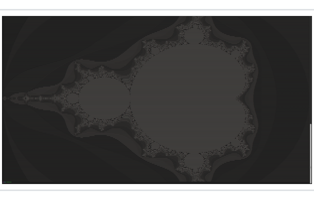
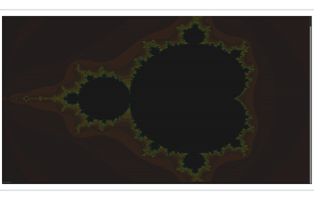
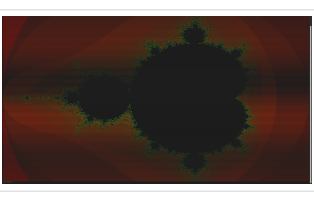
Mandelbrot set

Examples

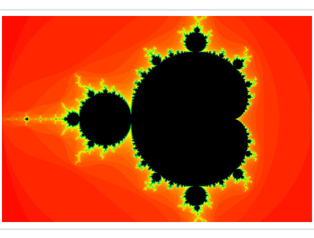
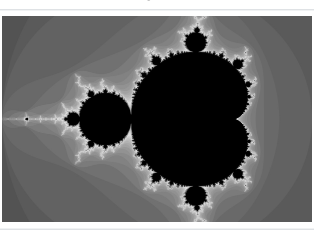
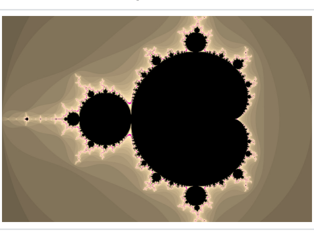
Mandelbrot set ASCII

Resolution 169 x 931; min zoom

Normal mode ASCII	Color mode ASCII	Color mode inverse ASCII
		

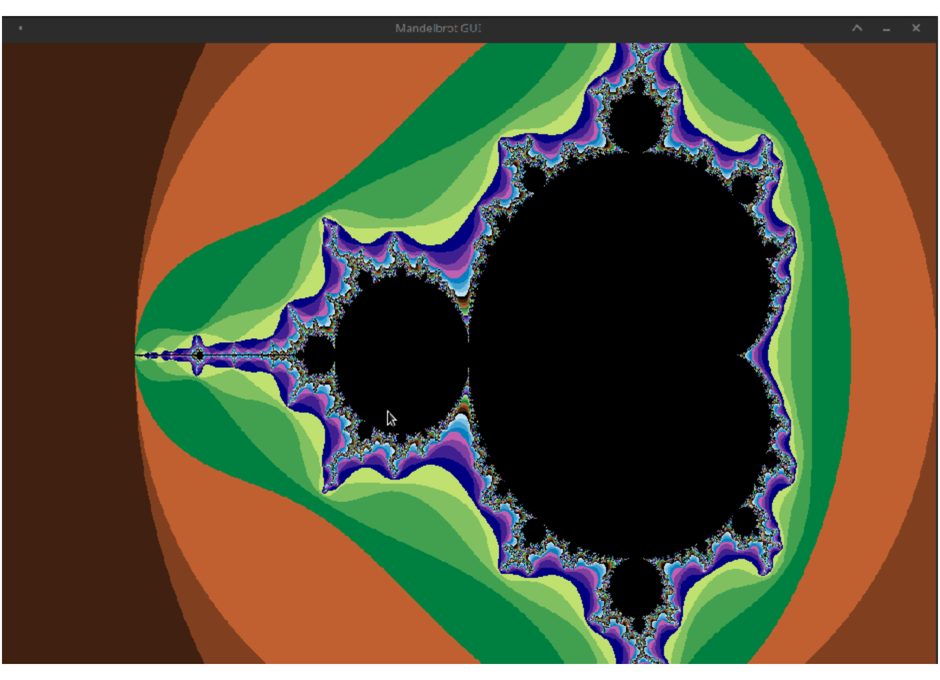
Mandelbrot set Rendered images

Rendered 3000 x 2000 using STB, 80 iterations

Color mode	Gray filter	Sepia filter
		

Mandelbrot set GUI (SDL)

Resolution 1080 x 720, made using SDL, 80 iterations



A little bit of theory

The equation for Mandelbrot set is: $f_c(z) = z^2 + c$

All we have to know (and realise) is in this table:

$z_0 = 0$	$z_{n+1} = z_n^2 + c$	$c = a + bi$	$i^2 = -1$

When plugged into the main equation, we get:
$z_1 = 0^2 + c \iff z_1 = a + bi$

So all we have now is $c \in \mathbb{C}$.

