/INFOMOV/

Optimization & Vectorization

J. Bikker - Sep-Nov 2019 - Lecture 9: “GPGPU (1)”

Welcome!

Global Agenda:

1. GPGPU (1) : Introduction, architecture, concepts
2. GPGPU (2) : Practical Code using GPGPU
3. GPGPU (3) : Parallel Algorithms, Optimizing for GPU

Today's Agenda:

- Introduction to GPGPU
- Example: Voronoi Noise
- GPGPU Programming Model
- OpenCL Template

“If you were plowing a field, which would you rather use? Two strong oxen, or 1024 chickens?”

- Seymour Cray

Introduction

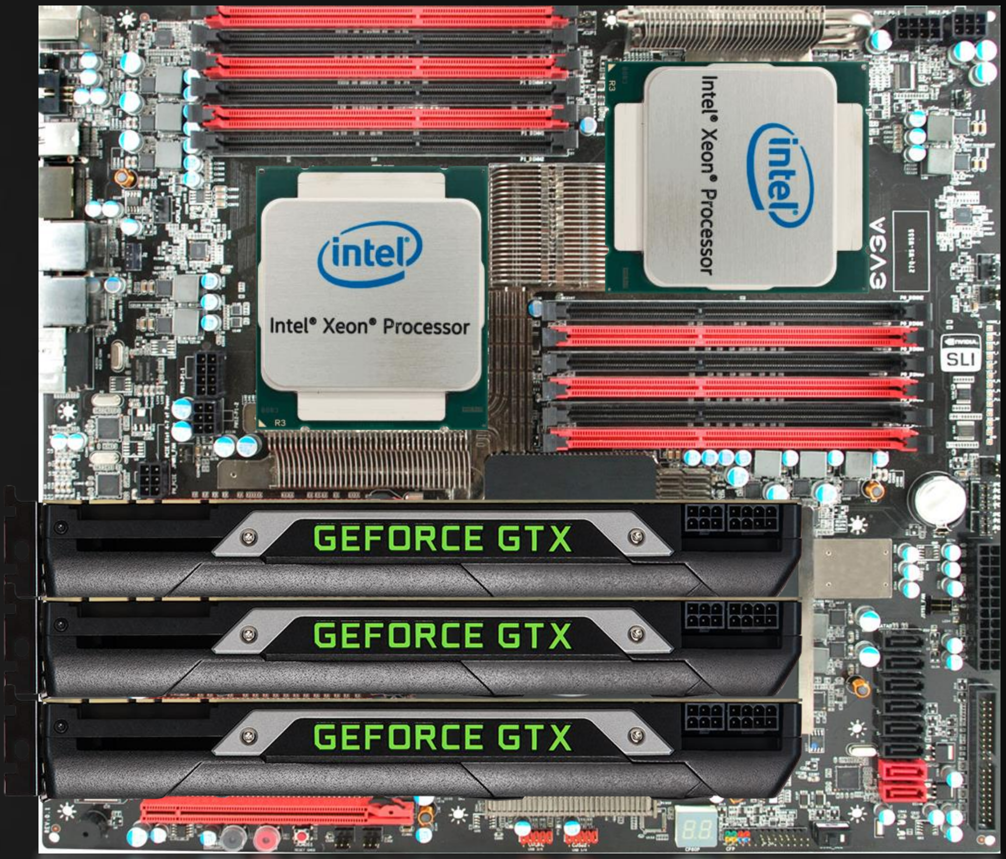
Heterogeneous Processing

The average computer contains:

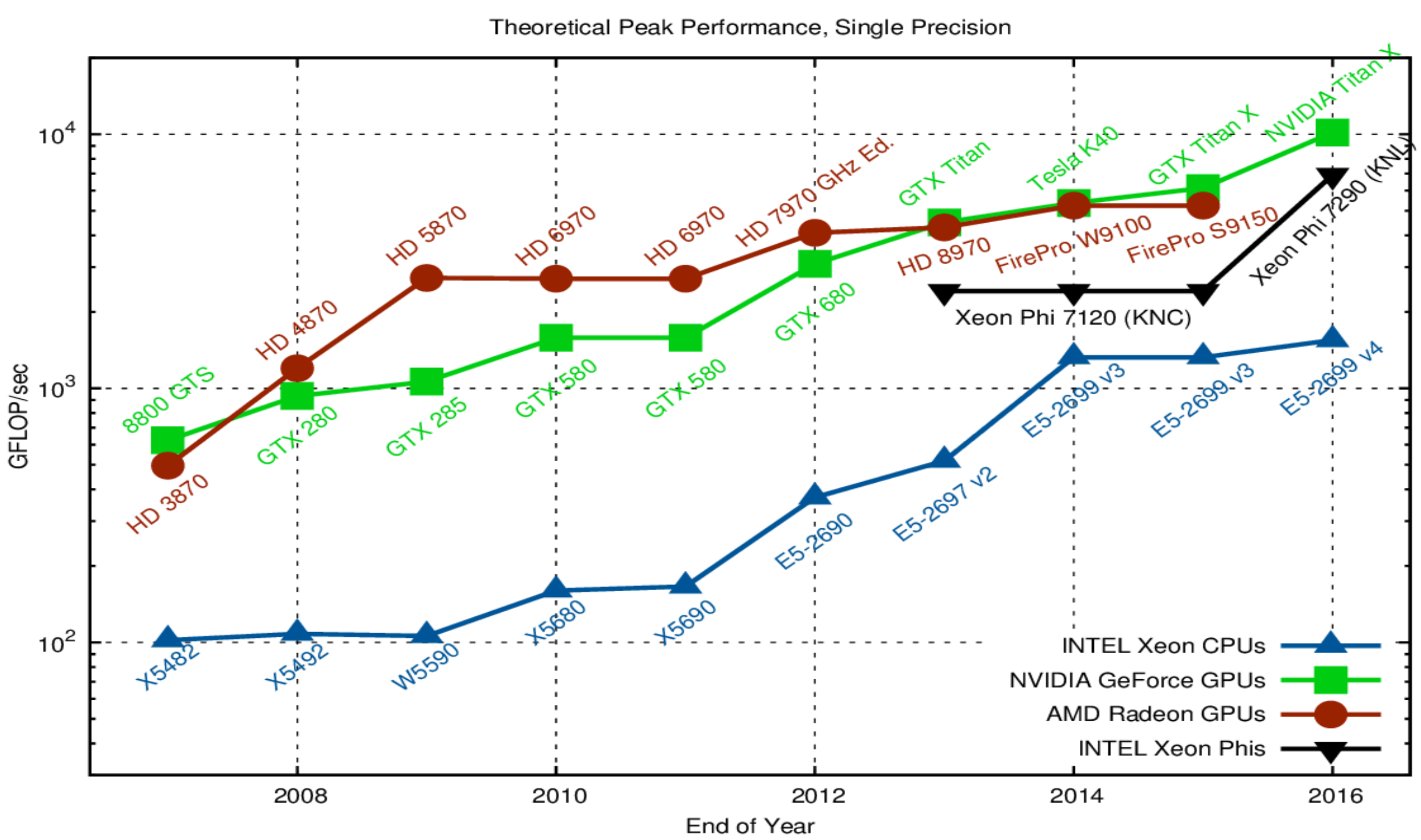
- 1 or more CPUs;
- 1 or more GPUs.

We have been optimizing CPU code.
A vast source of compute power has remained unused:

The Graphics Processing Unit.



Introduction



AMD: RX Vega 64 € 525	484 GB/s 13.7 TFLOPS
NVidia: GTX2080Ti $1200	616 GB/s 14 TFLOPS
Intel: i9-7980XE € 1978	50 GB/s 1.1 TFLOPS
Xeon Phi 7120P € 3167	352 GB/s ~6 TFLOPS

