ByteString.Lazy as Lazy

import Data.Char as C hiding (isAlpha, toUpper)
import Data.List as L
import Data.Map as M
import Data.Ord as O
import Data.Set as S
import Data.Word as W

import System.Environment (getArgs)

equating f a b = f a == f b

chain :: Ord a => Set a -> [a] -> UArray (Int, Int) Word64
chain wordSet input@(hinput:tinput) = runST $ do
  let n = S.size wordSet
      bs = ((0,0),((n-1),(n-1)))
      ix w = S.size (fst (w `S.split` wordSet))
      inc x | x == maxBound = maxBound
            | otherwise = x + 1
  arr <- newArray bs 0 :: ST s (STUArray s (Int, Int) Word64)
  context <- newSTRef (ix hinput)
  forM_ (tinput ++ [hinput]) $ \word -> do
    i <- readSTRef context
    let j = ix word
    writeArray arr (i, j) . inc =<< readArray arr (i, j)
    writeSTRef context j
  unsafeFreeze arr

prettyChain :: Int -> Set Strict.ByteString -> UArray (Int, Int) Word64 -> Lazy.↙
  ↳ ByteString
prettyChain maxLinks wordSet chain = Lazy.fromChunks . L.concat $
  [ L.intersperse spc ([context, col] ++ (L.map fst . L.take maxLinks . L.sortBy↙
    ↳ (flip (comparing snd))) [ (word, count) | (word, j) <- S.toList wordSet↙
    ↳ `L.zip` [i+0-i..], let count = chain A.! (i, j), count > 0 ]) ++ [eol] ↙
    ↳ | (context, i) <- S.toList wordSet `L.zip` [0..] ]
  where
    eol = Strict.pack [fromIntegral $ ord '\n']
    spc = Strict.pack [fromIntegral $ ord ' ']
    col = Strict.pack [fromIntegral $ ord ':']

histogram :: Ord a => [a] -> Map a Int
histogram = L.foldl' inc M.empty
  where
    inc m w = case M.lookup w m of
      Nothing -> M.insert w 1 m
      Just k -> let k' = k + 1 in k' `seq` M.insert w k' m

commonest :: Ord a => Map a Int -> [a]
commonest = L.map fst . L.sortBy (flip (comparing snd)) . M.toList
```

```
toWords :: String -> Lazy.ByteString -> [Strict.ByteString]
toWords tag = L.concatMap (lineWords tag) . L.map toStrict . llines

lineWords :: String -> Strict.ByteString -> [Strict.ByteString]
lineWords "irc" = \l -> case Strict.uncons (Strict.drop 9 l) of
  Just (c, l)
    | c == fromIntegral (ord '-') -> []
    | otherwise -> (L.drop 1 . L.filter isWord . Strict.groupBy (equating ↙
      ↳ isAlpha) . Strict.map toUpper) l
  Nothing -> []
lineWords "mail" = L.drop 1 . L.filter isWord . Strict.groupBy (equating ↙
  ↳ isAlpha) . Strict.map toUpper

isWord :: Strict.ByteString -> Bool
isWord s = 4 <= Strict.length s && Strict.all isAlpha s

isAlpha :: Word8 -> Bool
isAlpha = \c -> a <= c && c <= z
  where
    a = fromIntegral (ord 'A')
    z = fromIntegral (ord 'Z')

toUpper :: Word8 -> Word8
toUpper = \c -> if a <= c && c <= z then c - a + bigA else c
  where
    a = fromIntegral (ord 'a')
    z = fromIntegral (ord 'z')
    bigA = fromIntegral (ord 'A')

toStrict :: Lazy.ByteString -> Strict.ByteString
toStrict = Strict.concat . Lazy.toChunks

llines :: Lazy.ByteString -> [Lazy.ByteString]
llines s = if Lazy.null s then [] else l : llines (Lazy.drop 1 ls)
  where
    (l, ls) = Lazy.span neol s

neol = \c -> c /= eol
  where
    eol = fromIntegral (ord '\n')

slines :: Strict.ByteString -> [Strict.ByteString]
slines s = if Strict.null s then [] else l : slines (Strict.drop 1 ls)
  where
    (l, ls) = Strict.span neol s

nl = Strict.pack [fromIntegral $ ord '\n']

main :: IO ()
main = do
  args <- getArgs
  case args of
    [tag, "words", wordCount] -> Lazy.interact (Lazy.fromChunks . L.concatMap (\↙
      ↳ x->[x,nl]) . L.take (read wordCount) . commonest . histogram . toWords↙
      ↳  tag)
    [tag, "chain", wordFile] -> do
      wordList <- (S.fromList . slines) `fmap` Strict.readFile wordFile
```

```
110         Lazy.interact (prettyChain 32 wordList . chain wordList . L.filter (`S.member` wordList) . toWords tag)
```

10 Fractal/GraphGrow/Analysis/Statistics.hs

```
module Fractal.GraphGrow.Analysis.Statistics where

import Data.List (foldl')
import Data.Monoid (Monoid(..))

data Stat s = Stat{ s0, s1, s2 :: !s }
  deriving (Eq, Ord, Read, Show)

instance Num s => Monoid (Stat s) where
  mempty = Stat{ s0 = 0, s1 = 0, s2 = 0 }
  a `mappend` b = Stat{ s0 = s0 a + s0 b, s1 = s1 a + s1 b, s2 = s2 a + s2 b }
  mconcat = foldl' mappend mempty

stat :: Num s => s -> Stat s
stat s = Stat{ s0 = 1, s1 = s, s2 = s * s }

getCount :: Stat s -> s
getCount = s0

getSum :: Stat s -> s
getSum = s1

getMean :: Fractional s => Stat s -> s
getMean s = s1 s / s0 s

getVariance :: Fractional s => Stat s -> s
getVariance s = (s0 s * s2 s - s1 s * s1 s) / (s0 s * s0 s)

getStdDev :: Floating s => Stat s -> s
getStdDev = sqrt . getVariance

type StatOrd s = (Stat s, MinMax s)

statOrd :: Num s => s -> StatOrd s
statOrd s = (stat s, minMax s)

newtype MinMax s = MinMax{ getMinMax :: Maybe (s, s) }
  deriving (Eq, Ord, Read, Show)

minMax :: s -> MinMax s
minMax s = MinMax $! Just $! (((,) $! s) $! s)

instance Ord s => Monoid (MinMax s) where
  mempty = MinMax Nothing
  MinMax Nothing `mappend` b = b
  a `mappend` MinMax Nothing = a
  MinMax (Just (ain, aax)) `mappend` MinMax (Just (bin, bax)) = MinMax $! Just $! (((,) $! ain `min` bin) $! aax `max` bax)
  mconcat = foldl' mappend mempty
```

11 Fractal/GraphGrow/Editor/Graph.hs

```
{-# LANGUAGE MultiParamTypeClasses, TypeFamilies #-}
module Fractal.GraphGrow.Editor.Graph (GraphEditor, newGraphEditor) where

import Graphics.UI.Gtk.Toy.Prelude hiding (D, bg)

import Data.Colour.RGBSpace (uncurryRGB)
import Data.Colour.RGBSpace.HSV (hsv)
import Data.Colour.SRGB (sRGB, toSRGBBounded)
import Data.Fixed (mod')

import Data.Default (Default(def))
import Data.Label (get)
import qualified Data.Map as M
import Data.Maybe (maybeToList)

import qualified Graphics.UI.Gtk as G
import Control.Monad (forM_)
import Data.IORef (IORef, newIORef, readIORef, writeIORef)

import Fractal.GraphGrow.Engine.Geometry (Transform, scale, rotate, translate)
import Fractal.GraphGrow.Engine.Graph (Node(Node))

type GraphEditor = Toy Graph

newGraphEditor :: Node -> ([(Node, Transform)] -> IO ()) -> IO GraphEditor
newGraphEditor node putUpdates = newToy (graph node putUpdates)

setGraphEditorNodes :: GraphEditor -> [Node] -> IO ()
setGraphEditorNodes tb nodes = do
  g <- snd `fmap` readIORef (toyState tb)


phi :: Double
phi = (sqrt 5 + 1) / 2

nodeColour (Node n) = uncurryRGB sRGB $ hsv (360 * ((phi * fromIntegral n) `mod'` 1)) 1 1

type D = Draggable Cairo CairoDiagram -- every thing needs be draggable

-- knob and link ids
type KID = Int
type LID = (KID, KID)

-- things
data Thing = Background {-nextKnobID-}KID D | Knob {-isFixedPosition-}Bool KID D D | Link LID D D Node

-- visual representation
bg n = mkDraggable (r2 (300, 300)) $ rect 600 600 # fc (blend (1/16) (nodeColour n) white)
knob n fixed p =
    ( mkDraggable (r2 p) $ shape  5 # lc black # fc col
    , mkDraggable (r2 p) $ shape 12 # fcA (col `withOpacity` 0.5)
    )
  where
    col = nodeColour n
```

```
55      shape = if fixed then square . ((pi/2) *) else circle
    link n p@(x0,y0) q@(x1,y1) =
      ( mkDraggable (r2((x0+x1)/2,(y0+y1)/2)) $ circle 5 # lc black # fc col
      , mkDraggable (r2(0,0)) $ p2 p ~~ p2 q # stroke # lc col
      )
60    where
        col = nodeColour n

    -- extract diagrams
    tDiagram (Background _ d)   = [d]
65  tDiagram (Knob _ _ d1 d2)   = [d1, d2]  -- d1 is inner core, d2 is outer ring
    tDiagram (Link _   d1 d2 _) = [d1, d2]  -- d1 is inner core, d2 is line

    -- what did a mouse event do
    data Act
70    = Create KID
      | Delete KID
      | MoveStart KID
      | Moving    KID
      | MoveStop  KID
75    | LinkStart        KID  (Double, Double)
      | Linking              (Double, Double)
      | LinkStop (Maybe (KID, (Double, Double)))

    -- what mode are we in
80  data Mode
      = MMove KID                                        -- moving a knob
      | MLink KID (Double, Double) (Double, Double) -- creating a link

    data Graph = Graph
85    { gNode      :: Node
      , gGetNodes :: IO [Node]
      , gPutEdges :: [(Node, Transform)] -> IO ()
      , gMode      :: Maybe Mode
      , gThings    :: [Thing]
90    }

    -- update links when knobs are moved or deleted
    resort g@Graph{ gThings = ts } = g{ gThings = ts' }
      where
95      knobs = [ n | n@(Knob      {}) <- ts ]
        links = [ l | l@(Link      {}) <- ts ]
        backg = [ b | b@(Background{}) <- ts ]
        positions = M.fromList [ (i, unr2 $ get dragOffset d) | Knob _ i d _ <- ↙
            ↳ knobs ]
        links' =
100       [ Link ij d1 d2 n
          | Link ij@(i, j) _ _ n <- links
          , (d1, d2) <- maybeToList $
              liftA2 (link n) (M.lookup i positions) (M.lookup j positions)
          ]
105     ts' = knobs ++ links' ++ backg

    -- mouse handling
    -- linking knobs
    tMouse _ (Just(MLink j q _))(Just(False, 0)) p t@(Background _ _    ) ↙
        ↳                                    = (Just $ LinkStop Nothing      , [t↙
```

```
    ↳ ]) -- note: Background is the last Thing in the list
tMouse _ (Just(MLink j q _))(Just(False, 0)) p t@(Knob fixed i d1 d2) | j /= i ↙
    ↳ && clickInside d2 (p2 p)    = (Just $ LinkStop (Just (i, p)), [t])
tMouse _ (Just(MLink j q _))(Just(False, 0)) p t ↙
    ↳                                                    = (Nothing ↙
    ↳                        , [t])
tMouse _ (Just(MLink j q _))_                p t ↙
    ↳                                                    = (Just $ ↙
    ↳ Linking     p          , [t])
-- moving knobs
tMouse _ Nothing          m@(Just (True,  0)) p t@(Knob fixed i d1 d2) | ↙
    ↳ clickInside d1 (p2 p) && not fixed = (Just $ MoveStart i   , [Knob False i ↙
    ↳ (mouseDrag m p d1) (mouseDrag m p d2)])
                                                                         | ↙
                                                                           ↳ clickInside↙
                                                                           ↳  d2 ↙
                                                                           ↳ (p2 ↙
                                                                           ↳ p) ↙
                                                                           ↳                ↙
                                                                           ↳ = (↙
                                                                           ↳ Just↙
                                                                           ↳  $ ↙
                                                                           ↳ LinkStart↙
                                                                           ↳  i p↙
                                                                           ↳  ↙
                                                                           ↳          ↙
                                                                           ↳ , [t↙
                                                                           ↳ ])
tMouse _ (Just(MMove j)) m@(Just (False, 0)) p   (Knob False i d1 d2) | j == i ↙
    ↳                          = (Just $ MoveStop  i   , [Knob False i (↙
    ↳ mouseDrag m p d1) (mouseDrag m p d2)])
tMouse _ (Just(MMove j)) m                   p   (Knob False i d1 d2) | j == i ↙
    ↳                          = (Just $ Moving    i   , [Knob False i (↙
    ↳ mouseDrag m p d1) (mouseDrag m p d2)])
-- creating knobs
tMouse c Nothing          (Just (True,  0)) p   (Background i d) ↙
    ↳                                    = (Just $ Create    i   , [uncurry↙
    ↳  (Knob False i) (knob c False p), Background (i + 1) d])
tMouse _ Nothing          (Just (True,  1)) p   (Knob False i d1 d2) | ↙
    ↳ clickInside d1 (p2 p)          = (Just $ Delete    i   , [])
tMouse _ _currentMode     _mouseEvent     _ t@_thingToTest ↙
    ↳                                      = (Nothing           , [t])

-- concatMap until a thing signals something was done, then just copy the rest
tMouses _ _ _ _ a@(Just _) ws = (a, ws)
tMouses _ _ _ _ Nothing [] = (Nothing, [])
tMouses c d m p Nothing (w:ws) =
  let (a, ws') = tMouse c d m p w
  in  (ws' ++) `fmap` tMouses c d m p a ws

type instance V Graph = R2

graph node getNodes putUpdates = Graph node getNodes putUpdates Nothing
  [ uncurry (Knob True 1) (knob node True (500, 300))
  , uncurry (Knob True 0) (knob node True (100, 300))
  , Background 2 (bg node)
  ]
```

```
instance Interactive Graph where
  mouse = simpleMouse $ \m p g@(Graph{ gNode = c, gMode = d, gThings = ts}) -> ↙
      ↳ resort $ case (d, tMouses c d m p Nothing ts) of
    -- moving knobs
    (Nothing           , (Just (MoveStart i           ), ts'))          -> g{ ↙
        ↳ gThings = ts', gMode = Just (MMove i) }
    (Just (MMove j)    , (Just (Moving    i           ), ts')) | j == i -> g{ ↙
        ↳ gThings = ts', gMode = Just (MMove i) }
    (Just (MMove j)    , (Just (MoveStop  i           ), ts')) | j == i -> g{ ↙
        ↳ gThings = ts', gMode = Nothing }
    -- linking knobs
    (Nothing,            (Just (LinkStart i p         ), ts'))          -> g{ ↙
        ↳ gThings = ts', gMode = Just (MLink i p p) }
    (Just (MLink j q _), (Just (Linking     p         ), ts'))          -> g{ ↙
        ↳ gThings = ts', gMode = Just (MLink j q p) }
    (Just (MLink j q _), (Just (LinkStop (Just (i, p))), ts')) | j /= i -> g{ ↙
        ↳ gThings = uncurry (Link (j, i)) (link c q p) c: ts', gMode = Nothing }
    (Just (MLink j q _), (Just (LinkStop Nothing      ), ts'))          -> g{ ↙
        ↳ gThings = ts', gMode = Nothing }
    -- everything else
    (_, (_, ts')) -> g{ gThings = ts', gMode = Nothing }

instance Diagrammable Cairo Graph where
  diagram (Graph{ gMode = m, gThings = ts}) = mconcat . map diagram $ ↙
      ↳ modeDiagram ++ concatMap tDiagram ts
    where
      modeDiagram = case m of
        Just (MLink _ p q) -> [mkDraggable (r2(0,0)) $ p2 p ~~ p2 q # stroke # ↙
            ↳ lc black]
        _ -> []

instance GtkInteractive Graph where
  display = displayDiagram diagram

main :: IO ()
main = do
  G.initGUI
  graphsRef <- newIORef M.empty
  window <- G.windowNew
  G.windowSetDefaultSize window 600 600
  box <- G.hButtonBoxNew

  button <- G.buttonNewWithLabel "+"
  button `G.on` G.buttonActivated $ do
    graphs <- readIORef graphsRef
    let n = maybe (Node 0) ((\(Node m) -> Node (m+1)) . fst . fst) (M.↙
        ↳ maxViewWithKey graphs)
        gcol = uncurryRGB G.Color $ toSRGBBounded (nodeColour n)
    g <- newGraphEditor n (M.keys `fmap` readIORef graphsRef) (\_ -> return ())
    w <- G.windowNew
    G.windowSetGeometryHints w (Nothing `asTypeOf` Just w) (Just (600, 600)) (↙
        ↳ Just (600, 600)) Nothing Nothing Nothing
    G.set w $ [G.containerChild G.:= toyWindow g]
    writeIORef graphsRef (M.insert n (w, g) graphs)
    b <- G.buttonNew
    b `G.on` G.buttonActivated $ G.windowPresent{-WithTime-} w
```

```
      forM_ [G.StateNormal, G.StateActive, G.StatePrelight, G.StateSelected, G.↙
          ↳ StateInsensitive] $ \s ->
        G.widgetModifyBg b s gcol
      G.containerAdd box b
      G.widgetShowAll window
      G.widgetShowAll w

  G.containerAdd box button
  G.containerAdd window box
  G.widgetShowAll window
  G.mainGUI
```

12 Fractal/GraphGrow/Engine/Geometry.hs

```
module Fractal.GraphGrow.Engine.Geometry
  ( -- * Affine transforms.
    Transform(Transform)
  , identity
  , o
  , compose
  , scale
  , rotate
  , translate
    -- * Vectors.
  , Point(Point)
  , scalePoint
  , addPoint
  , distanceSquared
    -- * Inspecting transforms.
  , center
  , sizeSquared
    -- * Bounding boxes.
  , Box(Box)
  , makeBox
  , scaleBox
  , boxSize
  , clampBox
  , outsideBox
  , ) where

import Data.List (foldl')
import Foreign (Storable(..), castPtr)

import Fractal.GraphGrow.Utils (sqr, clamp)

data Transform = Transform !Double !Double !Double !Double !Double !Double
  deriving (Read, Show)
instance Storable Transform where
  alignment _ = alignment (0 :: Double)
  sizeOf _ = 6 * sizeOf (0 :: Double)
  poke p (Transform a b c d e f) = do
    let q = castPtr p
    pokeElemOff q 0 a
    pokeElemOff q 1 b
    pokeElemOff q 2 c
    pokeElemOff q 3 d
    pokeElemOff q 4 e
```

```
      pokeElemOff q 5 f
    peek p = do
      let q = castPtr p
      a <- peekElemOff q 0
      b <- peekElemOff q 1
      c <- peekElemOff q 2
      d <- peekElemOff q 3
      e <- peekElemOff q 4
      f <- peekElemOff q 5
      return (Transform a b c d e f)

identity :: Transform
identity = Transform 1 0 0 1 0 0

o :: Transform -> Transform -> Transform
Transform a b c d e f `o` Transform u v w x y z = Transform
  (a * u + b * w) (a * v + b * x)
  (c * u + d * w) (c * v + d * x)
  (a * y + b * z + e) (c * y + d * z + f)

compose :: [Transform] -> Transform
compose = foldl' o identity

scale :: Double -> Transform
scale factor = Transform factor 0 0 factor 0 0

rotate :: Double -> Transform
rotate turns = Transform c (-s) s c 0 0
  where
    a = 2 * pi * turns
    c = cos a
    s = sin a

translate :: Double -> Double -> Transform
translate x y = Transform 1 0 0 1 x y

data Point = Point !Double !Double
  deriving (Read, Show)

scalePoint :: Double -> Point -> Point
scalePoint factor (Point x y) = Point (factor * x) (factor * y)

addPoint :: Point -> Point -> Point
addPoint (Point x y) (Point u v) = Point (x + u) (y + v)

distanceSquared :: Point -> Point -> Double
distanceSquared (Point x y) (Point u v) = sqr (x - u) + sqr (y - v)

center :: Transform -> Point
center (Transform _ _ _ _ x y) = Point x y

sizeSquared :: Transform -> Double
sizeSquared (Transform a b _ _ _ _) = sqr a + sqr b

data Box = Box !Double !Double !Double !Double
  deriving (Read, Show)

```

```
makeBox :: Double -> Double -> Box
makeBox width height = Box (-width) (-height) width height

scaleBox :: Double -> Box -> Box
scaleBox factor (Box lx ly hx hy) = Box (cx - dx) (cy - dy) (cx + dx) (cy + dy)
  where
    cx = (hx + lx) / 2
    cy = (hy + ly) / 2
    dx = (hx - lx) / 2 * factor
    dy = (hy - ly) / 2 * factor

boxSize :: Box -> Double
boxSize (Box lx ly hx hy) = sqrt (sqr (hx - lx) + sqr (hy - ly))

clampBox :: Box -> Point -> Point
clampBox (Box lx ly hx hy) (Point x y) = Point (clamp x lx hx) (clamp y ly hy)

outsideBox :: Box -> Point -> Double -> Bool
outsideBox (Box lx ly hx hy) (Point ox oy) radiusSquared =
  let r = sqrt radiusSquared
  in  ox + r < lx || hx < ox - r || oy + r < ly || hy < oy - r
```

13 Fractal/GraphGrow/Engine/Graph.hs

```
{-# LANGUAGE GeneralizedNewtypeDeriving #-}
module Fractal.GraphGrow.Engine.Graph where

import Data.Ix (Ix(..))
import Data.Map (Map)
import qualified Data.Map as M
import Data.Maybe (catMaybes, fromMaybe)
import Data.Vector.Storable (Vector)
import qualified Data.Vector.Storable as V
import Data.Word (Word32)
import Foreign.Storable (Storable(..))

import Fractal.GraphGrow.Engine.Geometry
import Fractal.GraphGrow.Utils (SThree(..))

-- Word32 is probably enough, as each edge needs ~56 bytes...
newtype Node = Node Word32 deriving (Read, Show, Ix, Eq, Ord, Storable)
newtype Edge = Edge Word32 deriving (Read, Show, Ix, Eq, Ord, Storable)

class Graph g where
  edgesFrom :: g -> Node -> [SThree Edge Node Transform]
  edgeTransform :: g -> Edge -> Transform

data MGraph = MGraph
  { mGraph :: Map Node [(Node, Transform)]
  }

annotate :: MGraph -> MMGraph
annotate g = MMGraph
    { mNodes = M.fromListWith (++) [ (source, [edge]) | (edge, (source, _)) <- edges ]
    , mEdges = M.fromList [ (edge, tt) | (edge, (_, tt)) <- edges ]
    }
```

```
  where
    edges = map Edge [0..] `zip` [ (source, (target, transform)) | (source, tts)↙
        ↳ <- M.toAscList (mGraph g), (target, transform) <- tts ]

data MMGraph = MMGraph
  { mNodes :: Map Node [Edge]
  , mEdges :: Map Edge (Node, Transform)
  }

instance Graph MMGraph where
  edgesFrom g n = catMaybes
    [ (\(m,t) -> SThree e m t) `fmap` M.lookup e (mEdges g)
    | e <- fromMaybe [] (M.lookup n (mNodes g))
    ]
  edgeTransform g e = snd $ mEdges g M.! e

vectorize :: MMGraph -> Maybe VGraph
vectorize g
  | dense = Just VGraph
      { vNodeOffset = V.fromList . map (Offset . fromIntegral) . init . scanl ↙
          ↳ (+) 0 . map (length . snd) . M.toAscList . mNodes $ g
      , vNodeEdges  = V.fromList . concatMap snd . M.toAscList . mNodes $ g
      , vEdgeTargets = V.fromList . map (fst . snd) . M.toAscList . mEdges $ g
      , vEdgeTransforms = V.fromList . map (snd . snd) . M.toAscList . mEdges $ ↙
          ↳ g
      }
  | otherwise = Nothing
  where
    dense = fmap (fst . fst) (M.minViewWithKey (mNodes g)) == Just (Node 0)
        && fmap (fst . fst) (M.maxViewWithKey (mNodes g)) == Just (Node (↙
            ↳ fromIntegral (M.size (mNodes g) - 1)))
        && fmap (fst . fst) (M.minViewWithKey (mEdges g)) == Just (Edge 0)
        && fmap (fst . fst) (M.maxViewWithKey (mEdges g)) == Just (Edge (↙
            ↳ fromIntegral (M.size (mEdges g) - 1)))

newtype Offset = Offset Word32 deriving (Read, Show, Ix, Eq, Ord, Storable)

data VGraph = VGraph
  { vNodeOffset     :: Vector Offset     -- indexed by Node
  , vNodeEdges      :: Vector Edge       -- indexed by Offset
  , vEdgeTargets    :: Vector Node       -- indexed by Edge
  , vEdgeTransforms :: Vector Transform  -- indexed by Edge
  }

instance Graph VGraph where
  edgesFrom g (Node n) = fromMaybe [] $ do
    Offset start <- vNodeOffset g V.!? fromIntegral n
    let Offset end = fromMaybe (Offset . fromIntegral . V.length . vNodeEdges $ ↙
        ↳ g) $ vNodeOffset g V.!? (fromIntegral n + 1)
        go off =
          let edge@(Edge e) = vNodeEdges g V.! off
              e' = fromIntegral e
              target = vEdgeTargets g V.! e'
              transform = vEdgeTransforms g V.! e'
          in  SThree edge target transform
    return $ map go [fromIntegral start .. fromIntegral end - 1]
  edgeTransform g (Edge e) = vEdgeTransforms g V.! fromIntegral e
```

14 Fractal/GraphGrow/Engine/Grow.hs

```
module Fractal.GraphGrow.Engine.Grow where

import Data.List (partition)

import Fractal.GraphGrow.Engine.Geometry
import Fractal.GraphGrow.Engine.Graph
import Fractal.GraphGrow.Utils (sqr, SThree(..))

data Context = Context
  { ctxNode :: !Node
  , ctxPath :: [Edge]
  , ctxZoom :: !Double
  , ctxTransform :: !Transform
  }
  deriving (Read, Show)

type ContextPlus = SThree Context Point Double

plus :: Context -> ContextPlus
plus ctx = SThree ctx (center (ctxTransform ctx)) (sizeSquared (ctxTransform ctx↙
    ↳ ))

unplus :: ContextPlus -> Context
unplus (SThree ctx _ _) = ctx

renormalize :: Graph g => g -> Box -> Context -> [Context]
renormalize graph box ctx
  | ctxZoom ctx > 1e16 = []
  | otherwise = case map unplus $ grow graph box (16 * boxSize box) False ctx of
      ls@(_:_) ->
        [ let g = compose . map (edgeTransform graph) . reverse $ ctxPath c
          in  Context
                { ctxNode = ctxNode c
                , ctxPath = []
                , ctxZoom = ctxZoom c * sqrt (sizeSquared g)
                , ctxTransform = ctxTransform ctx `o` g
                }
        | c <- ls ]
      _ -> [ctx]

visible :: Box -> ContextPlus -> Bool
visible box (SThree _ c s) = not (outsideBox box c s)

grow :: Graph g => g -> Box -> Double -> Bool -> Context -> [ContextPlus]
grow graph box threshold keepAll = \ctx -> go [plus ctx]
  where
    thresholdSq = sqr threshold
    small (SThree _ _ sizeSq) = sizeSq < thresholdSq
    next = concatMap (map plus . split graph . unplus)
    go | keepAll = goKeepAll
       | otherwise = goDiscard
    goDiscard [] = []
    goDiscard ss =
      let (smalls, bigs) = (partition small . filter (visible box)) ss
      in  smalls ++ goDiscard (next bigs)
```

```
      goKeepAll [] = []
      goKeepAll ss =
        let bigs = (filter (visible box) . filter (not . small)) ss
        in  ss ++ goKeepAll (next bigs)

split :: Graph g => g -> Context -> [Context]
split g ctx =
  [ Context
      { ctxNode = m
      , ctxPath = e : ctxPath ctx
      , ctxZoom = ctxZoom ctx
      , ctxTransform = ctxTransform ctx `o` s
      }
  | SThree e m s <- edgesFrom g (ctxNode ctx)
  ]

zoom :: Transform -> Double -> Context -> Context
zoom z w ctx =
  ctx{ ctxTransform = z `o` ctxTransform ctx, ctxZoom = w * ctxZoom ctx }
```

15 Fractal/GraphGrow/Engine/Zoomer.hs

```
module Fractal.GraphGrow.Engine.Zoomer
  ( ZoomerOptions(..)
  , defaultZoomerOptions
  , Zoomer
  , zoomer
  , Zoomed(..)
  ) where

import Control.Parallel (par)
import Data.List (minimumBy)
import Data.Ord (comparing)
import System.Random (RandomGen, randomR)

import Fractal.GraphGrow.Engine.Geometry
import Fractal.GraphGrow.Engine.Graph
import Fractal.GraphGrow.Engine.Grow
import Fractal.GraphGrow.Utils

type Zoomer = Double -> Zoomed
data Zoomed = Zoomed{ zoomedPoints :: [STwo Point Double], zoomedZoomer :: ↙
    ↳ Zoomer }

data ZoomerOptions g = ZoomerOptions
  { zoomerOuterBox    :: Box
  , zoomerInnerBox    :: Box
  , zoomerPerturb     :: Double
  , zoomerReCenter    :: Double
  , zoomerZoomFactor  :: Double
  , zoomerGraph       :: g
  , zoomerSeed        :: [Context]
  , zoomerCenter      :: Point
  }

zoomer :: (RandomGen r, Graph g) => ZoomerOptions g -> r -> Zoomer
zoomer (ZoomerOptions a b c d e f g h) = zoomer' a b c d e f g h
```

```
35    where
        zoomer' box cbox perturb recenter zoomFactor graph = go
          where
            go seed centerP rg0 threshold =
              let points = concatMap (map deplus . grow graph box threshold True) ↙
                  ↳ seed
40                deplus (SThree _ p s) = STwo p s
                  (dx, rg1) = randomR (-1, 1) rg0
                  (dy, rg2) = randomR (-1, 1) rg1
                  dp = Point dx dy
                  target = clampBox cbox . addPoint centerP . scalePoint perturb $ ↙
                      ↳ dp
45                central = comparing (distanceSquared target)
                  minimumBy' _ [] = Point 0 0
                  minimumBy' cmp xs = minimumBy cmp xs
                  small = map fstTwo . filter ((<= threshold) . sndTwo)
                  centerP'@(Point x y) = minimumBy' central (small points)
50                z = translate (recenter * x) (recenter * y) `o`
                      scale zoomFactor `o`
                      translate (negate x) (negate y)
                  seed' = concatMap (renormalize graph box . zoom z zoomFactor) seed
                  next = go seed' centerP' rg2
55            in  centerP' `par` Zoomed points next

    defaultZoomerOptions :: g -> Node -> ZoomerOptions g
    defaultZoomerOptions graph node = ZoomerOptions
      { zoomerOuterBox    = box
60    , zoomerInnerBox    = scaleBox 0.5 box
      , zoomerPerturb     = 0.002 * w
      , zoomerReCenter    = 0.995
      , zoomerZoomFactor = 10 ** (1 / 60)
      , zoomerGraph       = graph
65    , zoomerSeed        = [Context node [] 1 identity]
      , zoomerCenter      = Point 0 0
      }
      where
        box = Box (-w) (-h) w h
70      w = aspect * h
        h = 16
        aspect = 16/9
```

16 Fractal/GraphGrow/GUI/DrawPoints.hs