But when we continue:
$z_2 = z_1^2 + c \iff z_2 = c^2 + c \iff z_1 = (a + bi)^2 + c$

Then $(a + bi)^2$ *using* $A^2 + 2AB + B^2$

$(a + bi)^2 = a^2 + 2abi + b^2 \cdot i^2 = a^2 - b^2 + 2abi$

Which is, as we can see, another complex number with real part $a^2 - b^2$ and imaginary one $2ab$.

This process will continue indefinitely, so we need to set limits → you can set whatever you want, I set **80** (on my PC it's still pretty fast :] and it looks nice (in color)). `#define LIMIT 80`

Programming integration

Now we need to incorporate all these simple mathematical calculations into the code.

First we need to define all the important values.

```
#define WIDTH 1080
#define HEIGHT 720

#define REAL_START -2.5   // start value for real part
#define REAL_END 1.0
#define IMAG_START -1     // start value for imaginary part
#define IMAG_END 1.0

#define ZOOM 2            // zoom starts at 2
#define ITERATION 80      // number of iterations - (higher = slower)
```

Now we have to represent "pixels". It's gonna be `x` and `y` loop.
We can calculate the starting a and b using the defined values.

```
double rs = REAL_START, re = REAL_END;
double is = IMAG_START, ie = IMAG_END;

// function() {
    for (int y = 0; y < HEIGHT; y++) {
        for (int x = 0; x < WIDTH; x++) {
            // a... real number;
            // b... imaginary number
            double a = rs + (((double) x / HEIGHT)/1.5) * (re - rs);
            double b = is + (((double) y / WIDTH)*1.5) * (ie - is);

            // c = a + bi;
            double complex c = CMPLX(a, b);

            // calculating mandelbrot
            int m = calculateMandel(c);
```

Let's integrate math and calculate the Mendelbrot set...
We can proceed as in the theoretical part. Let $z = 0$. We know that the Hausdorff measure is 2, so we won't have a higher value.

If $|z_n| \leq m$ and if n is less than the iterative limit (`ITERATION`), we can calculate using the basic equation: $z_{n+1} = z_n^2 + c$.

For clarity, I created the parameter `zz` , it's just a powered z.

The `Cpow` and `Cadd` functions are only for simple operations with complex numbers.

```
int calculateMandel(double complex c) {
    double complex zz, z = 0.0;
    int n = 0;

    // |z| <= 2;  Hausdorff measure = 2
    while ((cabs(z) <= 2) && (n < ITERATION)) {
        // zz = z^2
        // z = z^2 + c <=> z = zz + c
        zz = Cpow(z);
        z = Cadd(zz, c);

        n++;
    } return n;
}
```

Adding color

Mandelbrot set is much nicer when displayed in colors.
First we need to convert HSV (hue, saturation, value) to RGB (red, green, blue). I have created a simple converter, based on the basics from this website.

```
            int m = calculateMandel(c);

            if (m < ITERATION) {
                int R, G, B;

                int H = (255 * m) / ITERATION;
                int S = 100;
                int V = 100;

                int r = hsv_to_rgb(H, S, V, 0);
                int g = hsv_to_rgb(H, S, V, 1);
                int b = hsv_to_rgb(H, S, V, 2);
```

I have 4 ways to color it here.

1. red (main color)

Nothing changes, the RGB is calculated based on the previous function. They are just redefined to the resulting values from `r` to `R` etc.

```
                if (color_type == 0) {
                    R = r;
                    G = g;
                    B = b;
                }
```

2. randomly

Best looking filter (at least for me).

```
                else if (color_type == 1) {
                    R = m % 4 * 64;
                    G = m % 8 * 32;
                    B = m % 16 * 16;
                }
```

3. grey

Replacing RGB with one color - grey - is obtained by a well-known and simple equation. We then put this one color for all the variables `R`, `G`, `B`.

```
                else if (color_type == 2) {
                    int gray = 0.299*r + 0.587*g + 0.114*b;
                    R = G = B = gray;

                }
```

4. sepia

For sepia filter, we have known equations too.

```
                else if (color_type == 3) {
                    R = 0.393*r + 0.769*g + 0.189*b;
                    G = 0.349*r + 0.686*g + 0.168*b;
                    B = 0.272*r + 0.534*g + 0.131*b;
                }
```

And that's practically all. We just have to print the Mandelbrot set now.