Introduction

A Brief History of GPGPU

Introduction

A Brief History of GPGPU

Introduction

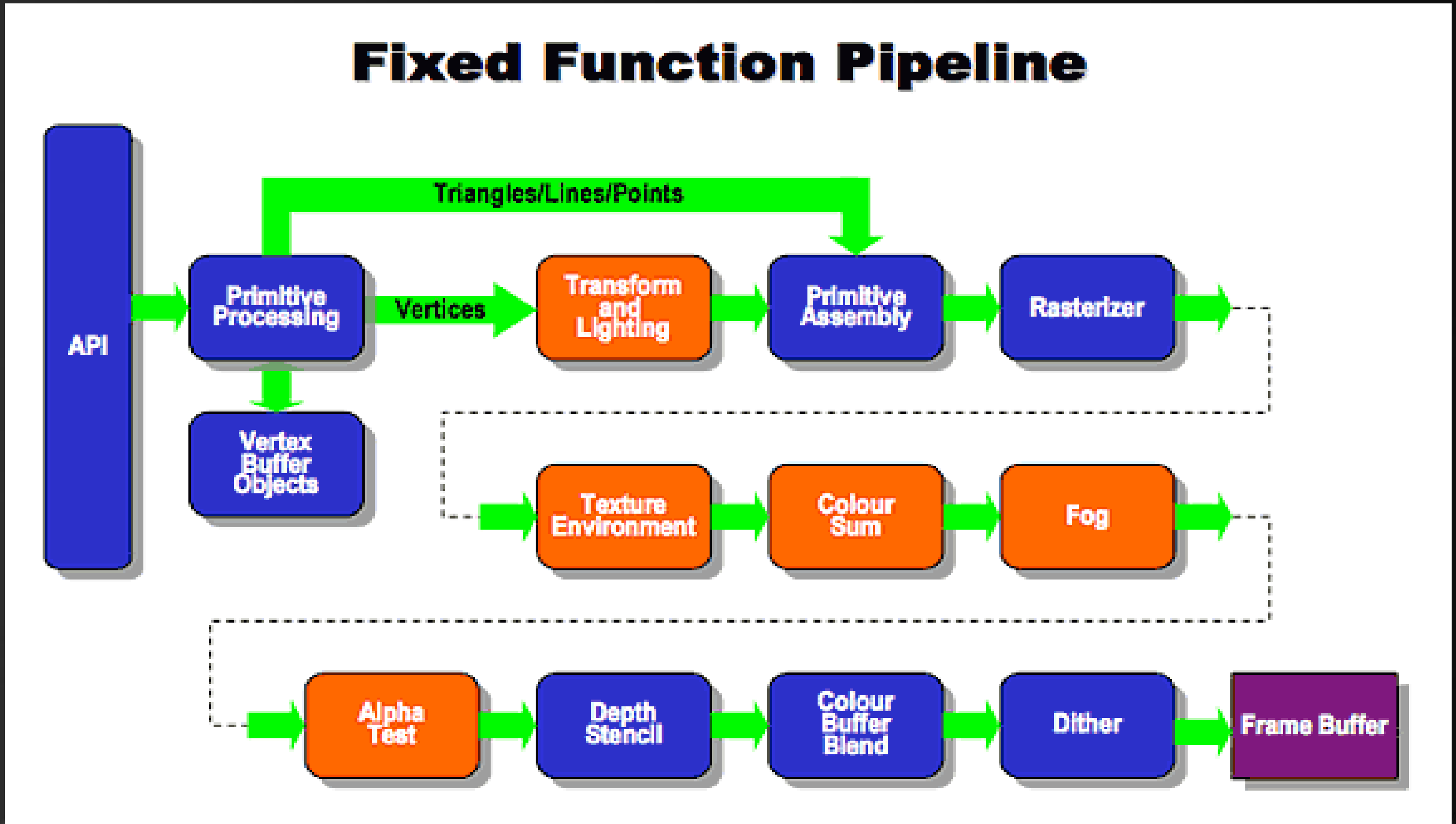
A Brief History of GPGPU

NVidia NV-1
(Diamond Edge 3D)
1995

3Dfx –
Diamond Monster 3D
1996

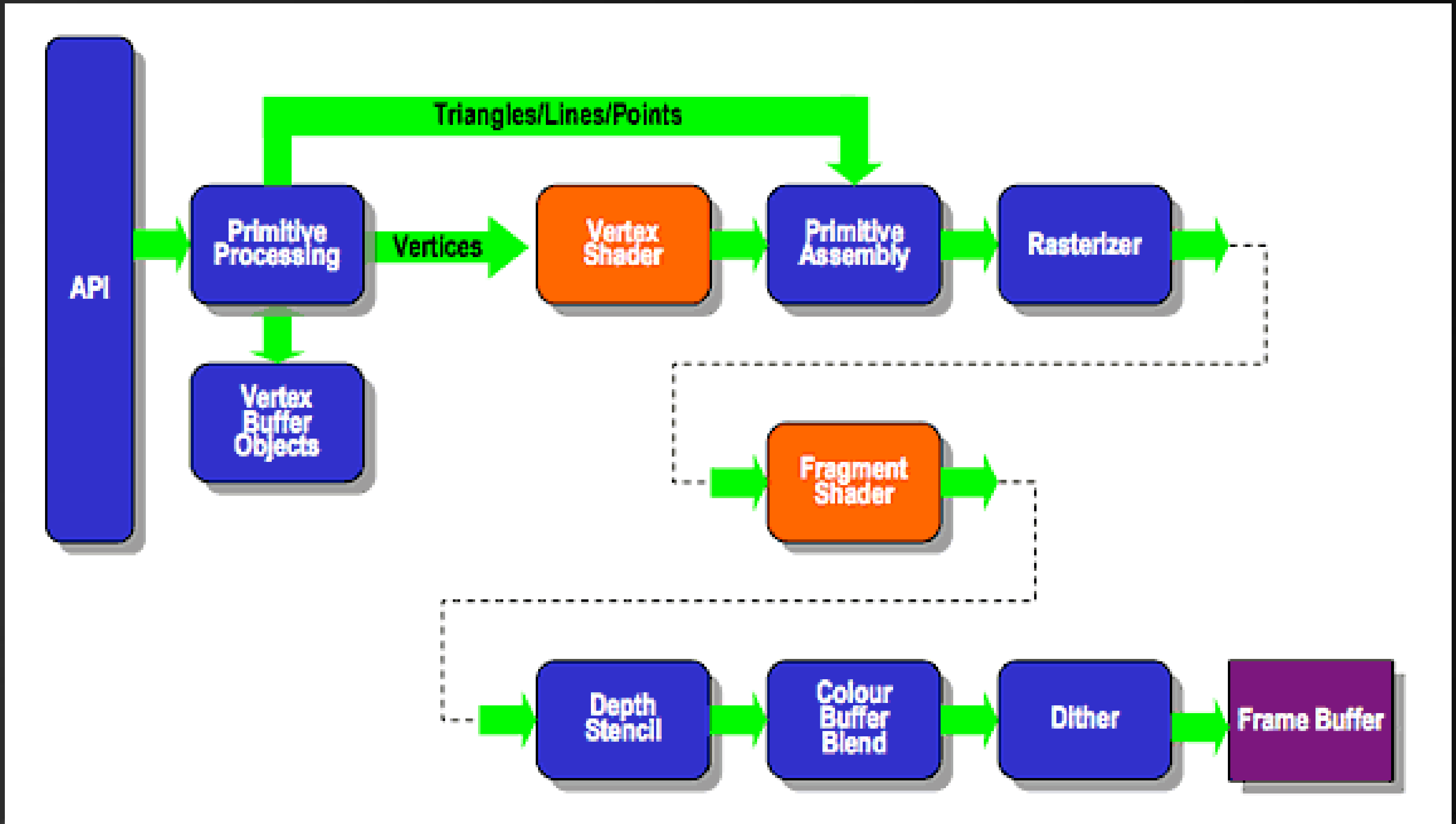
Introduction

A Brief History of GPGPU



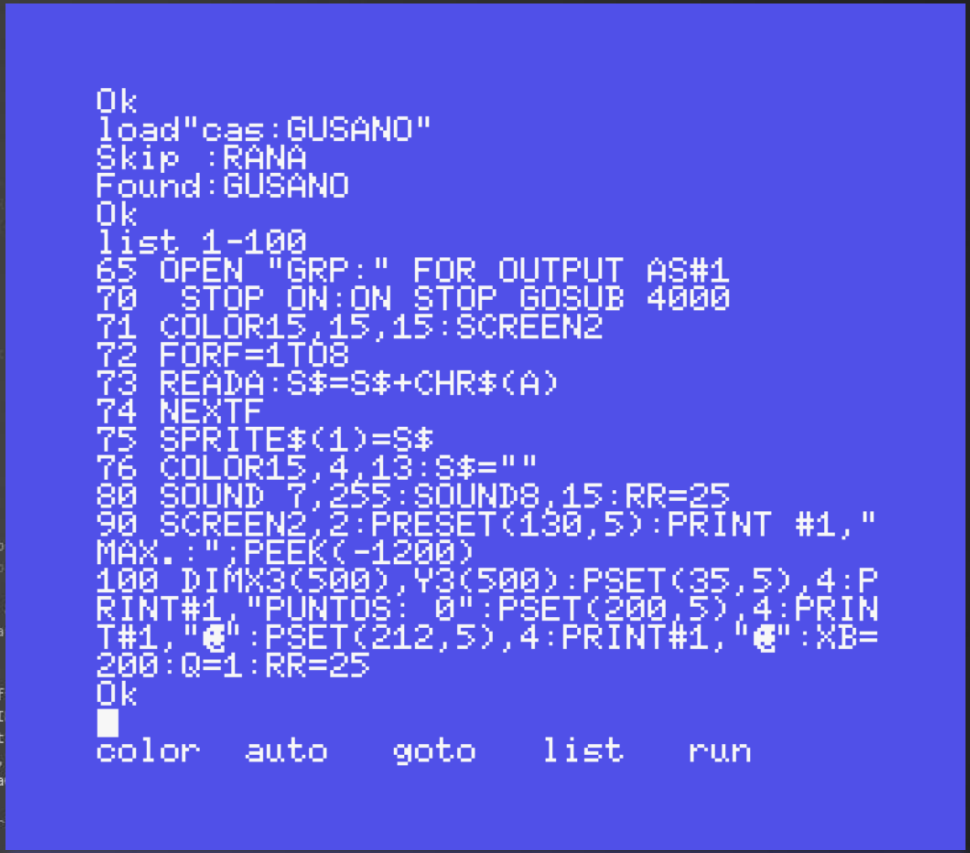
Introduction

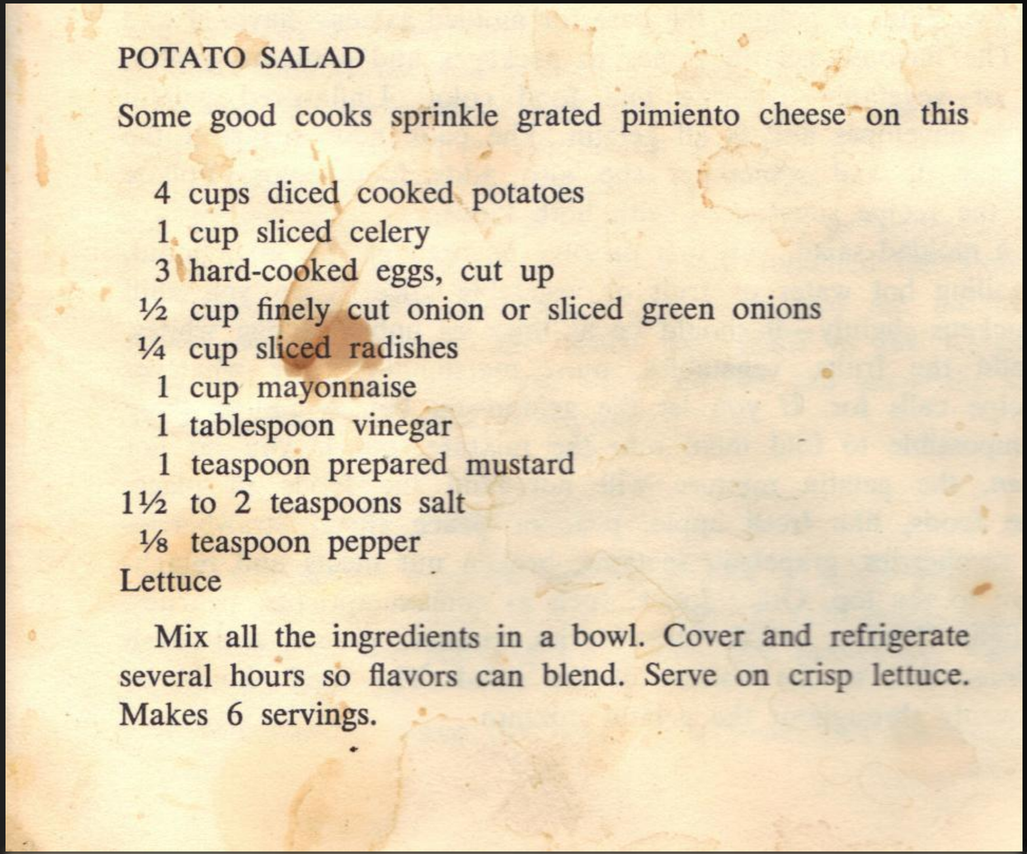
A Brief History of GPGPU



Introduction

A Brief History of GPGPU




POTATO SALAD

Some good cooks sprinkle grated pimiento cheese on this

4 cups diced cooked potatoes
1 cup sliced celery
3 hard-cooked eggs, cut up
½ cup finely cut onion or sliced green onions
¼ cup sliced radishes
1 cup mayonnaise
1 tablespoon vinegar
1 teaspoon prepared mustard
1½ to 2 teaspoons salt
⅛ teaspoon pepper
Lettuce

Mix all the ingredients in a bowl. Cover and refrigerate several hours so flavors can blend. Serve on crisp lettuce. Makes 6 servings.