```
    module Fractal.GraphGrow.GUI.DrawPoints
      ( withPointDraw
      , flattenPoints
      ) where
5
    import Control.Monad (forM_)
    import Foreign (Ptr, allocaArray, castPtr, pokeElemOff, with, withArray, peek, ↙
        ↳ nullPtr, sizeOf)
    import Foreign.C (withCString, peekCStringLen)
    import Foreign.ForeignPtr.Safe (ForeignPtr, mallocForeignPtrBytes, ↙
        ↳ withForeignPtr)
10  import Graphics.GL
    import Unsafe.Coerce (unsafeCoerce)
```

```
import Fractal.GraphGrow.Engine.Geometry (Point(..), Box(..))
import Fractal.GraphGrow.Utils (STwo(..), sum')

floatToGLfloat :: Float -> GLfloat
floatToGLfloat = unsafeCoerce

flatten :: [STwo Point Double] -> [GLfloat]
flatten fs = map (floatToGLfloat . realToFrac) $ concat [[x, y, z, 2 * pi * (t + 0.5) / 4] | STwo (Point x y) z <- fs, t <- [0,1,2,3]]

flattenPoints :: [STwo Point Double] -> IO [(ForeignPtr GLfloat, Int)]
flattenPoints [] = return []
flattenPoints ps = do
  let (now, later) = splitAt (chunkBytes `div` (16 * sizeOf (0::GLfloat))) ps
  fptr <- mallocForeignPtrBytes chunkBytes
  withForeignPtr fptr $ \ptr -> do
    count <- pokeArrayCount ptr (flatten now)
    rest <- flattenPoints later
    return $ (fptr, count `div` 16) : rest

chunkBytes :: Int
chunkBytes = 16 * 1024 * 4 * 4 * 4

withPointDraw :: Box -> (String -> IO a) -> (([(ForeignPtr GLfloat, Int)] -> IO Int) -> IO a) -> IO a
withPointDraw (Box lx ly hx hy) cbFail cbOk = do
  withProgram (Just circleVertSource) Nothing (Just circleFragSource) cbFail $ \circle -> do
    glUseProgram circle
    mvp' <- withCString "mvp" $ glGetUniformLocation circle . castPtr
    withArray [ realToFrac $ 2 / (hx - lx), 0, 0, realToFrac $ 2 / (hy - ly) ] $ glUniformMatrix2fv mvp' 1 (fromIntegral GL_FALSE)
    glUseProgram 0
    cbOk $ \ps -> if null ps then return 0 else do
      glClearColor 0 0 0 1
      glClear (fromIntegral GL_COLOR_BUFFER_BIT)
      glEnable GL_BLEND
      glBlendFunc GL_SRC_ALPHA GL_ONE
      glUseProgram circle
      glEnableVertexAttribArray 0
      forM_ ps $ \(fptr, count) -> withForeignPtr fptr $ \ptr -> do
        glVertexAttribPointer 0 4 GL_FLOAT (fromIntegral GL_FALSE) 0 ptr
        glDrawArrays GL_QUADS 0 (4 * fromIntegral count)
      glDisableVertexAttribArray 0
      glUseProgram 0
      return (sum' $ map snd ps)

pokeArrayCount :: Ptr GLfloat -> [GLfloat] -> IO Int
pokeArrayCount ptr vals0 = go vals0 0
  where
    go [] n       = return n
    go (val:vals) n = do pokeElemOff ptr n val; go vals (n + 1)

withProgram :: Maybe String -> Maybe String -> Maybe String -> (String -> IO a) -> (GLuint -> IO a) -> IO a
withProgram mv mg mf cbFail cbOk = do
  prog <- glCreateProgram
```

```
65    let compile _ Nothing = return ()
          compile t (Just src) = withCString src $ \s -> with s $ \p -> do
            sh <- glCreateShader t
            glShaderSource sh 1 (castPtr p) nullPtr
            glCompileShader sh
70          glAttachShader prog sh
            glDeleteShader sh
      compile GL_VERTEX_SHADER   mv
      compile GL_GEOMETRY_SHADER mg
      compile GL_FRAGMENT_SHADER mf
75    glLinkProgram prog
      result <- with 0 $ \p -> glGetProgramiv prog GL_LINK_STATUS p >> peek p
      logLen <- with 0 $ \p -> glGetProgramiv prog GL_INFO_LOG_LENGTH p >> peek p
      logTxt <- if logLen <= 1 then return "" else allocaArray (1 + fromIntegral ↙
          ↳ logLen) $ \p -> do
        glGetProgramInfoLog prog (fromIntegral logLen) nullPtr p
80      peekCStringLen (castPtr p, fromIntegral logLen - 1)
      r <- if result == fromIntegral GL_TRUE then cbOk prog else cbFail logTxt
      --glDeleteProgram prog
      return r

85  circleVertSource :: String
    circleVertSource = unlines
      [ "#version 330"
      , "uniform mat2 mvp;"
      , "layout (location = 0) in vec4 position;"
90    , "smooth out vec3 texCoord;"
      , "void main() {"
      , "  const float minSize = 1.0;"
      , "  const float maxSize = 512.0;"
      , "  const float brightness = 1.0 / 256.0;"
95    , "  const float gamma = 1.0;"
      , "  float scaling = length(mvp * vec2(1.0)) / length(vec2(1.0));"
      , "  float q = sqrt(1.0/3.0) * sqrt(position.z) / scaling;"
      , "  vec2 r = mvp * vec2(q);"
      , "  float size = length(r) / scaling;"
100   , "  float alpha = pow(brightness, pow(size / maxSize, gamma));"
      , "  float s = max(minSize * scaling, length(r));"
      , "  vec2 delta = sqrt(2.0) * vec2(cos(position.w), sin(position.w));"
      , "  gl_Position = vec4(mvp * (position.xy + s * delta), 0.0, 1.0);"
      , "  texCoord = vec3(delta, alpha);"
105   , "}"
      ]

    circleFragSource :: String
    circleFragSource = unlines
110   [ "#version 330"
      , "in vec3 texCoord;"
      , "out vec4 colour;"
      , "void main() {"
      , "  const float lineWidth = 1.0;"
115   , "  const vec3 blue   = vec3(0.0, 0.0, 1.0);"
      , "  const vec3 orange = vec3(1.0, 0.7, 0.0);"
      , "  vec2 p = texCoord.xy;"
      , "  vec2 dp = dFdx(p);"
      , "  float r = length(p);"
120   , "  float t = texCoord.z;"
```

```
    , "  if (r >= 1.0) {"
    , "    discard;"
    , "  } else if (r >= 1.0 - lineWidth * length(dp)) {"
    , "    colour = vec4(vec3(mix(0.0, 1.0, t)), t);"
125 , "  } else {"
    , "    discard;"
    , "  }"
    , "}"
    ]
```

17 Fractal/GraphGrow/GUI/FrameSync.hs

```
module Fractal.GraphGrow.GUI.FrameSync
  ( FrameSyncOptions(..)
  , defaultFrameSyncOptions
  , newFrameSync
5 , FrameSync
  , Deadline(..)
  , Statistics(..)
  ) where

10 import Prelude hiding ((++))

import Control.Monad (replicateM_)
import Data.IORef (newIORef, readIORef, writeIORef)
import Data.List (foldl')
15 import Data.Monoid (Monoid(..))

import Fractal.GraphGrow.Analysis.Statistics hiding (s0)

data Statistics = Statistics
20  { statFrameTime :: !(StatOrd Double)
  , statSpareTime :: !(StatOrd Double)
  , statOk        :: !(StatOrd Double)
  , statMissed    :: !Int
  , statCount     :: !Int
25  }

instance Monoid Statistics where
  mempty = let e = mempty in Statistics e e e 0 0
  Statistics a b c d e `mappend` Statistics s t u v w =
30    let (++) = mappend in Statistics (a++s)(b++t)(c++u)(d+v)(e+w)
  mconcat = foldl' mappend mempty

data Deadline = Missed | Ok !Double
  deriving (Read, Show, Eq, Ord)
35
type FrameSync = IO (Deadline, Statistics)

data FrameSyncOptions = FrameSyncOptions
  { frameSyncMeasure  :: Int
40  , frameSyncMultiple :: Int
  , frameSyncMissed   :: Double
  , frameSyncTarget   :: Double
  }

45 defaultFrameSyncOptions :: FrameSyncOptions
```

```
defaultFrameSyncOptions = FrameSyncOptions
  { frameSyncMeasure  = 60
  , frameSyncMultiple = 1
  , frameSyncMissed   = 1.5
  , frameSyncTarget   = 0.75
  }

newFrameSync :: IO Double -> IO () -> FrameSyncOptions -> IO (Double, FrameSync)
newFrameSync getTime swapBuffers opts = do
  frameInterval <- measureFrameInterval getTime swapBuffers (frameSyncMeasure ↙
      ↳ opts)
  statRef <- newIORef mempty
  frameTimeRef <- newIORef =<< getTime
  let interval = fromIntegral (frameSyncMultiple opts) * frameInterval
      frameSync = do
        lastTime <- readIORef frameTimeRef
        preTime <- getTime
        swapBuffers
        frameTime <- getTime
        writeIORef frameTimeRef frameTime
        s0 <- readIORef statRef
        let s = s0{ statFrameTime = statFrameTime s0 `mappend` statOrd (↙
            ↳ frameTime - lastTime)
                  , statSpareTime = statSpareTime s0 `mappend` statOrd (↙
                      ↳ frameTime - preTime )
                  , statCount     = statCount s0 + 1
                  }
            missed = frameTime - lastTime > interval * frameSyncMissed opts
            delta = (frameTime - preTime) / (interval * (1 - frameSyncTarget ↙
                ↳ opts))
            result@(_, s')
              | missed    = (Missed,   s{ statMissed = statMissed s + 1 })
              | otherwise = (Ok delta, s{ statOk = statOk s `mappend` statOrd ↙
                  ↳ delta })
        writeIORef statRef s'
        return result
  return (recip interval, frameSync)

measureFrameInterval :: IO Double -> IO () -> Int -> IO Double
measureFrameInterval getTime swapBuffers count = do
  swapBuffers
  startTime <- getTime
  replicateM_ count swapBuffers
  endTime <- getTime
  return $ (endTime - startTime) / fromIntegral count
```

18 Fractal/GraphGrow/Main.hs

```
module Main (main) where

import Control.Concurrent (forkIO, killThread)
import Control.Concurrent.BoundedChan (newBoundedChan, readChan, writeChan)
import Control.Monad (join, replicateM_, when)
import Data.IORef (newIORef, readIORef, writeIORef)
import qualified Data.Map as M
import Data.Maybe (fromMaybe)
import System.Environment (getArgs)
```

```
10  import System.Exit (exitFailure)
    import System.IO (hPutStrLn, stderr)
    import System.Random (newStdGen)

    import qualified Graphics.UI.Gtk        as G
15  import qualified Graphics.UI.Gtk.OpenGL as G
    import qualified System.Glib.GDateTime  as G

    import Fractal.GraphGrow.Engine.Geometry
    import Fractal.GraphGrow.Engine.Graph
20  import Fractal.GraphGrow.Engine.Zoomer
    import Fractal.GraphGrow.Text.Parse
    import Fractal.GraphGrow.Text.Compile
    import Fractal.GraphGrow.GUI.DrawPoints
    import Fractal.GraphGrow.GUI.FrameSync
25  import Fractal.GraphGrow.Utils
    import Fractal.GraphGrow.Analysis.Statistics

    readGraph :: Maybe FilePath -> Maybe String -> IO (Maybe (VGraph, Node))
    readGraph mf mw = do
30    s <- case mf of
        Nothing -> getContents
        Just f -> readFile f
      return $ do
        (ws, g) <- compileText `fmap` parseText s
35      v <- vectorize (annotate g)
        let n = fromMaybe (Node 0) ((`M.lookup` ws) =<< mw)
        return (v, n)

    errLn :: String -> IO ()
40  errLn = hPutStrLn stderr

    usageMessage :: IO ()
    usageMessage = errLn "usage: FIXME"

45  inputMessage :: IO ()
    inputMessage = errLn "bad input"

    vsyncMessage :: Double -> IO ()
    vsyncMessage fps = do
50    errLn$"insane fps: " ++ show fps
      errLn "enable OpenGL sync-to-vblank and retry"

    statsMessage :: Statistics -> IO ()
    statsMessage s = do
55    let frames = statCount s
          totalTime = (s1 . fst . statFrameTime) s
          fps = fromIntegral frames / totalTime
          pretty ss = "\t" ++ show mi ++ "\t" ++ show mean ++ "\t" ++ show ma ++ "\t↙
              ↳ " ++ show dev
            where
60            (mi, ma) = fromMaybe (0/0, 0/0) . getMinMax . snd $ ss
              mean = getMean (fst ss)
              dev = getStdDev (fst ss)
      errLn "[ STATISTICS"
      errLn $ "FPS\t" ++ show fps ++ "\t( " ++ show frames ++ " f / " ++ show ↙
          ↳ totalTime ++ " s ) [ " ++ show (statMissed s) ++ " MISSED ]"
```

```
    errLn $ "FRAME" ++ pretty (statFrameTime s)
    errLn $ "SPARE" ++ pretty (statSpareTime s)
    errLn $ "DELTA" ++ pretty (statOk s)
    errLn "]"

insaneFPS :: Double -> Bool
insaneFPS fps = fps < 20 || 200 < fps

parseArgs :: [String] -> Maybe Config
parseArgs [file] = Just defaultConfig{ configGraph = if file == "-" then Nothing else Just file }
parseArgs [file, node] = Just defaultConfig{ configGraph = if file == "-" then Nothing else Just file, configNode = Just node }
parseArgs _ = Nothing

data Config = Config
  { configGraph :: Maybe FilePath
  , configNode :: Maybe String
  , configWidth :: Int
  , configHeight :: Int
  , configMinQuality :: Double
  , configMaxQuality :: Double
  , configVerbose :: Bool
  }

defaultConfig :: Config
defaultConfig = Config
  { configGraph = Nothing
  , configNode = Nothing
  , configWidth = 1024
  , configHeight = 576
  , configMinQuality = recip 16
  , configMaxQuality = 16
  , configVerbose = False
  }

configSize :: Config -> Double
configSize config = sqrt (fromIntegral $ sqr (configWidth config) + sqr (configHeight config))

newtype Continue = Continue{ runContinue :: IO Continue }

skip :: Continue
skip = Continue (return skip)

abort :: IO Continue
abort = exitFailure >> return skip

main :: IO ()
main = do
  args <- getArgs
  case parseArgs args of
    Nothing -> usageMessage
    Just config -> do
      mgraph <- readGraph (configGraph config) (configNode config)
      case mgraph of
        Nothing -> inputMessage
```

```
        Just (graph, node) -> do
          let initial = defaultZoomerOptions graph node
          withGL "GraphGrow" (configWidth config) (configHeight config) $ \↙
              ↳ getTime swapBuffers -> do
            (fps, frameSync) <- newFrameSync getTime swapBuffers ↙
                ↳ defaultFrameSyncOptions
            if insaneFPS fps
              then vsyncMessage fps >> abort
              else withPointDraw (zoomerOuterBox initial) (\s -> errLn s >> ↙
                  ↳ abort) $ \draw -> do
                worker <- newIORef Nothing
                let queueSize = 2
                    restart = do
                      maybe (return ()) killThread =<< readIORef worker
                      qualityChan <- newBoundedChan queueSize
                      pointsChan <- newBoundedChan queueSize
                      writeIORef worker . Just =<< forkIO . workerThread (↙
                          ↳ readChan qualityChan) (writeChan pointsChan) . ↙
                          ↳ zoomer initial =<< newStdGen
                      replicateM_ queueSize $ writeChan qualityChan (↙
                          ↳ configMaxQuality config)
                      loop (readChan pointsChan) (writeChan qualityChan)
                    workerThread getQuality putPoints = go
                      where
                        go zoom = do
                          quality <- getQuality
                          let pixelSize = quality * boxSize (zoomerOuterBox ↙
                              ↳ initial) / configSize config
                              Zoomed points zoom' = zoom pixelSize
                              sanePoints = filter saneSize points
                              saneSize (STwo _ sizeSq) = sizeSq < sqr (boxSize (↙
                                  ↳ zoomerOuterBox initial)) / 4
                          if null sanePoints then putPoints [] else do
                            () <- putPoints =<< flattenPoints sanePoints
                            go zoom'
                    loop getPoints putQuality = go (configMaxQuality config)
                      where
                        go quality = do
                          points <- getPoints
                          if null points then restart else do
                            _drawnCount <- draw points
                            (deadline, stats) <- frameSync
                            when (configVerbose config && statCount stats `mod` ↙
                                ↳ 256 == 0) $
                              statsMessage stats
                            let e = negate . recip . fromIntegral $ 16 * ↙
                                ↳ queueSize
                                slew = case deadline of
                                  Missed -> sqrt 2
                                  Ok k
                                    | k > 1     -> k ** e
                                    | otherwise -> k ** e
                                slew' = clamp slew (sqrt 0.5) (sqrt 2)
                                quality' = clamp (quality * slew') (↙
                                    ↳ configMinQuality config) (configMaxQuality↙
                                    ↳  config)
                            putQuality quality'
```

```
                                return $ Continue (go quality')
                restart

withGL :: String -> Int -> Int -> (IO Double -> IO () -> IO Continue) -> IO ()
withGL title w h go = do
  _ <- G.initGUI
  window <- G.windowNew
  _ <- G.onDestroy window G.mainQuit
  G.windowSetDefaultSize window w h
  G.windowSetGeometryHints window (Nothing `asTypeOf` Just window) (Just (w, h))↙
      ↳ (Just (w, h)) Nothing Nothing Nothing
  canvas <- G.glDrawingAreaNew =<< G.glConfigNew [G.GLModeRGBA, G.GLModeDouble]
  G.widgetSetSizeRequest canvas w h
  continue <- newIORef skip
  swapBuffersR <- newIORef (return ())
  let getTime = do
        G.GTimeVal sec usec <- G.gGetCurrentTime
        return $ fromIntegral sec + fromIntegral usec / 1000000
      swapBuffers = join (readIORef swapBuffersR)
      tick = do
        _ <- G.withGLDrawingArea canvas $ \gl -> do
          writeIORef swapBuffersR (G.glDrawableSwapBuffers gl)
          writeIORef continue =<< runContinue =<< readIORef continue
          writeIORef swapBuffersR (return ())
        return True
  _ <- G.onRealize canvas $ do
    _ <- G.withGLDrawingArea canvas $ \gl -> do
      writeIORef swapBuffersR (G.glDrawableSwapBuffers gl)
      writeIORef continue =<< go getTime swapBuffers
      writeIORef swapBuffersR (return ())
    G.timeoutAddFull tick G.priorityDefaultIdle 1
  return ()
  event <- G.eventBoxNew
  _ <- G.onKeyPress event $ \_ -> G.mainQuit >> return True
  G.set event  [G.containerBorderWidth G.:= 0, G.containerChild G.:= canvas]
  G.set window [G.windowTitle G.:= title, G.containerChild G.:= event]
  G.widgetShowAll window
  G.mainGUI
```

19 Fractal/GraphGrow/Text/Compile.hs

```
module Fractal.GraphGrow.Text.Compile (compileText) where

import Control.Monad (forM_)
import Control.Monad.Identity (Identity, runIdentity)
import Control.Monad.Supply (SupplyT, evalSupplyT, supply)
import Control.Monad.State (StateT, execStateT, get, put)
import Control.Monad.Writer (WriterT, runWriterT, tell)
import Control.Monad.Trans (lift)
import Data.Map (Map)
import qualified Data.Map as M

import Fractal.GraphGrow.Engine.Geometry (Transform)
import Fractal.GraphGrow.Engine.Graph (MGraph(..), Node(..))
import Fractal.GraphGrow.Text.Glyphs (string, char)

-- the input
```

```
type Specification = [(String, [String])]

-- the output
type Environment = Map String Node

-- intermediate data
type PreGraph = [(Node, [(Node, Transform)])]

-- the main compiler monad stack
type Compile = StateT Environment (WriterT PreGraph (SupplyT Node Identity))

runCompile :: Compile () -> (Environment, MGraph)
runCompile = runIdentity . supplyingNodes . writingGraph . trackingEnvironment
  where
    supplyingNodes m = evalSupplyT m $ map Node [0..]
    writingGraph m = fmap (MGraph . M.fromListWith (++)) `fmap` runWriterT m
    trackingEnvironment m = execStateT m M.empty

-- allocate stable nodes for strings
namedNode :: String -> Compile Node
namedNode s = do
  m <- get
  case M.lookup s m of
    Nothing -> do
      n <- supply
      put $ M.insert s n m
      return n
    Just n -> do
      return n

-- allocate unique nodes for characters
node :: Compile Node
node = supply

-- add an edge to the directed graph
edge :: Node -> Node -> Transform -> Compile ()
edge from to transform = tell [(from, [(to, transform)])]

-- the main compiler program
-- maps each stroke of each character in each "source" string..
-- .. to one of that source's "target" strings
compileText :: Specification -> (Environment, MGraph)
compileText graph = runCompile $ do
  forM_ graph $ \(source, targets) -> do
    sourceNode <- namedNode source
    flip evalSupplyT (cycle targets) $ do
      -- re-using supply makes sense, but either
      --   a) there are a lot of 'lift's (as in this code)
      --   b) needs orphan instances to automatigally lift
      forM_ (source `zip` string (length source)) $ \(sourceChar, charTransform)↙
          ↳ -> do
        charNode <- lift node
        lift $ edge sourceNode charNode charTransform
        forM_ (char sourceChar) $ \strokeTransform -> do
          target <- supply
          targetNode <- lift $ namedNode target
          lift $ edge charNode targetNode strokeTransform
```

20 Fractal/GraphGrow/Text/Glyphs.hs

```
module Fractal.GraphGrow.Text.Glyphs
  ( -- * The characters within a string.
    string
    -- * The strokes within a character.
  , char
  ) where

import Data.Char (toUpper)
import Data.Maybe (fromMaybe)
import Data.Map as M

import Fractal.GraphGrow.Engine.Geometry (Transform, o, scale, rotate, translate)
import Fractal.GraphGrow.Utils (sqr)

string :: Int -> [Transform]
string n =
  [ translate (2 * (fromIntegral i / n' - 0.5)) 0 `o` scale (2 / n')
  | i <- [1 .. n]
  ]
  where
    n' = fromIntegral n + 1

char :: Char -> [Transform]
char c = fromMaybe [] $ M.lookup (toUpper c) chars

chars :: Map Char [Transform]
chars = M.fromList
  [ ( c
    , [ let x = (x1 + x0) / 2
            y = (y1 + y0) / 2
            u = (x1 - x0) / 2
            v = (y1 - y0) / 2
            a = atan2 v u / (2 * pi) - strokeTilt
            s = sqrt $ sqr u + sqr v
        in  scale characterSize `o` translate x y `o` scale s `o` rotate a
      | ((x0,y0),(x1,y1)) <- strokes
      ]
    )
  | (c, strokes) <- font
  ]

characterSize :: Double
characterSize = 1 / sqrt 7

strokeTilt :: Double
strokeTilt = phi / 100

phi :: Double
phi = (sqrt 5 + 1) / 2

type Coord = (Double, Double)

type Stroke = (Coord, Coord)
```

```
font :: [(Char, [Stroke])]
font =
  [('A',[((-1,-1),(-1,0)),((-1,0),(0,1)),((0,1),(1,0)),((1,0),(1,-1)),((-1,0)↙
      ↳ ,(1,0))])
  ,('B',[((-1,1),(-1,0)),((-1,0),(-1,-1)),((-1,0),(1,0)),((1,0),(1,-1)),((1,-1)↙
      ↳ ,(-1,-1))])
  ,('C',[((1,1),(-1,1)),((-1,1),(-1,-1)),((-1,-1),(1,-1))])
  ,('D',[((1,1),(1,0)),((1,0),(1,-1)),((1,0),(-1,0)),((-1,0),(-1,-1)),((-1,-1)↙
      ↳ ,(1,-1))])
  ,('E',[((-1,1),(-1,0)),((-1,0),(-1,-1)),((-1,1),(1,1)),((-1,0),(0,0)),((-1,-1)↙
      ↳ ,(1,-1))])
  ,('F',[((-1,1),(-1,0)),((-1,0),(-1,-1)),((-1,1),(1,1)),((-1,0),(0,0))])
  ,('G',[((1,1),(-1,1)),((-1,1),(-1,-1)),((-1,-1),(1,-1)),((1,-1),(1,0)),((1,0)↙
      ↳ ,(0,0))])
  ,('H',[((-1,-1),(-1,1)),((-1,0),(1,0)),((1,-1),(1,1))])
  ,('I',[((0,1),(0,-1))])
  ,('J',[((0,1),(0,-1)),((0,-1),(-1,-1))])
  ,('K',[((-1,-1),(-1,1)),((-1,0),(1,1)),((-1,0),(1,-1))])
  ,('L',[((-1,1),(-1,-1)),((-1,-1),(1,-1))])
  ,('M',[((-1,-1),(-1,1)),((-1,1),(0,0)),((0,0),(1,1)),((1,1),(1,-1))])
  ,('N',[((-1,-1),(-1,1)),((-1,1),(1,-1)),((1,-1),(1,1))])
  ,('O',[((1,1),(-1,1)),((-1,1),(-1,-1)),((-1,-1),(1,-1)),((1,-1),(1,1))])
  ,('P',[((-1,-1),(-1,0)),((-1,0),(-1,1)),((-1,0),(1,0)),((1,0),(1,1)),((1,1)↙
      ↳ ,(-1,1))])
  ,('Q',[((1,-1),(1,0)),((1,0),(1,1)),((1,0),(-1,0)),((-1,0),(-1,1)),((-1,1)↙
      ↳ ,(1,1))])
  ,('R',[((-1,0),(-1,-1)),((-1,0),(1,0))])
  ,('S',[((1,1),(-1,1)),((-1,1),(-1,0)),((-1,0),(1,0)),((1,0),(1,-1)),((1,-1)↙
      ↳ ,(-1,-1))])
  ,('T',[((-1,1),(1,1)),((0,1),(0,-1))])
  ,('U',[((-1,1),(-1,-1)),((-1,-1),(1,-1)),((1,-1),(1,1))])
  ,('V',[((-1,1),(0,-1)),((0,-1),(1,1))])
  ,('W',[((-1,1),(-1,-1)),((-1,-1),(0,0)),((0,0),(1,-1)),((1,-1),(1,1))])
  ,('X',[((-1,-1),(0,0)),((0,0),(1,1)),((-1,1),(0,0)),((0,0),(1,-1))])
  ,('Y',[((-1,1),(0,0)),((1,1),(0,0)),((0,0),(0,-1))])
  ,('Z',[((-1,1),(1,1)),((1,1),(-1,-1)),((-1,-1),(1,-1))])
  ]
```

21 Fractal/GraphGrow/Text/Parse.hs

```
module Fractal.GraphGrow.Text.Parse (parseText) where

parseText :: String -> Maybe [(String, [String])]
parseText = mapM (uncons . words) . lines
  where
    uncons (w:_:ws) = Just (w, ws)
    uncons _ = Nothing
```

22 Fractal/GraphGrow/Utils.hs

```
module Fractal.GraphGrow.Utils
  ( -- * Miscellaneous maths.
    sum'
  , sqr
  , clamp
  , roundUpTwo
```

```
    -- * Strict tuples.
  , STwo(..)
  , SThree(..)
    -- * Ordered lists.
  , mergeSortedBy
  , mergeSortedsBy
  ) where

import Data.List (foldl')

sum' :: Num a => [a] -> a
sum' = foldl' (+) 0

sqr :: Num a => a -> a
sqr a = a * a

clamp :: Ord a => a -> a -> a -> a
clamp x mi ma = mi `max` x `min` ma

roundUpTwo :: (Num a, Ord a) => a -> a
roundUpTwo n = head . dropWhile (< n) . iterate (2 *) $ 1

data STwo a b = STwo{ fstTwo :: !a, sndTwo :: !b }
  deriving (Read, Show, Eq, Ord)

data SThree a b c = SThree{ fstThree :: !a, sndThree :: !b, thdThree :: !c }
  deriving (Read, Show, Eq, Ord)

mergeSortedBy :: (a -> a -> Ordering) -> [a] -> [a] -> [a]
mergeSortedBy cmp = go
  where
    go [] ys = ys
    go xs [] = xs
    go xxs@(x:xs) yys@(y:ys) = case x `cmp` y of
      LT -> x : go xs yys
      EQ -> x : y : go xs ys
      GT -> y : go xxs ys

mergeSortedsBy :: (a -> a -> Ordering) -> [[a]] -> [a]
mergeSortedsBy cmp = foldr (mergeSortedBy cmp) []
```

23 .gitignore

```
.cabal-sandbox
cabal.sandbox.config
dist
-
*.ogv
*.wav
*.tif
c/graphgrow-filter
*.glsl.c
```

24 graphgrow3/audio/.gitignore

```
graphgrow-audio
graphgrow-audio-test
```

25 graphgrow3/audio/graphgrow-audio.cc

```
#include <assert.h>
#include <math.h>
#include <stdint.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <jack/jack.h>
#include <lo/lo.h>

#define PI 3.141592653589793
#define SR 48000
#define BLOCKSIZE 64
// DELAYSIZE must be a multiple of BLOCKSIZE
#define DELAYSIZE 2048

#define GG_HIP 25.0f
#define GG_LOP 5000.0f

typedef float sample;

// 256 is BLOCKSIZE * sizeof(sample)
typedef float    signal __attribute__ ((vector_size (256)));
typedef int32_t isignal __attribute__ ((vector_size (256)));

// 8192 is DELAYSIZE * sizeof(sample)
typedef sample delaybuffer __attribute__ ((vector_size (8192)));

#define   likely(x) __builtin_expect((x),1)
#define unlikely(x) __builtin_expect((x),0)

// postcondition: 0 <= phase <= 1
static inline float cos_reduce(float phase) {
  float p = fabsf(phase);
  // p >= 0
  if (likely(p < (1 << 24))) {
    int q = p;
    return p - q;
  } else {
    if (unlikely(isnanf(p) || isinff(p))) {
      // return NaN
      return p - p;
    } else {
      // int could overflow, and it will be integral anyway
      return 0.0f;
    }
  }
}

signal cos_reduce(const signal &phase) {
  signal p = phase >= 0.0f ? phase : -phase;
  isignal i = isignal(p);
  signal q = signal(i);
  return p < sample(1 << 24) ? p - q : 0.0f;
}
```

```
// precondition: 0 <= phase <= 1
static inline float cos_unsafe(float phase) {
  float p = fabsf(4.0f * phase - 2.0f) - 1.0f;
  // p in -1 .. 1
  float s
    = 1.5707963267948965580e+00f * p
    - 6.4596271553942852250e-01f * p * p * p
    + 7.9685048314861006702e-02f * p * p * p * p * p
    - 4.6672571910271187789e-03f * p * p * p * p * p * p * p
    + 1.4859762069630022552e-04f * p * p * p * p * p * p * p * p * p;
  // compiler figures out optimal simd multiplications
  return s;
}

signal cos_unsafe(const signal &phase) {
  signal p = 4.0f * phase - 2.0f;
  p = p >= 0.0f ? p : -p;
  p -= 1.0f;
  // p in -1 .. 1
  signal p2 = p * p;
  signal p3 = p2 * p;
  signal p5 = p2 * p3;
  signal p7 = p2 * p5;
  signal p9 = p2 * p7;
  signal s
    = 1.5707963267948965580e+00f * p
    - 6.4596271553942852250e-01f * p3
    + 7.9685048314861006702e-02f * p5
    - 4.6672571910271187789e-03f * p7
    + 1.4859762069630022552e-04f * p9;
  return s;
}

inline sample cos_poly(sample phase) {
  return cos_unsafe(cos_reduce(phase));
}

inline sample sin_poly(sample phase) {
  return cos_poly(phase - 0.25f);
}

signal cos(const signal &phase) {
  return cos_unsafe(cos_reduce(phase));
}

signal sin(const signal &phase) {
  return cos(phase - 0.25f);
}

inline sample dbtorms(sample f) {
  return expf(0.5f * 0.23025850929940458f * (fminf(f, 870.0f) - 100.0f));
}

inline sample rmstodb(sample f) {
  return 100.0f + 2.0f * 4.3429448190325175f * logf(f);
}
```

