OpenCL exercise 2: Mandelbrot set

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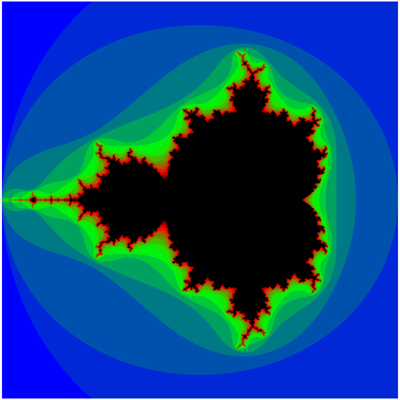
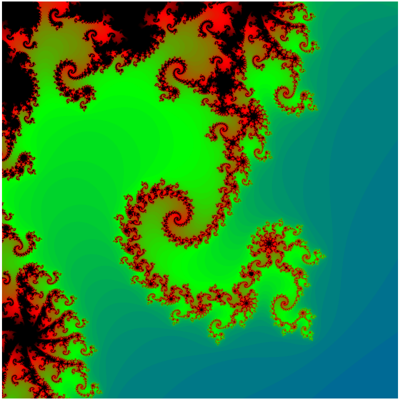
Mandelbrot set



$x \in [-2, 1], y \in [-1.5, 1.5], n = 20$



$x \in [-0.813, -0.791],$
$y \in [-0.188, -0.166], n = 110$

Mandelbrot set

- Complex sequence: $z_0 = 0$, $z_{n+1} = z_n^2 + c$ ($c \in \mathbb{C}$, $z \in \mathbb{C}$, $n \in \mathbb{N}$)
- Mandelbrot set: set of complex numbers c constrained that the sequence z_n remains bounded.
- Once $|z_n| > 2$ the sequence diverges
- In images: Complex plane for c values is displayed
  - in Mandelbrot set: black
  - not in Mandelbrot set: color shows iteration where $|z_n|$ exceeds 2

Host code

```
for (size_t i = 0; i < countX; i = i + 1) { //loop in the x-dir.
  float xc = xmin + (xmax - xmin) / (countX - 1) * i; //xc=real(c)
  for (size_t j = 0; j < countY; j = j + 1) { //loop in the y-dir.
    float yc = ymin + (ymax - ymin) / (countY - 1) * j;//yc=imag(c)
    float x = 0.0; //x=real(z_k)
    float y = 0.0; //y=imag(z_k)
    for (size_t k = 0; k < niter; k = k + 1) { //iteration loop
      float tempx = x * x - y * y + xc; //real of z_{n+1}=(z_n)^2+c
      float tempy = 2 * x * y + yc; //imaginary part of z_{n+1}
      x = tempx;
      y = tempy;
      float r2 = x * x + y * y; //r2=|z_{n+1}|^2
      if ((r2 > 4) || k == niter - 1) { //divergence condition
        h_output[i + j * countX] = k;
        break;
      }
    }
  }
}
```

Task 1

- Implement mandelbrot set on GPU
- Use 2D index space
  - one work item for each complex value in the complex plain
- Check which loops in the CPU implementation can be parallelized
  - all work item run the same kernel code
- Time for CPU, GPU, memory transfer, speedups

- Check results

Task 2

- Use the second parameter set
- Explain the results
- Explain the effect on the speedup

Task 3

- Modify the number of work items per work group and the number of work groups.
- What happens?

OpenCL Types

OpenCL C	C++	Info
`char`	`cl_char`	signed 8-bit integer
`uchar`	`cl_uchar`	unsigned 8-bit integer
`short`	`cl_short`	signed 16-bit integer
`ushort`	`cl_ushort`	unsigned 16-bit integer
`int`	`cl_int`	signed 32-bit integer
`uint`	`cl_uint`	unsigned 32-bit integer
`long`	`cl_long`	signed 64-bit integer
`ulong`	`cl_ulong`	unsigned 64-bit integer
`float`	`cl_float`	32-bit float
`double`	`cl_double`	64-bit float
`bool`	-	boolean value (`true` or `false`)
`size_t`	-	pointer-sized unsigned integer
`__global T*`	`cl::Buffer`	pointer to data in global memory

OpenCL Types

- When passing a value to the kernel using `kernel.setArg()`, always specify the (C++) type of the parameter:
  - `__kernel void fooKernel(__global int* p, int i, float f);`
  - `fooKernel.setArg<cl::Buffer>(0, d_output);`
  - `fooKernel.setArg<cl_int>(1, intValue);`
  - `fooKernel.setArg<cl_float>(2, floatValue);`
- Pointers to global memory in the kernel (`__global T*`) are `cl::Buffer` in C++
  - The pointed-to type which matches `__global int* i` in the kernel should e.g. be allocated as `std::vector<cl_int>` in C++
- `cl_float` = `float`, `cl_double` = `double`

Syntax: Launching a 2D kernel

Syntax:

```
cl::CommandQueue::enqueueNDRangeKernel(Kernel kernel,
    NDRange offset, NDRange global, NDRange local,
    eventsToWaitFor = NULL, cl::Event* event=NULL) const;
```

Example for 2D NDRange:

```
queue.enqueueNDRangeKernel(kernel, cl::NullRange,
    cl::NDRange(globalX, globalY),
    cl::NDRange(localX, localY), NULL, &event);
```

`globalX` / `globalY` = Overall number of work items in X/Y-direction
`localX` / `localY` = Number of work items per work group in X/Y-direction

Syntax: Kernel code

Get global index of the current work item in the x-direction:

```
size_t i = get_global_id(0);
```

Get global index of the current work item in the y-direction:

```
size_t j = get_global_id(1);
```

Get global size in the x-direction:

```
size_t countX = get_global_size(0);
```

Get global size in the y-direction:

```
size_t countY = get_global_size(1);
```