Introduction

A Brief History of GPGPU

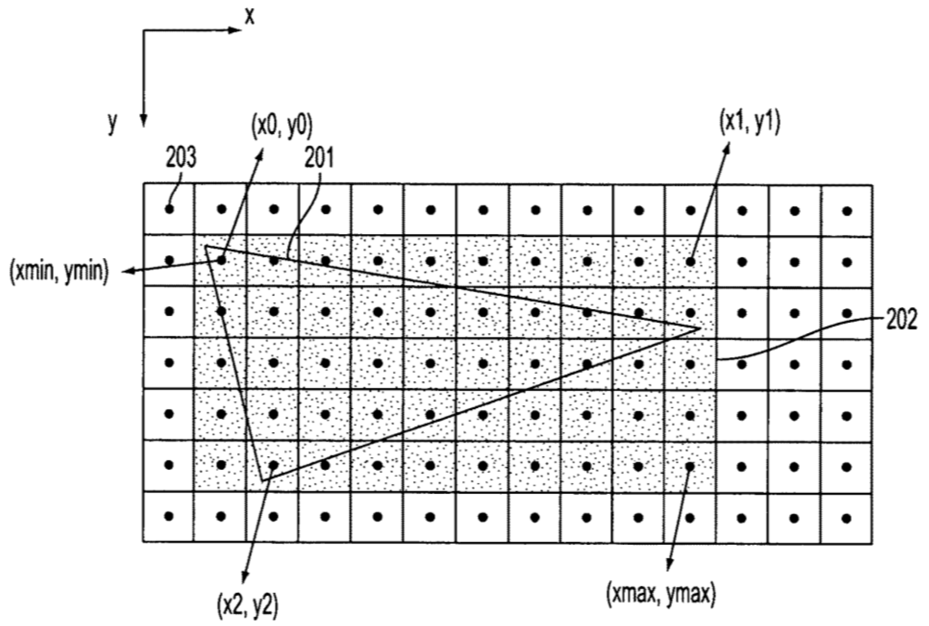


FIG. 4

GPU - conveyor belt:

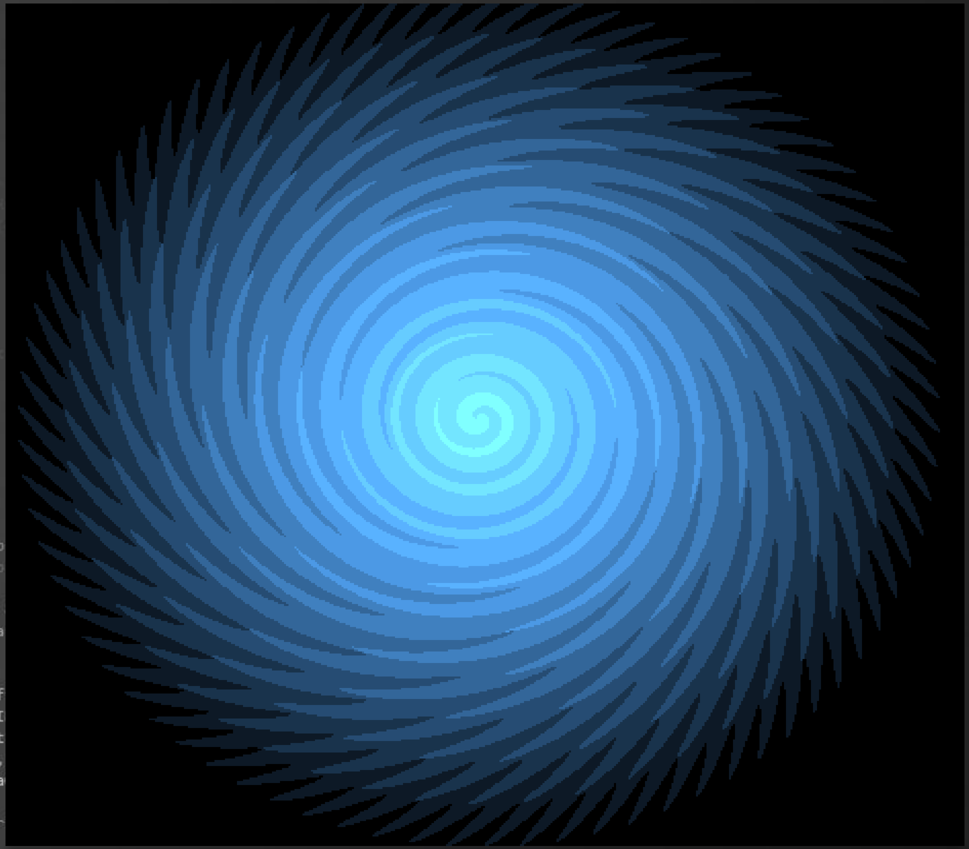
input = vertices + connectivity

step 1: transform
step 2: rasterize
step 3: shade
step 4: z-test

output = pixels

Introduction

A Brief History of GPGPU



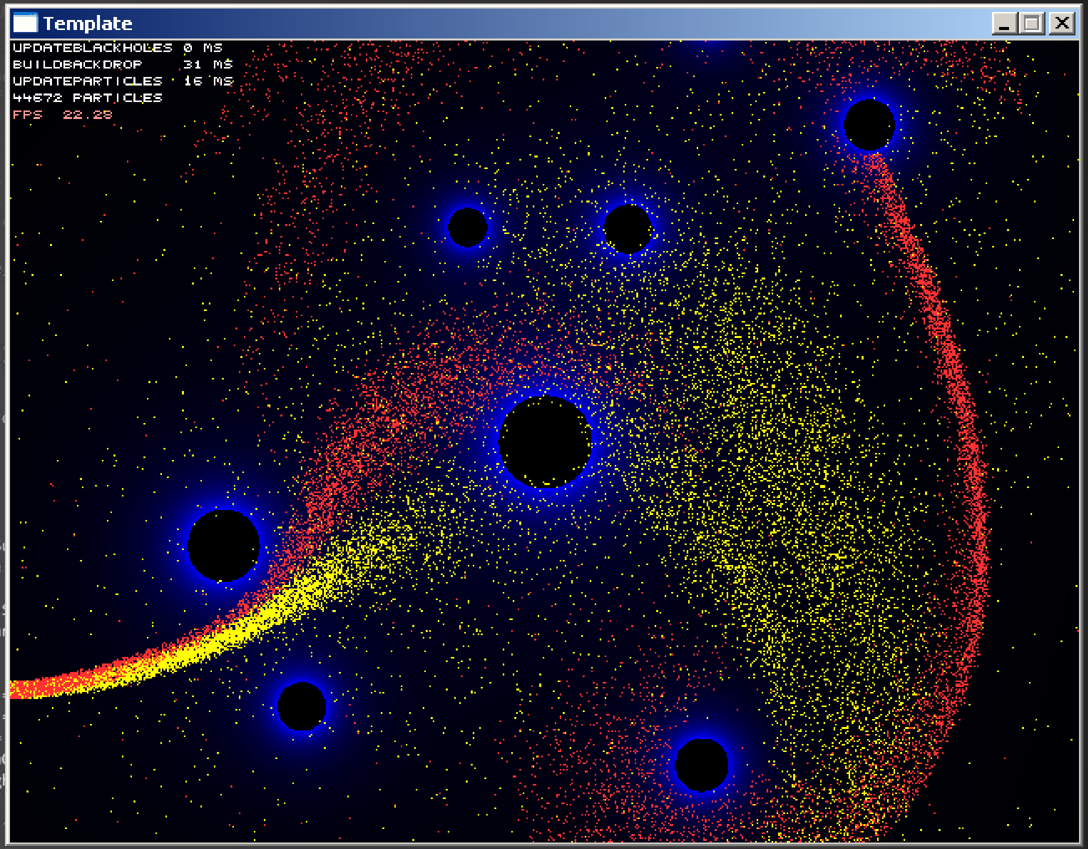
https://www.shadertoy.com/view/4sjSRt

```
void main(void)
{
    float t = iGlobalTime;
    vec2 uv = gl_FragCoord.xy / iResolution.y;
    float r = length(uv), a = atan(uv.y,uv.x);
    float i = floor(r*10);
    a *= floor(pow(128,i/10));
    a += 20.*sin(0.5*t)+123.34*i-100.*
        (r*i/10)*cos(0.5*t);
    r += (0.5+0.5*cos(a)) / 10;
    r = floor(N*r)/10;
    gl_FragColor = (1-r)*vec4(0.5,1,1.5,1);
}
```

GLSL ES code

Introduction

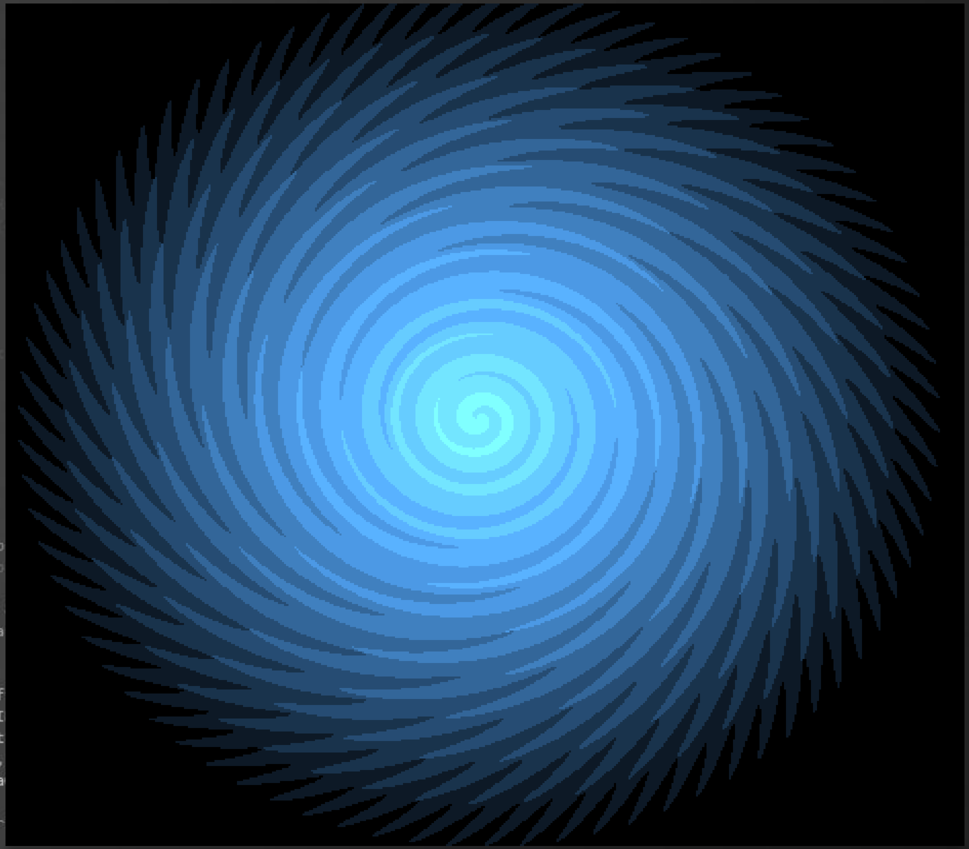
A Brief History of GPGPU




```
void Game::BuildBackdrop()
{
    Pixel* dst = m_Surface->GetBuffer();
    float fy = 0;
    for ( unsigned int y = 0; y < SCRHEIGHT; y++,
    {
        float fx = 0;
        for ( unsigned int x = 0; x < SCRWIDTH; x+
        {
            float g = 0;
            for ( unsigned int i = 0; i < HOLES; i
            {
                float dx = m_Hole[i]->x - fx, dy =
                float squareddist = ( dx * dx + dy
                g += (250.0f * m_Hole[i]->g) / squ
            }
            if (g > 1) g = 0;
            *dst++ = (int)(g * 255.0f);
```