```
inline sample wrap(sample a) {
  return a - floorf(a);
}

signal wrap(const signal &a) {
  signal c;
  for (int i = 0; i < BLOCKSIZE; ++i)
    c[i] = wrap(a[i]);
  return c;
#if 0
  isignal i = isignal(a) + (a < 0.0f); // vector compare produces ~0
  signal q = signal(i);
  return a - q;
#endif
}

signal exp(const signal &a)
{
  signal c;
  for (int i = 0; i < BLOCKSIZE; ++i)
    c[i] = expf(a[i]);
  return c;
}

signal log(const signal &a)
{
  signal c;
  for (int i = 0; i < BLOCKSIZE; ++i)
    c[i] = logf(a[i]);
  return c;
}

signal sqrt(const signal &a)
{
  signal c;
  for (int i = 0; i < BLOCKSIZE; ++i)
    c[i] = sqrtf(a[i]);
  return c;
}

signal tanh(const signal &a)
{
  signal c;
  for (int i = 0; i < BLOCKSIZE; ++i)
    c[i] = tanhf(a[i]);
  return c;
}

signal sqr(const signal &a)
{
  return a * a;
}

signal min(const signal &a, const signal &b) {
  return a < b ? a : b;
}
```

```
170
    signal min(const signal &a, sample b) {
      return a < b ? a : b;
    }

175 signal min(sample a, const signal &b) {
      return a < b ? a : b;
    }

    sample min(sample a, sample b) {
180   return a < b ? a : b;
    }

    signal dbtorms(const signal &f)
    {
185   return exp(0.5f * 0.23025850929940458f * (min(f, 870.0f) - 100.0f));
    }

    signal rmstodb(const signal &f)
    {
190   return 100.0f + 2.0f * 4.3429448190325175f * log(f);
    }

    struct lop
    {
195   // http://www.arpchord.com/pdf/coeffs_first_order_filters_0p1.pdf
      sample k, k12, x1, y1;
      lop(sample hz) : x1(0.0f), y1(0.0f)
      {
        double a = 2 * PI * hz / double(SR);
200     k = (1 - sin(a)) / cos(a);
        k12 = (1 - k) / 2;
      };
      signal operator()(const signal &x)
      {
205     signal y;
        sample last_x = x1;
        sample last_y = y1;
        for (int i = 0; i < BLOCKSIZE; ++i)
        {
210       sample now_x = x[i];
          last_y = y[i] = (now_x + last_x) * k12 + k * last_y;
          last_x = now_x;
        }
        x1 = last_x;
215     y1 = last_y;
        return y;
      };
    };

220 struct hip
    {
      // http://www.arpchord.com/pdf/coeffs_first_order_filters_0p1.pdf
      sample k, k12, x1, y1;
      hip(sample hz) : x1(0.0f), y1(0.0f)
225   {
        double a = 2 * PI * hz / double(SR);
```

```
    k = (1 - sin(a)) / cos(a);
    k12 = (1 + k) / 2;
  };
  signal operator()(const signal &x)
  {
    signal y;
    sample last_x = x1;
    sample last_y = y1;
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      sample now_x = x[i];
      last_y = y[i] = (now_x - last_x) * k12 + k * last_y;
      last_x = now_x;
    }
    x1 = last_x;
    y1 = last_y;
    return y;
  };
};

struct vsig
{
  sample x1;
  vsig(sample x) : x1(x)
  {
  };
  signal operator()(sample x)
  {
    signal y;
    sample last_x = x1;
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      sample t = (sample(i) + 0.5f) / sample(BLOCKSIZE);
      y[i] = last_x + (x - last_x) * t;
    }
    x1 = x;
    return y;
  };
};

struct phasor
{
  sample p;
  phasor() : p(0.0f)
  {
  };
  signal operator()(const signal &hz)
  {
    signal y;
    sample last_p = p;
    for (int i = 0; i < BLOCKSIZE; ++i)
      last_p = y[i] = wrap(last_p + hz[i] / sample(SR));
    p = last_p;
    return y;
  };
};
```

```
struct noise
{
  // pd-0.47-0/src/d_osc.c
  static int32_t seed;
  int32_t val;
  noise()
  {
    val = (seed *= 1319);
  };
  signal operator()()
  {
    signal y;
    int32_t v = val;
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      y[i] = sample((v & 0x7fffffff) - 0x40000000) * sample(1.0 / 0x40000000);
      v = v * 435898247 + 382842987;
    }
    val = v;
    return y;
  };
};
int32_t noise::seed = 307;

struct delay
{
  delaybuffer v;
  int w1;
  delay() : w1(0)
  {
    for (int i = 0; i < DELAYSIZE; ++i)
      v[i] = 0.0f;
  };
  void write(const signal &x)
  {
    int w = w1;
    assert(w + BLOCKSIZE <= DELAYSIZE);
    for (int i = 0; i < BLOCKSIZE; ++i)
      v[w + i] = x[i];
    w += BLOCKSIZE;
    if (w == DELAYSIZE)
      w = 0;
    w1 = w;
  };
  signal operator()(sample ms)
  {
    signal y;
    int w = w1;
    int r = roundf(ms * sample(SR / 1000.0f));
    assert(0 <= r);
    assert(r < DELAYSIZE - BLOCKSIZE);
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      int k = w - r + i;
      k = k < 0 ? k + DELAYSIZE : k;
      assert(0 <= k);
      assert(k < DELAYSIZE);
```

```
      y[i] = v[k];
    }
    return y;
  };
  signal operator()(const signal &ms)
  {
    // https://en.wikipedia.org/wiki/Cubic_Hermite_spline#↙
       ↪ Interpolation_on_the_unit_interval_without_exact_derivatives
    signal y;
    int w = w1;
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      sample d = ms[i] * sample(SR / 1000.0f);
      int d1 = floorf(d);
      int d0 = d1 - 1;
      int d2 = d1 + 1;
      int d3 = d1 + 2;
      sample t = d - d1;
      assert(0 <= d0);
      assert(d3 < DELAYSIZE - BLOCKSIZE);
      assert(0 <= t);
      assert(t < 1);
      int r0 = w - d0 + i;
      int r1 = w - d1 + i;
      int r2 = w - d2 + i;
      int r3 = w - d3 + i;
      r0 = r0 < 0 ? r0 + DELAYSIZE : r0;
      r1 = r1 < 0 ? r1 + DELAYSIZE : r1;
      r2 = r2 < 0 ? r2 + DELAYSIZE : r2;
      r3 = r3 < 0 ? r3 + DELAYSIZE : r3;
      assert(0 <= r0);
      assert(0 <= r1);
      assert(0 <= r2);
      assert(0 <= r3);
      assert(r0 < DELAYSIZE);
      assert(r1 < DELAYSIZE);
      assert(r2 < DELAYSIZE);
      assert(r3 < DELAYSIZE);
      sample y0 = v[r0];
      sample y1 = v[r1];
      sample y2 = v[r2];
      sample y3 = v[r3];
      sample a0 = -t*t*t + 2.0f*t*t - t;
      sample a1 = 3.0f*t*t*t - 5.0f*t*t + 2.0f;
      sample a2 = -3.0f*t*t*t + 4.0f*t*t + t;
      sample a3 = t*t*t - t*t;
      y[i] = 0.5f * (a0 * y0 + a1 * y1 + a2 * y2 + a3 * y3);
    }
    return y;
  };
};

struct pitchshift
{
  delay del;
  phasor p;
  signal operator()(const signal &audio, const signal &transpose)
```

```
  {
    const sample d = 20.0f;
    del.write(audio);
    signal hz = (1.0f - exp(transpose * 0.05776f)) * (1000.0f / d);
    signal phase1 = p(hz);
    signal phase2 = wrap(phase1 + 0.5f);
    return cos((phase1 - 0.5f) * 0.5f) * del(d * phase1 + 2.0f)
        + cos((phase2 - 0.5f) * 0.5f) * del(d * phase2 + 2.0f);
  };
};

struct compress
{
  sample threshold;
  sample factor;
  hip hi;
  lop lo1, lo2;
  compress(sample db)
  : threshold(db), factor(0.25f / dbtorms((100.0f - db) * 0.125f + db)), hi(5.0f↙
    ↳ ), lo1(10.0f), lo2(25.0f)
  {
  };
  signal operator()(const signal &audio)
  {
    signal rms = lo2(0.01f + sqrt(lo1(sqr(hi(audio)))));
    signal db = rmstodb(rms);
    db = db > threshold ? threshold + (db - threshold) * 0.125f : threshold;
    signal gain = factor * dbtorms(db);
    return tanh(audio / rms * gain);
  };
};

struct edge
{
  signal *inl, *inr;
  signal *outl, *outr;
  pitchshift psl, psr;
  vsig scale, pan, level;
  edge(signal *from_l, signal *from_r, signal *to_l, signal *to_r)
  : inl(from_l), inr(from_r), outl(to_l), outr(to_r), scale(0.5), pan(0.5), ↙
    ↳ level(0)
  {
  };
  edge() : edge(0, 0, 0, 0) { };
  void operator()(sample iscale, sample ipan, sample ilevel)
  {
    signal vscale = scale(iscale);
    signal vpan = pan(0.25f * ipan);
    signal vlevel = level(ilevel) * vscale;
    signal transpose = log(vscale * 2.0f) * sample(-12.0f / logf(2.0f));
    *outl += vlevel * cos(vpan) * psl(*inl, transpose);
    *outr += vlevel * sin(vpan) * psr(*inr, transpose);
  };
};

struct rule
{
```

```
  signal send_l, send_r, return_l, return_r;
  signal *out_l, *out_r;
  delay delayl, delayr;
  noise noisel, noiser;
  hip hipl, hipr;
  lop lopl, lopr;
  compress compressl, compressr;
  sample delaytime;
  rule(signal *outl, signal *outr, sample delaytime)
  : out_l(outl), out_r(outr), hipl(GG_HIP), hipr(GG_HIP), lopl(GG_LOP), lopr(
    ↘ GG_LOP), compressl(48.0f), compressr(48.0f), delaytime(delaytime)
  {
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      send_l[i] = 0.0f;
      send_r[i] = 0.0f;
      return_l[i] = 0.0f;
      return_r[i] = 0.0f;
    }
  };
  rule() : rule(0, 0, 2) { };
  void operator()()
  {
    send_l = noisel() * 1.0e-6f + delayl(delaytime);
    send_r = noiser() * 1.0e-6f + delayr(delaytime);
    signal l = compressl(lopl(hipl(return_l)));
    signal r = compressr(lopr(hipr(return_r)));
    // one block delay
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      return_l[i] = 0.0f;
      return_r[i] = 0.0f;
    }
    delayl.write(l);
    delayr.write(r);
    *out_l += l;
    *out_r += r;
  };
};

struct graphgrow
{
  signal out_l, out_r;
  hip hil, hir;
  compress compressl, compressr;
  rule    rules[4];
  edge    edges[4][4][8];
  /* { osc 1152 bytes { */
  sample  scale[4][4][8];
  sample  pan  [4][4][8];
  uint8_t level[4][4][8];
  /* } osc } */
  uint8_t last_level[4][4][8];
  graphgrow()
  : hil(GG_HIP), hir(GG_HIP), compressl(48.0f), compressr(48.0f)
  {
    for (int i = 0; i < BLOCKSIZE; ++i)
```

```
    {
      out_l[i] = 0.0f;
      out_r[i] = 0.0f;
    }
    for (int i = 0; i < 4; ++i)
      rules[i] = rule(&out_l, &out_r, 10.0f + sample(i));
    for (int i = 0; i < 4; ++i)
      for (int j = 0; j < 4; ++j)
        for (int k = 0; k < 8; ++k)
        {
          edges[i][j][k] = edge(&rules[i].send_l, &rules[i].send_r, &rules[j].↙
              ↪ return_l, &rules[j].return_r);
          scale[i][j][k] = 0.5f;
          pan  [i][j][k] = 0.5f;
          level[i][j][k] = 0;
          last_level[i][j][k] = 0;
        }
  };
  void operator()()
  {
    for (int i = 0; i < BLOCKSIZE; ++i)
    {
      out_l[i] = 0.0f;
      out_r[i] = 0.0f;
    }
    for (int i = 0; i < 4; ++i)
      rules[i]();
    for (int i = 0; i < 4; ++i)
      for (int j = 0; j < 4; ++j)
        for (int k = 0; k < 8; ++k)
        {
          if (level[i][j][k] || last_level[i][j][k])
            edges[i][j][k](scale[i][j][k], pan[i][j][k], level[i][j][k]);
          last_level[i][j][k] = level[i][j][k];
        }
    out_l = compressl(hil(out_l));
    out_r = compressr(hir(out_r));
  };
};

struct control
{
  sample  scale[4][4][8];
  sample  pan  [4][4][8];
  uint8_t level[4][4][8];
};


struct
{
  graphgrow G;
  int count;
  jack_client_t *client;
  jack_port_t *out_port[2];
  volatile int in_processcb;
  volatile int running;
  control C;
```

```
} S;

int processcb(jack_nframes_t nframes, void *arg)
{
  S.in_processcb = 1;
  jack_default_audio_sample_t *out_l = (jack_default_audio_sample_t *) ↙
      ↳ jack_port_get_buffer(S.out_port[0], nframes);
  jack_default_audio_sample_t *out_r = (jack_default_audio_sample_t *) ↙
      ↳ jack_port_get_buffer(S.out_port[1], nframes);

  for (int i = 0; i < 4; ++i)
    for (int j = 0; j < 4; ++j)
      for (int k = 0; k < 8; ++k)
      {
        S.G.scale[i][j][k] = S.C.scale[i][j][k];
        S.G.pan  [i][j][k] = S.C.pan  [i][j][k];
        S.G.level[i][j][k] = S.C.level[i][j][k];
      }

  int count = S.count;
  for (jack_nframes_t i = 0; i < nframes; ++i)
  {
    if (count == 0)
      S.G();
    out_l[i] = S.G.out_l[count];
    out_r[i] = S.G.out_r[count];
    count = (count + 1) % BLOCKSIZE;
  }
  S.count = count;

  S.in_processcb = 0;
  return 0;
  (void) arg;
}

void errorcb(int num, const char *msg, const char *path)
{
  fprintf(stderr, "liblo server error %d in path %s: %s\n", num, path, msg);
}

int audiocb(const char *path, const char *types, lo_arg **argv, int argc, void *↙
    ↳ message, void *user_data)
{
  const int bytes = sizeof(S.C);
  int    size =  argv[0]->blob.size;
  void *data = &argv[0]->blob.data;
  if (size == bytes)
  {
    while (S.in_processcb)
      ;
    memcpy(&S.C, data, bytes);
  }
  return 0;
  (void) path;
  (void) types;
  (void) argc;
  (void) message;
```

```
  (void) user_data;
}

int quitcb(const char *path, const char *types, lo_arg **argv, int argc, void *↙
    ↳ message, void *user_data)
{
  S.running = 0;
  return 0;
  (void) path;
  (void) types;
  (void) argv;
  (void) argc;
  (void) message;
  (void) user_data;
}

int main()
{

   if (! (S.client = jack_client_open("graphgrow", JackNoStartServer, 0))) {
    fprintf(stderr, "jack server not running?\n");
    return 1;
  }
  jack_set_process_callback(S.client, processcb, 0);
  S.out_port[0] = jack_port_register(S.client, "output_1", ↙
      ↳ JACK_DEFAULT_AUDIO_TYPE, JackPortIsOutput, 0);
  S.out_port[1] = jack_port_register(S.client, "output_2", ↙
      ↳ JACK_DEFAULT_AUDIO_TYPE, JackPortIsOutput, 0);
  if (jack_activate(S.client)) {
    fprintf (stderr, "cannot activate JACK client");
    return 1;
  }
  if (jack_connect(S.client, "graphgrow:output_1", "system:playback_1")) {
    fprintf(stderr, "cannot connect output port\n");
  }
  if (jack_connect(S.client, "graphgrow:output_2", "system:playback_2")) {
    fprintf(stderr, "cannot connect output port\n");
  }

  S.running = 1;

  lo_server_thread lo = lo_server_thread_new("6060", errorcb);
  lo_server_thread_add_method(lo, "/audio", "b", audiocb, 0);
  lo_server_thread_add_method(lo, "/quit", "", quitcb, 0);
  lo_server_thread_start(lo);

  while (S.running)
    sleep(1);

  lo_server_thread_free(lo);

  jack_client_close(S.client);

  return 0;
}
```

26 graphgrow3/audio/graphgrow-audio-test.cc

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <lo/lo.h>

struct control
{
  float   scale[4][4][8];
  float   pan  [4][4][8];
  uint8_t level[4][4][8];
};

int main()
{
  control C;
  memset(&C, 0, sizeof(C));

  lo_address t = lo_address_new("255.255.255.255", "6060");

  while (1)
  {
    sleep(1);

    int i = rand() % 4;
    int j = rand() % 4;
    int k = rand() % 8;
    float   scale =  rand() / (double) RAND_MAX; scale *= scale; scale *= scale;
    float   pan   = (rand() / (double) RAND_MAX - 0.5) * 0.5 + 0.5;
    uint8_t level =  rand() % 2;
    C.scale[i][j][k] = scale;
    C.pan  [i][j][k] = pan;
    C.level[i][j][k] = level;

    int count = 0;
    for (i = 0; i < 4; ++i)
      for (j = 0; j < 4; ++j)
        for (k = 0; k < 8; ++k)
          count += C.level[i][j][k];
    fprintf(stderr, "  %d\r", count);

    lo_blob blob = lo_blob_new(sizeof(C), &C);
    if (blob)
    {
      if (lo_send(t, "/audio", "b", blob) == -1)
        fprintf(stderr, "OSC error %d: %s\n", lo_address_errno(t), ↙
            ↳ lo_address_errstr(t));
      lo_blob_free(blob);
    }
    else
      fprintf(stderr, "OSC error: couldn't lo_blob_new\n");

  }
  return 0;
}
```

27 graphgrow3/Audio.hs

```
module Audio (audioNew, Audio) where

import System.IO (Handle, hPutStr, hFlush)
import Data.IORef (IORef, newIORef, atomicModifyIORef)

import Control.Concurrent (threadDelay)

import Data.Map (Map)
import qualified Data.Map.Strict as M
import qualified Data.Map.Strict.Merge as M

import System.Process (createProcess, proc, close_fds, std_in, terminateProcess,↙
    ↪ StdStream(CreatePipe))

import Paths_graphgrow3 (getDataFileName)
import Types (NID, RID)

type Audio = (Int, [(NID, NID, RID, Double, Double)])

data AudioEngine = AudioEngine
  { aOld :: IORef (Map (RID, NID, NID) (RID, Double, Double))
  , aPull :: IO (Map RID Audio)
  , aPdSend :: Handle
  }

audioNew :: IO (Map RID Audio) -> IO (IO (), IO ())
audioNew pull = do
  aOld' <- newIORef M.empty
  patch <- getDataFileName "graphgrow3.pd"
  (_, _, _, pd) <- createProcess (proc "pd" ["-nogui", patch]){ close_fds = True↙
      ↪ }
  threadDelay (1000 * 1000)
  (Just h, _, _, pdsend) <- createProcess (proc "pdsend"  ["6060"]){ close_fds =↙
      ↪ True, std_in = CreatePipe }
  return (audio AudioEngine
    { aOld = aOld'
    , aPull = pull
    , aPdSend = h
    }, terminateProcess pdsend >> terminateProcess pd)

audio :: AudioEngine -> IO ()
audio a = do
  m <- aPull a
  let m' = M.fromList
             [ ((r0, min n0 n1, max n0 n1), (r1, s, x))
             | (r0, (_, es)) <- M.toList m
             , (n0, n1, r1, s, x) <- es
             ]
  m0' <- atomicModifyIORef (aOld a) $ \m0' -> (m', m0')
  let toDelete = m0' `M.difference` m'
      toAdd    = m' `M.difference` m0'
      toUpdate = M.merge
                   (M.mapMissing $ \_ (_, s1, x1) -> (Nothing, Just s1, Just x1))
                   M.dropMissing
                   (M.zipWithMatched $ \_ (r1, s1, x1) (r0, s0, x0) ->
```

```
                    ( if r1 == r0 then Nothing else Just r1
                    , if s1 == s0 then Nothing else Just s1
                    , if x1 == x0 then Nothing else Just x1
                    )
                  )
                  m' m0'
      deletes = unlines
        [ "delete " ++ (unwords $ map show [r0, n0, n1]) ++ ";"
        | (r0, n0, n1) <- M.keys toDelete
        ]
      adds = unlines
        [ "add " ++ (unwords $ map show [r0, n0, n1, r1]) ++ ";"
        | ((r0, n0, n1), (r1, _, _)) <- M.toList toAdd
        ]
      updateTargets = unlines
        [ "set " ++ (unwords $ map show [r0, n0, n1]) ++ " target " ++ show r1 ++ ";"
        | ((r0, n0, n1), (Just r1, _, _)) <- M.toList toUpdate
        ]
      updateScales = unlines
        [ "set " ++ (unwords $ map show [r0, n0, n1]) ++ " scale " ++ show s ++ ";"
        | ((r0, n0, n1), (_, Just s, _)) <- M.toList toUpdate
        ]
      updatePans = unlines
        [ "set " ++ (unwords $ map show [r0, n0, n1]) ++ " pan " ++ show x ++ ";"
        | ((r0, n0, n1), (_, _, Just x)) <- M.toList toUpdate
        ]
      packet = deletes ++ adds ++ updateTargets ++ updatePans ++ updateScales
  hPutStr (aPdSend a) packet
  hFlush (aPdSend a)
```

28 graphgrow3/audio/Makefile

```
all: graphgrow-audio graphgrow-audio-test

clean:
	-rm graphgrow-audio graphgrow-audio-test

graphgrow-audio: graphgrow-audio.cc
	g++ -std=c++11 -Wall -Wextra -pedantic -Wno-variadic-macros -O3 -march=native -ffast-math -I$(HOME)/opt/include -L$(HOME)/opt/lib -o graphgrow-audio graphgrow-audio.cc -ljack -llo

graphgrow-audio-test: graphgrow-audio-test.cc
	g++ -std=c++11 -Wall -Wextra -pedantic -Wno-variadic-macros -O3 -march=native -ffast-math -I$(HOME)/opt/include -L$(HOME)/opt/lib -o graphgrow-audio-test graphgrow-audio-test.cc -llo
```

29 graphgrow3/audio/README

```
Needs liblo from https://github.com/radarsat1/liblo
Tested with HEAD at 276dc11db2038b44f04fe67cdb425929427a5337
```

30 graphgrow3/colour.frag

```
#version 130
uniform sampler2DArray src;
uniform float speed;

in vec2 texCoord;

out vec4 colour;

void main() {
  vec2 p = texCoord;
  vec2 z = texture(src, vec3(p, 0.0)).xy;
  float n = z.x * speed;
  vec3 yuv;
  if (n < 0.0) {
    yuv = vec3(0.0);
  } else {
    yuv = vec3(clamp(log(1.0 + n / 4.0), 0.0, 1.0), 0.125 * sin(n), -0.125 * cos(n));
  }
  vec3 rgb = yuv * mat3(1.0, 0.0, 1.4, 1.0, -0.395, -0.581, 1.0, 2.03, 0.0);
  colour = vec4(rgb, 1.0);
}
```

31 graphgrow3/colour.vert

```
#version 130

out vec2 texCoord;

void main() {
  float t = 0.5 * 500.0 / 2048.0;
  switch (gl_VertexID) {
    default:
    case 0:
      gl_Position = vec4(-1.0, -1.0, 0.0, 1.0);
      texCoord = vec2(0.5 - t, 0.5 + t);
      break;
    case 1:
      gl_Position = vec4( 1.0, -1.0, 0.0, 1.0);
      texCoord = vec2(0.5 + t, 0.5 + t);
      break;
    case 2:
      gl_Position = vec4(-1.0,  1.0, 0.0, 1.0);
      texCoord = vec2(0.5 - t, 0.5 - t);
      break;
    case 3:
      gl_Position = vec4( 1.0,  1.0, 0.0, 1.0);
      texCoord = vec2(0.5 + t, 0.5 - t);
      break;
  }
}
```

32 graphgrow3/compress~.pd

```
#N canvas 275 94 452 587 10;
#X obj 28 28 inlet~;
#X obj 27 543 outlet~;
#X obj 58 82 hip~ 5;
#X obj 58 108 *~;
#X obj 281 25 inlet;
#X obj 87 281 rmstodb~;
#X obj 86 353 dbtorms~;
#X obj 27 474 *~;
#X obj 57 135 lop~ 10;
#X obj 87 221 lop~ 25;
#X obj 25 272 /~;
#X obj 201 390 dbtorms;
#X obj 86 417 /~ 0;
#X obj 87 179 sqrt~;
#X obj 86 442 *~ 0.25;
#X obj 310 55 loadbang;
#X obj 310 79 f \$1;
#X obj 27 514 expr~ tanh($v1);
#X obj 86 314 expr~ if($v1>$f2 \, $f2+($v1-$f2)/8 \, $f2);
#X obj 201 366 expr (100-$f1)/8+$f1;
#X obj 88 202 +~ 0.01;
#X connect 0 0 2 0;
#X connect 0 0 10 0;
#X connect 2 0 3 0;
#X connect 2 0 3 1;
#X connect 3 0 8 0;
#X connect 4 0 18 1;
#X connect 4 0 19 0;
#X connect 5 0 18 0;
#X connect 6 0 12 0;
#X connect 7 0 17 0;
#X connect 8 0 13 0;
#X connect 9 0 10 1;
#X connect 9 0 5 0;
#X connect 10 0 7 0;
#X connect 11 0 12 1;
#X connect 12 0 14 0;
#X connect 13 0 20 0;
#X connect 14 0 7 1;
#X connect 15 0 16 0;
#X connect 16 0 18 1;
#X connect 16 0 19 0;
#X connect 17 0 1 0;
#X connect 18 0 6 0;
#X connect 19 0 11 0;
#X connect 20 0 9 0;
```

33 graphgrow3/Dimension.hs

```
-- |
-- Compute Hausdorff dimension of a graph directed iterated function system of
-- similarities specified by adjacency matrix, assuming the open set condition
-- is satisfied.  For example:
--
-- > -- Koch snowflake
-- > > dimH (listArray ((0,0),(0,0)) [[1/3,1/3,1/3,1/3]])
```

```
-- > Just 1.2618595361709595
--
-- > -- Sierpinski triangle
-- > > dimH (listArray ((0,0),(0,0)) [[1/2,1/2,1/2]])
-- > Just 1.5849626064300537
--
-- > -- Koch + Sierpinski hybrid
-- > > dimH (listArray ((0,0),(1,1)) ↙
    ↳ [[1/3,1/3,1/3,1/3],[1/2],[1/3],[1/2,1/2,1/2]])
-- > Just 1.7465347051620483

module Dimension (dimH) where

import Data.Array (Array, (!), (//), bounds, indices, listArray)

import Data.Graph.Inductive.PatriciaTree (Gr)
import Data.Graph.Inductive.Query.DFS (scc)
import Data.Graph.Inductive.Graph (mkGraph, subgraph, noNodes, labNodes, ↙
    ↳ labEdges)

-- compute dimension as maximum over components
dimH :: Array (Int, Int) [Double] -> Maybe Double
dimH = maximum . (Nothing:) . map dimSCC . components

-- precondition: m is square
components :: Array (Int, Int) [Double] -> [Array (Int, Int) [Double]]
components m = map fromGraph $ map (`subgraph` g) (scc g)
  where
    g = toGraph m

toGraph :: Array (Int, Int) [Double] -> Gr Int [Double]
toGraph m = mkGraph
    [(i, i) | i <- [0..n]]
    [ (i, j, m ! (i, j)) | (i, j) <- indices m, not (null (m ! (i, j))) ]
  where
    ((0, 0), (n, _n)) = bounds m

fromGraph :: Gr Int [Double] -> Array (Int, Int) [Double]
fromGraph g = listArray ((0, 0), (n, n)) (replicate ((n + 1) * (n + 1)) []) //
    [ ((i',j'), l)
    | (i, j, l) <- es, Just i' <- [lookup i ns], Just j' <- [lookup j ns]
    ]
  where
    n = noNodes g - 1
    ns = map fst (labNodes g) `zip` [0..]
    es = labEdges g

-- precondition: g corresponds to a strongly connected component
dimSCC :: Array (Int, Int) [Double] -> Maybe Double
dimSCC g = findZero f 0 10
  where
   f s = fmap (subtract 1) $ spectralRadius (fmap (sum . map (** s)) g)

-- precondition: m is square
spectralRadius :: Array (Int, Int) Double -> Maybe Double
spectralRadius m = go 0 1 0 ones
  where
```

```
    ((0, 0), (m1,_m1)) = bounds m
    ones = listArray (0, m1) (replicate (m1 + 1) 1)
    go :: Int -> Double -> Double -> Array Int Double -> Maybe Double
    go n h r v
      | n > 1000 = Nothing
      | abs h < 0.00001 = Just r
      | otherwise = go (n + 1) h' r' v'
      where
        h' = r' - r
        r' = dot v' v / dot v v
        v' = mul m v

-- precondition: a and b have the same bounds
dot :: Array Int Double -> Array Int Double -> Double
dot a b = sum [ a ! i * b ! i | i <- indices a ]

-- precondition: m is square matching the dimensions of v
mul :: Array (Int, Int) Double -> Array Int Double -> Array Int Double
mul m v = listArray (bounds v)
  [ sum [ m ! (i, j) * v ! j | j <- indices v ] | i <- indices v ]

-- precondition: f is continuous and monotonic with a zero between x1 and x2
findZero :: (Double -> Maybe Double) -> Double -> Double -> Maybe Double
findZero f x1' x2' = do
  y1 <- f x1'
  y2 <- f x2'
  case () of
    _ | zero y1 -> Just x1'
      | zero y2 -> Just x2'
      | y1 > 0 && y2 > 0 -> Nothing
      | y1 < 0 && y2 < 0 -> Nothing
      | otherwise -> go x1' y1 x2' y2
  where
    zero x = abs x < 0.0000001
    go x1 y1 x2 y2 = do
      let x = (x1 + x2) / 2
      y <- f x
      case () of
        _ | zero y -> Just x
          | (y2 > 0 && y > 0) || (y2 < 0 && y < 0) -> go x1 y1 x y
          | (y2 > 0 && y < 0) || (y2 < 0 && y > 0) -> go x y x2 y2
          | otherwise -> Nothing
```