1. Printing into terminal - no color

The best is, to use characters sorted by brightness and then print them by m value.

```
#define ASCII "M@#W$BG5E20Tbca?1!;:+=-,._` "
#define ASCII2 " `_.,-=+:;!1?acbT02E5GB$W#@M" // reversed chars

//          [...]
            int m = calculateMandel(c);

            if (m >= ITERATION) {
                printf(" ");
            } else {
                printf("%c", ASCII2[(m - 1) % strlen(ASCII2)]);
            }
```

2. Printing into terminal - color

First we define the ANSI code for rgb and for returning to the normal cursor color. Then we just need to print using our known predefined values `R`, `G`, `B`.

```
#define ANSI_f_start "\x1b[38;2;"
#define ANSI_end "\x1b[0m"

// [...]
                printf("%s%d;%d;%dm%c%s", ANSI_f_start, r, g, b, ASCII2[(m) % strlen(ASCII2)], ANSI_end);
```

3. Rendering to image - color

To render the image I used the STB library (stored in `/fractal/src/stb/` you have to make this directory and download `stb_image.h` and `stb_image_write.h`)

```
#define STB_IMAGE_IMPLEMENTATION
#define STB_IMAGE_WRITE_IMPLEMENTATION
#include "../stb/stb_image.h"
#include "../stb/stb_image_write.h"
```

First, we allocate data memory for future use.
3 = three channels R, G, B

```
    size_t check = WIDTH * HEIGHT * 3;
    unsigned char *data = calloc(check, sizeof *data);
    int n = 0;
```

In the color functions we need to replace R, G, B and replace them with the expression `data[n++] = (unsigned char)` . (Like this:)

```
                else if (color == 1) {
                    data[n++] = (unsigned char)m % 4 * 64;
                    data[n++] = (unsigned char)m % 8 * 32;
                    data[n++] = (unsigned char)m % 16 * 16;
                }
```

And then after all the loops, we select the image format and then render it.

```
        // rendering png
        stbi_write_png("mandelbrot_rendered_image.png", WIDTH, HEIGHT, 3, data, width*3);
        // rendering jpg
        stbi_write_jpg("madnelbrot_rendered_image.jpg", WIDTH, HEIGHT, 3, data, 100);
```

4. Live viewing using GUI

This part was made using SDL library. You'll import it using:

```
#include <SDL.h>
#include <SDL2/SDL.h>
```

And then you update and enter data in each loop.

```
void drawMandelbrot(SDL_Window *win, SDL_Surface *win_surface) {
    static SDL_Rect rect;

    // mandelbrot calculation loop
    for (int y = 0; y < HEIGHT; y++) {
        for (int x = 0; x < WIDTH; x++) {
            // [...]
            int m = calculateMandel(c);

            if (m < ITERATION) {
                // [...]
                ((Uint32*)win_surface->pixels)[(y * win_surface->w) + x] = (m >= ITERATION)? 0 :
                    SDL_MapRGB(win_surface->format, R, G, B);
            } else {
                ((Uint32*)win_surface->pixels)[(y * win_surface->w) + x] = (m >= ITERATION)? 0 :
                    SDL_MapRGB(win_surface->format, 0, 0, 0);
            }
        }
    }
    SDL_UpdateWindowSurface(win);
}
```

Zooming

Nothing hard, just recalculate `REAL` & `IMAG_START` and `REAL` & `IMAG_END` according to the new `x` and `y` values (by the mouse click location - coordinates).

```
void Zoom(double zoom, double x, double y) {
    // mouse clicked axes to set the center
    double a = rs + (re - rs)*x / WIDTH;
    double b = is + (ie - is)*y / HEIGHT;

    // aa --> real; bb --> imaginary
    double aa = a - (re - rs) / 2 / zoom;
    re = a + (re - rs) / 2 / zoom;
    rs = aa;

    double bb = b - (ie - is) / 2 / zoom;
    ie = b + (ie - is) / 2 / zoom;
    is = bb;
}
```