Introduction

A Brief History of GPGPU



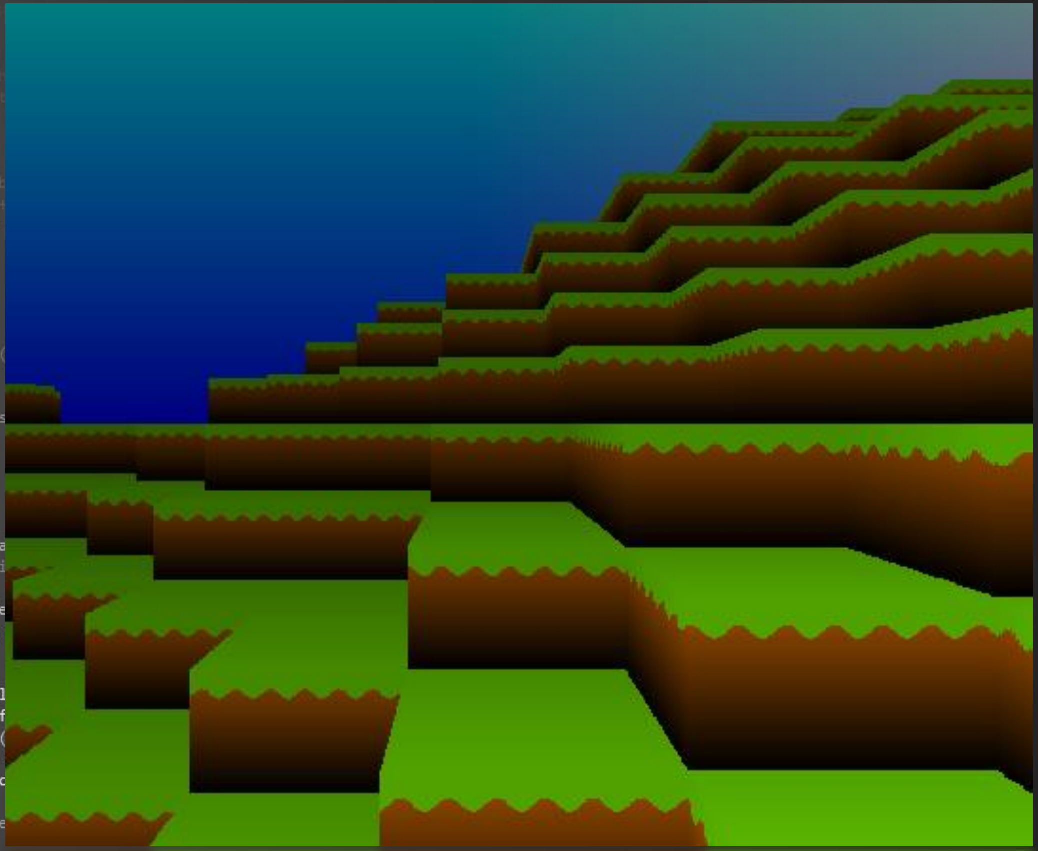
https://www.shadertoy.com/view/4sjSRt

```
void main(void)
{
    float t = iGlobalTime;
    vec2 uv = gl_FragCoord.xy / iResolution.y;
    float r = length(uv), a = atan(uv.y,uv.x);
    float i = floor(r*10);
    a *= floor(pow(128,i/10));
    a += 20.*sin(0.5*t)+123.34*i-100.*
        (r*i/10)*cos(0.5*t);
    r += (0.5+0.5*cos(a)) / 10;
    r = floor(N*r)/10;
    gl_FragColor = (1-r)*vec4(0.5,1,1.5,1);
}
```

GLSL ES code

Introduction

A Brief History of GPGPU



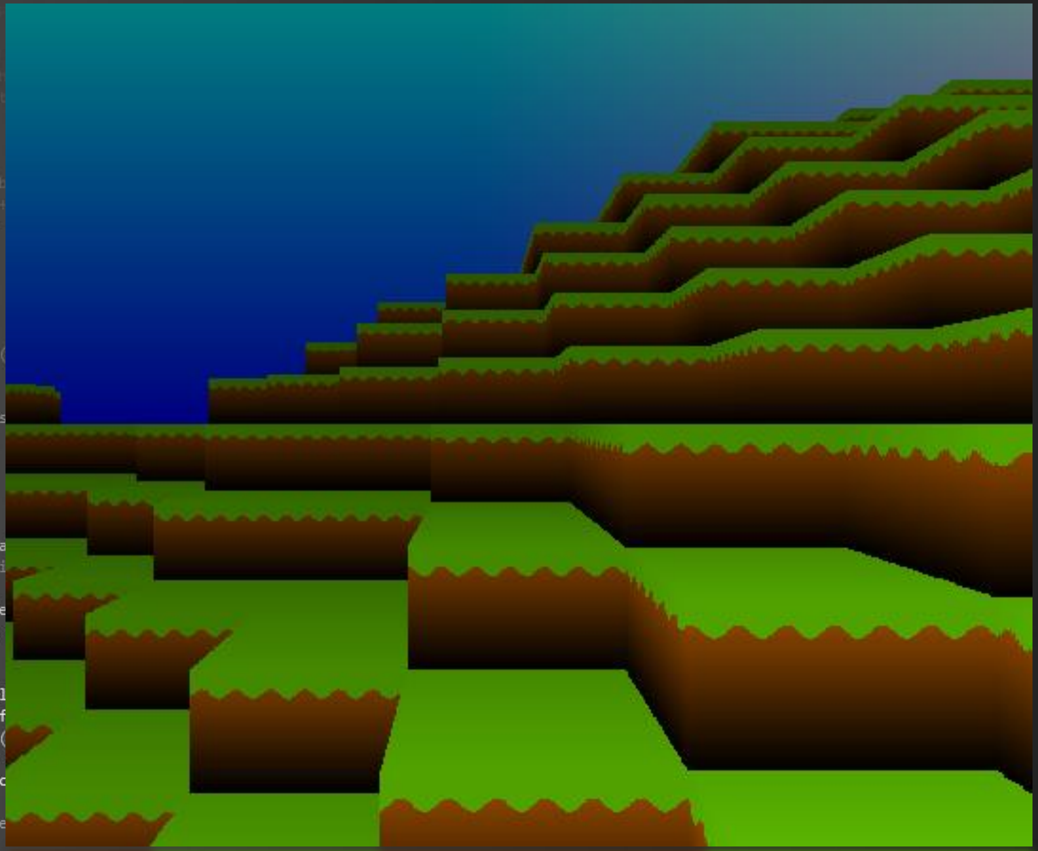
https://www.shadertoy.com/view/4tsGD7

```
void mainImage( out vec4 z, in vec2 w ) {
  vec3 d = vec3(w,1)/iResolution-.5, p, c, f;
  vec3 g = d, o, y = vec3( 1,2,0 );
   o.y = 3. * cos((o.x=.3)*(o.z = iDate.w));
   for( float i=.0; i<9.; i+=.01 ) {
      f = fract(c = o += d*i*.01),
      p = floor( c )*.3;
      if( cos(p.z) + sin(p.x) > ++p.y ) {
       g = (f.y - .04*cos((c.x+c.z)*40.)>.8?y:
            f.y * y.yxz) / i;
       break;
} } z.xyz = g; }
```

GLSL ES code

Introduction

A Brief History of GPGPU



GPUs perform well because they have a constrained execution model, based on massive parallelism.

CPU: Designed to run one thread as fast as possible.

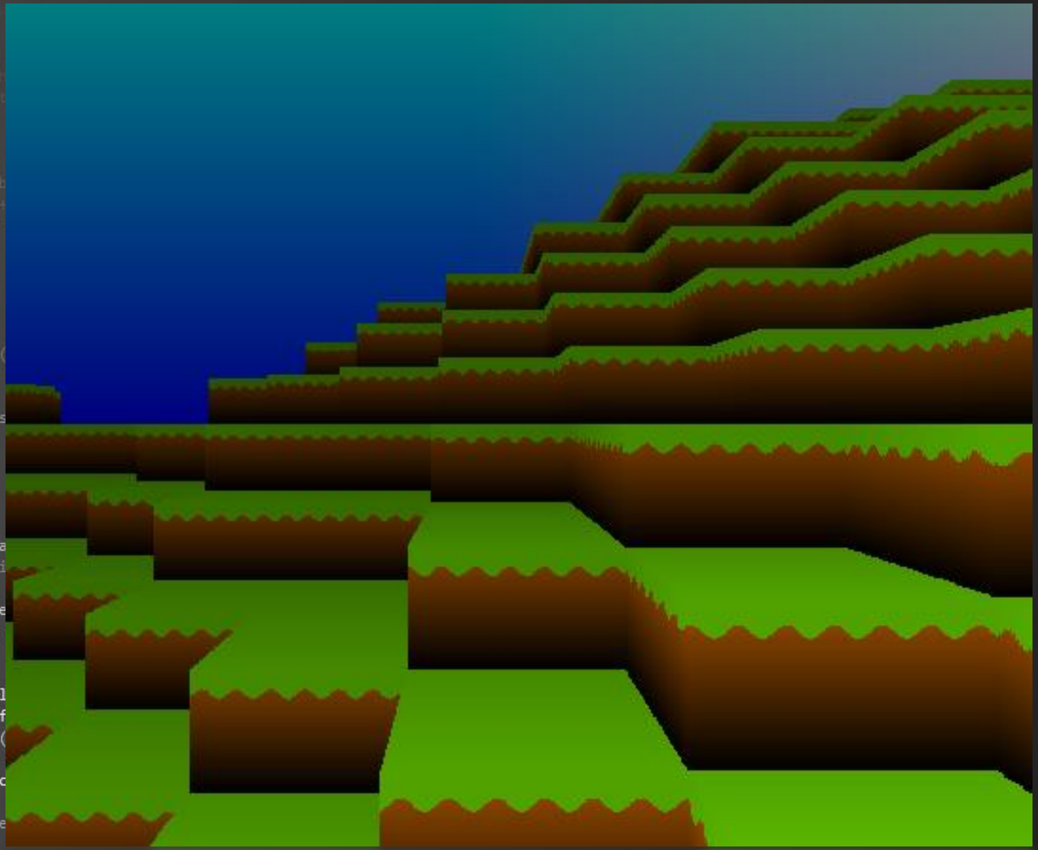
- Use caches to minimize memory latency
- Use pipelines and branch prediction
- Multi-core processing: *task parallelism*

Tricks:

- SIMD
- “Hyperthreading”

Introduction

A Brief History of GPGPU



GPUs perform well because they have a constrained execution model, based on massive parallelism.

GPU: Designed to combat latency using many threads.

- Hide latency by computation
- Maximize parallelism
- Streaming processing ➔ Data parallelism ➔ SIMT

Tricks:

- Use typical GPU hardware (filtering etc.)
- Cache anyway

Introduction

GPU Architecture

CPU

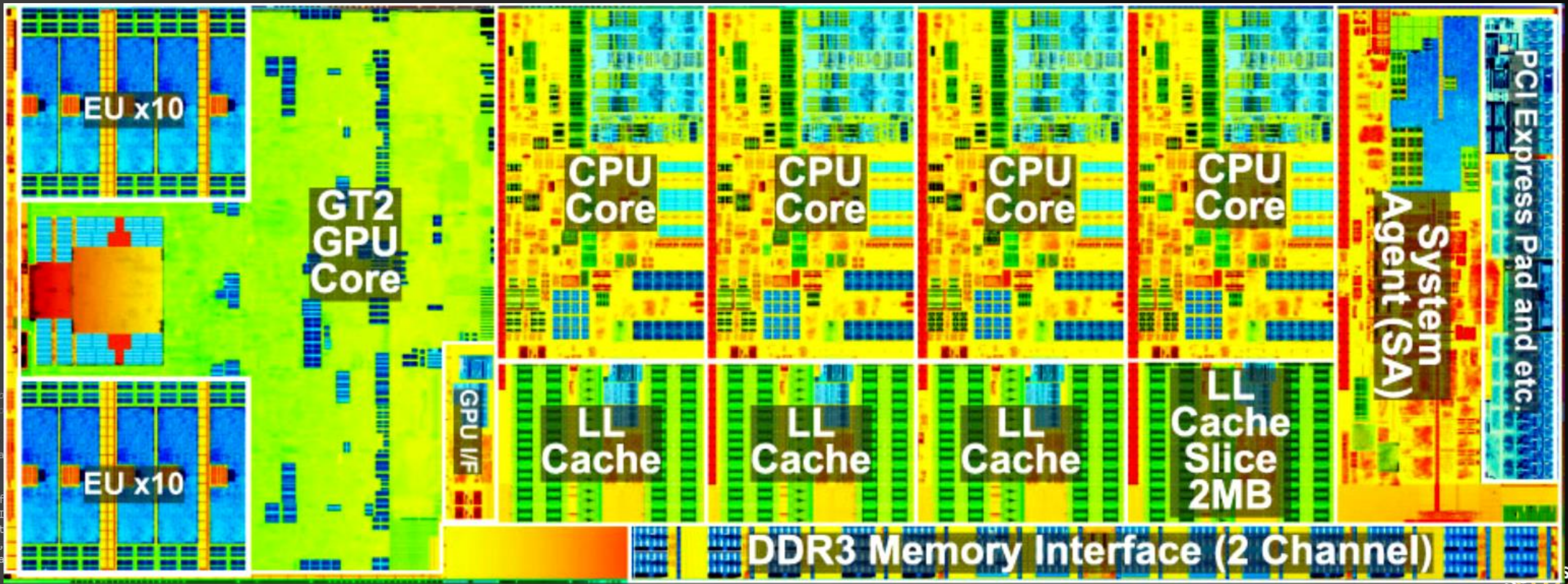
- Multiple tasks = multiple threads
- Tasks run different instructions
- 10s of complex threads execute on a few cores
- Thread execution managed explicitly