34 graphgrow3/edge~.pd

```
#N canvas 3 93 450 358 10;
#X obj 40 198 pitchshift~;
#X obj 178 44 r EDGE;
#X obj 178 66 route \$1;
#X obj 178 88 route \$2;
#X obj 178 110 route \$3;
#X obj 113 174 vline~;
#X obj 114 129 f;
#X obj 228 179 f;
#X obj 40 243 *~;
#X obj 72 244 vline~;
#X obj 114 154 expr -12*log(\$f1/0.5)/log(2);
```

```
#X obj 39 314 throw~ RULE-\$4-l;
#X obj 163 314 throw~ RULE-\$4-r;
#X obj 38 287 *~;
#X obj 164 291 *~;
#X obj 251 251 expr 3.141592653/2*$f1;
#X obj 251 274 expr cos($f1) \; sin($f1);
#X obj 66 287 vline~;
#X obj 197 290 vline~;
#X obj 41 43 r~ RULE-\$1-l;
#X obj 52 71 r~ RULE-\$1-r;
#X obj 50 218 pitchshift~;
#X obj 52 264 *~;
#X msg 229 200 set RULE-\$1-l;
#X msg 238 220 set RULE-\$1-r;
#X msg 320 154 \; \$1 bang;
#X obj 178 132 route scale target pan echo active;
#X obj 360 201 switch~;
#X obj 382 166 f;
#X obj 371 81 loadbang;
#X msg 371 103 1;
#X connect 0 0 8 0;
#X connect 1 0 2 0;
#X connect 2 0 3 0;
#X connect 3 0 4 0;
#X connect 4 0 26 0;
#X connect 5 0 0 1;
#X connect 5 0 21 1;
#X connect 6 0 9 0;
#X connect 6 0 10 0;
#X connect 7 0 23 0;
#X connect 7 0 24 0;
#X connect 8 0 13 0;
#X connect 9 0 8 1;
#X connect 9 0 22 1;
#X connect 10 0 5 0;
#X connect 13 0 11 0;
#X connect 14 0 12 0;
#X connect 15 0 16 0;
#X connect 16 0 17 0;
#X connect 16 1 18 0;
#X connect 17 0 13 1;
#X connect 18 0 14 1;
#X connect 19 0 0 0;
#X connect 20 0 21 0;
#X connect 21 0 22 0;
#X connect 22 0 14 0;
#X connect 23 0 11 0;
#X connect 24 0 12 0;
#X connect 26 0 6 0;
#X connect 26 1 7 0;
#X connect 26 2 15 0;
#X connect 26 3 25 0;
#X connect 26 4 28 0;
#X connect 28 0 27 0;
#X connect 29 0 30 0;
#X connect 30 0 28 0;
```

35 graphgrow3/graphgrow3.cabal

```
name:                graphgrow3
version:             3
synopsis:            graph-directed iterated function system fractals
description:
  graphgrow3 for graph-directed iterated function system fractals.
  .
  GraphGrow3 has a graphical node editor, visualization with
  OpenGL and sonification via messages to Pure-data.
  .
  > pd graphgrow3.pd &
  > graphgrow3 | pdsend 6060

homepage:            https://mathr.co.uk/blog/graphgrow.html
license:             GPL-3
license-file:        LICENSE
author:              Claude Heiland-Allen
maintainer:          claude@mathr.co.uk
category:            Graphics
build-type:          Simple
cabal-version:       >=1.8
extra-doc-files:     README.md
data-files:
  initial.vert
  initial.frag
  colour.vert
  colour.frag
  step.vert
  step.frag
  graphgrow3.pd
  rule~.pd
  edge~.pd
  compress~.pd
  pitchshift~.pd

executable graphgrow3
  main-is:  Main.hs
  other-modules:
    Types
    Audio
    Video
    Dimension
  build-depends:
    base >= 4.9 && < 4.10,
    array >= 0.5 && < 0.6,
    colour >= 2.3 && < 2.4,
    containers >= 0.5.8 && < 0.6,
    fgl >= 5.5 && < 5.6,
    glib >= 0.13 && < 0.14,
    gtk >= 0.14 && < 0.15,
    gtkglext >= 0.13 && < 0.14,
    lens >= 4.15 && < 4.16,
    linear >= 1.20 && < 1.21,
    mtl >= 2.2 && < 2.3,
    OpenGLRaw >= 3.2 && < 3.3,
    process >= 1.4.2 && < 1.5,
```

```
    toy-gtk-diagrams >= 0.4 && < 0.5
  ghc-options: -Wall -threaded

Source-repository head
  type:                git
  location:            https://code.mathr.co.uk/graphgrow.git
  subdir:              graphgrow3

Source-repository this
  type:                git
  location:            https://code.mathr.co.uk/graphgrow.git
  subdir:              graphgrow3
  tag:                 v3
```

36 graphgrow3/graphgrow3.pd

```
#N canvas 24 92 520 592 10;
#N canvas 3 143 450 300 RULES 0;
#X obj 41 35 rule~ 0;
#X obj 41 57 rule~ 1;
#X obj 41 79 rule~ 2;
#X obj 41 101 rule~ 3;
#X obj 41 123 rule~ 4;
#X obj 41 145 rule~ 5;
#X obj 41 167 rule~ 6;
#X obj 41 189 rule~ 7;
#X restore 32 139 pd RULES;
#X obj 61 283 dac~;
#N canvas 3 143 450 300 EDGES 0;
#X restore 32 112 pd EDGES;
#X obj 215 51 netreceive 6060;
#X obj 278 401 list prepend obj 10 10 edge~;
#X obj 278 423 list trim;
#X obj 298 530 s pd-EDGES;
#X obj 278 445 t b b a b;
#X msg 295 467 loadbang;
#X msg 338 491 \; pd dsp 0;
#X msg 268 489 \; pd dsp 1;
#X msg 420 466 clear;
#X obj 33 205 hip~ 5;
#X obj 33 165 catch~ OUT-l;
#X obj 129 187 hip~ 5;
#X obj 129 165 catch~ OUT-r;
#X obj 41 318 env~ 16384;
#X floatatom 41 340 5 0 0 0 - - -, f 5;
#X obj 120 318 env~ 16384;
#X floatatom 120 340 5 0 0 0 - - -, f 5;
#X obj 259 267 s EDGE;
#X obj 311 269 r ECHO;
#X msg 312 295 0;
#X obj 216 303 list prepend;
#X obj 216 202 t a a b;
#X msg 296 221 1;
#X obj 216 352 route 0 1;
#X obj 216 325 list trim;
#X msg 216 374 \$1 \$2 \$3 active 1 \, \$1 \$2 \$3 target \$4;
#X obj 216 396 s EDGE;
```

```
#X obj 215 123 route add delete set;
#X text 219 143 ffff;
#X text 274 142 fff;
#X msg 277 174 \$1 \$2 \$3 active 0;
#X obj 277 196 s EDGE;
#X text 321 143 fffsf;
#X obj 336 196 s EDGE;
#X msg 259 245 \$1 \$2 \$3 echo symbol ECHO;
#X obj 35 487 writesf~ 2;
#X msg 54 453 stop;
#X obj 35 24 loadbang;
#X msg 35 70 \; pd dsp 1;
#X msg 18 429 open -bytes 4 audio.wav \, start;
#X obj 33 231 compress~ 48;
#X obj 128 230 compress~ 48;
#X obj 116 257 *~ 1;
#X obj 34 254 *~ 1;
#N canvas 529 88 593 502 RANDOMIZE 0;
#X obj 87 11 inlet;
#X obj 96 73 random 8;
#X obj 96 95 + 1;
#X msg 164 72 clear;
#X obj 164 94 s pd-EDGES;
#X msg 245 71 \; pd dsp 0;
#X obj 96 175 * 3;
#X obj 96 197 until;
#X obj 84 289 random;
#X obj 98 379 pack f f f f f f;
#X obj 237 285 random;
#X obj 176 285 f 0;
#X obj 204 285 + 1;
#X msg 140 290 0;
#X obj 96 219 t b b b b b b;
#X obj 297 300 t f f;
#X obj 297 322 *;
#X obj 446 301 - 0.5;
#X obj 446 323 * 0.5;
#X obj 446 345 + 0.5;
#X obj 96 114 t f b f;
#X obj 114 157 + 2;
#X obj 114 135 random 3;
#X msg 159 187 0;
#X msg 94 406 add \$1 \$2 \$3 \$4 \, set \$1 \$2 \$3 scale \$5 \, set
\$1 \$2 \$3 pan \$6;
#X obj 91 437 outlet;
#X msg 30 77 \; pd dsp 1;
#X obj 298 256 random 1e+06;
#X obj 297 278 / 1e+06;
#X obj 448 257 random 1e+06;
#X obj 446 279 / 1e+06;
#X obj 87 33 t b b b b b;
#X msg 425 65 ----------;
#X connect 0 0 31 0;
#X connect 1 0 2 0;
#X connect 2 0 20 0;
#X connect 3 0 4 0;
#X connect 6 0 7 0;
```

```
#X connect 7 0 14 0;
#X connect 8 0 9 0;
#X connect 9 0 24 0;
#X connect 10 0 9 3;
#X connect 11 0 12 0;
#X connect 11 0 9 2;
#X connect 12 0 11 1;
#X connect 13 0 9 1;
#X connect 14 0 8 0;
#X connect 14 1 13 0;
#X connect 14 2 11 0;
#X connect 14 3 10 0;
#X connect 14 4 27 0;
#X connect 14 5 29 0;
#X connect 15 0 16 0;
#X connect 15 1 16 1;
#X connect 16 0 9 4;
#X connect 17 0 18 0;
#X connect 18 0 19 0;
#X connect 19 0 9 5;
#X connect 20 0 6 0;
#X connect 20 1 22 0;
#X connect 20 1 23 0;
#X connect 20 2 8 1;
#X connect 20 2 10 1;
#X connect 21 0 6 1;
#X connect 22 0 21 0;
#X connect 23 0 11 1;
#X connect 24 0 25 0;
#X connect 27 0 28 0;
#X connect 28 0 15 0;
#X connect 29 0 30 0;
#X connect 30 0 17 0;
#X connect 31 0 26 0;
#X connect 31 1 1 0;
#X connect 31 2 3 0;
#X connect 31 3 5 0;
#X connect 31 4 32 0;
#X connect 32 0 25 0;
#X restore 380 93 pd RANDOMIZE;
#X obj 382 61 bng 15 250 50 0 empty empty empty 17 7 0 10 -262144 -1
-1;
#X obj 399 122 print -n;
#X obj 35 46 delay 1;
#X connect 3 0 30 0;
#X connect 4 0 5 0;
#X connect 5 0 7 0;
#X connect 7 0 10 0;
#X connect 7 1 8 0;
#X connect 7 2 6 0;
#X connect 7 3 9 0;
#X connect 8 0 6 0;
#X connect 11 0 6 0;
#X connect 12 0 43 0;
#X connect 13 0 12 0;
#X connect 14 0 44 0;
#X connect 15 0 14 0;
```

```
#X connect 16 0 17 0;
#X connect 18 0 19 0;
#X connect 21 0 22 0;
#X connect 22 0 23 1;
#X connect 23 0 27 0;
#X connect 24 0 23 0;
#X connect 24 1 37 0;
#X connect 24 2 25 0;
#X connect 25 0 23 1;
#X connect 26 0 28 0;
#X connect 26 1 4 0;
#X connect 27 0 26 0;
#X connect 28 0 29 0;
#X connect 30 0 24 0;
#X connect 30 1 33 0;
#X connect 30 2 36 0;
#X connect 33 0 34 0;
#X connect 37 0 20 0;
#X connect 39 0 38 0;
#X connect 40 0 50 0;
#X connect 42 0 38 0;
#X connect 43 0 46 0;
#X connect 44 0 45 0;
#X connect 45 0 18 0;
#X connect 45 0 1 1;
#X connect 45 0 38 1;
#X connect 46 0 1 0;
#X connect 46 0 16 0;
#X connect 46 0 38 0;
#X connect 47 0 30 0;
#X connect 47 0 49 0;
#X connect 48 0 47 0;
#X connect 50 0 41 0;
```

37 graphgrow3/iface/deselected.png

38 graphgrow3/iface/.gitignore

```
graphgrow-iface
*.raw
```

39 graphgrow3/iface/graphgrow-iface.cc

```
#include <stdint.h>
#include <stdio.h>
#include <string.h>
#include <vector>
#include <GL/glew.h>
#include <GLFW/glfw3.h>
#include <glm/glm.hpp>
#include <lo/lo.h>

// ------------------------------ declarations -------------------------

struct video_control;
struct audio_control;

enum graph_mode
{
  mode_create_node,
  mode_delete_node,
  mode_move_node,
  mode_create_link,
  mode_delete_link,
  mode_flip_link,
  mode_target_link,
  mode_help
};

struct graph_node;
struct graph_link;
struct graph_arrow;
struct graph_cord;
struct graph_designer;

typedef bool (*node_mouse_t)(graph_node *, double, double);
typedef bool (*link_mouse_t)(graph_link *, double, double);
typedef bool (*arrow_mouse_t)(graph_arrow *, double, double);
typedef bool (*cord_mouse_t)(graph_cord *, double, double);
typedef bool (*designer_mouse_t)(graph_designer *, double, double);

graph_link *link_new(graph_designer *designer, graph_node *from, graph_node *to)↙
    ↳ ;
void link_delete(graph_link *link);
void link_leave_mode(graph_link *link);
void link_enter_mode(graph_link *link, graph_mode mode);
void link_update(graph_link *link);
graph_arrow *arrow_new();
void arrow_delete(graph_arrow *arrow);
void arrow_leave_mode(graph_arrow *arrow);
void arrow_enter_mode(graph_arrow *arrow, graph_mode mode);
graph_cord *cord_new(double x1, double y1, double x2, double y2);
```

```
    void cord_delete(graph_cord *cord);
50  graph_node *node_new(graph_designer *designer, double x, double y, bool fixed);
    void node_delete(graph_node *node);
    bool nodes_linked(graph_node *a, graph_node *b);
    void node_leave_mode(graph_node *node);
    bool node_mouse_hit(graph_node *node, double x, double y);
55  bool node_mouse_down_new(graph_node *node, double x, double y);
    bool node_mouse_down_delete(graph_node *node, double x, double y);
    bool node_mouse_down_move(graph_node *node, double x, double y);
    bool node_mouse_down_link(graph_node *node, double x, double y);
    bool node_mouse_up_corded(graph_node *node, double x, double y);
60  void node_enter_mode(graph_node *node, graph_mode mode);
    graph_designer *designer_new(int id);
    void designer_leave_mode(graph_designer *designer);
    void designer_enter_mode(graph_designer *designer, graph_mode mode);
    void node_move_by(graph_node *node, double dx, double dy);
65  bool designer_mouse_down(graph_designer *designer, double x, double y);
    bool designer_mouse_down_node_new(graph_designer *designer, double x, double y);
    bool designer_mouse_move_dragging(graph_designer *designer, double x, double y);
    bool designer_mouse_move_dragged(graph_designer *designer, double x, double y);
    bool designer_mouse_move_cording(graph_designer *designer, double x, double y);
70  bool designer_mouse_move_corded(graph_designer *designer, double x, double y);

    // ----------------------------- constants -----------------------------

    const glm::vec3 white = glm::vec3(1.0f);
75  const glm::vec3 black = glm::vec3(0.0f);
    const glm::vec3 colours[4] =
      { glm::vec3(1.0f, 0.5f, 0.0f)
      , glm::vec3(0.5f, 1.0f, 0.0f)
      , glm::vec3(0.0f, 0.5f, 1.0f)
80    , glm::vec3(0.5f, 0.0f, 1.0f)
      };

    const double minimum_x = 50;
    const double minimum_y = 50;
85  const double maximum_x = 750;
    const double maximum_y = 750;

    // ----------------------------- controls -----------------------------

90  struct video_control
    {
      int32_t active;
      int32_t count    [4];
      int32_t source   [4][8];
95    float   scale    [4][8];
      float   transform[4][8][3][3];
    };

    struct audio_control
100 {
      float   scale[4][4][8];
      float   pan  [4][4][8];
      uint8_t level[4][4][8];
    };
105
```

```
// ------------------------------ structs -------------------------------

struct graph_link
{
  graph_designer *designer;
  graph_node *from, *to;
  double x1, y1, x2, y2;
  int target;
  bool flipped;
  graph_arrow *arrow;
  link_mouse_t on_mouse_down, on_mouse_move, on_mouse_up;
};

struct graph_arrow
{
  graph_link *link;
  double x1, y1, x2, y2, x3, y3;
  arrow_mouse_t on_mouse_down, on_mouse_move, on_mouse_up;
};

struct graph_cord
{
  double x1, y1, x2, y2;
};

struct graph_node
{
  graph_designer *designer;
  std::vector< graph_link * > link1, link2;
  bool fixed;
  double x;
  double y;
  double dragx;
  double dragy;
  node_mouse_t on_mouse_down, on_mouse_move, on_mouse_up;
};

struct graph_designer
{
  int id;
  graph_node *start_node;
  graph_node *end_node;
  graph_node *dragging_node;
  graph_node *cording_node;
  graph_cord *cord;
  std::vector< graph_link  * >  links;
  std::vector< graph_arrow * > arrows;
  std::vector< graph_node  * >  nodes;
  designer_mouse_t on_mouse_down, on_mouse_move, on_mouse_up;
};

struct graph_draw
{
  int components;
  float tri[4096];
  GLuint vbo_tri;
  GLuint vao_tri;
```

```
  GLuint vao_quad;
  GLuint prog_circle;
  GLuint prog_arrow;
  GLuint prog_line;
  GLuint prog_buttons;
  GLuint prog_help;
  GLuint tex[3];
  GLint u_mode;
};

// ----------------------------- link ---------------------------------

graph_link *link_new(graph_designer *designer, graph_node *from, graph_node *to)
{
  graph_link *link = new graph_link();
  link->designer = designer;
  link->from = from;
  link->to = to;
  link->x1 = from->x;
  link->y1 = from->y;
  link->x2 = to->x;
  link->y2 = to->y;
  link->target = designer->id;
  link->arrow = new graph_arrow();
  link->arrow->link = link;
  from->link1.push_back(link);
  to->link2.push_back(link);
  designer->links.push_back(link);
  designer->arrows.push_back(link->arrow);
  link_update(link);
  return link;
}

void link_delete(graph_link *link)
{
  for (int i = 0; i < link->from->link1.size(); )
    if (link == link->from->link1[i])
      link->from->link1.erase(link->from->link1.begin() + i);
    else
      ++i;
  for (int i = 0; i < link->to->link2.size(); )
    if (link == link->to->link2[i])
      link->to->link2.erase(link->to->link2.begin() + i);
    else
      ++i;
  for (int i = 0; i < link->designer->links.size(); )
    if (link == link->designer->links[i])
      link->designer->links.erase(link->designer->links.begin() + i);
    else
      ++i;
  for (int i = 0; i < link->designer->arrows.size(); )
    if (link->arrow == link->designer->arrows[i])
      link->designer->arrows.erase(link->designer->arrows.begin() + i);
    else
      ++i;
  arrow_delete(link->arrow);
  link->arrow = 0;
```

```
220     link->from = 0;
        link->to = 0;
        link->designer = 0;
        delete link;
    }
225
    void link_leave_mode(graph_link *link)
    {
      (void) link;
    }
230
    void link_enter_mode(graph_link *link, graph_mode mode)
    {
      (void) link;
      (void) mode;
235 }

    void link_update(graph_link *link)
    {
      const double w = 30;
240   const double c = w * -0.5;
      const double s = w * 0.8660254037844387;
      double x1 = link->x1;
      double y1 = link->y1;
      double x2 = link->x2;
245   double y2 = link->y2;
      double dx = x2 - x1;
      double dy = y2 - y1;
      if (link->flipped)
      {
250     dx = -dx;
        dy = -dy;
      }
      double r = sqrt(dx * dx + dy * dy);
      dx /= r;
255   dy /= r;
      double ox = (x1 + x2) / 2;
      double oy = (y1 + y2) / 2;
      link->arrow->x1 = ox + w * dx;
      link->arrow->y1 = oy + w * dy;
260   link->arrow->x2 = ox + c * dx + s * dy;
      link->arrow->y2 = oy - s * dx + c * dy;
      link->arrow->x3 = ox + c * dx - s * dy;
      link->arrow->y3 = oy + s * dx + c * dy;
    }
265
    // ---------------------------- arrow --------------------------------

    graph_arrow *arrow_new()
    {
270   graph_arrow *arrow = new graph_arrow();
      arrow->on_mouse_down = 0;
      arrow->on_mouse_move = 0;
      arrow->on_mouse_up   = 0;
      return arrow;
275 }
```

```
void arrow_delete(graph_arrow *arrow)
{
  delete arrow;
}

void arrow_leave_mode(graph_arrow *arrow)
{
  arrow->on_mouse_down = 0;
  arrow->on_mouse_move = 0;
  arrow->on_mouse_up   = 0;
}

bool arrow_hit(graph_arrow *arrow, double x, double y)
{
  double x0 = (arrow->x1 + arrow->x2 + arrow->x3) / 3;
  double y0 = (arrow->y1 + arrow->y2 + arrow->y3) / 3;
  double dx = x - x0;
  double dy = y - y0;
  double r2 = dx * dx + dy * dy;
  return r2 < 500;
}

bool arrow_mouse_down_delete(graph_arrow *arrow, double x, double y)
{
  if (arrow_hit(arrow, x, y))
  {
    link_delete(arrow->link);
    // arrow is deleted
    return true;
  }
  return false;
}

bool arrow_mouse_down_flip(graph_arrow *arrow, double x, double y)
{
  if (arrow_hit(arrow, x, y))
  {
    arrow->link->flipped = !(arrow->link->flipped);
    link_update(arrow->link);
    return true;
  }
  return false;
}

bool arrow_mouse_down_target(graph_arrow *arrow, double x, double y)
{
  if (arrow_hit(arrow, x, y))
  {
    arrow->link->target = (arrow->link->target + 1) % 4;
    link_update(arrow->link);
    return true;
  }
  return false;
}

void arrow_enter_mode(graph_arrow *arrow, graph_mode mode)
{
```

```
  switch (mode)
  {
    case mode_delete_link:
      arrow->on_mouse_down = arrow_mouse_down_delete;
      break;
    case mode_flip_link:
      arrow->on_mouse_down = arrow_mouse_down_flip;
      break;
    case mode_target_link:
      arrow->on_mouse_down = arrow_mouse_down_target;
      break;
    case mode_create_link:
    case mode_create_node:
    case mode_delete_node:
    case mode_move_node:
    case mode_help:
      break;
  }
}

// ------------------------------ cord ---------------------------------

graph_cord *cord_new(double x1, double y1, double x2, double y2)
{
  graph_cord *cord = new graph_cord();
  cord->x1 = x1;
  cord->y1 = y1;
  cord->x2 = x2;
  cord->y2 = y2;
  return cord;
}

void cord_delete(graph_cord *cord)
{
  delete cord;
}

// ------------------------------ node ---------------------------------

graph_node *node_new(graph_designer *designer, double x, double y, bool fixed)
{
  graph_node *node = new graph_node();
  node->fixed = fixed;
  node->x = fmin(fmax(x, minimum_x), maximum_x);
  node->y = fmin(fmax(y, minimum_y), maximum_y);
  node->dragx = node->x;
  node->dragy = node->y;
  node->designer = designer;
  designer->nodes.push_back(node);
  return node;
}

void node_delete(graph_node *node)
{
  graph_designer *designer = node->designer;
  for (int i = 0; i < designer->nodes.size(); )
    if (node == designer->nodes[i])
```

```
        designer->nodes.erase(designer->nodes.begin() + i);
      else
        ++i;
  while (node->link1.size())
    link_delete(node->link1[0]);
  while (node->link2.size())
    link_delete(node->link2[0]);
  node->designer = 0;
  delete node;
}

bool nodes_linked(graph_node *a, graph_node *b)
{
  for (int i = 0; i < a->link1.size(); ++i)
    if (a->link1[i]->to == b)
      return true;
  for (int i = 0; i < b->link1.size(); ++i)
    if (b->link1[i]->to == a)
      return true;
  return false;
}

void node_leave_mode(graph_node *node)
{
  node->on_mouse_down = 0;
  node->on_mouse_move = 0;
  node->on_mouse_up   = 0;
}

bool node_mouse_hit(graph_node *node, double x, double y)
{
  double dx = x - node->x;
  double dy = y - node->y;
  double r2 = dx * dx + dy * dy;
  return r2 < 500;
}

bool node_mouse_down_new(graph_node *node, double x, double y)
{
  return node_mouse_hit(node, x, y);
}

bool node_mouse_down_delete(graph_node *node, double x, double y)
{
  if (node_mouse_hit(node, x, y))
  {
    node_delete(node);
    return true;
  }
  return false;
}

bool node_mouse_down_move(graph_node *node, double x, double y)
{
  if (node_mouse_hit(node, x, y))
  {
    node->designer->dragging_node = node;
```

```
      node->designer->on_mouse_move = designer_mouse_move_dragging;
      node->designer->on_mouse_up   = designer_mouse_move_dragged;
      node->dragx = fmin(fmax(x, minimum_x), maximum_x);
      node->dragy = fmin(fmax(y, minimum_y), maximum_y);
      return true;
    }
    return false;
}

bool node_mouse_down_link(graph_node *node, double x, double y)
{
  if (node_mouse_hit(node, x, y) && node->designer->links.size() < 8)
  {
    node->designer->cording_node = node;
    node->designer->cord = cord_new(node->x, node->y, x, y);
    for (int i = 0; i < node->designer->nodes.size(); ++i)
      if (node != node->designer->nodes[i] && ! nodes_linked(node, node->designer->nodes[i]))
        node->designer->nodes[i]->on_mouse_up = node_mouse_up_corded;
    node->designer->on_mouse_move = designer_mouse_move_cording;
    node->designer->on_mouse_up   = designer_mouse_move_corded;
    return true;
  }
  return false;
}

bool node_mouse_up_corded(graph_node *node, double x, double y)
{
  if (node_mouse_hit(node, x, y))
  {
    link_new(node->designer, node->designer->cording_node, node);
    node->designer->cording_node = 0;
    delete node->designer->cord;
    node->designer->cord = 0;
    for (int i = 0; i < node->designer->nodes.size(); ++i)
      node->designer->nodes[i]->on_mouse_up = 0;
    node->designer->on_mouse_move = 0;
    node->designer->on_mouse_up   = 0;
    return true;
  }
  return false;
}

void node_enter_mode(graph_node *node, graph_mode mode)
{
  switch (mode)
  {
    case mode_create_node:
      node->on_mouse_down = node_mouse_down_new;
      break;
    case mode_delete_node:
      if (! node->fixed)
        node->on_mouse_down = node_mouse_down_delete;
      break;
    case mode_move_node:
      if (! node->fixed)
        node->on_mouse_down = node_mouse_down_move;
```

```
        break;
      case mode_create_link:
        node->on_mouse_down = node_mouse_down_link;
        break;
      case mode_delete_link:
      case mode_flip_link:
      case mode_target_link:
      case mode_help:
        break;
    }
  }

// ------------------------------ designer ------------------------------

graph_designer *designer_new(int id)
{
  graph_designer *designer = new graph_designer();
  designer->id = id;
  designer->start_node = node_new(designer, 100, 400, true);
  designer->end_node   = node_new(designer, 700, 400, true);
  designer->dragging_node = 0;
  designer->cording_node = 0;
  designer->on_mouse_down = 0;
  designer->on_mouse_move = 0;
  designer->on_mouse_up   = 0;
  return designer;
}

void designer_leave_mode(graph_designer *designer)
{
  for (int i = 0; i < designer->links.size(); ++i)
    link_leave_mode(designer->links[i]);
  for (int i = 0; i < designer->arrows.size(); ++i)
    arrow_leave_mode(designer->arrows[i]);
  for (int i = 0; i < designer->nodes.size(); ++i)
    node_leave_mode(designer->nodes[i]);
  designer->on_mouse_down = 0;
  designer->on_mouse_move = 0;
  designer->on_mouse_up   = 0;
}

void designer_enter_mode(graph_designer *designer, graph_mode mode)
{
  for (int i = 0; i < designer->links.size(); ++i)
    link_enter_mode(designer->links[i], mode);
  for (int i = 0; i < designer->arrows.size(); ++i)
    arrow_enter_mode(designer->arrows[i], mode);
  for (int i = 0; i < designer->nodes.size(); ++i)
    node_enter_mode(designer->nodes[i], mode);
  switch (mode)
  {
    case mode_create_node:
      designer->on_mouse_down = designer_mouse_down_node_new;
      break;
    case mode_delete_node:
    case mode_move_node:
    case mode_create_link:
```

```
      case mode_delete_link:
      case mode_flip_link:
      case mode_target_link:
      case mode_help:
        break;
    }
}

void node_move_by(graph_node *node, double dx, double dy)
{
  for (int i = 0; i < node->link2.size(); ++i)
  {
    node->link2[i]->x2 = fmin(fmax(node->link2[i]->x2 + dx, minimum_x), ↙
        ↳ maximum_x);
    node->link2[i]->y2 = fmin(fmax(node->link2[i]->y2 + dy, minimum_y), ↙
        ↳ maximum_y);
    link_update(node->link2[i]);
  }
  for (int i = 0; i < node->link1.size(); ++i)
  {
    node->link1[i]->x1 = fmin(fmax(node->link1[i]->x1 + dx, minimum_x), ↙
        ↳ maximum_x);
    node->link1[i]->y1 = fmin(fmax(node->link1[i]->y1 + dy, minimum_y), ↙
        ↳ maximum_y);
    link_update(node->link1[i]);
  }
  node->x = fmin(fmax(node->x + dx, minimum_x), maximum_x);
  node->y = fmin(fmax(node->y + dy, minimum_y), maximum_y);
}

bool designer_mouse_down(graph_designer *designer, double x, double y)
{
  for (int i = 0; i < designer->nodes.size(); ++i)
    if (designer->nodes[i]->on_mouse_down)
      if (designer->nodes[i]->on_mouse_down(designer->nodes[i], x, y))
        return true;
  for (int i = 0; i < designer->arrows.size(); ++i)
    if (designer->arrows[i]->on_mouse_down)
      if (designer->arrows[i]->on_mouse_down(designer->arrows[i], x, y))
        return true;
  if (designer->on_mouse_down)
    return designer->on_mouse_down(designer, x, y);
  return false;
}

bool designer_mouse_move(graph_designer *designer, double x, double y)
{
  for (int i = 0; i < designer->nodes.size(); ++i)
    if (designer->nodes[i]->on_mouse_move)
      if (designer->nodes[i]->on_mouse_move(designer->nodes[i], x, y))
        return true;
  if (designer->on_mouse_move)
    return designer->on_mouse_move(designer, x, y);
  return false;
}

bool designer_mouse_up(graph_designer *designer, double x, double y)
```

```
{
  for (int i = 0; i < designer->nodes.size(); ++i)
    if (designer->nodes[i]->on_mouse_up)
      if (designer->nodes[i]->on_mouse_up(designer->nodes[i], x, y))
        return true;
  if (designer->on_mouse_up)
    return designer->on_mouse_up(designer, x, y);
  return false;
}

bool designer_mouse_down_node_new(graph_designer *designer, double x, double y)
{
  if (minimum_x <= x && x <= maximum_x && minimum_y <= y && y <= maximum_y && ↙
      ↳ designer->nodes.size() < 18)
  {
    graph_node *node = node_new(designer, x, y, false);
    node_enter_mode(node, mode_create_node);
  }
  return true;
}

bool designer_mouse_move_dragging(graph_designer *designer, double x, double y)
{
  double dx = fmin(fmax(x, minimum_x), maximum_x) - designer->dragging_node->↙
      ↳ dragx;
  double dy = fmin(fmax(y, minimum_y), maximum_y) - designer->dragging_node->↙
      ↳ dragy;
  designer->dragging_node->dragx = fmin(fmax(x, minimum_x), maximum_x);
  designer->dragging_node->dragy = fmin(fmax(y, minimum_y), maximum_y);
  node_move_by(designer->dragging_node, dx, dy);
  return true;
}

bool designer_mouse_move_dragged(graph_designer *designer, double x, double y)
{
  designer_mouse_move_dragging(designer, x, y);
  designer->on_mouse_move = 0;
  designer->on_mouse_up = 0;
  designer->dragging_node = 0;
  return true;
}

bool designer_mouse_move_cording(graph_designer *designer, double x, double y)
{
  designer->cord->x2 = fmin(fmax(x, minimum_x), maximum_x);
  designer->cord->y2 = fmin(fmax(y, minimum_y), maximum_y);
  return true;
}

bool designer_mouse_move_corded(graph_designer *designer, double x, double y)
{
  for (int i = 0; i < designer->nodes.size(); ++i)
    designer->nodes[i]->on_mouse_up = 0;
  designer->on_mouse_move = 0;
  designer->on_mouse_up = 0;
  designer->cording_node = 0;
  delete designer->cord;
```

```
  designer->cord = 0;
  return true;
  (void) x;
  (void) y;
}

// ----------------------------- drawing -----------------------------

int draw_enqueue_triangle(graph_draw *draw, int k, double x1, double y1, double x2, double y2, double x3, double y3, glm::vec3 colour)
{
  draw->tri[k++] = x1;
  draw->tri[k++] = y1;
  draw->tri[k++] = 1;
  draw->tri[k++] = 0;
  draw->tri[k++] = 0;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  draw->tri[k++] = x2;
  draw->tri[k++] = y2;
  draw->tri[k++] = 0;
  draw->tri[k++] = 1;
  draw->tri[k++] = 0;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  draw->tri[k++] = x3;
  draw->tri[k++] = y3;
  draw->tri[k++] = 0;
  draw->tri[k++] = 0;
  draw->tri[k++] = 1;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  return k;
}

int draw_enqueue_quad(graph_draw *draw, int k, double x1, double y1, double x2, double y2, double x3, double y3, double x4, double y4, glm::vec3 colour)
{
  draw->tri[k++] = x1;
  draw->tri[k++] = y1;
  draw->tri[k++] = 0;
  draw->tri[k++] = 0;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  draw->tri[k++] = x2;
  draw->tri[k++] = y2;
  draw->tri[k++] = 0;
  draw->tri[k++] = 1;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  draw->tri[k++] = x3;
```

```
  draw->tri[k++] = y3;
  draw->tri[k++] = 1;
  draw->tri[k++] = 0;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  draw->tri[k++] = x3;
  draw->tri[k++] = y3;
  draw->tri[k++] = 1;
  draw->tri[k++] = 0;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  draw->tri[k++] = x2;
  draw->tri[k++] = y2;
  draw->tri[k++] = 0;
  draw->tri[k++] = 1;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  draw->tri[k++] = x4;
  draw->tri[k++] = y4;
  draw->tri[k++] = 1;
  draw->tri[k++] = 1;
  draw->tri[k++] = colour[0];
  draw->tri[k++] = colour[1];
  draw->tri[k++] = colour[2];
  return k;
}


int draw_enqueue_line(graph_draw *draw, int k, double x1, double y1, double x2, ↙
    ↳ double y2, double w, glm::vec3 colour)
{
  double dx = x2 - x1;
  double dy = y2 - y1;
  double r = sqrt(dx * dx + dy * dy);
  dx /= r;
  dy /= r;
  k = draw_enqueue_quad(draw, k, x1 - w * dy, y1 + w * dx, x2 - w * dy, y2 + w *↙
      ↳  dx, x1 + w * dy, y1 - w * dx, x2 + w * dy, y2 - w * dx, colour);
  return k;
}

int draw_enqueue_circle(graph_draw *draw, int k, double x, double y, double w, ↙
    ↳ glm::vec3 colour)
{
  k = draw_enqueue_quad(draw, k, x - w, y - w, x + w, y - w, x - w, y + w, x + w↙
      ↳ , y + w, colour);
  return k;
}

void draw_designer(graph_draw *draw, graph_designer *designer, bool is_active, ↙
    ↳ bool big)
{
  glm::vec3 bg = glm::mix(colours[designer->id], black, 0.75f);
  if (! is_active)
```

```
775       bg = glm::mix(bg, black, 0.5f);
        glClearColor(bg[0], bg[1], bg[2], 0);
        glClear(GL_COLOR_BUFFER_BIT);
        int k = 0;
        for (int i = 0; i < designer->links.size() && k <= draw->components - 7 * 6; ↙
            ↳ ++i)
780     {
          double w = big ? 8 : 16;
          double x1 = designer->links[i]->x1;
          double y1 = designer->links[i]->y1;
          double x2 = designer->links[i]->x2;
785       double y2 = designer->links[i]->y2;
          glm::vec3 colour = colours[designer->links[i]->target];
          k = draw_enqueue_line(draw, k, x1, y1, x2, y2, w, colour);
        }
        if (designer->cord)
790     {
          double w = big ? 8 : 16;
          double x1 = designer->cord->x1;
          double y1 = designer->cord->y1;
          double x2 = designer->cord->x2;
795       double y2 = designer->cord->y2;
          k = draw_enqueue_line(draw, k, x1, y1, x2, y2, w, colours[designer->id]);
        }
        glBufferSubData(GL_ARRAY_BUFFER, 0, k * sizeof(float), &draw->tri[0]);
        glBindVertexArray(draw->vao_quad);
800     glUseProgram(draw->prog_line);
        glDrawArrays(GL_TRIANGLES, 0, k / 7);
        k = 0;
        for (int i = 0; i < designer->arrows.size() && k < draw->components - 8 * 3; ↙
            ↳ ++i)
        {
805       double x1 = designer->arrows[i]->x1;
          double y1 = designer->arrows[i]->y1;
          double x2 = designer->arrows[i]->x2;
          double y2 = designer->arrows[i]->y2;
          double x3 = designer->arrows[i]->x3;
810       double y3 = designer->arrows[i]->y3;
          glm::vec3 colour = colours[designer->arrows[i]->link->target];
          k = draw_enqueue_triangle(draw, k, x1, y1, x2, y2, x3, y3, colour);
        }
        glBufferSubData(GL_ARRAY_BUFFER, 0, k * sizeof(float), &draw->tri[0]);
815     glBindVertexArray(draw->vao_tri);
        glUseProgram(draw->prog_arrow);
        glDrawArrays(GL_TRIANGLES, 0, k / 8);
        k = 0;
        for (int i = 0; i < designer->nodes.size() && k <= draw->components - 7 * 6; ↙
            ↳ ++i)
820     {
          const double w = 20;
          double x = designer->nodes[i]->x;
          double y = designer->nodes[i]->y;
          glm::vec3 colour = colours[designer->nodes[i]->designer->id];
825       if (designer->nodes[i]->fixed)
            colour = white;
          k = draw_enqueue_circle(draw, k, x, y, w, colour);
        }
```

```
  glBufferSubData(GL_ARRAY_BUFFER, 0, k * sizeof(float), &draw->tri[0]);
  glBindVertexArray(draw->vao_quad);
  glUseProgram(draw->prog_circle);
  glDrawArrays(GL_TRIANGLES, 0, k / 7);
}

void draw_buttons(graph_draw *draw, glm::vec3 colour, graph_mode mode)
{
  glm::vec3 bg = glm::mix(colour, black, 0.75f);
  glClearColor(bg[0], bg[1], bg[2], 0);
  glClear(GL_COLOR_BUFFER_BIT);
  int k = 0;
  k = draw_enqueue_quad(draw, k, -1, -1, 1, -1, -1, 1, 1, 1, colour);
  glBufferSubData(GL_ARRAY_BUFFER, 0, k * sizeof(float), &draw->tri[0]);
  glBindVertexArray(draw->vao_quad);
  glUseProgram(draw->prog_buttons);
  glUniform1i(draw->u_mode, mode);
  glDrawArrays(GL_TRIANGLES, 0, k / 7);
}

void draw_help(graph_draw *draw, glm::vec3 colour)
{
  glm::vec3 bg = glm::mix(colour, black, 0.75f);
  glClearColor(bg[0], bg[1], bg[2], 0);
  glClear(GL_COLOR_BUFFER_BIT);
  int k = 0;
  k = draw_enqueue_quad(draw, k, -1, -1, 1, -1, -1, 1, 1, 1, colour);
  glBufferSubData(GL_ARRAY_BUFFER, 0, k * sizeof(float), &draw->tri[0]);
  glBindVertexArray(draw->vao_quad);
  glUseProgram(draw->prog_help);
  glDrawArrays(GL_TRIANGLES, 0, k / 7);
}

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_COMPUTE_SHADER: type_str = "compute"; 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;
}

const char *draw_circle_vert =
"#version 330 core\n"
"layout (location = 0) in vec2 pos;\n"
"layout (location = 1) in vec2 tcd;\n"
"layout (location = 2) in vec3 clr;\n"
"out vec2 v_texcoord;\n"
"out vec3 v_colour;\n"
"void main() {\n"
"  gl_Position = vec4(2.0/800.0 * pos - vec2(1.0,1.0), 0.0, 1.0);\n"
"  v_texcoord = tcd * 2.0 - vec2(1.0, 1.0);\n"
"  v_colour = clr;\n"
```

```
    "}\n"
    ;

945 const char *draw_circle_frag =
    "#version 330 core\n"
    "in vec2 v_texcoord;\n"
    "in vec3 v_colour;\n"
    "out vec4 colour;\n"
950 "void main() {\n"
    "  float r = length(v_texcoord);\n"
    "  float d = mix(length(dFdx(v_texcoord)), length(dFdy(v_texcoord)), 0.5);\n"
    "  colour = vec4(v_colour * (smoothstep(0.2, 0.2 + d, r) - smoothstep(0.8 - d, ↙
        ↳ 0.8, r)), 1.0 - smoothstep(1.0 - d, 1.0, r));\n"
    "}\n"
955 ;

    const char *draw_arrow_vert =
    "#version 330 core\n"
    "layout (location = 0) in vec2 pos;\n"
960 "layout (location = 1) in vec3 tcd;\n"
    "layout (location = 2) in vec3 clr;\n"
    "out vec3 v_texcoord;\n"
    "out vec3 v_colour;\n"
    "void main() {\n"
965 "  gl_Position = vec4(2.0/800.0 * pos - vec2(1.0,1.0), 0.0, 1.0);\n"
    "  v_texcoord = tcd;\n"
    "  v_colour = clr;\n"
    "}\n"
    ;
970
    const char *draw_arrow_frag =
    "#version 330 core\n"
    "in vec3 v_texcoord;\n"
    "in vec3 v_colour;\n"
975 "out vec4 colour;\n"
    "void main() {\n"
    "  vec3 w = fwidth(v_texcoord);\n"
    "  vec3 a = smoothstep(vec3(0.1), vec3(0.1) + w, v_texcoord);\n"
    "  vec3 b = smoothstep(vec3(0.0), vec3(0.0) + w, v_texcoord);\n"
980 "  float e1 = max(min(min(a.x, a.y), a.z), 1.0 - smoothstep(0.05, 0.05 + length(↙
        ↳ w), abs(v_texcoord.y - v_texcoord.z)));\n"
    "  float e2 = min(min(b.x, b.y), b.z);\n"
    "  colour = vec4(v_colour * e1, e2);\n"
    "}\n"
    ;
985
    const char *draw_line_vert =
    "#version 330 core\n"
    "layout (location = 0) in vec2 pos;\n"
    "layout (location = 1) in vec2 tcd;\n"
990 "layout (location = 2) in vec3 clr;\n"
    "out vec2 v_texcoord;\n"
    "out vec3 v_colour;\n"
    "void main() {\n"
    "  gl_Position = vec4(2.0/800.0 * pos - vec2(1.0,1.0), 0.0, 1.0);\n"
995 "  v_texcoord = tcd * 2.0 - vec2(1.0, 1.0);\n"
    "  v_colour = clr;\n"
```

```
    "}\n"
    ;

1000 const char *draw_line_frag =
    "#version 330 core\n"
    "in vec2 v_texcoord;\n"
    "in vec3 v_colour;\n"
    "out vec4 colour;\n"
1005 "void main() {\n"
    "  float r = abs(v_texcoord.x);\n"
    "  float d = abs(dFdx(v_texcoord.x)) + abs(dFdy(v_texcoord.x));\n"
    "  colour = vec4(v_colour * (1.0 - smoothstep(0.333 - d, 0.333, r)), 1.0 - ↙
        ↳ smoothstep(1.0 - d, 1.0, r));\n"
    "}\n"
1010 ;

    const char *draw_buttons_vert =
    "#version 330 core\n"
    "layout (location = 0) in vec2 pos;\n"
1015 "layout (location = 1) in vec2 tcd;\n"
    "layout (location = 2) in vec3 clr;\n"
    "out vec2 v_texcoord;\n"
    "out vec3 v_colour;\n"
    "void main() {\n"
1020 "  gl_Position = vec4(pos, 0.0, 1.0);\n"
    "  v_texcoord = vec2(tcd.y, 1.0 - tcd.x);\n"
    "  v_colour = clr;\n"
    "}\n"
    ;
1025
    const char *draw_buttons_frag =
    "#version 330 core\n"
    "uniform sampler2D selected;\n"
    "uniform sampler2D deselected;\n"
1030 "uniform int mode;\n"
    "in vec2 v_texcoord;\n"
    "in vec3 v_colour;\n"
    "out vec4 colour;\n"
    "void main() {\n"
1035 "  int me = int(floor(v_texcoord.y * 8.0));\n"
    "  float a = me == mode ? texture(selected, v_texcoord).r : texture(deselected, ↙
        ↳ v_texcoord).r;\n"
    "  colour = vec4(v_colour, a);\n"
    "}\n"
    ;
1040
    const char *draw_help_vert =
    "#version 330 core\n"
    "layout (location = 0) in vec2 pos;\n"
    "layout (location = 1) in vec2 tcd;\n"
1045 "layout (location = 2) in vec3 clr;\n"
    "out vec2 v_texcoord;\n"
    "out vec3 v_colour;\n"
    "void main() {\n"
    "  gl_Position = vec4(pos, 0.0, 1.0);\n"
1050 "  v_texcoord = vec2(tcd.y, 1.0 - tcd.x);\n"
    "  v_colour = clr;\n"
```

```
"}\n"
;

const char *draw_help_frag =
"#version 330 core\n"
"uniform sampler2D help;\n"
"in vec2 v_texcoord;\n"
"in vec3 v_colour;\n"
"out vec4 colour;\n"
"void main() {\n"
"  float a = texture(help, v_texcoord).r;\n"
"  colour = vec4(v_colour, a);\n"
"}\n"
;

unsigned char *read_file(const char *name) {
  FILE *f = fopen(name, "rb");
  fseek(f, 0, SEEK_END);
  long len = ftell(f);
  fseek(f, 0, SEEK_SET);
  unsigned char *p = (unsigned char *) malloc(len);
  fread(p, len, 1, f);
  fclose(f);
  return p;
}

graph_draw *draw_new()
{
  graph_draw *draw = new graph_draw();
  draw->components = 4096;
  glGenBuffers(1, &draw->vbo_tri);
  glBindBuffer(GL_ARRAY_BUFFER, draw->vbo_tri);
  glBufferData(GL_ARRAY_BUFFER, draw->components * sizeof(GLfloat), 0, ↙
      ↳ GL_DYNAMIC_DRAW);
  glGenVertexArrays(1, &draw->vao_tri);
  glBindVertexArray(draw->vao_tri);
  glVertexAttribPointer(0, 2, GL_FLOAT, GL_FALSE, 8 * sizeof(GLfloat), 0);
  glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 8 * sizeof(GLfloat), ((char *)↙
      ↳ 0) + 2 * sizeof(GLfloat));
  glVertexAttribPointer(2, 3, GL_FLOAT, GL_FALSE, 8 * sizeof(GLfloat), ((char *)↙
      ↳ 0) + 5 * sizeof(GLfloat));
  glEnableVertexAttribArray(0);
  glEnableVertexAttribArray(1);
  glEnableVertexAttribArray(2);
  glGenVertexArrays(1, &draw->vao_quad);
  glBindVertexArray(draw->vao_quad);
  glVertexAttribPointer(0, 2, GL_FLOAT, GL_FALSE, 7 * sizeof(GLfloat), 0);
  glVertexAttribPointer(1, 2, GL_FLOAT, GL_FALSE, 7 * sizeof(GLfloat), ((char *)↙
      ↳ 0) + 2 * sizeof(GLfloat));
  glVertexAttribPointer(2, 3, GL_FLOAT, GL_FALSE, 7 * sizeof(GLfloat), ((char *)↙
      ↳ 0) + 4 * sizeof(GLfloat));
  glEnableVertexAttribArray(0);
  glEnableVertexAttribArray(1);
  glEnableVertexAttribArray(2);
  glGenTextures(3, &draw->tex[0]);
  unsigned char *g;
  glActiveTexture(GL_TEXTURE0 + 1);
```

```
  glBindTexture(GL_TEXTURE_2D, draw->tex[0]);
  g = read_file("deselected.raw");
  glTexImage2D(GL_TEXTURE_2D, 0, GL_RED, 240, 800, 0, GL_RED, GL_UNSIGNED_BYTE, g);
  free(g);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
  glActiveTexture(GL_TEXTURE0 + 2);
  glBindTexture(GL_TEXTURE_2D, draw->tex[1]);
  g = read_file("selected.raw");
  glTexImage2D(GL_TEXTURE_2D, 0, GL_RED, 240, 800, 0, GL_RED, GL_UNSIGNED_BYTE, g);
  free(g);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
  glActiveTexture(GL_TEXTURE0 + 0);
  glBindTexture(GL_TEXTURE_2D, draw->tex[2]);
  g = read_file("help.raw");
  glTexImage2D(GL_TEXTURE_2D, 0, GL_RED, 800, 800, 0, GL_RED, GL_UNSIGNED_BYTE, g);
  free(g);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
  draw->prog_circle  = vertex_fragment_shader(draw_circle_vert,  draw_circle_frag);
  draw->prog_arrow   = vertex_fragment_shader(draw_arrow_vert,   draw_arrow_frag);
  draw->prog_line    = vertex_fragment_shader(draw_line_vert,    draw_line_frag);
  draw->prog_buttons = vertex_fragment_shader(draw_buttons_vert, draw_buttons_frag);
  draw->prog_help    = vertex_fragment_shader(draw_help_vert,    draw_help_frag);
  glUseProgram(draw->prog_buttons);
  glUniform1i(glGetUniformLocation(draw->prog_buttons, "deselected"), 1);
  glUniform1i(glGetUniformLocation(draw->prog_buttons, "selected"), 2);
  draw->u_mode = glGetUniformLocation(draw->prog_buttons, "mode");
  glUseProgram(0);
  glDisable(GL_DEPTH_TEST);
  glEnable(GL_SCISSOR_TEST);
  glEnable(GL_BLEND);
  glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);
  return draw;
}

struct {
  graph_mode current_mode;
  int active;
  graph_designer *designer[4];
  graph_draw *draw;
  double x, y;
} S;

void keycb(GLFWwindow *window, int key, int scancode, int action, int mods)
{
  glfwSetWindowShouldClose(window, GL_TRUE);
  (void) key;
```

```
  (void) scancode;
  (void) action;
  (void) mods;
}

void motioncb(GLFWwindow *window, double x, double y)
{
  y = 800 - 1 - y;
  designer_mouse_move(S.designer[S.active], x - 240, y);
  S.x = x;
  S.y = y;
  (void) window;
}

void buttoncb(GLFWwindow *window, int button, int action, int mods)
{
  if (button == GLFW_MOUSE_BUTTON_LEFT)
  {
    if (S.x < 240)
    {
      int active = 4 - S.y / 200;
      if (active < 0)
        active = 0;
      if (active > 3)
        active = 3;
      designer_leave_mode(S.designer[S.active]);
      S.active = active;
      designer_enter_mode(S.designer[S.active], S.current_mode);
    }
    else if (S.x > 1040)
    {
      int mode = 8 - S.y / 100;
      if (mode < 0)
        mode = 0;
      if (mode > 7)
        mode = 7;
      designer_leave_mode(S.designer[S.active]);
      designer_enter_mode(S.designer[S.active], S.current_mode = graph_mode(mode
          ↪ ));
    }
    else
    {
      double x = S.x - 240;
      if (action == GLFW_PRESS)
        designer_mouse_down(S.designer[S.active], x, S.y);
      if (action == GLFW_RELEASE)
        designer_mouse_up(S.designer[S.active], x, S.y);
    }
  }
  (void) window;
  (void) mods;
}

int main()
{
  glfwInit();
  glfwWindowHint(GLFW_CLIENT_API, GLFW_OPENGL_API);
```

```
  glfwWindowHint(GLFW_CONTEXT_VERSION_MAJOR, 3);
  glfwWindowHint(GLFW_CONTEXT_VERSION_MINOR, 3);
  glfwWindowHint(GLFW_OPENGL_PROFILE, GLFW_OPENGL_CORE_PROFILE);
  glfwWindowHint(GLFW_OPENGL_FORWARD_COMPAT, GL_TRUE);
  glfwWindowHint(GLFW_RESIZABLE, GL_FALSE);
  GLFWwindow *window = glfwCreateWindow(1280, 800, "graphgrow", 0, 0);
  glfwMakeContextCurrent(window);
  glewExperimental = GL_TRUE;
  glewInit();
  glGetError(); // discard common error from glew
  glfwSetKeyCallback(window, keycb);
  glfwSetCursorPosCallback(window, motioncb);
  glfwSetMouseButtonCallback(window, buttoncb);

  S.designer[0] = designer_new(0);
  S.designer[1] = designer_new(1);
  S.designer[2] = designer_new(2);
  S.designer[3] = designer_new(3);
  designer_enter_mode(S.designer[S.active = 0], S.current_mode = mode_help);
  S.draw = draw_new();

  lo_address at = lo_address_new("255.255.255.255", "6060");
  lo_address vt = lo_address_new("255.255.255.255", "6061");

  int frame = 0;
  while (1)
  {
    glfwPollEvents();
    if (glfwWindowShouldClose(window)) { break; }

    glScissor(0, 0, 240, 200);
    glViewport(20, 0, 200, 200);
    draw_designer(S.draw, S.designer[3], 3 == S.active, false);

    glScissor(0, 200, 240, 200);
    glViewport(20, 200, 200, 200);
    draw_designer(S.draw, S.designer[2], 2 == S.active, false);

    glScissor(0, 400, 240, 200);
    glViewport(20, 400, 200, 200);
    draw_designer(S.draw, S.designer[1], 1 == S.active, false);

    glScissor(0, 600, 240, 200);
    glViewport(20, 600, 200, 200);
    draw_designer(S.draw, S.designer[0], 0 == S.active, false);

    glScissor(240, 0, 800, 800);
    glViewport(240, 0, 800, 800);
    draw_designer(S.draw, S.designer[S.active], true, true);
    if (S.current_mode == mode_help)
      draw_help(S.draw, colours[S.active]);

    glScissor(1040, 0, 240, 800);
    glViewport(1040, 0, 240, 800);
    draw_buttons(S.draw, colours[S.active], S.current_mode);

    glfwSwapBuffers(window);
```

```
    GLint e = glGetError();
    if (e)
      fprintf(stderr, "OpenGL ERROR %d\n", e);

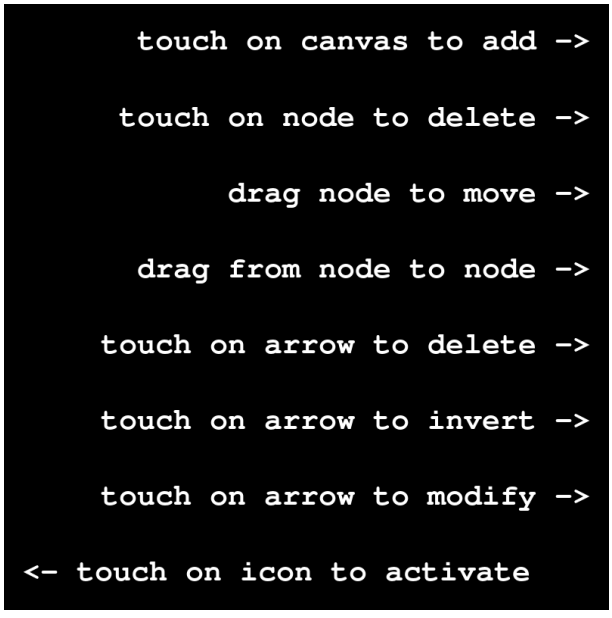
    audio_control a;
    memset(&a, 0, sizeof(a));
    for (int i = 0; i < 4; ++i)
      for (int k = 0; k < 8 && k < S.designer[i]->links.size(); ++k)
      {
        graph_link *l = S.designer[i]->links[k];
        int j = l->target;
        double dx = l->x2 - l->x1;
        double dy = l->y2 - l->y1;
        double ox = l->x2 + l->x1;
        a.scale[i][j][k] = sqrt(dx * dx + dy * dy) / 600;
        a.pan  [i][j][k] = (0.5 * ox - 400) / 400 * 0.5 + 0.5;
        a.level[i][j][k] = 1;
      }
    lo_blob ablob = lo_blob_new(sizeof(a), &a);
    if (ablob)
    {
      if (lo_send(at, "/audio", "b", ablob) == -1)
        fprintf(stderr, "OSC error %d: %s\n", lo_address_errno(at), ↙
            ↳ lo_address_errstr(at));
      lo_blob_free(ablob);
    }
    else
      fprintf(stderr, "OSC error: couldn't lo_blob_new\n");

    video_control v;
    memset(&v, 0, sizeof(v));
    v.active = S.active;
    for (int i = 0; i < 4; ++i)
    {
      v.count[i] = S.designer[i]->links.size();
      for (int j = 0; j < S.designer[i]->links.size() && j < 8; ++j)
      {
        graph_link *l = S.designer[i]->links[j];
        double dx = l->x2 - l->x1;
        double dy = l->y2 - l->y1;
        if (l->flipped)
        {
          dx = -dx;
          dy = -dy;
        }
        double ox = (l->x2 + l->x1) / 2;
        double oy = (l->y2 + l->y1) / 2;
        double s  = sqrt(dx * dx + dy * dy);
        dx /= 600;
        dy /= 600;
        s  /= 600;
        ox -= 400;
        oy -= 400;
        ox /= 600;
        oy /= 600;
        oy = -oy;
```

```
          v.source[i][j] = l->target;
          v.scale [i][j] = s;
          glm::mat3 transform = glm::mat3(float(dx), float(dy), float(ox), float(-↙
              ↳ dy), float(dx), float(oy), 0.0f, 0.0f, 1.0f);
1325      transform = glm::inverse(transform);
          for (int p = 0; p < 3; ++p)
            for (int q = 0; q < 3; ++q)
              v.transform[i][j][p][q] = transform[p][q];
        }
1330    }
      lo_blob vblob = lo_blob_new(sizeof(v), &v);
      if (vblob)
      {
        if (lo_send(vt, "/video", "b", vblob) == -1)
1335      fprintf(stderr, "OSC error %d: %s\n", lo_address_errno(vt), ↙
              ↳ lo_address_errstr(vt));
        lo_blob_free(vblob);
      }
      else
        fprintf(stderr, "OSC error: couldn't lo_blob_new\n");
1340
      frame++;
    }

    glfwDestroyWindow(window);
1345  glfwTerminate();
    return 0;
}
```

40 graphgrow3/iface/help.png



41 graphgrow3/iface/iface.xcf

41.1 Layer 0

41.2 Layer 1

41.3 Layer 2

41.4 Layer 3

41.5 Layer 4

41.6 Layer 5

41.7 Layer 6

41.8 Layer 7

41.9 Layer 8

41.10 Layer 9

41.11 Layer 10

41.12 Layer 11

41.13 Layer 12

41.14 Layer 13

41.15 Layer 14

41.16 Layer 15

41.17 Layer 16

41.18 Layer 17

42 graphgrow3/iface/Makefile

```
all: graphgrow-iface selected.raw deselected.raw help.raw

clean:
	-rm graphgrow-iface selected.raw deselected.raw help.raw

graphgrow-iface: graphgrow-iface.cc
	g++ -std=c++11 -Wall -Wextra -pedantic -Wno-variadic-macros -Wno-sign-compare -O3 -march=native -ffast-math -I$(HOME)/opt/include -L$(HOME)/opt/lib -o graphgrow-iface graphgrow-iface.cc -lGL -lGLEW -lglfw -llo

selected.raw: selected.png
	pngtopnm < selected.png | tail -c 192000 > selected.raw

deselected.raw: deselected.png
	pngtopnm < deselected.png | tail -c 192000 > deselected.raw

help.raw: help.png
	pngtopnm < help.png | tail -c 640000 > help.raw
```

43 graphgrow3/iface/README

```
Needs liblo from https://github.com/radarsat1/liblo
Tested with HEAD at 276dc11db2038b44f04fe67cdb425929427a5337
```

44 graphgrow3/iface/selected.png

45 graphgrow3/initial.frag

```
#version 130
uniform float er;
uniform float rho;

in vec2 texCoord;

out vec4 colour;

void main() {
  vec2 p = er * atanh(texCoord * 2.0 - vec2(1.0));
  float l = length(p);
  float n = (log(clamp(l, er * rho, er)) - log(er)) / log(rho);
  colour = vec4(n, 1.0, 0.0, 0.0);
}
```

46 graphgrow3/initial.vert

```
#version 130

out vec2 texCoord;

void main() {
  switch (gl_VertexID) {
    default:
    case 0:
      gl_Position = vec4(-1.0, -1.0, 0.0, 1.0);
      texCoord = vec2(0.0, 0.0);
      break;
    case 1:
```

```
        gl_Position = vec4( 1.0, -1.0, 0.0, 1.0);
        texCoord = vec2(1.0, 0.0);
        break;
      case 2:
        gl_Position = vec4(-1.0,  1.0, 0.0, 1.0);
        texCoord = vec2(0.0, 1.0);
        break;
      case 3:
        gl_Position = vec4( 1.0,  1.0, 0.0, 1.0);
        texCoord = vec2(1.0, 1.0);
        break;
    }
}
```