GPU

- SIMD: same instructions on multiple data
- 10.000s of light-weight threads on 100s of cores
- Threads are managed and scheduled by hardware

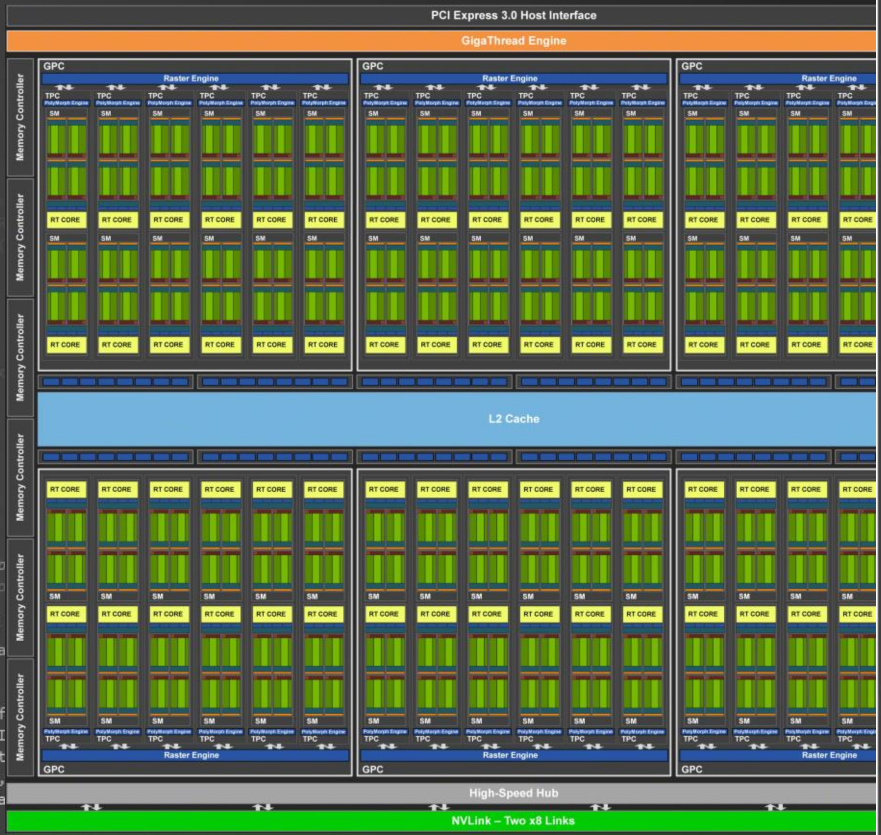
Introduction

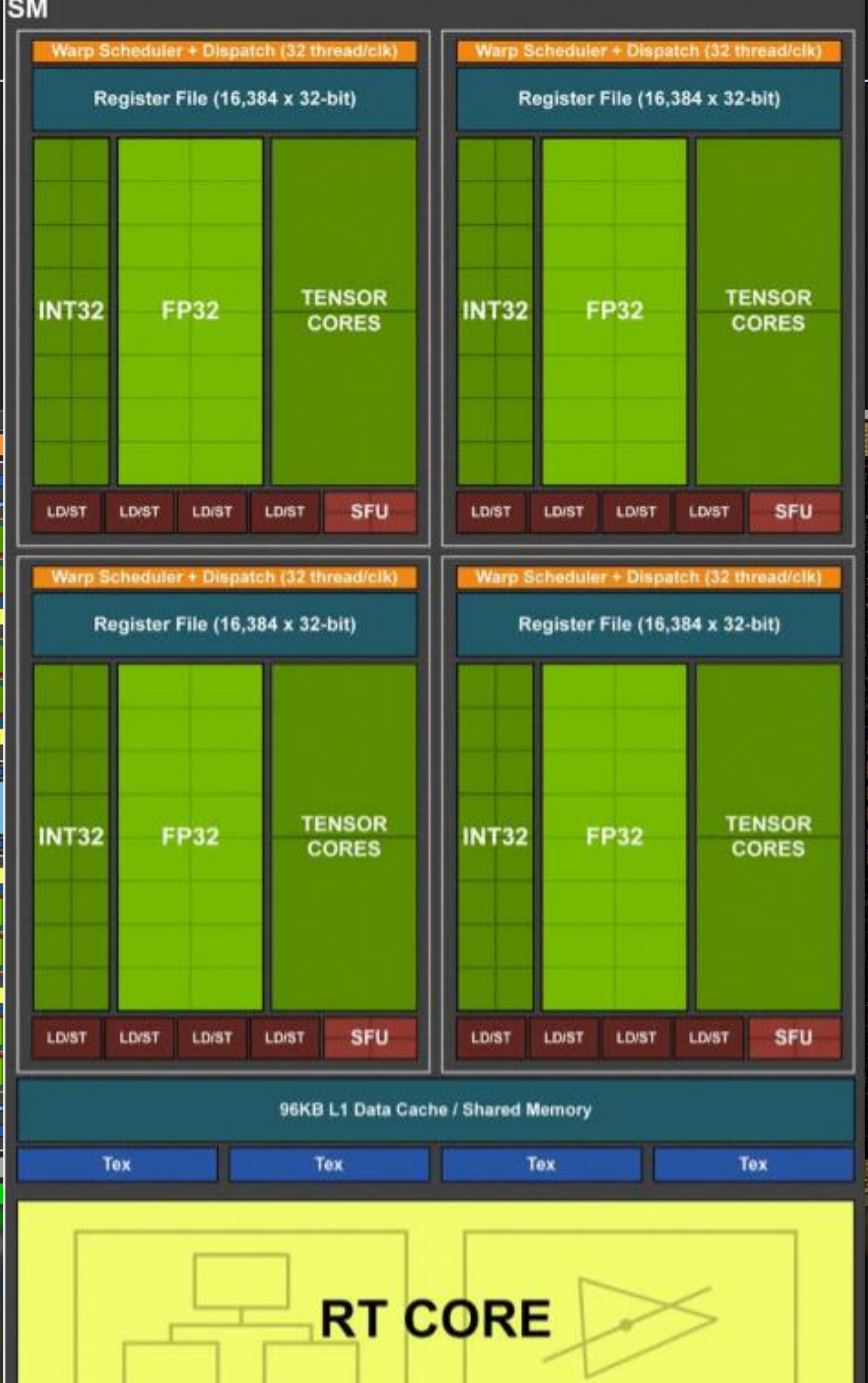
CPU Architecture…

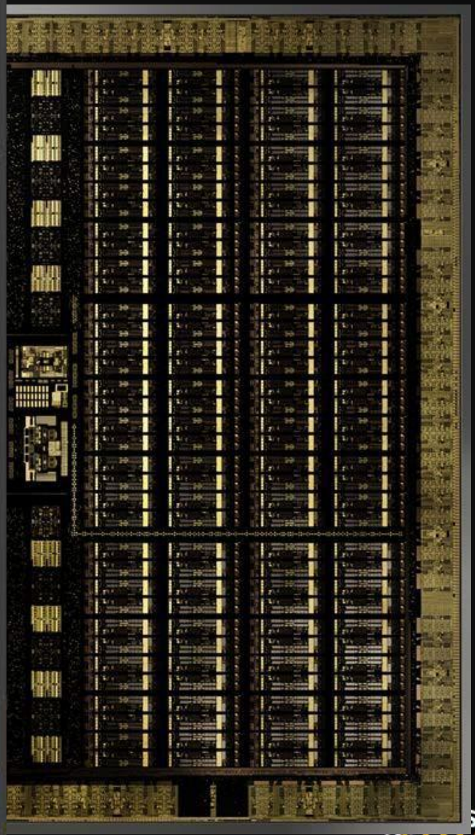


Introduction

versus GPU Architecture:

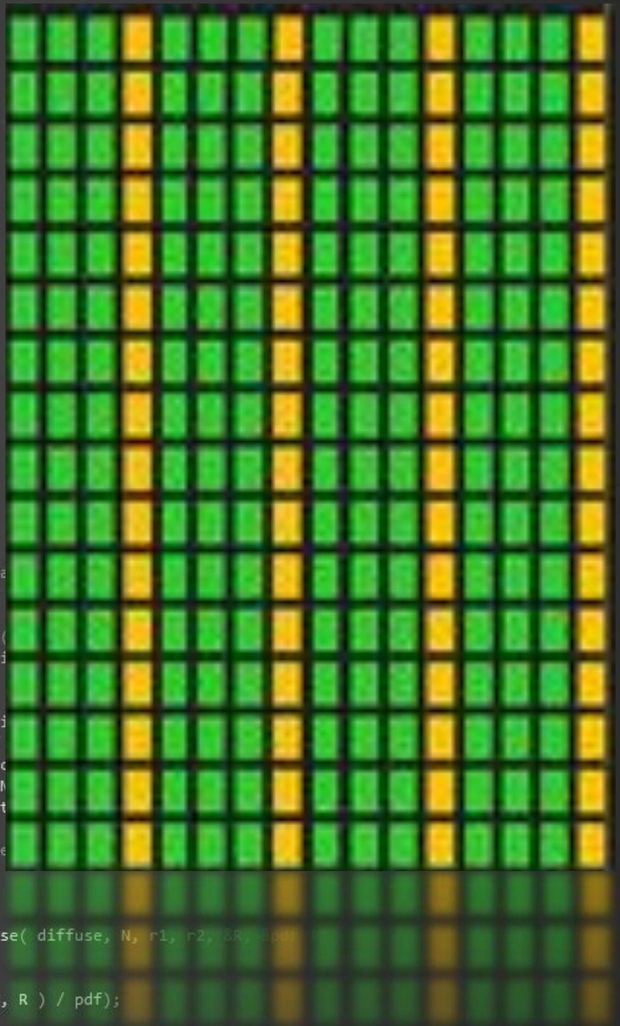






Introduction

GPU Architecture

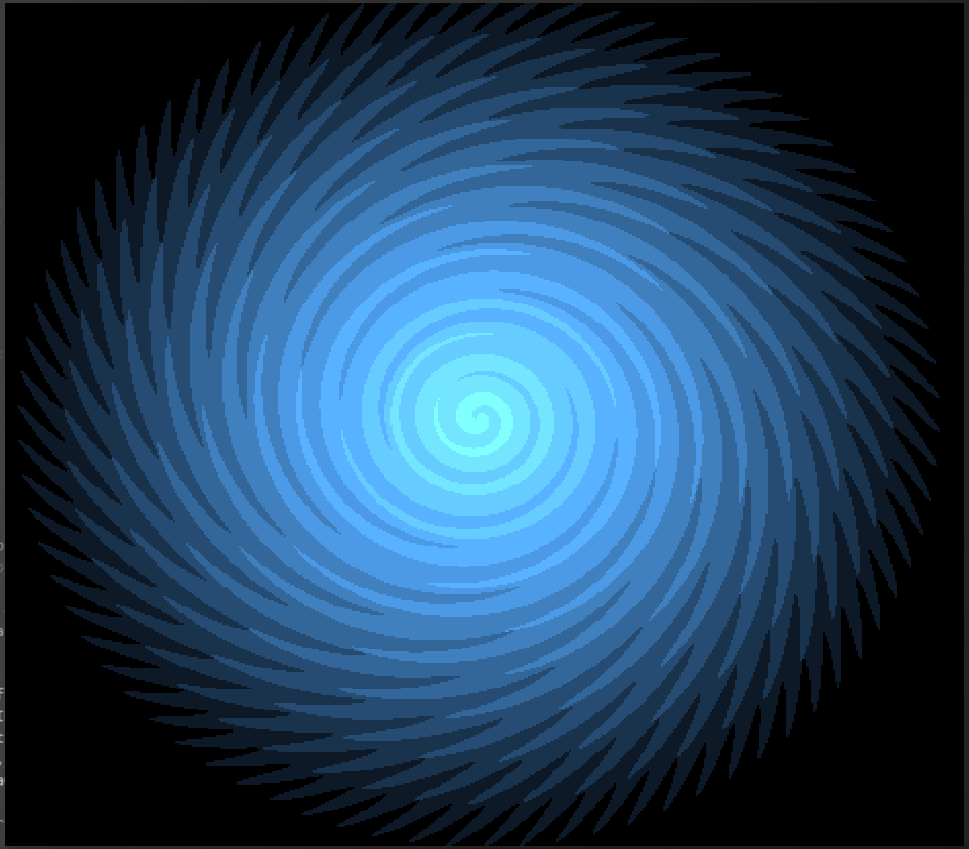


SIMT Thread execution:

- Group 32 threads (vertices, pixels, primitives) into *warps*
- Each warp executes the same instruction
- In case of latency, switch to different warp (thus: switch out 32 threads for 32 different threads)
- Flow control: …

Introduction

GPGPU Programming



https://www.shadertoy.com/view/4sjSRt

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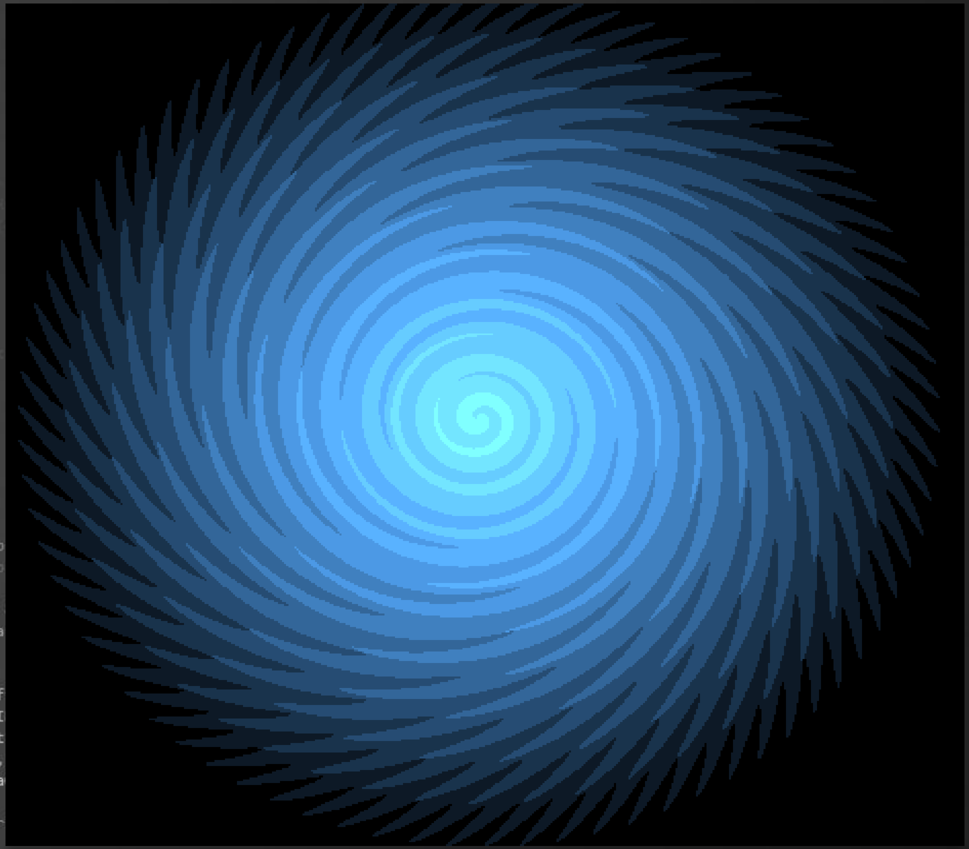
```

Introduction

GPGPU Programming



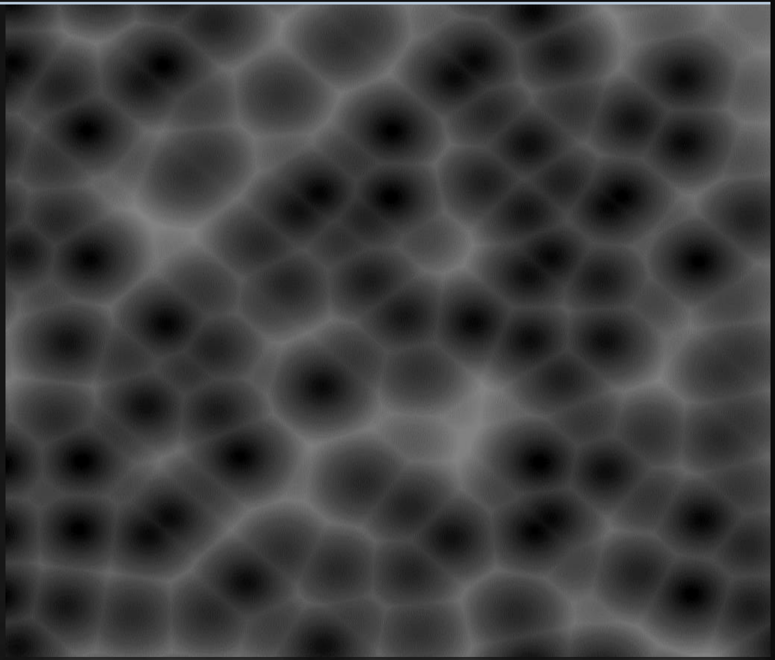
Easy to port to GPU:

- Image postprocessing
- Particle effects
- Ray tracing
- …

Today’s Agenda:

- Introduction to GPGPU
- Example: Voronoi Noise
- GPGPU Programming Model
- OpenCL Template

Example



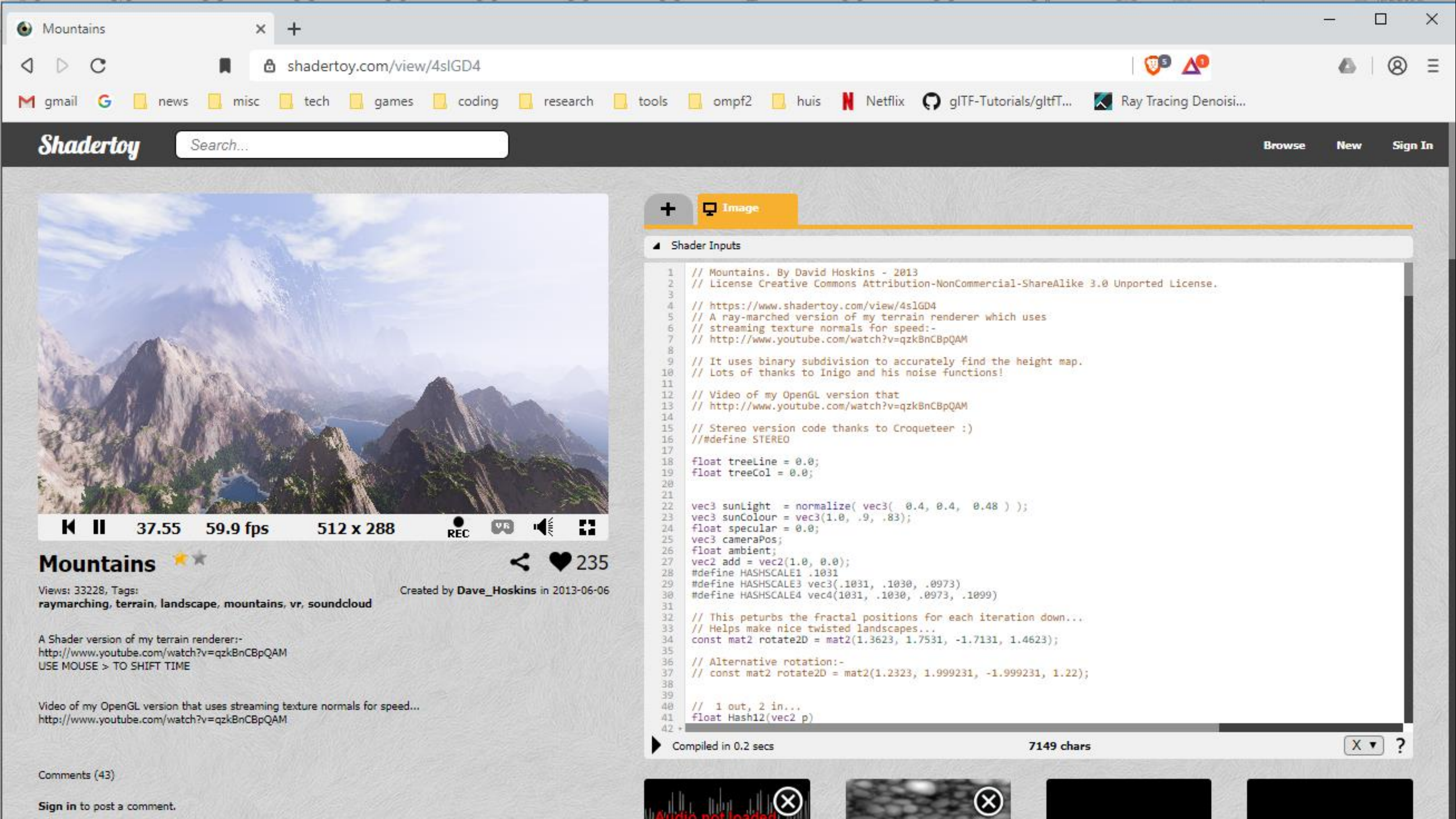
Voronoi Noise / Worley Noise*

Given a random set of uniformly distributed points,
and a position x in $\mathbb{R}^2$, $\boldsymbol{F_1(x)}$ = distance of x to closest point.

For Worley noise, we use a Poisson distribution for the points.
In a lattice, we can generate this as follows:

1. The expected number of points in a region is constant (Poisson);
2. The probability of each point count in a region is computed using the discrete Poisson distribution function;
3. The point count and coordinates of each point can be determined using a random seed based on the coordinates of the region in the lattice (so: *on the fly*)

*A Cellular Texture Basis Function, Worley, 1996


Mountains
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gmail
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misc
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games
coding
research
tools
ompf2
huis
Netflix
glTF-Tutorials/gltfT...
Ray Tracing Denoisi...
Shadertoy
Search...
Browse
New
Sign In
37.55
59.9 fps
512 x 288
REC
Mountains
235
Views: 33228, Tags:
raymarching, terrain, landscape, mountains, vr, soundcloud
Created by Dave_Hoskins in 2013-06-06
A Shader version of my terrain renderer:-
http://www.youtube.com/watch?v=qzkBnCBpQAM
USE MOUSE > TO SHIFT TIME
Video of my OpenGL version that uses streaming texture normals for speed...
http://www.youtube.com/watch?v=qzkBnCBpQAM
Comments (43)
Sign in to post a comment.
Image
Shader Inputs
// Mountains. By David Hoskins - 2013
// License Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License.
// https://www.shadertoy.com/view/4slGD4
// A ray-marched version of my terrain renderer which uses
// streaming texture normals for speed:-
// http://www.youtube.com/watch?v=qzkBnCBpQAM
// It uses binary subdivision to accurately find the height map.
// Lots of thanks to Inigo and his noise functions!
// Video of my OpenGL version that
// http://www.youtube.com/watch?v=qzkBnCBpQAM
// Stereo version code thanks to Croqueteer :)
//#define STEREO
float treeLine = 0.0;
float treeCol = 0.0;
vec3 sunLight = normalize(vec3(0.4, 0.4, 0.48));
vec3 sunColour = vec3(1.0, .9, .83);
float specular = 0.0;
vec3 cameraPos;
float ambient;
vec2 add = vec2(1.0, 0.0);
#define HASHSCALE1 .1031
#define HASHSCALE3 vec3(.1031, .1030, .0973)
#define HASHSCALE4 vec4(1031, .1030, .0973, .1099)
// This peturbs the fractal positions for each iteration down...
// Helps make nice twisted landscapes...
const mat2 rotate2D = mat2(1.3623, 1.7531, -1.7131, 1.4623);
// Alternative rotation:-
// const mat2 rotate2D = mat2(1.2323, 1.999231, -1.999231, 1.22);
// 1 out, 2 in...
float Hash12(vec2 p)
Compiled in 0.2 secs
7149 chars
Audio not loaded

Example

Voronoi Noise / Worley Noise*