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Version 3, 29 June 2007

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48 graphgrow3/Main.hs

```
{-# LANGUAGE MultiParamTypeClasses, TypeFamilies, FlexibleContexts, ↙
    ↳ ForeignFunctionInterface #-}
module Main (main) where

import Graphics.UI.Toy.Gtk.Prelude hiding (D, bg, clamp, arrow, size, with)

import qualified Graphics.UI.Gtk        as G
import qualified Graphics.UI.Gtk.OpenGL as G


import Control.Monad (when, replicateM_, forM_)
import Control.Monad.IO.Class (liftIO)
import Data.IORef (IORef, newIORef, readIORef, writeIORef, atomicModifyIORef)

import Data.Colour.RGBSpace (uncurryRGB)
import Data.Colour.RGBSpace.HSV (hsv)
import Data.Colour.SRGB (sRGB, toSRGBBounded)
import Data.Fixed (mod')

import Linear (V2, V3, M33, (!*!), norm, (^-^), inv33)
import Data.Foldable (toList)

import Control.Lens (view)
import Data.Map (Map)
import qualified Data.Map.Strict as M
import qualified Data.Map.Strict.Merge as M
import Data.Maybe (maybeToList)

import System.IO (hFlush, stdout)

import Types
import Audio
import Video

type D = Draggable CairoDiagram -- every thing needs be draggable

mkD :: V2 Double -> CairoDiagram -> D
mkD = mkDraggable

-- things
data Thing = Background {-nextNodeID-}NID D | Node {-isFixedPosition-}Bool NID D↙
    ↳ D | Link LID D D D RID

-- visual representation
bg :: Int -> D
bg r = mkDraggable (r2 (250, 250)) $ (rect 500 500 # fc (blend 0.8 white (↙
    ↳ ruleColour r)))
```

```
node :: Int -> Bool -> V2 Double -> (D, D)
node r fixed p =
    ( mkDraggable p $ shape  5 # lc black # fc col
    , mkDraggable p $ shape 12 # fcA (col `withOpacity` 0.5)
    )
  where col = ruleColour r ; shape = if fixed then square . ((pi/2) *) else circle

link :: Int -> V2 Double -> V2 Double -> (D, D, D)
link r p@(V2 x0 y0) q@(V2 x1 y1) =
    ( mkD pc $ circle 5 # lc black # fc col
    , mkD pa $ arrow # scale 3 # strokeLocTrail # lc black # fc col # rotate a
    , mkD (V2 0 0) $ P p ~~ P q # strokeP # lc col
    )
  where
    col = ruleColour r
    pc@(V2 cx cy) = V2 ((x0+x1)/2) ((y0+y1)/2)
    pa = V2 (cx + 16 * dx) (cy + 16 * dy)
    ux = x1 - x0
    uy = y1 - y0
    a = (realToFrac $ atan2 uy ux) @@ rad
    l = case sqrt (ux * ux + uy * uy) of
      x | x == 0 -> 1
        | otherwise -> x
    dx =   uy / l
    dy = - ux / l
    arrow = (`at` p2(0,0)) . closeTrail . fromVertices . map p2 $ [(-3,-1),(1,-1),(1,-2),(3,0),(1,2),(1,1),(-3,1)]

-- extract diagrams
tDiagram :: Thing -> [D]
tDiagram (Background _ d)   = [d]
tDiagram (Node _ _ d1 d2)   = [d1, d2]  -- d1 is inner core, d2 is outer ring
tDiagram (Link _   d1 d2 d3 _) = [d1, d2, d3]  -- d1 is inner core, d3 is line, d2 is arrow

-- what did a mouse event do
data Act
  = Create NID
  | Delete NID
  | MoveStart NID
  | Moving    NID
  | MoveStop  NID
  | LinkStart        NID  (V2 Double)
  | Linking               (V2 Double)
  | LinkStop (Maybe (NID, (V2 Double)))
  | Adjust LID
  | ReverseLink LID
  | DeleteLink LID

-- what mode are we in
data Mode
  = MMove NID                          -- moving a node
  | MLink NID (V2 Double) (V2 Double) -- creating a link

data State = State (IORef (Map RID (Maybe G.Window, Toy State), IORef (Map RID Video, Map RID Audio))) RID (Maybe Mode) [Thing] Video Audio
```

```
100 -- update links when nodes are moved or deleted
    resort :: [RID] -> State -> State
    resort rs (State gs r m ts _ _) = State gs r m ts' trs adjs
      where
        adjs = (length nodes,
105       [ (i, j, lr, s, x)
          | Link (i, j) _ _ _ lr <- links'
          , let Just p0 = M.lookup i positions
          , let Just p1 = M.lookup j positions
          , let scale = norm (node0Position ^-^ node1Position)
110       , let s = norm (p0 ^-^ p1) / scale
          , let x = (view _x (lerp 0.5 p0 p1 ^-^ node0Position) / scale - 0.5) * 0.5↙
              ↳ + 0.5
          ])
        trs =
          [ (c, scaleFactor, transformMatrix)
115       | Link ij@(i, j) _ _ _ lr <- links'
          , let c = if lr `elem` rs then lr else 0
          , let Just p0 = M.lookup i positions
          , let Just p1 = M.lookup j positions
          , let (scaleFactor, transformMatrix) = linkTransformation p0 p1
120       ]
        nodes = [ n | n@(Node      {}) <- ts ]
        -- strip multiple links between the same pair of nodes (FIXME is this the ↙
            ↳ best way?)
        links = (M.elems . M.fromList) [ (sortPair ij, l) | l@(Link ij _ _ _ _) <- ↙
            ↳ ts ]
        backg = [ b | b@(Background{}) <- ts ]
125     positions = M.fromList [ (i, view dragOffset d) | Node _ i d _ <- nodes ]
        links' =
          [ Link ij d1 d2 d3 c
          | Link ij@(i, j) _ _ _ lr <- links
          , let c = if lr `elem` rs then lr else 0
130       , (d1, d2, d3) <- maybeToList $
              liftA2 (link c) (M.lookup i positions) (M.lookup j positions)
          ]
        ts' = nodes ++ links' ++ backg

135 linkTransformation :: V2 Double -> V2 Double -> (Double, M33 Double)
    linkTransformation p0@(V2 x0 y0) p1@(V2 x1 y1) = (scaleFactor, inv33 matrix)
      where
        scale = norm (node0Position ^-^ node1Position)
        scaleFactor = norm (p0 ^-^ p1) / scale
140     angle = -atan2 (y1 - y0) (x1 - x0)
        translation = (((p0 + p1)^/2) ^-^ ((node0Position + node1Position)^/2)) ^/ ↙
            ↳ scale
        matrix = transformRST angle scaleFactor translation

    transformRST :: Double -> Double -> V2 Double -> M33 Double
145 transformRST a l (V2 x y) = V3 (V3 c s x) (V3 (-s) c y) (V3 0 0 1)
      where
        c = l * cos a
        s = l * sin a

150

    -- mouse handling
```

```
tMouse :: Int -> Maybe Mode -> Maybe (Bool, Int) -> V2 Double -> Thing -> (Maybe Act, [Thing])
-- linking nodes
tMouse _ (Just(MLink j q _))(Just(False, 0)) p t@(Background _ _    ) = (Just $ LinkStop Nothing      , [t]) -- note: Background is the last Thing in the list
tMouse _ (Just(MLink j q _))(Just(False, 0)) p t@(Node fixed i d1 d2) | j /= i && clickInside d2 (P p)     = (Just $ LinkStop (Just (i, p)), [t])
tMouse _ (Just(MLink j q _))(Just(False, 0)) p t                                = (Nothing                        , [t])
tMouse _ (Just(MLink j q _))_                p t                                = (Just $ Linking     p         , [t])
-- adjusting links
tMouse _ Nothing           (Just (True,  0)) p   (Link i d1 d2 d3 r)  | clickInside d1 (P p)              = (Just $ Adjust      i, [Link i d1 d2 d3 (r + 1)])
                                                                     | clickInside d2 (P p)              = (Just $ ReverseLink i, [Link i d2 d1 d3 r])
tMouse _ Nothing           (Just (True,  1)) p   (Link i d1 d2 d3 _)  | clickInside d1 (P p)              = (Just $ DeleteLink  i, [])
-- moving nodes
tMouse _ Nothing         m@(Just (True,  0)) p t@(Node fixed i d1 d2) | clickInside d1 (P p) && not fixed  = (Just $ MoveStart i  , [Node False i (mouseDrag m q d1) (mouseDrag m q d2)])
                                                                     | clickInside d2 (P p)              = (Just $ LinkStart   i (view _2 q), [])
```

```
                                                                    ↳ dragOffset↙
                                                                    ↳  d1)↙
                                                                    ↳ , [t↙
                                                                    ↳ ]) ↙
                                                                    ↳
                                                                    ↳ where↙
                                                                    ↳  q =↙
                                                                    ↳  ↙
                                                                    ↳ clamp↙
                                                                    ↳ ' p
tMouse _ (Just(MMove j)) m@(Just (False, 0)) p   (Node False i d1 d2) | j == i ↙
    ↳                              = (Just $ MoveStop  i   , [Node False i (↙
    ↳ mouseDrag m q d1) (mouseDrag m q d2)]) where q = clamp' p
tMouse _ (Just(MMove j)) m                    p   (Node False i d1 d2) | j == i ↙
    ↳                              = (Just $ Moving    i   , [Node False i (↙
    ↳ mouseDrag m q d1) (mouseDrag m q d2)]) where q = clamp' p
-- creating nodes
tMouse c Nothing           (Just (True,  0)) p   (Background i d) ↙
    ↳                                    = (Just $ Create    i   , [uncurry↙
    ↳  (Node False i) (node c False p), Background (i + 1) d])
tMouse _ Nothing           (Just (True,  1)) p   (Node False i d1 d2) | ↙
    ↳ clickInside d1 (P p)               = (Just $ Delete    i   , [])
tMouse _ _currentMode      _mouseEvent       _ t@_thingToTest ↙
    ↳                                          = (Nothing             , [t])

clamp' :: V2 Double -> V2 Double
clamp' (V2 x y) = V2 (c x) (c y) where c z = 5 `max` z `min` 495

-- concatMap until a thing signals something was done, then just copy the rest
tMouses :: Int -> Maybe Mode -> Maybe (Bool, Int) -> V2 Double -> Maybe Act -> [↙
    ↳ Thing] -> (Maybe Act, [Thing])
tMouses _ _ _ _ a@(Just _) ws = (a, ws)
tMouses _ _ _ _ Nothing [] = (Nothing, [])
tMouses c d m p Nothing (w:ws) =
  let (a, ws') = tMouse c d m p w
  in  (ws' ++) `fmap` tMouses c d m p a ws

type instance N State = Double
type instance V State = V2

graph :: IORef (Map RID (Maybe G.Window, Toy State), IORef (Map RID Video, Map ↙
    ↳ RID Audio)) -> RID -> State
graph gs r = State gs r Nothing
  [ uncurry (Node True 0) (node r True node0Position)
  , uncurry (Node True 1) (node r True node1Position)
  , Background 2 (bg r)
  ] [] (2, [])

node0Position :: V2 Double
node0Position = V2 100 250

node1Position :: V2 Double
node1Position = V2 400 250

instance Interactive Gtk State where
  mouse _m _p s@(State g0 c0 _ _ _ _) = do
    rs <- (M.keys . fst) `fmap` readIORef g0
```

```
    s' <- simpleMouse ( \m p (State g c d ts trs adjs) -> resort rs $ case (d, ↙
        ↳ tMouses c d m p Nothing ts) of
        -- moving nodes
        (Nothing           , (Just (MoveStart i          ), ts'))         -> ↙
            ↳ State g c (Just (MMove i)) ts' trs adjs
        (Just (MMove j)    , (Just (Moving    i          ), ts')) | j == i -> ↙
            ↳ State g c (Just (MMove i)) ts' trs adjs
        (Just (MMove j)    , (Just (MoveStop  i          ), ts')) | j == i -> ↙
            ↳ State g c Nothing          ts' trs adjs
        -- linking nodes
        (Nothing,            (Just (LinkStart i p        ), ts'))         -> ↙
            ↳ State g c (Just (MLink i p p)) ts' trs adjs
        (Just (MLink j q _), (Just (Linking     p        ), ts'))         -> ↙
            ↳ State g c (Just (MLink j q p)) ts' trs adjs
        (Just (MLink j q _), (Just (LinkStop (Just (i, p))), ts')) | j /= i -> ↙
            ↳ State g c Nothing (uncurry3 (Link (j, i)) (link c q p) c : ts') ↙
            ↳ trs adjs
        (Just (MLink j q _), (Just (LinkStop Nothing      ), ts'))         -> ↙
            ↳ State g c Nothing ts' trs adjs
        -- everything else
        (_, (_, ts')) -> State g c Nothing ts' trs adjs
      ) _m _p s
    case s' of
      State g1 _ _ _ trs adjs -> do
        trsref <- snd `fmap` readIORef g1
        (trsmap, adjmap) <- readIORef trsref
        writeIORef trsref (M.insert c0 trs trsmap, M.insert c0 adjs adjmap)
    return s'

instance Diagrammable Cairo V2 Double Any State where
  diagram (State _ _ m ts _ _) = mconcat . map diagram $ modeDiagram ++ ↙
      ↳ concatMap tDiagram ts
    where
      modeDiagram = case m of
        Just (MLink _ p q) -> [mkD (V2 0 0) $ P p ~~ P q # strokeP # lc black]
        _ -> []

instance GtkDisplay State where
  display = displayDiagram diagram

main :: IO ()
main = do
  G.initGUI
  transforms <- newIORef (M.empty, M.empty)
  graphsRef <- newIORef (M.empty, transforms)
  window <- G.windowNew
  G.onDestroy window G.mainQuit
  G.set window [G.windowTitle G.:= "GG"]
  G.windowSetDefaultSize window 10 10
  G.windowSetTypeHint window G.WindowTypeHintDialog
  box <- G.hButtonBoxNew

  vis <- videoNew (fst <$> readIORef transforms)
  vbutton <- G.buttonNewWithLabel "V"
  vbutton `G.on` G.buttonActivated $ do
    G.windowPresent vis
    return ()
```

```
  G.containerAdd box vbutton

  (audio, audioQuit) <- audioNew (snd <$> readIORef transforms)
  G.timeoutAddFull (audio >> return True) G.priorityDefaultIdle 100

  button <- G.buttonNewWithLabel "+"
  button `G.on` G.buttonActivated $ do
    graphs <- fst `fmap` readIORef graphsRef
    let r = maybe 0 (succ . fst . fst) (M.maxViewWithKey graphs)
        gcol = uncurryRGB G.Color $ toSRGBBounded (ruleColour r)
    g <- newToy (graph graphsRef r)
    writeIORef graphsRef (M.insert r (Nothing, g) graphs, transforms)
    b <- G.buttonNew
    forM_ [G.StateNormal, G.StateActive, G.StatePrelight, G.StateSelected, G.StateInsensitive] $ \s ->
      G.widgetModifyBg b s gcol
    b `G.on` G.buttonActivated $ do
      graphs <- fst `fmap` readIORef graphsRef
      case M.lookup r graphs of
        Just (Just w,  g) -> G.windowPresent{-WithTime-} w
        Just (Nothing, g) -> do
          w <- G.windowNew
          w `G.on` G.deleteEvent $ do
            liftIO $ G.widgetHide w
            return True
          writeIORef graphsRef (M.insert r (Just w, g) graphs, transforms)
          G.windowSetGeometryHints w (Nothing `asTypeOf` Just w) (Just (500, 500)) (Just (500, 500)) Nothing Nothing Nothing
          G.set w [G.containerChild G.:= toyWindow g, G.windowTitle G.:= "GG#" ++ show r]
          G.widgetShowAll w
        _ -> return ()
    G.containerAdd box b
    G.widgetShowAll window

  G.containerAdd box button
  G.containerAdd window box
  G.widgetShowAll window

  G.mainGUI
  audioQuit

phi :: Double
phi = (sqrt 5 + 1) / 2

ruleColour :: Int -> Colour Double
ruleColour r = uncurryRGB sRGB $ hsv (360 * ((phi * fromIntegral r) `mod'` 1)) 1 1
```

49 graphgrow3/pitchshift~.pd

```
#N canvas 77 85 502 515 10;
#X obj 113 278 cos~;
#X obj 113 305 *~;
#X obj 113 334 +~;
#X obj 282 196 wrap~;
#X obj 282 288 cos~;
```

```
#X obj 282 315 *~;
#X obj 282 169 +~ 0.5;
#X obj 113 226 -~ 0.5;
#X obj 113 252 *~ 0.5;
#X obj 282 227 -~ 0.5;
#X obj 282 260 *~ 0.5;
#X obj 114 110 phasor~;
#X obj 115 59 inlet~;
#X obj 345 290 vd~ \$0-del;
#X obj 176 278 vd~ \$0-del;
#X obj 112 361 outlet~;
#X obj 13 7 inlet~;
#X obj 345 261 +~ 2;
#X obj 176 252 +~ 2;
#X obj 345 228 *~ 50;
#X obj 176 226 *~ 50;
#X obj 114 84 expr~ (1-exp($v1*0.05776))*1000.0/$f2;
#X obj 379 35 loadbang;
#X msg 376 61 20;
#X obj 12 34 delwrite~ \$0-del 25;
#X connect 0 0 1 0;
#X connect 1 0 2 0;
#X connect 2 0 15 0;
#X connect 3 0 9 0;
#X connect 3 0 19 0;
#X connect 4 0 5 0;
#X connect 5 0 2 1;
#X connect 6 0 3 0;
#X connect 7 0 8 0;
#X connect 8 0 0 0;
#X connect 9 0 10 0;
#X connect 10 0 4 0;
#X connect 11 0 7 0;
#X connect 11 0 6 0;
#X connect 11 0 20 0;
#X connect 12 0 21 0;
#X connect 13 0 5 1;
#X connect 14 0 1 1;
#X connect 16 0 24 0;
#X connect 17 0 13 0;
#X connect 18 0 14 0;
#X connect 19 0 17 0;
#X connect 20 0 18 0;
#X connect 21 0 11 0;
#X connect 22 0 23 0;
#X connect 23 0 21 1;
#X connect 23 0 19 1;
#X connect 23 0 20 1;
```

50 graphgrow3/README.md

```
# GraphGrow3

graph-directed iterated function system fractals

node editor with audiovisualisation
```

```
## Requirements

At runtime you need Pure-data executables 'pd' and 'pdsend' which should be in
your 'PATH'. Configure your '~/.pdrc' so that the correct audio device and
sample rate is set automatically. 'pd' will listen on network port '6060' to
receive messages from 'graphgrow3'. To build 'graphgrow3' you need 'ghc-8.0.1'
(other 'ghc' versions are untested) and recent 'cabal-install' (supporting
sandboxes). The visualisation uses OpenGL, hardware acceleration essential.

## Quick start

    git clone https://code.mathr.co.uk/toy-interface.git
    git clone https://code.mathr.co.uk/toy-diagrams.git
    git clone https://code.mathr.co.uk/toy-gtk.git
    git clone https://code.mathr.co.uk/toy-gtk-diagrams.git
    git clone https://code.mathr.co.uk/graphgrow.git
    cd graphgrow/graphgrow3
    cabal sandbox init
    cabal sandbox add-source ../../toy-*/
    cabal install
    .cabal-sandbox/bin/graphgrow3

## Usage

On startup the visualisation window "GG#V" is displayed, along with the "GG"
toolbar. The "V" button reshows the visualisation if it is closed. The "+"
button adds a new rule, which are colour coded. Clicking the coloured rule
buttons opens the editor for each rule. All windows apart from the "GG" toolbar
can be closed and re-opened later.

In the rule editor, left-click on empty space creates a new node. Nodes can be
left-mouse dragged by their centers to move them, and nodes are deleted with a
right-click. Left-mouse dragging between the outer rings of two nodes creates
a link. Links are deleted by right-clicking on their center. The direction of
a link can be reversed by left-clicking on the arrow. Left-clicking on the
center of a link changes the target rule for that link, cycling through the
available rules.

The square nodes are fixed, and correspond to the identity transformation (if
there were a link between them, but see bugs below).

## Bugs

Links longer than a bit less than one unit (the length between the two fixed
square nodes) slow down rendering a lot and might cause a denial of service to
your desktop session.

Adding more than 4 rules may break visualisation.

Adding more than 8 rules may break sonification.

Untested on anything apart from GNU/Linux/Debian/Testing/amd64.
```

51 graphgrow3/rule~.pd

```
#N canvas 3 113 450 300 10;
#X obj 44 200 compress~ 48;
```

```
#X obj 76 55 noise~;
#X obj 76 77 *~ 1e-06;
#X obj 43 175 lop~ 5000;
#X obj 43 153 hip~ 25;
#X obj 321 23 loadbang;
#X obj 321 45 f \$1;
#X obj 73 228 throw~ OUT-l;
#X obj 44 97 s~ RULE-\$1-l;
#X obj 43 131 catch~ RULE-\$1-l;
#X obj 167 176 lop~ 5000;
#X obj 167 154 hip~ 25;
#X obj 167 132 catch~ RULE-\$1-r;
#X obj 174 228 throw~ OUT-r;
#X obj 183 68 noise~;
#X obj 183 90 *~ 1e-06;
#X obj 151 110 s~ RULE-\$1-r;
#X obj 164 200 compress~ 48;
#X obj 321 89 + 2;
#X obj 321 67 * 0.1;
#X obj 154 46 delread~ RULE-\$1-r 2;
#X obj 43 24 delread~ RULE-\$1-l 2;
#X obj 128 279 delwrite~ RULE-\$1-r 5;
#X obj 42 255 delwrite~ RULE-\$1-l 5;
#X connect 0 0 7 0;
#X connect 0 0 23 0;
#X connect 1 0 2 0;
#X connect 2 0 8 0;
#X connect 3 0 0 0;
#X connect 4 0 3 0;
#X connect 5 0 6 0;
#X connect 6 0 19 0;
#X connect 9 0 4 0;
#X connect 10 0 17 0;
#X connect 11 0 10 0;
#X connect 12 0 11 0;
#X connect 14 0 15 0;
#X connect 15 0 16 0;
#X connect 17 0 13 0;
#X connect 17 0 22 0;
#X connect 18 0 20 0;
#X connect 18 0 21 0;
#X connect 19 0 18 0;
#X connect 20 0 16 0;
#X connect 21 0 8 0;
```

52 graphgrow3/Setup.hs

```
import Distribution.Simple
main = defaultMain
```

53 graphgrow3/step.frag

```
#version 130
#define MAXCOUNT 16
uniform float er;
uniform int count;
```

```
uniform mat3 transform[MAXCOUNT];
uniform float scaleFactor[MAXCOUNT];
uniform float source[MAXCOUNT];
uniform float layer;

uniform sampler2DArray src;

in vec2 texCoord;

out vec4 colour;

void main() {
  vec2 p0 = er * atanh(texCoord * 2.0 - vec2(1.0));
  float escape = -1000.0;
  float factor = 1.0;
  for (int i = 0; i < count && i < MAXCOUNT; ++i) {
    vec3 p = transform[i] * vec3(p0, 1.0);
    vec2 q = p.xy / p.z;
    float l = length(q);
    if (l < er) {
      vec2 z = texture(src, vec3((tanh(clamp(q / er, -vec2(4.0), vec2(4.0))) + ↙
          ↳ vec2(1.0)) / 2.0, source[i])).xy;
      if (escape < z.x) { escape = z.x; factor = 1.0/scaleFactor[i] * z.y; }
    }
  }
  escape += 1.0;
  vec2 z = texture(src, vec3(texCoord, layer)).xy;
  if (escape > z.x) {
    z.x = escape;
    z.y = factor;
  }
  colour = vec4(z, 0.0, 0.0);
}
```

54 graphgrow3/step.vert

```
#version 130

out vec2 texCoord;

void main() {
  switch (gl_VertexID) {
    default:
    case 0:
      gl_Position = vec4(-1.0, -1.0, 0.0, 1.0);
      texCoord = vec2(0.0, 0.0);
      break;
    case 1:
      gl_Position = vec4( 1.0, -1.0, 0.0, 1.0);
      texCoord = vec2(1.0, 0.0);
      break;
    case 2:
      gl_Position = vec4(-1.0,  1.0, 0.0, 1.0);
      texCoord = vec2(0.0, 1.0);
      break;
    case 3:
      gl_Position = vec4( 1.0,  1.0, 0.0, 1.0);
```

```
      texCoord = vec2(1.0, 1.0);
      break;
  }
}
```

55 graphgrow3/Types.hs

```
module Types where

import Data.Foldable (toList)
import Linear (M33)

-- rule, node and link ids
type RID = Int
type NID = Int
type LID = (NID, NID)

swapPair :: (a, b) -> (b, a)
swapPair (a, b) = (b, a)

sortPair :: Ord a => (a, a) -> (a, a)
sortPair ab@(a, b) = if a <= b then ab else (b, a)

uncurry3 :: (a -> b -> c -> r) -> (a, b, c) -> r
uncurry3 f (a, b, c) = f a b c

toLists :: M33 a -> [[a]]
toLists = map toList . toList
```

56 graphgrow3/video/.gitignore

```
graphgrow-video
graphgrow-video-test
```

57 graphgrow3/video/graphgrow-video.cc

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

#include <GL/glew.h>
#include <GLFW/glfw3.h>

#include <lo/lo.h>

// 1428 bytes < 1500 MTU
struct control
{
  int32_t active;
  int32_t count    [4];
  int32_t source   [4][8];
  float   scale    [4][8];
```

```
  float   transform[4][8][3][3];
};

#define FPS 30
#define WIDTH 1920
#define HEIGHT 1080
#define SKIP 1
#define SCALE 1
#define MIPMAP 3
#define QUALITY 10

static struct {
  int running;
  struct control control;
  // graphics
  int which;
  GLuint fbo[11];
  GLuint program[5];
  GLint p0which;
  GLint p0quality;
  GLint p0anim;
  GLint p0source;
  GLint p0count;
  GLint p1which;
  GLint p1quality;
  GLint p1layer;
  GLint p3count;
  GLint p3p;
  GLint p3q;
  GLint p4icount;
  GLint p4hcount;
  GLuint pbo[3];
} S;

void errorcb(int num, const char *msg, const char *path)
{
  fprintf(stderr, "liblo server error %d in path %s: %s\n", num, path, msg);
}

int videocb(const char *path, const char *types, lo_arg **argv, int argc, void *↙
    ↳ message, void *user_data)
{
  const int bytes = sizeof(S.control);
  int   size =  argv[0]->blob.size;
  void *data = &argv[0]->blob.data;
  if (size == bytes)
    memcpy(&S.control, data, bytes);
  return 0;
  (void) path;
  (void) types;
  (void) argc;
  (void) message;
  (void) user_data;
}

int quitcb(const char *path, const char *types, lo_arg **argv, int argc, void *↙
    ↳ message, void *user_data)
```

```
{
  S.running = 0;
  return 0;
  (void) path;
  (void) types;
  (void) argv;
  (void) argc;
  (void) message;
  (void) user_data;
}

static const char *step_vert =
"#version 330 core\n"
"layout(location = 0) in vec2 pos;\n"
"layout(location = 1) in vec2 tc;\n"
"out vec2 coord;\n"
"void main() {\n"
"  gl_Position = vec4(pos, 0.0, 1.0);\n"
"  coord = vec2(tc.x, 1.0 - tc.y);\n"
"}\n"
;

static const char *step_frag =
"#version 330 core\n"
"#define MAXCOUNT 8\n"
"uniform sampler2DArray which;\n"
"uniform int quality;\n"
"uniform int layer;\n"
"uniform int count;\n"
"uniform mat3 transform[MAXCOUNT];\n"
"uniform int source[MAXCOUNT];\n"
"in vec2 coord;\n"
"layout(location = 0) out vec3 colour;\n"
"const vec3[4] shade = vec3[4]\n"
"  ( vec3(1.00, 0.95, 0.90)\n"
"  , vec3(0.95, 1.00, 0.90)\n"
"  , vec3(0.90, 0.95, 1.00)\n"
"  , vec3(0.95, 0.90, 1.00)\n"
"  );\n"
"vec2 fromSquare(vec2 z) {\n"
"  return clamp(atanh(2.0 * z - vec2(1.0)), -4.0, 4.0);\n"
"}"
"vec2 toSquare(vec2 z) {\n"
"  return (tanh(clamp(z, -4.0, 4.0)) + vec2(1.0)) / 2.0;\n"
"}\n"
"float gain(vec2 z, vec2 z0) {\n"
"  vec4 d0 = vec4(dFdx(z), dFdy(z));\n"
"  vec4 d1 = vec4(dFdx(z0), dFdy(z0));\n"
"  return dot(d1,d1) / dot(d0, d0);\n"
"}\n"
"vec3 lookup(vec2 z, vec2 z0, float l) {\n"
"  vec2 w = toSquare(z);\n"
"  return gain(z, z0) * texture(which, vec3(w, l)).rgb;\n"
"}\n"
"void main() {\n"
"  vec3[4] levels = vec3[4]\n"
"    ( texelFetch(which, ivec3(0,0,0), quality).rgb\n"
```

```
"     , texelFetch(which, ivec3(0,0,1), quality).rgb\n"
"     , texelFetch(which, ivec3(0,0,2), quality).rgb\n"
"     , texelFetch(which, ivec3(0,0,3), quality).rgb\n"
"     );\n"
"   float[4] level = float[4]\n"
"     ( max(max(levels[0].r, levels[0].g), levels[0].b)\n"
"     , max(max(levels[1].r, levels[1].g), levels[1].b)\n"
"     , max(max(levels[2].r, levels[2].g), levels[2].b)\n"
"     , max(max(levels[3].r, levels[3].g), levels[3].b)\n"
"     );\n"
"   vec2 z = fromSquare(coord);\n"
"   vec3 total = vec3(0.001);\n"
"   for (int i = 0; i < count && i < MAXCOUNT; ++i) {\n"
"     vec3 w = transform[i] * vec3(z, 1.0);\n"
"     total += shade[source[i]] * lookup(w.xy / w.z, coord, float(source[i])) / level[source[i]];\n"
"   }\n"
"   colour = clamp(total, 0.0, 16777216.0);\n"
"}\n"
;

static const char *show_vert =
"#version 330 core\n"
"uniform int quality;\n"
"uniform float aspect;\n"
"layout(location = 0) in vec2 pos;\n"
"layout(location = 1) in vec2 tc;\n"
"out vec2 coord;\n"
"void main() {\n"
"   gl_Position = vec4(pos, 0.0, 1.0);\n"
"   coord = 2.0 * vec2((tc.x - 0.5), (0.5 - tc.y) / aspect);\n"
"}\n"
;

static const char *show_frag =
"#version 330 core\n"
"uniform sampler2DArray which;\n"
"uniform float level;\n"
"uniform int layer;\n"
"in vec2 coord;\n"
"layout(location = 0) out vec4 colour;\n"
"vec2 toSquare(vec2 z) {\n"
"   return (tanh(clamp(z, -4.0, 4.0)) + vec2(1.0)) / 2.0;\n"
"}\n"
"void main() {\n"
"   vec3 c = texture(which, vec3(toSquare(coord), float(layer))).rgb;\n"
"   colour = vec4(c, dot(vec3(1.0 / 3.0), c));\n"
"}\n"
;

static const char *tone_vert =
"#version 330 core\n"
"layout(location = 0) in vec2 pos;\n"
"layout(location = 1) in vec2 tc;\n"
"out vec2 coord;\n"
"void main() {\n"
"   gl_Position = vec4(pos, 0.0, 1.0);\n"
```

```
    "  coord = vec2(tc.x, tc.y);\n"
    "}\n"
    ;

    static const char *tone_frag =
    "#version 330 core\n"
    "uniform sampler2D source;\n"
    "in vec2 coord;\n"
    "layout(location = 0) out vec4 colour;\n"
    "void main() {\n"
    "  vec4 v = texture(source, coord);\n"
    "  colour = vec4(pow(v.a, 4.0) * v.rgb / max(max(v.r, v.g), v.b), 1.0);\n"
    "}\n"
    ;

    static const char *sort_comp =
    "#version 440 core\n"
    "layout(local_size_x = 1024) in;\n"
    "layout(std430, binding = 0) buffer src {\n"
    "  restrict readonly float srcdata[];\n"
    "};\n"
    "layout(std430, binding = 1) buffer dst {\n"
    "  restrict writeonly float dstdata[];\n"
    "};\n"
    "uniform uint count;\n"
    "uniform uint p;\n"
    "uniform uint q;\n"
    "void main() {\n"
    "  uint i = gl_GlobalInvocationID.x;\n"
    "  uint d = 1u << (p - q);\n"
    "  if ((i & d) == 0 && i < count) {\n"
    "    float a = srcdata[i];\n"
    "    if ((i | d) < count) {\n"
    "      bool up = ((i >> p) & 2) == 0;\n"
    "      float b = srcdata[i | d];\n"
    "      if ((a > b) == up) {\n"
    "        float t = a; a = b; b = t;\n"
    "      }\n"
    "      dstdata[i | d] = b;\n"
    "    }\n"
    "    dstdata[i] = a;\n"
    "  }\n"
    "}\n"
    ;

    static const char *look_comp =
    "#version 440 core\n"
    "layout(local_size_x = 1024) in;\n"
    "layout(std430, binding = 0) buffer img {\n"
    "  restrict readonly float imgdata[];\n"
    "};\n"
    "layout(std430, binding = 1) buffer hst {\n"
    "  restrict readonly float hstdata[];\n"
    "};\n"
    "layout(std430, binding = 2) buffer dst {\n"
    "  restrict writeonly float dstdata[];\n"
    "};\n"
```

```
    "uniform uint icount;\n"
    "uniform uint hcount;\n"
    "void main() {\n"
    "  uint i = gl_GlobalInvocationID.x;\n"
    "  if (i < icount) {\n"
    "    float x = imgdata[4 * i + 3];\n"
    "    uint l = 0;\n"
    "    uint r = hcount;\n"
    "    uint m = (l + r) / 2;\n"
    "    for (uint p = 0; p < 24; ++p) {\n"
    "      if (r < l + 64) {\n"
    "        break;\n"
    "      }\n"
    "      float y = hstdata[m];\n"
    "      if (x < y) {\n"
    "        r = m;\n"
    "        m = (l + r) / 2;\n"
    "        continue;\n"
    "      } else if (x > y) {\n"
    "        l = m;\n"
    "        m = (l + r) / 2;\n"
    "        continue;\n"
    "      } else {\n"
    "       break;\n"
    "      }\n"
    "    }\n"
    "    dstdata[4 * i + 0] = imgdata[4 * i + 0];\n"
    "    dstdata[4 * i + 1] = imgdata[4 * i + 1];\n"
    "    dstdata[4 * i + 2] = imgdata[4 * i + 2];\n"
    "    dstdata[4 * i + 3] = float(m) / float(hcount);\n"
    "  }\n"
    "}\n"
    ;

  static void debug_program(GLuint program, const char *name) {
    if (program) {
      GLint linked = GL_FALSE;
      glGetProgramiv(program, GL_LINK_STATUS, &linked);
      if (linked != GL_TRUE) {
        fprintf(stderr, "%s: OpenGL shader program link failed\n", name);
      }
      GLint length = 0;
      glGetProgramiv(program, GL_INFO_LOG_LENGTH, &length);
      char *buffer = (char *) malloc(length + 1);
      glGetProgramInfoLog(program, length, 0, buffer);
      buffer[length] = 0;
      if (buffer[0]) {
        fprintf(stderr, "%s: OpenGL shader program info log\n", name);
        fprintf(stderr, "%s\n", buffer);
      }
      free(buffer);
      assert(linked == GL_TRUE);
    } else {
      fprintf(stderr, "%s: OpenGL shader program creation failed\n", name);
    }
  }
```

```
static void debug_shader(GLuint shader, GLenum type, const char *name) {
  const char *tname = 0;
  switch (type) {
    case GL_VERTEX_SHADER:   tname = "vertex";   break;
    case GL_FRAGMENT_SHADER: tname = "fragment"; break;
    case GL_COMPUTE_SHADER:  tname = "compute";  break;
    default:                 tname = "unknown";  break;
  }
  if (shader) {
    GLint compiled = GL_FALSE;
    glGetShaderiv(shader, GL_COMPILE_STATUS, &compiled);
    if (compiled != GL_TRUE) {
      fprintf(stderr, "%s: OpenGL %s shader compile failed\n", name, tname);
    }
    GLint length = 0;
    glGetShaderiv(shader, GL_INFO_LOG_LENGTH, &length);
    char *buffer = (char *) malloc(length + 1);
    glGetShaderInfoLog(shader, length, 0, buffer);
    buffer[length] = 0;
    if (buffer[0]) {
      fprintf(stderr, "%s: OpenGL %s shader info log\n", name, tname);
      fprintf(stderr, "%s\n", buffer);
    }
    free(buffer);
    assert(compiled == GL_TRUE);
  } else {
    fprintf(stderr, "%s: OpenGL %s shader creation failed\n", name, tname);
  }
}

static void compile_shader(GLint program, GLenum type, const char *name, const ↙
    ↳ GLchar *source) {
  GLuint shader = glCreateShader(type);
  glShaderSource(shader, 1, &source, 0);
  glCompileShader(shader);
  debug_shader(shader, type, name);
  glAttachShader(program, shader);
  glDeleteShader(shader);
}

static GLint compile_program(const char *name, const GLchar *vert, const GLchar ↙
    ↳ *frag) {
  GLint program = glCreateProgram();
  if (vert) { compile_shader(program, GL_VERTEX_SHADER   , name, vert); }
  if (frag) { compile_shader(program, GL_FRAGMENT_SHADER, name, frag); }
  glLinkProgram(program);
  debug_program(program, name);
  return program;
}

static GLint compile_compute(const char *name, const GLchar *comp) {
  GLint program = glCreateProgram();
  if (comp) { compile_shader(program, GL_COMPUTE_SHADER, name, comp); }
  glLinkProgram(program);
  debug_program(program, name);
  return program;
}
```

```
static void key_press_handler(GLFWwindow *window, int key, int scancode, int ↙
    ↳ action, int mods) {
  (void) key;
  (void) scancode;
  (void) action;
  (void) mods;
  glfwSetWindowShouldClose(window, GL_TRUE);
}

static GLFWwindow *create_window(int major, int minor, int width, int height, ↙
    ↳ const char *title) {
  glfwWindowHint(GLFW_CONTEXT_VERSION_MAJOR, major);
  glfwWindowHint(GLFW_CONTEXT_VERSION_MINOR, minor);
  glfwWindowHint(GLFW_OPENGL_FORWARD_COMPAT, GL_TRUE);
  glfwWindowHint(GLFW_OPENGL_PROFILE, GLFW_OPENGL_CORE_PROFILE);
  glfwWindowHint(GLFW_OPENGL_DEBUG_CONTEXT, GL_TRUE);
  glfwWindowHint(GLFW_RESIZABLE, GL_FALSE);
  glfwWindowHint(GLFW_DECORATED, GL_FALSE);
  GLFWwindow *window = glfwCreateWindow(width, height, title, 0, 0);
  if (! window) {
    fprintf(stderr, "couldn't create window with OpenGL core %d.%d context\n", ↙
        ↳ major, minor);
  }
  assert(window);
  return window;
}

static int debug_error_count = 0;
static void debug_callback(GLenum source, GLenum type, GLuint id, GLenum ↙
    ↳ severity, GLsizei length, const GLchar *message, const GLvoid *user) {
  (void) user;
  (void) length;
  const char *source_str = "unknown";
  switch (source) {
    case GL_DEBUG_SOURCE_API:             source_str = "OpenGL";          break;
    case GL_DEBUG_SOURCE_WINDOW_SYSTEM:   source_str = "window system";   break;
    case GL_DEBUG_SOURCE_SHADER_COMPILER: source_str = "shader compiler"; break;
    case GL_DEBUG_SOURCE_THIRD_PARTY:     source_str = "third party";     break;
    case GL_DEBUG_SOURCE_APPLICATION:     source_str = "application";     break;
    case GL_DEBUG_SOURCE_OTHER:           source_str = "application";     break;
  }
  const char *type_str = "unknown";
  switch (type) {
    case GL_DEBUG_TYPE_ERROR:       type_str = "error";       break;
    case GL_DEBUG_TYPE_DEPRECATED_BEHAVIOR: type_str = "deprecated behavior"; ↙
        ↳ break;
    case GL_DEBUG_TYPE_UNDEFINED_BEHAVIOR:  type_str = "undefined behavior";  ↙
        ↳ break;
    case GL_DEBUG_TYPE_PORTABILITY: type_str = "portability"; break;
    case GL_DEBUG_TYPE_PERFORMANCE: type_str = "performance"; break;
    case GL_DEBUG_TYPE_MARKER:      type_str = "marker";      break;
    case GL_DEBUG_TYPE_PUSH_GROUP:  type_str = "push group";  break;
    case GL_DEBUG_TYPE_POP_GROUP:   type_str = "pop group";   break;
    case GL_DEBUG_TYPE_OTHER:       type_str = "other";       break;
  }
  const char *severity_str = "unknown";
```

```
  switch (severity) {
    case GL_DEBUG_SEVERITY_HIGH:         severity_str = "high";         break;
    case GL_DEBUG_SEVERITY_MEDIUM:       severity_str = "medium";       break;
    case GL_DEBUG_SEVERITY_LOW:          severity_str = "low";          break;
    case GL_DEBUG_SEVERITY_NOTIFICATION: severity_str = "notification"; break;
  }
  bool should_print = true;
  if (should_print) {
    fprintf(stderr, "graphgrow-video: %s %s %u %s: %s\n", source_str, type_str, ↙
        ↳ id, severity_str, message);
  }
  if (severity == GL_DEBUG_SEVERITY_HIGH && type == GL_DEBUG_TYPE_ERROR) {
    if (++debug_error_count > 10) {
      abort();
    }
  }
}

static GLFWwindow *create_context(int width, int height, const char *title) {
  int glfw_initialized = glfwInit();
  if (! glfw_initialized) {
    fprintf(stderr, "couldn't initialize glfw\n");
    assert(glfw_initialized);
    return 0;
  }
  int major, minor;
  GLFWwindow *window = create_window(major = 4, minor = 4, width, height, title)↙
      ↳ ;
  if (! window) {
    fprintf(stderr, "couldn't create window\n");
    assert(window);
    return 0;
  }
  glfwMakeContextCurrent(window);
  glewExperimental = GL_TRUE;
  glewInit();
  glGetError();
  glDebugMessageCallback(debug_callback, 0);
  return window;
}

static void initialize_gl(int tex_width, int tex_height, int win_width, int ↙
    ↳ win_height) {

  // initialize vertex data for full-screen triangle strip
  GLuint vao;
  glGenVertexArrays(1, &vao);
  glBindVertexArray(vao);
  GLuint vbo;
  glGenBuffers(1, &vbo);
  glBindBuffer(GL_ARRAY_BUFFER, vbo);
  GLfloat vbo_data[] =
    { -1, -1, 0, 1
    , -1,  1, 0, 0
    ,  1, -1, 1, 1
    ,  1,  1, 1, 0
    };
```

```
  glBufferData(GL_ARRAY_BUFFER, 16 * sizeof(GLfloat), vbo_data, GL_STATIC_DRAW);
  glVertexAttribPointer(0, 2, GL_FLOAT, GL_FALSE, 4 * sizeof(GLfloat), 0);
465 glVertexAttribPointer(1, 2, GL_FLOAT, GL_FALSE, 4 * sizeof(GLfloat), ((char *)↙
      ↳ 0) + 2 * sizeof(GLfloat));
  glEnableVertexAttribArray(0);
  glEnableVertexAttribArray(1);

  // create textures for ping pong square
470 GLuint t_buffer[2];
  glGenTextures(2, t_buffer);
  for (int i = 0; i < 2; ++i) {
    glActiveTexture(GL_TEXTURE0 + i);
    glBindTexture(GL_TEXTURE_2D_ARRAY, t_buffer[i]);
475 glTexImage3D(GL_TEXTURE_2D_ARRAY, 0, GL_RGB32F, tex_width, tex_height, 4, 0,↙
      ↳ GL_RGB, GL_FLOAT, 0);
    glGenerateMipmap(GL_TEXTURE_2D_ARRAY);
    glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_MIN_FILTER, ↙
      ↳ GL_LINEAR_MIPMAP_LINEAR);
    glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_WRAP_S, GL_CLAMP);
480 glTexParameteri(GL_TEXTURE_2D_ARRAY, GL_TEXTURE_WRAP_T, GL_CLAMP);
  }

  // create texture for rectangular view
  GLuint t_screen;
485 glGenTextures(1, &t_screen);
  glActiveTexture(GL_TEXTURE0 + 2);
  glBindTexture(GL_TEXTURE_2D, t_screen);
  glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA32F, win_width, win_height, 0, GL_RGBA, ↙
      ↳ GL_FLOAT, 0);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
490 glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_MIRRORED_REPEAT);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_MIRRORED_REPEAT);

  // create framebuffers for ping pong square
495 glViewport(0, 0, tex_width, tex_height);
  glClearColor(1, 1, 1, 1);
  glGenFramebuffers(9, S.fbo);
  for (int i = 0; i < 8; ++i) {
    glBindFramebuffer(GL_FRAMEBUFFER, S.fbo[i]);
500 glFramebufferTextureLayer(GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, t_buffer[1 ↙
      ↳ - i / 4], 0, i % 4);
    GLenum dbuf = GL_COLOR_ATTACHMENT0;
    glDrawBuffers(1, &dbuf);
    GLenum status = glCheckFramebufferStatus(GL_FRAMEBUFFER);
    if (status != GL_FRAMEBUFFER_COMPLETE) {
505   fprintf(stderr, "OpenGL framebuffer not complete\n");
    }
    assert(status == GL_FRAMEBUFFER_COMPLETE);
    glClear(GL_COLOR_BUFFER_BIT);
  }
510 glActiveTexture(GL_TEXTURE0 + 0);
  glGenerateMipmap(GL_TEXTURE_2D_ARRAY);
  glActiveTexture(GL_TEXTURE0 + 1);
  glGenerateMipmap(GL_TEXTURE_2D_ARRAY);
```

```
515   // create framebuffer for rectangular view
      glBindFramebuffer(GL_FRAMEBUFFER, S.fbo[8]);
      glFramebufferTexture2D(GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, GL_TEXTURE_2D, ↙
          ↳ t_screen, 0);
      GLenum dbuf = GL_COLOR_ATTACHMENT0;
      glDrawBuffers(1, &dbuf);
520   GLenum status = glCheckFramebufferStatus(GL_FRAMEBUFFER);
      if (status != GL_FRAMEBUFFER_COMPLETE) {
        fprintf(stderr, "OpenGL framebuffer not complete\n");
      }
      assert(status == GL_FRAMEBUFFER_COMPLETE);
525   glClear(GL_COLOR_BUFFER_BIT);

      // compile shaders
      S.program[0] = compile_program("step", step_vert, step_frag);
      S.p0which = glGetUniformLocation(S.program[0], "which");
530   S.p0quality = glGetUniformLocation(S.program[0], "quality");
      S.p0anim  = glGetUniformLocation(S.program[0], "transform");
      S.p0source  = glGetUniformLocation(S.program[0], "source");
      S.p0count = glGetUniformLocation(S.program[0], "count");
      S.program[1] = compile_program("show", show_vert, show_frag);
535   glUseProgram(S.program[1]);
      S.p1which = glGetUniformLocation(S.program[1], "which");
      S.p1quality = glGetUniformLocation(S.program[1], "quality");
      S.p1layer = glGetUniformLocation(S.program[1], "layer");
      GLuint aspect = glGetUniformLocation(S.program[1], "aspect");
540   glUniform1f(aspect, WIDTH / (float) HEIGHT);
      S.which = 0;
      S.program[2] = compile_program("tone", tone_vert, tone_frag);
      glUseProgram(S.program[2]);
      GLint p2source = glGetUniformLocation(S.program[2], "source");
545   glUniform1i(p2source, 2);

      // pixel buffers for ping pong histogram equalisation
      int logsize = ceil(log2(win_width * win_height));
      glGenBuffers(3, &S.pbo[0]);
550   for (int i = 0; i < 3; ++i) {
        glBindBuffer(GL_PIXEL_PACK_BUFFER, S.pbo[i]);
        glBufferData(GL_PIXEL_PACK_BUFFER, 4 * (1 << logsize) * sizeof(float), 0, ↙
            ↳ GL_DYNAMIC_COPY);
      }

555   // compute shaders
      S.program[3] = compile_compute("sort", sort_comp);
      S.p3count = glGetUniformLocation(S.program[3], "count");
      S.p3p = glGetUniformLocation(S.program[3], "p");
      S.p3q = glGetUniformLocation(S.program[3], "q");
560   S.program[4] = compile_compute("look", look_comp);
      S.p4icount = glGetUniformLocation(S.program[4], "icount");
      S.p4hcount = glGetUniformLocation(S.program[4], "hcount");

    }
565
    extern int main(int argc, char **argv) {
      memset(&S, 0, sizeof(S));
      int quality = QUALITY;
      int tex_width = 1 << quality, tex_height = 1 << quality;
```

```
570     int win_width = WIDTH/SCALE, win_height = HEIGHT/SCALE;
        int hist_width = win_width >> MIPMAP;
        int hist_height = win_height >> MIPMAP;
        int logsize = ceil(log2(hist_width * hist_height));
        GLFWwindow *window = create_context(win_width, win_height, "graphgrow");
575     if (! window) {
          assert(window);
          return 1;
        }
        glfwSetKeyCallback(window, key_press_handler);
580     initialize_gl(tex_width, tex_height, win_width, win_height);

        GLuint src = S.pbo[0];
        GLuint dst = S.pbo[1];
        GLuint img = S.pbo[2];
585
        GLuint timers[7];
        glGenQueries(7, timers);

        lo_server_thread lo = lo_server_thread_new("6061", errorcb);
590     lo_server_thread_add_method(lo, "/video", "b", videocb, 0);
        lo_server_thread_add_method(lo, "/quit", "", quitcb, 0);
        lo_server_thread_start(lo);

        int frame = 0;
595     S.running = 1;
        while (S.running && ! glfwWindowShouldClose(window)) {

          if ((frame % 60) == 0 && frame > 0)
          {
600         GLuint64 tifs = 0, tflat = 0, tpbo = 0, tsort = 0, tlup = 0, ttex = 0, ↙
                ↳ tdisp = 0;
            glGetQueryObjectui64v(timers[0], GL_QUERY_RESULT, &tifs);
            glGetQueryObjectui64v(timers[1], GL_QUERY_RESULT, &tflat);
            glGetQueryObjectui64v(timers[2], GL_QUERY_RESULT, &tpbo);
            glGetQueryObjectui64v(timers[3], GL_QUERY_RESULT, &tsort);
605         glGetQueryObjectui64v(timers[4], GL_QUERY_RESULT, &tlup);
            glGetQueryObjectui64v(timers[5], GL_QUERY_RESULT, &ttex);
            glGetQueryObjectui64v(timers[6], GL_QUERY_RESULT, &tdisp);
            double ifs = tifs / 1000.0;
            double flat = tflat / 1000.0;
610         double pbo = tpbo / 1000.0;
            double sort = tsort / 1000.0;
            double lup = tlup / 1000.0;
            double tex = ttex / 1000.0;
            double disp = tdisp / 1000.0;
615         fprintf(stderr, " IFS( %f ) FLAT( %f ) PBO( %f ) SORT( %f ) LUP( %f ) TEX(↙
                ↳ %f ) DISP( %f )\r", ifs, flat, pbo, sort, lup, tex, disp);
            glDeleteQueries(7, timers);
            glGenQueries(7, timers);
          }

620       // iterated function system
          if ((frame % 60) == 0) glBeginQuery(GL_TIME_ELAPSED, timers[0]);
          glUseProgram(S.program[0]);
          glViewport(0, 0, tex_width, tex_height);
          for (int layer = 0; layer < 4; ++layer)
```

```
625       {
            glUniformMatrix3fv(S.p0anim, 8, GL_TRUE, &S.control.transform[layer↙
                ↳ ][0][0][0]);
            glUniform1iv(S.p0source, 8, &S.control.source[layer][0]);
            glUniform1i(S.p0count, S.control.count[layer]);
            glUniform1i(S.p0which, S.which);
630         glUniform1i(S.p0quality, quality);
            glBindFramebuffer(GL_FRAMEBUFFER, S.fbo[S.which * 4 + layer]);
            glDrawArrays(GL_TRIANGLE_STRIP, 0, 4);
          }
          S.which = 1 - S.which;
635       glActiveTexture(GL_TEXTURE0 + S.which);
          glGenerateMipmap(GL_TEXTURE_2D_ARRAY);
          if ((frame % 60) == 0) glEndQuery(GL_TIME_ELAPSED);

          // flatten from square texture to rectangular view
640       if ((frame % 60) == 0) glBeginQuery(GL_TIME_ELAPSED, timers[1]);
          glViewport(0, 0, win_width, win_height);
          glBindFramebuffer(GL_FRAMEBUFFER, S.fbo[8]);
          glUseProgram(S.program[1]);
          glUniform1i(S.p1which, S.which);
645       glUniform1i(S.p1quality, quality);
          glUniform1i(S.p1layer, S.control.active);
          glDrawArrays(GL_TRIANGLE_STRIP, 0, 4);
          if ((frame % 60) == 0) glEndQuery(GL_TIME_ELAPSED);

650       if ((frame % 60) == 0) glBeginQuery(GL_TIME_ELAPSED, timers[2]);
          glActiveTexture(GL_TEXTURE0 + 2);
          if (frame % SKIP == 0)
          {
            // copy to PBO
655         glGenerateMipmap(GL_TEXTURE_2D);
            glBindBuffer(GL_PIXEL_PACK_BUFFER, src);
            float infty = 1.0 / 0.0;
            glClearBufferSubData(GL_PIXEL_PACK_BUFFER, GL_R32F, 0, (1 << logsize) * ↙
                ↳ sizeof(float), GL_RED, GL_FLOAT, &infty);
            glBindBuffer(GL_PIXEL_PACK_BUFFER, src);
660         glGetTexImage(GL_TEXTURE_2D, MIPMAP, GL_ALPHA, GL_FLOAT, 0);
          }
          glBindBuffer(GL_PIXEL_PACK_BUFFER, img);
          glGetTexImage(GL_TEXTURE_2D, 0, GL_RGBA, GL_FLOAT, 0);
          glBindBuffer(GL_PIXEL_PACK_BUFFER, 0);
665       if ((frame % 60) == 0) glEndQuery(GL_TIME_ELAPSED);

          if ((frame % 60) == 0) glBeginQuery(GL_TIME_ELAPSED, timers[3]);
          if (frame % SKIP == 0)
          {
670         // ping pong merge sort
            glUseProgram(S.program[3]);
            glUniform1ui(S.p3count, 1 << logsize);
            for (int i = 0; i < logsize; ++i) {
              for (int j = 0; j <= i; ++j) {
675             glBindBufferBase(GL_SHADER_STORAGE_BUFFER, 0, src);
                glBindBufferBase(GL_SHADER_STORAGE_BUFFER, 1, dst);
                glUniform1ui(S.p3p, i);
                glUniform1ui(S.p3q, j);
                glDispatchCompute((1 << logsize) / 1024, 1, 1);
```

```
680             { GLuint t = src; src = dst; dst = t; }
              }
            }
          }
          if ((frame % 60) == 0) glEndQuery(GL_TIME_ELAPSED);

          // binary search lookup
          if ((frame % 60) == 0) glBeginQuery(GL_TIME_ELAPSED, timers[4]);
          glUseProgram(S.program[4]);
          glUniform1ui(S.p4icount, win_width * win_height);
          glUniform1ui(S.p4hcount, hist_width * hist_height);
          glBindBufferBase(GL_SHADER_STORAGE_BUFFER, 0, img);
          glBindBufferBase(GL_SHADER_STORAGE_BUFFER, 1, src);
          glBindBufferBase(GL_SHADER_STORAGE_BUFFER, 2, dst);
          glDispatchCompute((win_width * win_height + 1024 - 1) / 1024, 1, 1);
          if ((frame % 60) == 0) glEndQuery(GL_TIME_ELAPSED);

          // copy to texture
          if ((frame % 60) == 0) glBeginQuery(GL_TIME_ELAPSED, timers[5]);
          glActiveTexture(GL_TEXTURE0 + 2);
          glBindBuffer(GL_PIXEL_UNPACK_BUFFER, dst);
          glTexSubImage2D(GL_TEXTURE_2D, 0, 0, 0, win_width, win_height, GL_RGBA, ↙
              ↳ GL_FLOAT, 0);
          glBindBuffer(GL_PIXEL_UNPACK_BUFFER, 0);
          if ((frame % 60) == 0) glEndQuery(GL_TIME_ELAPSED);

          // display final image
          if ((frame % 60) == 0) glBeginQuery(GL_TIME_ELAPSED, timers[6]);
          glUseProgram(S.program[2]);
          glBindFramebuffer(GL_FRAMEBUFFER, 0);
          glDrawArrays(GL_TRIANGLE_STRIP, 0, 4);
          if ((frame % 60) == 0) glEndQuery(GL_TIME_ELAPSED);

          glfwSwapBuffers(window);

          // handle UI and quit conditions
          glfwPollEvents();
          int e = glGetError();
          if (e) { fprintf(stderr, "OpenGL Error %d\n", e); }
          frame++;

        }

        glfwTerminate();
        fprintf(stderr, "\n%d\n", frame);
        return 0;
        (void) argc;
        (void) argv;
      }
```

58 graphgrow3/video/graphgrow-video-test.cc

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

```
#include <lo/lo.h>
#include <glm/glm.hpp>

struct control
{
  int32_t active;
  int32_t count    [4];
  int32_t source   [4][8];
  float   scale    [4][8];
  glm::mat3 transform[4][8];
};

int main()
{
  control C;
  memset(&C, 0, sizeof(C));
  for (int i = 0; i < 4; ++i)
    for (int j = 0; j < 8; ++j)
    {
      float s  = rand() / (double) RAND_MAX; s *= s;
      float r =  rand() / (double) RAND_MAX * 2 * 3.141592653589793;
      float tx = rand() / (double) RAND_MAX - 0.5;
      float ty = rand() / (double) RAND_MAX - 0.5;
      float co = cosf(r) * s;
      float si = sinf(r) * s;
      C.source   [i][j] = rand() % 4;
      C.scale    [i][j] = s;
      C.transform[i][j][0][0] = co;
      C.transform[i][j][0][1] = si;
      C.transform[i][j][0][2] = tx;
      C.transform[i][j][1][0] = -si;
      C.transform[i][j][1][1] = co;
      C.transform[i][j][1][2] = ty;
      C.transform[i][j][2][0] = 0;
      C.transform[i][j][2][1] = 0;
      C.transform[i][j][2][2] = 1;
      C.transform[i][j] = glm::inverse(C.transform[i][j]);
    }

  lo_address t = lo_address_new("255.255.255.255", "6061");

  while (1)
  {
    sleep(1);

    C.active = (C.active + 1) % 4;
    int i = rand() % 4;
    C.count[i] = (rand() % 8) + 1;
    int j = rand() % 8;
    float s  = rand() / (double) RAND_MAX; s *= s;
    float r =  rand() / (double) RAND_MAX * 2 * 3.141592653589793;
    float tx = rand() / (double) RAND_MAX - 0.5;
    float ty = rand() / (double) RAND_MAX - 0.5;
    float co = cosf(r) * s;
    float si = sinf(r) * s;
    C.source   [i][j] = rand() % 4;
    C.scale    [i][j] = s;
```

```
      C.transform[i][j][0][0] = co;
      C.transform[i][j][0][1] = si;
      C.transform[i][j][0][2] = tx;
      C.transform[i][j][1][0] = -si;
      C.transform[i][j][1][1] = co;
      C.transform[i][j][1][2] = ty;
      C.transform[i][j][2][0] = 0;
      C.transform[i][j][2][1] = 0;
      C.transform[i][j][2][2] = 1;
      C.transform[i][j] = glm::inverse(C.transform[i][j]);

      lo_blob blob = lo_blob_new(sizeof(C), &C);
      if (blob)
      {
        if (lo_send(t, "/video", "b", blob) == -1)
          fprintf(stderr, "OSC error %d: %s\n", lo_address_errno(t), ↙
              ↳ lo_address_errstr(t));
        lo_blob_free(blob);
      }
      else
        fprintf(stderr, "OSC error: couldn't lo_blob_new\n");

    }
    return 0;
}
```

59 graphgrow3/Video.hs

```
module Video (videoNew, Video) where

import Control.Monad (when, replicateM_, forM_, unless)
import Control.Monad.IO.Class (liftIO)

import System.IO (hPutStrLn, stderr)

import Data.IORef (IORef, newIORef, readIORef, writeIORef)

import Foreign (nullPtr, castPtr, peek, with, withArray, allocaBytes)
import Foreign.C (withCString, peekCStringLen)

import Data.Map (Map)
import qualified Data.Map.Strict as M

import qualified Graphics.UI.Gtk        as G
import qualified Graphics.UI.Gtk.OpenGL as G

import Graphics.GL

import Linear (M33)

import Paths_graphgrow3 (getDataFileName)
import Types

type Video = [(Int, Double, M33 Double)]

videoNew :: IO (Map RID Video) -> IO G.Window
videoNew transforms = do
```

```
    let w = 500
        h = 500
    window <- G.windowNew
    _ <- window `G.on` G.deleteEvent $ do
      liftIO $ G.widgetHide window
      return True
    G.windowSetDefaultSize window w h
    G.windowSetGeometryHints window (Nothing `asTypeOf` Just window) (Just (w, h))↙
        ↳ (Just (w, h)) Nothing Nothing Nothing
    canvas <- G.glDrawingAreaNew =<< G.glConfigNew [G.GLModeRGBA, G.GLModeDouble]
    G.widgetSetSizeRequest canvas w h
    let redraw ref = do
          _ <- G.withGLDrawingArea canvas $ \gl -> do
            trs <- transforms
            st <- readIORef ref
            when (vTrs st /= trs) $ do
              writeIORef ref st{ vTrs = trs }
              visualize ref
            when (M.null trs) $ do
              glClear GL_COLOR_BUFFER_BIT
            G.glDrawableSwapBuffers gl
          return True
    _ <- G.onRealize canvas $ do
      _ <- G.withGLDrawingArea canvas $ \gl -> do
        ref <- newIORef =<< initialize
        visualize ref
        G.glDrawableSwapBuffers gl
        G.timeoutAddFull (redraw ref) G.priorityDefaultIdle 100
      return ()
    G.set window [G.windowTitle G.:= "GG#V", G.containerChild G.:= canvas]
    G.widgetShowAll window
    return window

size :: Int
size = 2048

er :: Double
er = 4

data St = St
  { pInitial :: GLuint, pInitial'er, pInitial'rho :: GLint
  , pStep :: GLuint, pStep'er, pStep'count, pStep'ts, pStep'ws, pStep'ls, pStep'↙
      ↳ layer, pStep'src :: GLint
  , pColour :: GLuint, pColour'src, pColour'speed :: GLint
  , tPing, tPong :: GLuint
  , fBuffer :: GLuint
  , vTrs :: Map RID Video
  }

getUniformLocation :: GLuint -> String -> IO GLint
getUniformLocation program name = withCString name $ glGetUniformLocation ↙
    ↳ program

initialize :: IO St
initialize = do
  pInitial'     <- compileProgram (Just "initial.vert") (Just "initial.frag")
  pInitial'er'  <- getUniformLocation pInitial' "er"
```