```
vec2 Hash2( vec2 p, float t )
{
   float r = 523.0f * sinf( dot( p, vec2(53.3158f, 43.6143f)
   return vec2( frac( 15.32354f * r + t ), frac( 17.25865f *
}

float Noise( vec2 p, float t )
{
   p *= 16;
   float d = 1.0e10;
   vec2 fp = floor( p );
   for( int xo = -1; xo <= 1; xo++ ) for (int yo = -1; yo <= 1; yo++)
   {
      vec2 tp = fp + vec2(xo, yo);
      tp = p - tp - Hash2( vec2( fmod( tp.x, 16.0f ),
         fmod( tp.y, 16.0f ) ), t ), d = min( d, dot( tp, tp ) );
   }
   return sqrtf( d );
}
```

* https://www.shadertoy.com/view/4djGRh

Characteristics of this code:

- Pixels are independent, and can be calculated in arbitrary order;
- No access to data (other than function arguments and local variables);
- Very compute-intensive;
- Very little input data required.

Example

Voronoi Noise / Worley Noise*

Timing of the Voronoi code in C++:

~250ms per image (1280 x 720 pixels), ~65 with multiple threads.

Executing the same code in OpenCL (GPU: GTX1060, mobile):

~1.2ms (faster).

Example

Voronoi Noise / Worley Noise

GPGPU allows for efficient execution of tasks that expose a lot of potential parallelism.

- Tasks must be independent;
- Tasks must come in great numbers;
- Tasks must require little data from CPU.

Notice that these requirements are met for rasterization:

- For thousands of pixels,
- fetch a pixel from a texture,
- apply illumination from a few light sources,
- and draw the pixel to the screen.

Today's Agenda:

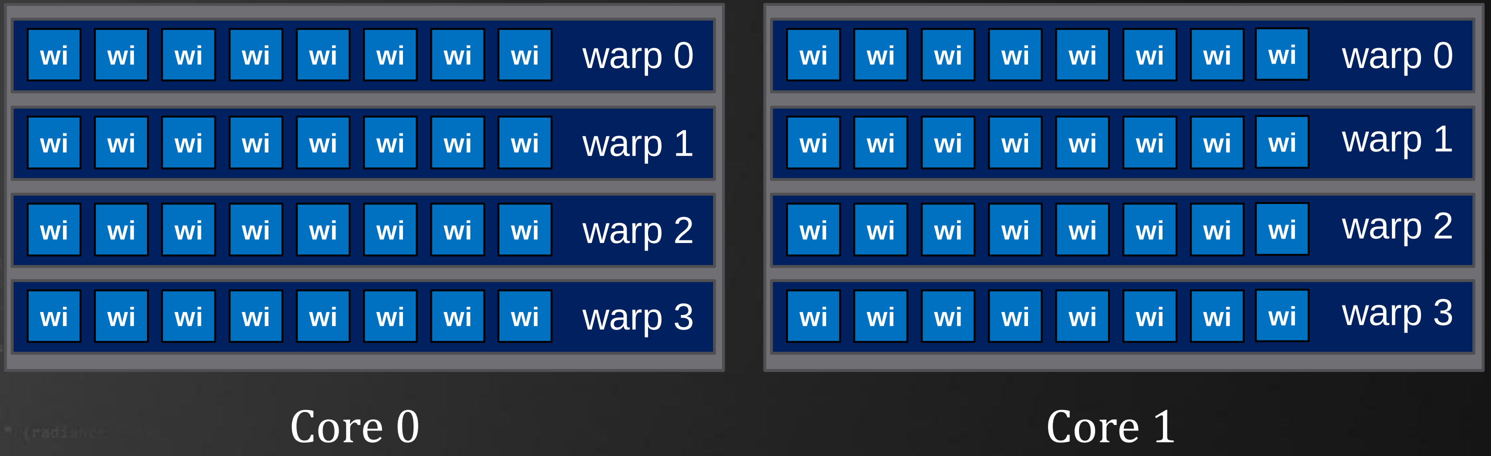
- Introduction to GPGPU
- Example: Voronoi Noise
- GPGPU Programming Model
- OpenCL Template

Programming Model

GPU Architecture

A typical GPU:

- Has a small number of ‘shading multiprocessors’ (comparable to CPU cores);
- Each core runs a small number of ‘warps’ (comparable to hyperthreading);
- Each warp consists of 32 ‘threads’ that run in lockstep (comparable to SIMD).



Programming Model

GPU Architecture

Multiple warps on a core:

The core will switch between warps whenever there is a stall in the warp (e.g., the warp is waiting for memory). Latencies are thus hidden by having many tasks.
This is only possible if you feed the GPU enough tasks: $cores \times warps \times 32$.

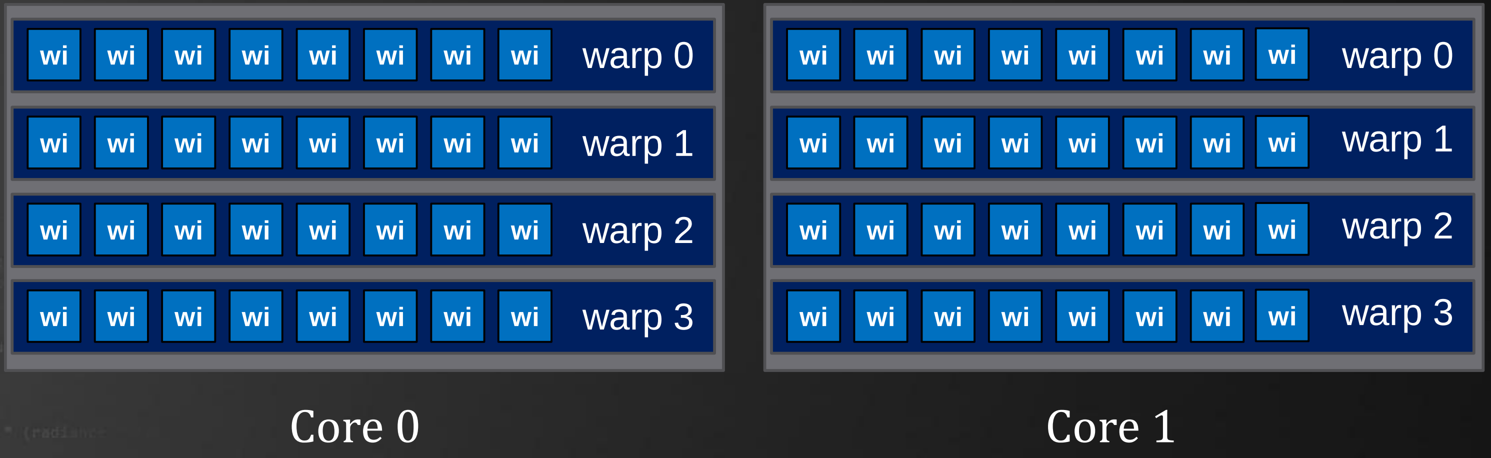
Core 0 Core 1

Programming Model

GPU Architecture

Threads in a warp running in lockstep:

At each cycle, all ‘threads’ in a warp must execute the same instruction. Conditional code is handled by temporarily disabling threads for which the condition is not true. If-then-else is handled by sequentially executing the ‘if’ and ‘else’ branches. Conditional code thus reduces the number of active threads (occupancy). Note the similarity to SIMD code!



Programming Model

SIMT

The GPU execution model is referred to as SIMT: Single Instruction, Multiple Threads.

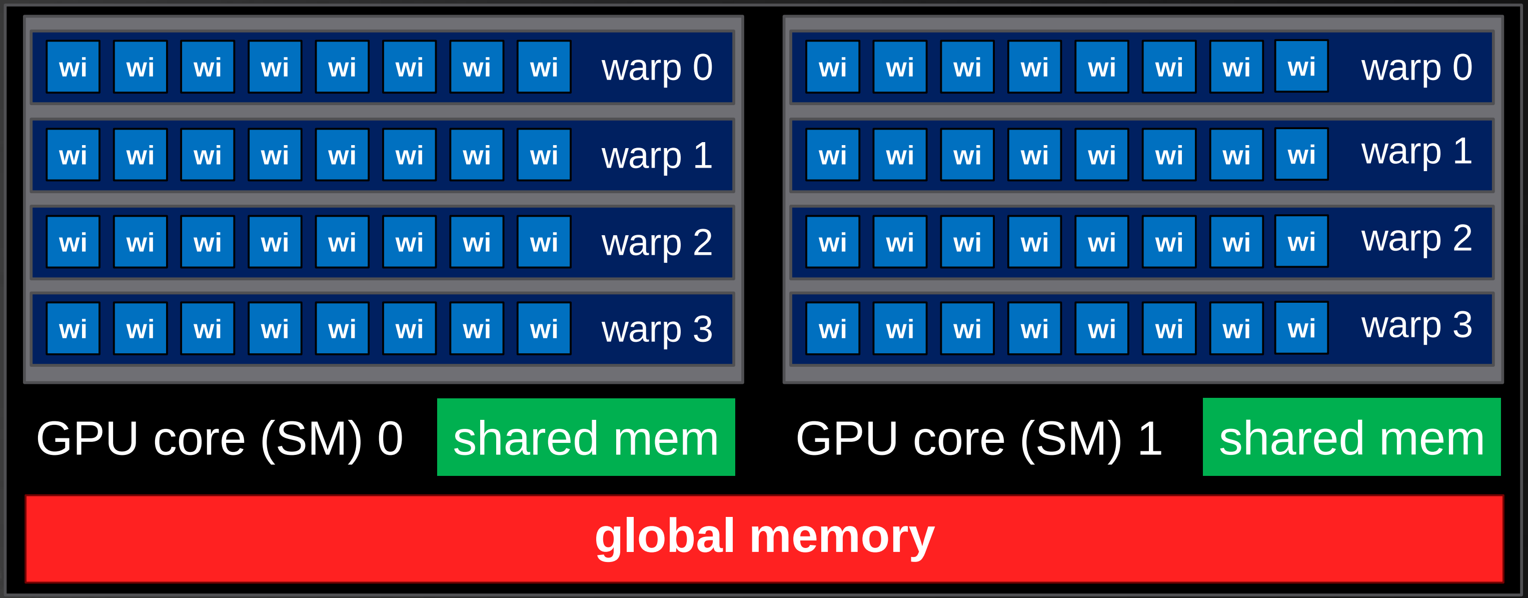
A GPU is therefore a very wide vector processor.

Converting code to GPGPU is similar to vectorizing code on the CPU.

Core 0 Core 1

Programming Model

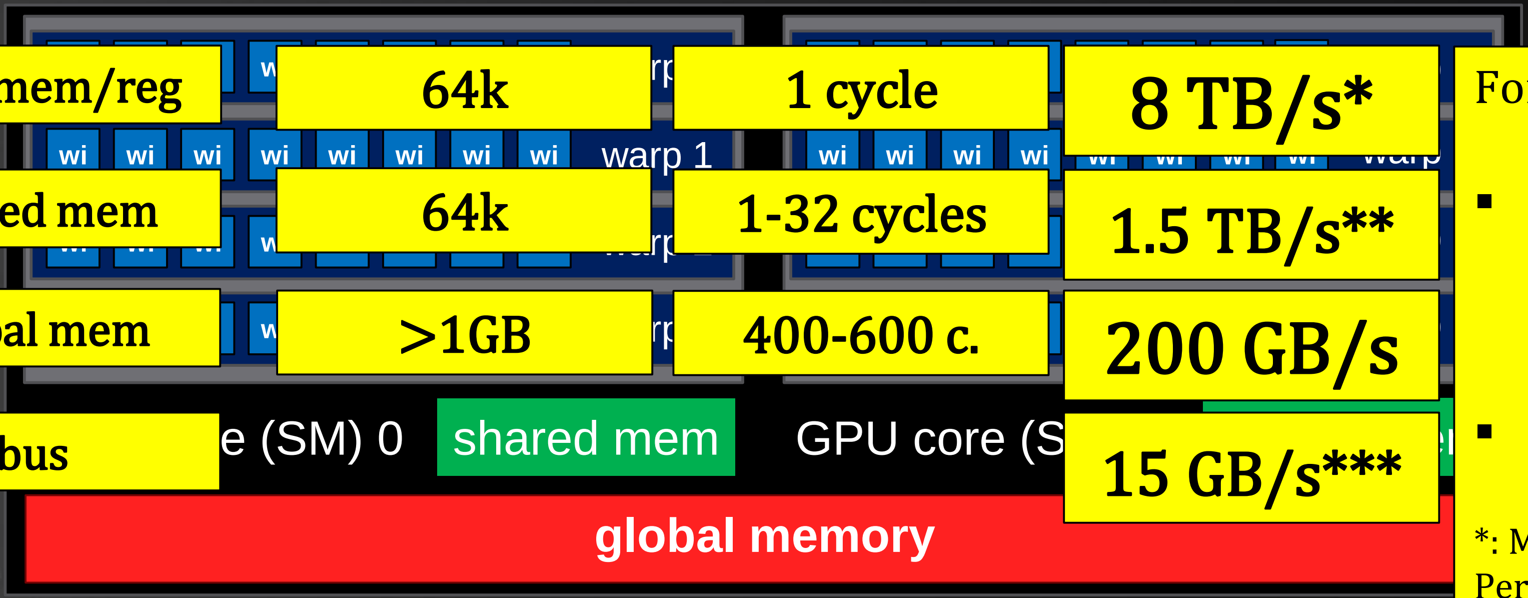
GPU Memory Model



- Each SM has a large number of registers, which is shared between the warps.
- Each SM has shared memory, comparable to L1 cache on a CPU.
- The GPU has global memory, comparable to CPU RAM.
- The GPU communicates with the 'host' over a bus.

Programming Model

GPU Memory Model



local mem/reg	64k	1 cycle	8 TB/s*
shared mem	64k	1-32 cycles	1.5 TB/s**
global mem	>1GB	400-600 c.	200 GB/s
bus			15 GB/s***

For reference, Core i7-3960X:

- RAM bandwidth for quad-channel DDR3-1866 memory: **18.1GB/s**
- L2 bandwidth: 46.8GB/s*

*: Molka et al., Main Memory and Cache Performance of Intel Sandy Bridge and AMD Bulldozer. 2014.

** Values for NVidia G80 (Tesla)*
*** Fermi uses L1 cache*
**** PCIe 3.0*

Programming Model

GPU Memory Model

There appear to be many similarities between a CPU and a GPU:

- Cores, with hyperthreading
- A memory hierarchy
- SIMD

However, there are fundamental differences in each of these.

- One GPU core will execute up to 64 warps (instead of 2 on the CPU);
- The memory hierarchy is explicit on the GPU, rather than implicit on the CPU;
- GPU SIMD on the other hand is implicit (SIMT model).

Programming Model

GPGPU Programming Model

A number of APIs is available to run general purpose GPU code:

Pixel shaders:

- Executed as part of the rendering pipeline
- The number of tasks is equal to the number of pixels

Graphics-centric work:
Shading, postprocessing (using a full-screen quad)

Compute shaders:

- Executed as part of the rendering pipeline
- More control over the number of tasks

Graphics-centric work:
Preparing data, output to textures / vertex buffers / …

OpenCL / CUDA:

- Executed independent of rendering pipeline
- Full control over memory hierarchy and division of tasks over hardware

General Purpose

Programming Model

GPGPU Programming Model

APIs like CUDA and OpenCL may look like C, but are in fact heavily influenced by the underlying hardware model.