```
    pInitial'rho' <- getUniformLocation pInitial' "rho"
    pStep'        <- compileProgram (Just "step.vert") (Just "step.frag")
    pStep'er'     <- getUniformLocation pStep' "er"
    pStep'count'  <- getUniformLocation pStep' "count"
    pStep'ts'     <- getUniformLocation pStep' "transform"
    pStep'ws'     <- getUniformLocation pStep' "source"
    pStep'ls'     <- getUniformLocation pStep' "scaleFactor"
    pStep'layer'  <- getUniformLocation pStep' "layer"
    pStep'src'    <- getUniformLocation pStep' "src"
    pColour'      <- compileProgram (Just "colour.vert") (Just "colour.frag")
    pColour'src'  <- getUniformLocation pColour' "src"
    pColour'speed'<- getUniformLocation pColour' "speed"
    tPing'        <- newTex size
    tPong'        <- newTex size
    fBuffer'      <- newFBO
    glClampColor GL_CLAMP_VERTEX_COLOR   (fromIntegral GL_FALSE)
    glClampColor GL_CLAMP_READ_COLOR     (fromIntegral GL_FALSE)
    glClampColor GL_CLAMP_FRAGMENT_COLOR (fromIntegral GL_FALSE)
    return St
      { pInitial = pInitial', pInitial'er = pInitial'er', pInitial'rho = pInitial'↙
          ↳ rho'
      , pStep = pStep', pStep'er = pStep'er', pStep'count = pStep'count', pStep'ts↙
          ↳  = pStep'ts', pStep'ws = pStep'ws', pStep'ls = pStep'ls', pStep'layer ↙
          ↳ = pStep'layer', pStep'src = pStep'src'
      , pColour = pColour', pColour'src = pColour'src', pColour'speed = pColour'↙
          ↳ speed'
      , tPing = tPing', tPong = tPong', fBuffer = fBuffer'
      , vTrs = M.empty
      }

clamp :: Ord a => a -> a -> a -> a
clamp mi ma x = mi `max` x `min` ma

visualize :: IORef St -> IO ()
visualize sR = do
  s0 <- readIORef sR
  glViewport 0 0 (fromIntegral size) (fromIntegral size)
  glLoadIdentity
  glOrtho 0 1 0 1 (-1) 1
  let nlayers = M.size (vTrs s0)
      layers = [0 .. fromIntegral nlayers - 1]
  forM_ layers $ \layer -> do
    bindFBO (fBuffer s0) (tPing s0) (fromIntegral layer)
    glUseProgram (pInitial s0)
    glUniform1f (pInitial'er s0) (realToFrac er)
    glUniform1f (pInitial'rho s0) (realToFrac (maximum (0:[ rho | Just (_, rho, ↙
        ↳ _) <- sequence $ M.lookup layer (vTrs s0) ])))
    unitQuad
    glUseProgram 0
    unbindFBO
    reportErrors "initialize layer"
  let rho = maximum (0:[ rho' | (_, rho', _) <- concat $ M.elems (vTrs s0) ])
      passes = clamp 16 4096 . round . logBase rho $ 0.001
  replicateM_ passes $ do
    s <- readIORef sR
    glBindTexture GL_TEXTURE_2D_ARRAY (tPing s)
    glUseProgram (pStep s)
```

```
      glUniform1f (pStep'er s) (realToFrac er)
      glUniform1i (pStep'src s) 0
      forM_ layers $ \layer -> case fmap (fromIntegral . length) $ M.lookup layer ↙
          ↳ (vTrs s) of
        Just count -> do
          bindFBO (fBuffer s) (tPong s) (fromIntegral layer)
          glUniform1i (pStep'count s) count
          withArray (concatMap (\(_,_,m) -> map realToFrac . concat . toLists $ m↙
              ↳ ) $ vTrs s M.! layer) $ glUniformMatrix3fv (pStep'ts s) count (↙
              ↳ fromIntegral GL_TRUE)
          withArray (map (\(_,l,_) -> realToFrac l) $ vTrs s M.! layer) $ ↙
              ↳ glUniform1fv (pStep'ls s) count
          withArray (map (\(i,_,_) -> fromIntegral i) $ vTrs s M.! layer) $ ↙
              ↳ glUniform1fv (pStep'ws s) count
          glUniform1f (pStep'layer s) (realToFrac layer)
          unitQuad
          unbindFBO
          reportErrors "step layer"
        Nothing -> return ()
      glUseProgram 0
      glBindTexture GL_TEXTURE_2D_ARRAY 0
      writeIORef sR s{ tPing = tPong s, tPong = tPing s }
      reportErrors "step pass"

    s <- readIORef sR
    glViewport 0 0 500 500
    glBindTexture GL_TEXTURE_2D_ARRAY (tPing s)
    glUseProgram (pColour s)
    glUniform1i (pColour'src s) 0
    glUniform1f (pColour'speed s) (2 * pi / fromIntegral passes)
    fullQuad
    glUseProgram 0
    glBindTexture GL_TEXTURE_2D_ARRAY 0
    reportErrors "draw"

newTex :: Int -> IO GLuint
newTex s = do
  let maxLayers = 4
  t <- with 0 $ \p -> glGenTextures 1 p >> peek p
  glBindTexture GL_TEXTURE_2D_ARRAY t
  glTexImage3D GL_TEXTURE_2D_ARRAY 0 (fromIntegral GL_R32F) (fromIntegral s) (↙
      ↳ fromIntegral s) maxLayers 0 GL_RED GL_UNSIGNED_BYTE nullPtr
  glTexParameteri GL_TEXTURE_2D_ARRAY GL_TEXTURE_MIN_FILTER (fromIntegral ↙
      ↳ GL_LINEAR)
  glTexParameteri GL_TEXTURE_2D_ARRAY GL_TEXTURE_MAG_FILTER (fromIntegral ↙
      ↳ GL_LINEAR)
  glBindTexture GL_TEXTURE_2D_ARRAY 0
  return t

newFBO :: IO GLuint
newFBO = with 0 $ \p -> glGenFramebuffers 1 p >> peek p

bindFBO :: GLuint -> GLuint -> GLint -> IO ()
bindFBO f t layer = do
  glBindFramebuffer GL_FRAMEBUFFER f
  glFramebufferTextureLayer GL_FRAMEBUFFER GL_COLOR_ATTACHMENT0 t 0 layer
  with GL_COLOR_ATTACHMENT0 $ glDrawBuffers 1
```

```
185
unbindFBO :: IO ()
unbindFBO = do
  glFramebufferTextureLayer GL_FRAMEBUFFER GL_COLOR_ATTACHMENT0 0 0 0
  glBindFramebuffer GL_FRAMEBUFFER 0
190
unitQuad :: IO ()
unitQuad = glDrawArrays GL_TRIANGLE_STRIP 0 4

fullQuad :: IO ()
195 fullQuad = glDrawArrays GL_TRIANGLE_STRIP 0 4

reportErrors :: String -> IO ()
reportErrors s = do
  e <- glGetError
200   when (e /= 0) $ do
    hPutStrLn stderr $ s ++ " OpenGL ERROR " ++ show e
    reportErrors s

compileProgram :: Maybe FilePath -> Maybe FilePath -> IO GLuint
205 compileProgram mV mF = do
  p <- glCreateProgram
  case mV of
    Nothing -> return ()
    Just v -> do
210       vert <- glCreateShader GL_VERTEX_SHADER
      source <- readFile =<< getDataFileName v
      shaderSource vert source
      glCompileShader vert
      glAttachShader p vert
215   case mF of
    Nothing -> return ()
    Just f -> do
      frag <- glCreateShader GL_FRAGMENT_SHADER
      source <- readFile =<< getDataFileName f
220       shaderSource frag source
      glCompileShader frag
      glAttachShader p frag
  glLinkProgram p
  n <- with (0 :: GLint) $ \q -> do
225     glGetProgramiv p GL_INFO_LOG_LENGTH q
    peek q
  l <- allocaBytes (fromIntegral n + 1) $ \q -> do
    glGetProgramInfoLog p (fromIntegral n) nullPtr q
    peekCStringLen (castPtr q, fromIntegral n)
230   unless (null l) $ do
    hPutStrLn stderr l
  return p

shaderSource :: GLuint -> String -> IO ()
235 shaderSource shader source = do
  withCString source $ \ptr -> with ptr $ \ptr' ->
    glShaderSource shader 1 (castPtr ptr') nullPtr
```

60 graphgrow3/video/Makefile

```
all: graphgrow-video graphgrow-video-test
```

```
clean:
	-rm graphgrow-video graphgrow-video-test

graphgrow-video: graphgrow-video.cc
	g++ -std=c++11 -Wall -Wextra -pedantic -Wno-variadic-macros -O3 -march=native -ffast-math -I$(HOME)/opt/include -L$(HOME)/opt/lib -o graphgrow-video graphgrow-video.cc -lGL -lGLEW -lglfw -llo

graphgrow-video-test: graphgrow-video-test.cc
	g++ -std=c++11 -Wall -Wextra -pedantic -Wno-variadic-macros -O3 -march=native -ffast-math -I$(HOME)/opt/include -L$(HOME)/opt/lib -o graphgrow-video-test graphgrow-video-test.cc -llo
```

61 graphgrow3/video/README

```
Needs liblo from https://github.com/radarsat1/liblo
Tested with HEAD at 276dc11db2038b44f04fe67cdb425929427a5337
```

62 graphgrow.cabal

```
name:                graphgrow
version:             2.1
synopsis:            graph-directed iterated function system fractals
description:
  graphgrow renders graph-directed iterated function system fractals.
  currently the iterated functions are based on text.
  .
  examples:
  .
  > echo "GRAPHGROW : GRAPHGROW" | graphgrow -
  > echo -e "HELLO : WORLD\nWORLD : HELLO" | graphgrow -
  > echo -e "HELLO : WORLD\nGOODBYE : WORLD\nWORLD : HELLO GOODBYE" | graphgrow -
  > for graph in data/*.gg ; do graphgrow $graph ; done

homepage:            https://code.mathr.co.uk/graphgrow
license:             GPL-3
license-file:        LICENSE
author:              Claude Heiland-Allen
maintainer:          claude@mathr.co.uk
category:            Graphics
build-type:          Simple
cabal-version:       >=1.8

executable graphgrow
  main-is:  Fractal/GraphGrow/Main.hs
  other-modules:
      Fractal.GraphGrow.Analysis.Statistics
      Fractal.GraphGrow.Engine.Geometry
      Fractal.GraphGrow.Engine.Graph
      Fractal.GraphGrow.Engine.Grow
      Fractal.GraphGrow.Engine.Zoomer
      Fractal.GraphGrow.GUI.DrawPoints
      Fractal.GraphGrow.GUI.Editor
      Fractal.GraphGrow.GUI.FrameSync
```

```
        Fractal.GraphGrow.Text.Compile
        Fractal.GraphGrow.Text.Glyphs
        Fractal.GraphGrow.Text.Parse
        Fractal.GraphGrow.Utils

    build-depends:
      base >= 4.9 && < 4.10,
      BoundedChan >= 1.0 && < 1.1,
      containers >= 0.5 && < 0.6,
      glib >= 0.13 && < 0.14,
      gtk >= 0.14 && < 0.15,
      gtkglext >= 0.13 && < 0.14,
--      gtk-toy-diagrams >= 0.1,
      monad-supply >= 0.6 && < 0.7,
      mtl >= 2.2 && < 2.3,
      OpenGLRaw >= 3.2 && < 3.3,
      parallel >= 3.2 && < 3.3,
      random >= 1.1 && < 1.2,
      vector >= 0.11 && < 0.12

    ghc-options: -Wall -threaded -funbox-strict-fields -rtsopts -with-rtsopts "-
        ↪ A64M -N"

Source-repository head
  type:                 git
  location:             https://code.mathr.co.uk/graphgrow.git

Source-repository this
  type:                 git
  location:             https://code.mathr.co.uk/graphgrow.git
  tag:                  v2.1
```

63 LICENSE

```
                    GNU GENERAL PUBLIC LICENSE
                       Version 3, 29 June 2007

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```

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```

64 README

```
data/ has some larger example graphs
  bible-pg10.gg2    http://www.gutenberg.org/ebooks/10
  haskell-irc.gg2   http://tunes.org/~nef/logs/haskell/
  netbehaviour.gg2  http://www.netbehaviour.org/pipermail/netbehaviour/

extra/mk.hs can be used to extract markov chain word graphs from text
```

65 Setup.hs

```
import Distribution.Simple
main = defaultMain
```

66 the-sky-cracked-open/ChangeLog.md

```
# Revision history for the-sky-cracked-open

## 0.1.0.0  -- YYYY-mm-dd

* First version. Released on an unsuspecting world.
```

67 the-sky-cracked-open/colour.frag

```
#version 130
uniform sampler2DArray src;
uniform float er;
uniform float rho;
uniform float pixelSize;
uniform float speed;
```

```
void main() {
  vec2 p = gl_TexCoord[0].xy;
  vec2 z = texture(src, vec3(p, 0.0)).xy;
/*
  float zk = er * pow(1.0/rho, fract(z.x));
  float d = zk * log(zk) / z.y;
  float g = tanh(clamp(d / length(dFdx(p)), 0.0, 4.0));
  gl_FragData[0] = vec4(vec3(g), 1.0);
*/
  float n = z.x * speed;
  vec3 yuv;
  if (n < 0.0) {
    yuv = vec3(0.0);
  } else {
    yuv = vec3(clamp(log(1.0 + n / 4.0), 0.0, 1.0), 0.125 * sin(n), -0.125 * cos↙
        ↳ (n));
  }
  vec3 rgb = yuv * mat3(1.0, 0.0, 1.4, 1.0, -0.395, -0.581, 1.0, 2.03, 0.0);
  gl_FragData[0] = vec4(rgb, 1.0);
}
```

68 the-sky-cracked-open/initial.frag

```
#version 130
uniform float er;
uniform float rho;

void main() {
  vec2 p = er * (gl_TexCoord[0].xy * 2.0 - vec2(1.0));
  float l = length(p);
  float n;
  if (l >= er) {
    n = 0.0;
  } else if (er > l && l >= rho * er) {
    n = (log(er) - log(l)) / -log(rho);
  } else {
    n = -1.0;
  }
  gl_FragData[0] = vec4(n, 1.0, 0.0, 0.0);
}
```

69 the-sky-cracked-open/LICENSE

```
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```

70 the-sky-cracked-open/main.hs

```
{-# LANGUAGE PatternSynonyms #-}
import Control.Monad (when, replicateM_, forM_)
import System.Exit (exitSuccess)
import Graphics.UI.GLUT hiding (FramebufferObject)
5 import Graphics.GL
  ( glTexImage3D, pattern GL_TEXTURE_2D_ARRAY, pattern GL_RG32F, pattern GL_RG
  , pattern GL_UNSIGNED_BYTE, pattern GL_FALSE, glClampColor
  , pattern GL_CLAMP_VERTEX_COLOR, pattern GL_CLAMP_READ_COLOR, pattern ↙
    ↳ GL_CLAMP_FRAGMENT_COLOR
  , glGenFramebuffers, glBindFramebuffer, glFramebufferTextureLayer, ↙
    ↳ glTexParameteri
10  , pattern GL_FRAMEBUFFER, pattern GL_COLOR_ATTACHMENT0, glUniformMatrix3fv
  , GLuint, GLint, GLfloat, GLdouble, glUniform1fv, glBindTexture
  , pattern GL_TEXTURE_MIN_FILTER, pattern GL_TEXTURE_MAG_FILTER, pattern ↙
    ↳ GL_LINEAR
  )
import Foreign (alloca, peek, nullPtr, withArray)
15 import Data.IORef (IORef, newIORef, readIORef, writeIORef)
import Numeric.GSL.Root
```

```
import qualified Numeric.LinearAlgebra as L
import Numeric.LinearAlgebra hiding (R, dim, size)
import Unsafe.Coerce (unsafeCoerce)

import Shader (shader)
import Snapshot (writeSnapshot)

mXm :: L.Matrix R -> L.Matrix R -> L.Matrix R
mXm = (<>)

size :: Int
size = 2048

er :: R
er = 4

data St = St
  { pInitial :: Program, pInitial'er, pInitial'rho :: UniformLocation
  , pStep :: Program, pStep'er, pStep'count, pStep'ts, pStep'ws, pStep'ls, pStep'layer, pStep'src :: UniformLocation
  , pColour :: Program, pColour'src, pColour'er, pColour'rho, pColour'pixelSize, pColour'speed :: UniformLocation
  , tPing, tPong :: TextureObject
  , fBuffer :: FramebufferObject
  , vTrs :: [[L.Matrix R]], vLs :: [[R]], vT :: Int, vPasses :: Int, vRho :: (R, R)
  }

main :: IO ()
main = do
  _ <- getArgsAndInitialize
  initialWindowSize $= Size 1280 720
  _ <- createWindow "spiral!"
  pInitial'     <- shader Nothing (Just "initial.frag")
  pInitial'er'  <- get $ uniformLocation pInitial' "er"
  pInitial'rho' <- get $ uniformLocation pInitial' "rho"
  pStep'        <- shader Nothing (Just "step.frag")
  pStep'er'     <- get $ uniformLocation pStep' "er"
  pStep'count'  <- get $ uniformLocation pStep' "count"
  pStep'ts'     <- get $ uniformLocation pStep' "transform"
  pStep'ws'     <- get $ uniformLocation pStep' "source"
  pStep'ls'     <- get $ uniformLocation pStep' "scaleFactor"
  pStep'layer'  <- get $ uniformLocation pStep' "layer"
  pStep'src'    <- get $ uniformLocation pStep' "src"
  pColour'      <- shader Nothing (Just "colour.frag")
  pColour'src'  <- get $ uniformLocation pColour' "src"
  pColour'er'   <- get $ uniformLocation pColour' "er"
  pColour'rho'  <- get $ uniformLocation pColour' "rho"
  pColour'pixelSize' <- get $ uniformLocation pColour' "pixelSize"
  pColour'speed'<- get $ uniformLocation pColour' "speed"
  tPing'        <- newTex size
  tPong'        <- newTex size
  fBuffer'      <- newFBO
  glClampColor GL_CLAMP_VERTEX_COLOR   (fromIntegral GL_FALSE)
  glClampColor GL_CLAMP_READ_COLOR     (fromIntegral GL_FALSE)
  glClampColor GL_CLAMP_FRAGMENT_COLOR (fromIntegral GL_FALSE)
  sR <- newIORef St
```

```
      { pInitial = pInitial', pInitial'er = pInitial'er', pInitial'rho = pInitial'↙
        ↘ rho'
      , pStep = pStep', pStep'er = pStep'er', pStep'count = pStep'count', pStep'ts↙
        ↘  = pStep'ts', pStep'ws = pStep'ws', pStep'ls = pStep'ls', pStep'layer ↙
        ↘ = pStep'layer', pStep'src = pStep'src'
      , pColour = pColour', pColour'src = pColour'src', pColour'er = pColour'er', ↙
        ↘ pColour'rho = pColour'rho', pColour'pixelSize = pColour'pixelSize', ↙
        ↘ pColour'speed = pColour'speed'
      , tPing = tPing', tPong = tPong', fBuffer = fBuffer'
75    , vTrs = [[], []], vLs = [[], []], vT = 0, vPasses = 16, vRho = (0, 0)
      }
    reset sR
    displayCallback $= display sR
    addTimerCallback 100 (timer sR)
80  mainLoop

timer :: IORef St -> IO ()
timer sR = do
  addTimerCallback 100 (timer sR)
85  reset sR
  postRedisplay Nothing

reset :: IORef St -> IO ()
reset sR = do
90  s <- readIORef sR
--  when (vT s > 0) $ writeSnapshot (show (vT s) ++ ".ppm") (Position 0 0) (Size↙
    ↘  1280 720)
--  when (vT s >= 375) $ exitSuccess
  let dim1 = 1.001 + 0.75 * abs (sin(pi/2 * fromIntegral (vT s) / 30.0))
      dim2 = 1.001 + 0.75 * abs (sin(pi/2 * fromIntegral (vT s) / 37.5))
95    spiral1 = spiral dim1
      spiral2 = spiral dim2
      ls = [map fst spiral1, map fst spiral2]
      rhos = concat ls
      mrhos = map maximum ls
100   rho = (minimum rhos, maximum rhos)
      trs1 = map snd spiral1
      trs2 = map snd spiral2
      passes = clamp 16 4096 . round . logBase (snd rho) $ 0.001
  writeIORef sR s{ vTrs = [trs1, trs2], vLs = ls, vT = vT s + 1, vPasses = ↙
    ↘ passes, vRho = rho }
105 viewport $= (Position 0 0, Size (fromIntegral size) (fromIntegral size))
  loadIdentity
  ortho2D 0 1 0 1
  forM_ [0,1] $ \layer -> do
    bindFBO (fBuffer s) (tPing s) (fromIntegral layer)
110   currentProgram $= Just (pInitial s)
    uniform (pInitial'er s) $= TexCoord1 (realToFrac er :: GLfloat)
    uniform (pInitial'rho s) $= TexCoord1 (realToFrac (mrhos !! layer) :: ↙
      ↘ GLfloat)
    unitQuad
    currentProgram $= Nothing
115   unbindFBO

clamp :: Ord a => a -> a -> a -> a
clamp mi ma x = mi `max` x `min` ma
```

```
120 display :: IORef St -> IO ()
    display sR = do
      s0 <- readIORef sR
      replicateM_ (vPasses s0) $ do
        s <- readIORef sR
125     viewport $= (Position 0 0, Size (fromIntegral size) (fromIntegral size))
        glBindTexture GL_TEXTURE_2D_ARRAY (case tPing s of TextureObject t -> t)
        currentProgram $= Just (pStep s)
        uniform (pStep'er s) $= TexCoord1 (realToFrac er :: GLfloat)
        uniform (pStep'src s) $= TexCoord1 (0 :: GLint)
130     forM_ [0,1] $ \layer -> do
          bindFBO (fBuffer s) (tPong s) (fromIntegral layer)
          uniform (pStep'count s) $= TexCoord1 (3 :: GLint)
          withArray (map (realToFrac :: R -> GLfloat) . concat . concatMap L.toLists↙
              ↪ . (!! layer) . vTrs $ s) $ glUniformMatrix3fv (unsafeCoerce $ pStep↙
              ↪ 'ts s) 3 1
          withArray (map (realToFrac :: R -> GLfloat) . (!! layer) . vLs $ s) $ ↙
              ↪ glUniform1fv (unsafeCoerce $ pStep'ls s) 3
135       withArray ([[0, 1, 0], [1, 0, 1 :: GLfloat]] !! layer) $ glUniform1fv (↙
              ↪ unsafeCoerce $ pStep'ws s) 3
          uniform (pStep'layer s) $= TexCoord1 (realToFrac layer :: GLfloat)
          unitQuad
          unbindFBO
        currentProgram $= Nothing
140     glBindTexture GL_TEXTURE_2D_ARRAY 0
        writeIORef sR s{ tPing = tPong s, tPong = tPing s }

      s <- readIORef sR
      viewport $= (Position 0 0, Size 1280 720)
145   glBindTexture GL_TEXTURE_2D_ARRAY (case tPong s of TextureObject t -> t)
      currentProgram $= Just (pColour s)
      uniform (pColour'src s) $= TexCoord1 (0 :: GLint)
      uniform (pColour'er s) $= TexCoord1 (realToFrac er :: GLfloat)
      uniform (pColour'rho s) $= TexCoord1 (realToFrac (fst $ vRho s) :: GLfloat)
150   uniform (pColour'pixelSize s) $= TexCoord1 (0.1 :: GLfloat)
      uniform (pColour'speed s) $= TexCoord1 (2 * pi / fromIntegral (vPasses s) :: ↙
          ↪ GLfloat)
      fullQuad
      currentProgram $= Nothing
      glBindTexture GL_TEXTURE_2D_ARRAY 0
155   swapBuffers
      reportErrors

    newTex :: Int -> IO TextureObject
    newTex s = do
160   [TextureObject t] <- genObjectNames 1
      glBindTexture GL_TEXTURE_2D_ARRAY t
      glTexImage3D GL_TEXTURE_2D_ARRAY 0 (fromIntegral GL_RG32F) (fromIntegral s) (↙
          ↪ fromIntegral s) 2 0 GL_RG GL_UNSIGNED_BYTE nullPtr
      glTexParameteri GL_TEXTURE_2D_ARRAY GL_TEXTURE_MIN_FILTER (fromIntegral ↙
          ↪ GL_LINEAR)
      glTexParameteri GL_TEXTURE_2D_ARRAY GL_TEXTURE_MAG_FILTER (fromIntegral ↙
          ↪ GL_LINEAR)
165   glBindTexture GL_TEXTURE_2D_ARRAY 0
      return (TextureObject t)

    newtype FramebufferObject = FramebufferObject GLuint
```

```
newFBO :: IO FramebufferObject
newFBO = fmap FramebufferObject (alloca $ \p -> glGenFramebuffers 1 p >> peek p)

bindFBO :: FramebufferObject -> TextureObject -> GLint -> IO ()
bindFBO (FramebufferObject f) (TextureObject t) layer = do
  glBindFramebuffer GL_FRAMEBUFFER f
  glFramebufferTextureLayer GL_FRAMEBUFFER GL_COLOR_ATTACHMENT0 t 0 layer

unbindFBO :: IO ()
unbindFBO = do
  glFramebufferTextureLayer GL_FRAMEBUFFER GL_COLOR_ATTACHMENT0 0 0 0
  glBindFramebuffer GL_FRAMEBUFFER 0

unitQuad :: IO ()
unitQuad = renderPrimitive Quads $ do
    t 0 1 >> v 0 1
    t 0 0 >> v 0 0
    t 1 0 >> v 1 0
    t 1 1 >> v 1 1
  where
    t, v :: GLdouble -> GLdouble -> IO ()
    t x y = texCoord (TexCoord2 x y)
    v x y = vertex (Vertex2 x y)

fullQuad :: IO ()
fullQuad = renderPrimitive Quads $ do
    t (0.5-tx) (0.5+ty) >> v 0 1
    t (0.5-tx) (0.5-ty) >> v 0 0
    t (0.5+tx) (0.5-ty) >> v 1 0
    t (0.5+tx) (0.5+ty) >> v 1 1
  where
    tx = 0.5 / er
    ty = 0.5 / er * 9 / 16
    t, v :: GLdouble -> GLdouble -> IO ()
    t x y = texCoord (TexCoord2 x y)
    v x y = vertex (Vertex2 x y)

type R = Double

transformRST :: R -> R -> L.Vector R -> L.Matrix R
transformRST a l p = (3><3)[ c, s, x, -s, c, y, 0, 0, 1 ]
  where x:y:_ = toList p
        c = l * cos a
        s = l * sin a

findZero :: (R -> R) -> R -> R
findZero f = head . fst . root Hybrids 1e-12 1000 ((:[]) . f . head) . (:[])

spiral :: R -> [(R, L.Matrix R)]
spiral d = [(l1, inv t1), (l2, inv t2), (l3, inv t3)]
  where
    f l = 2 * sqrt ((1 - l * l) / 4) ** d + l ** d - 1
    l1 = sin (acos l2) / 2
    l2 = findZero f (d - 1)
    l3 = l1
    a1 = pi / 2 - acos l2
```

```
    a2 = -acos l2
    a3 = a1
    x1 = 0
    y1 = 0
    x2 =  l1 * cos a1
    y2 = -l1 * sin a1
    x3 = 1 - x2
    y3 = 0 - y2
    v1 = 2 |> [ x1, y1 ]
    v2 = 2 |> [ x2, y2 ]
    v3 = 2 |> [ x3, y3 ]
    t1 = post `mXm` transformRST a1 l1 v1 `mXm` pre
    t2 = post `mXm` transformRST a2 l2 v2 `mXm` pre
    t3 = post `mXm` transformRST a3 l3 v3 `mXm` pre
    pre  = transformRST 0 1 (2|>[ 0.5,0])
    post = transformRST 0 1 (2|>[-0.5,0])
```

71 the-sky-cracked-open/Setup.hs

```
import Distribution.Simple
main = defaultMain
```

72 the-sky-cracked-open/Shader.hs

```
module Shader (shader) where

import Graphics.Rendering.OpenGL

shader :: Maybe FilePath -> Maybe FilePath -> IO Program
shader mV mF = do
  p <- createProgram
  vs <- case mV of
    Nothing -> return []
    Just v -> do
      vert <- createShader VertexShader
      source <- readFile v
      shaderSource vert $= [ source ]
      compileShader vert
      print =<< get (shaderInfoLog vert)
      return [vert]
  fs <- case mF of
    Nothing -> return []
    Just f -> do
      frag <- createShader FragmentShader
      source <- readFile f
      shaderSource frag $= [ source ]
      compileShader frag
      print =<< get (shaderInfoLog frag)
      return [frag]
  attachedShaders p $= (vs ++ fs)
  linkProgram p
  print =<< get (programInfoLog p)
  return p
```

73 the-sky-cracked-open/Snapshot.hs

```
module Snapshot (hSnapshot, writeSnapshot, snapshotWith) where

import Control.Monad(forM_)
import System.IO(Handle())
import Graphics.Rendering.OpenGL(
  readPixels,
  Position,
  Size(Size),
  PixelData(PixelData),
  PixelFormat(RGB),
  DataType(UnsignedByte))
import Foreign.Marshal.Alloc(allocaBytes)
import Foreign.Ptr(plusPtr)
import qualified Data.ByteString.Internal as BSI
import qualified Data.ByteString as BS

-- save a screenshot as binary PPM
snapshotWith :: (BS.ByteString -> IO b) -> Position -> Size -> IO b
snapshotWith f p0 vp@(Size vw vh) = do
  let fi q = fromIntegral q
      p6 = "P6\n" ++ show vw ++ " " ++ show vh ++ " 255\n"
  allocaBytes (fi (vw*vh*3)) $ \ptr -> do
    readPixels p0 vp $ PixelData RGB UnsignedByte ptr
    px <- BSI.create (fi $ vw * vh * 3) $ \d -> forM_ [0..vh-1] $ \y ->
      BSI.memcpy
        (d `plusPtr` fi(y*vw*3))
        (ptr `plusPtr` fi ((vh-1-y)*vw*3))
        (fi(vw*3))
    f $ BS.pack (map (toEnum . fromEnum) p6) `BS.append` px

hSnapshot :: Handle -> Position -> Size -> IO ()
hSnapshot h = snapshotWith (BS.hPutStr h)

writeSnapshot :: FilePath -> Position -> Size -> IO ()
writeSnapshot f = snapshotWith (BS.writeFile f)
```

74 the-sky-cracked-open/step.frag

```
#version 130
#define MAXCOUNT 16
uniform float er;
uniform int count;
uniform mat3 transform[MAXCOUNT];
uniform float scaleFactor[MAXCOUNT];
uniform float source[MAXCOUNT];
uniform float layer;

uniform sampler2DArray src;

void main() {
  vec2 p0 = er * (gl_TexCoord[0].xy * 2.0 - vec2(1.0));
  float escape = -1.0;
  float factor = 1.0;
  for (int i = 0; i < count && i < MAXCOUNT; ++i) {
    vec3 p = transform[i] * vec3(p0, 1.0);
    vec2 q = p.xy / p.z;
    float l = length(q);
```

```
      if (l < er) {
        vec2 z = texture(src, vec3((q / er + vec2(1.0)) / 2.0, source[i])).xy;
        if (escape < z.x) { escape = z.x; factor = 1.0/scaleFactor[i] * z.y; }
      }
    }
    if (escape >= 0.0) {
      escape += 1.0;
    }
    vec2 z = texture(src, vec3((p0 / er + vec2(1.0)) / 2.0, layer)).xy;
    if (escape > z.x) {
      z.x = escape;
      z.y = factor;
    }
    gl_FragData[0] = vec4(z, 0.0, 0.0);
}
```

75 the-sky-cracked-open/the-sky-cracked-open.cabal

```
name:                the-sky-cracked-open
version:             0.1.0.0
synopsis:            A short fractal video loop rendered with continuous escape time for an iterated function system.
homepage:            https://mathr.co.uk/blog/2011-12-31_the_sky_cracked_open.html
license:             GPL-3
license-file:        LICENSE
author:              Claude Heiland-Allen
maintainer:          claude@mathr.co.uk
category:            Demo
build-type:          Simple
extra-source-files:  ChangeLog.md
cabal-version:       >=1.10

executable the-sky-cracked-open
  main-is:             main.hs
  other-modules:       Shader Snapshot
  build-depends:       base >=4.9 && <4.10, bytestring >=0.10 && <0.11, OpenGL >= 3.0 && < 3.1, OpenGLRaw >= 3.2 && < 3.3, GLUT >= 2.7 && < 2.8, hmatrix >= 0.18 && < 0.19, hmatrix-gsl >= 0.18 && < 0.19
  default-language:    Haskell2010
  other-extensions:    PatternSynonyms
```