```
__kernel void task( write_only image2d_t outimg, __global uint* logBuffer )
{
   float t = 1;
   int column = get_global_id( 0 );
   int line = get_global_id( 1 );
   float c = Cells( (float2)((float)column / 500, (float)line / 500), t );
   write_imagef( outimg, (int2)(column, line), c );
}
```

- Kernel: one task (of which we need thousands to run efficiently);
- get_global(0,1): identifies a single task from a 2D array of tasks.

Many threads will execute the same kernel. We can not execute different code in parallel.

Programming Model

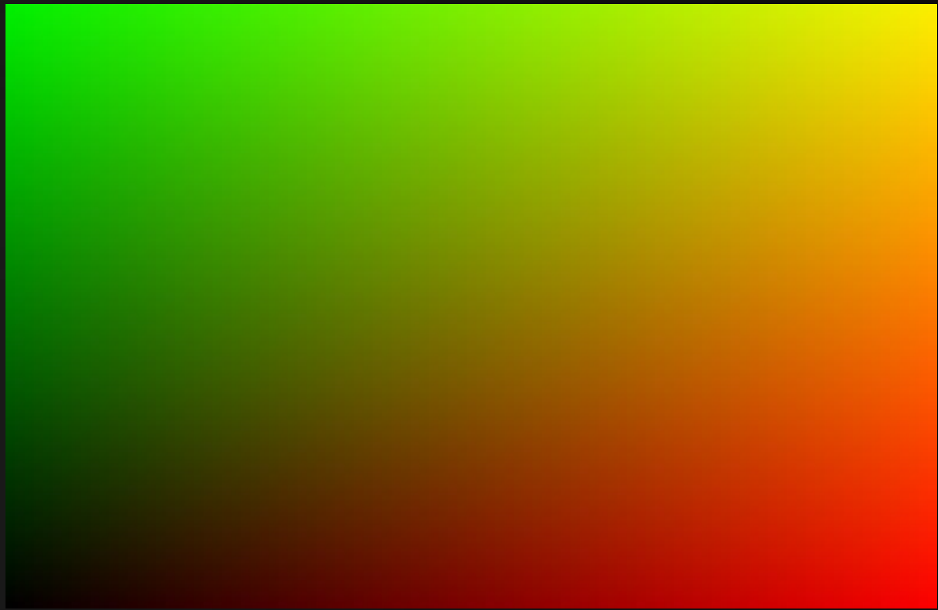
GPGPU Programming Model

Kernels are invoked from the host:

```
size_t workSize[2] = { SCRWIDTH, SCRHEIGHT };
void Kernel::Run( cl_mem* buffers, int count )
{
   …
   clEnqueueNDRangeKernel( queue, kernel, 2, 0, workSize, NULL, 0, 0, 0 );
   …
}
```

Device code:

```
__kernel void main( write_only image2d_t outimg )
{
   int column = get_global_id( 0 );
   int line = get_global_id( 1 );
   float red = column / 800.;
   float green = line / 480.;
   float4 color = { red, green, 0, 1 };
   write_imagef( outimg, (int2)(column, line), color );
}
```



Programming Model

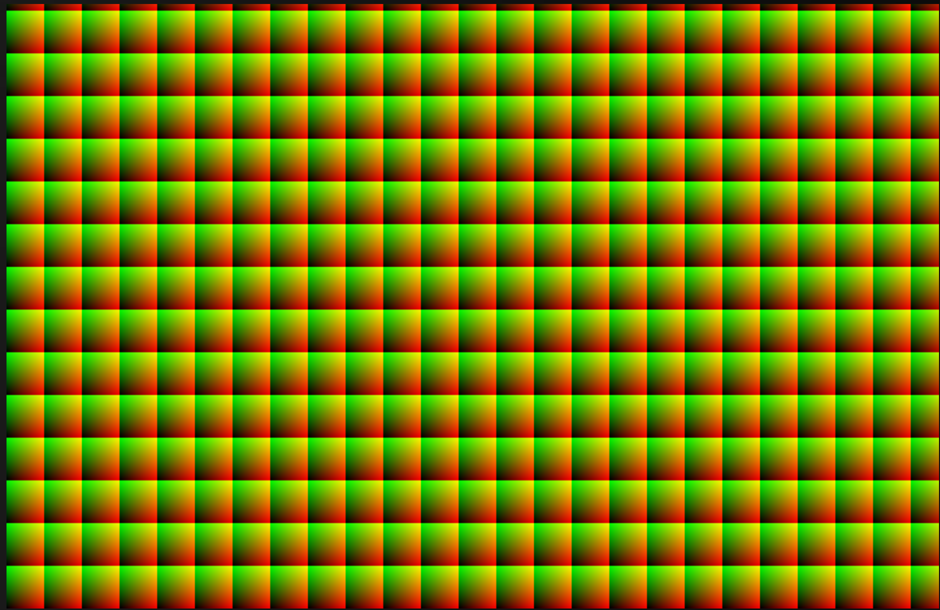
GPGPU Programming Model

Kernels are invoked from the host:

```
size_t workSize[2] = { SCRWIDTH, SCRHEIGHT }, localSize[2] = { 32, 32 };
void Kernel::Run( cl_mem* buffers, int count )
{
    …
    clEnqueueNDRangeKernel( queue, kernel, 2, 0, workSize, localSize, 0, 0, 0 );
    …
}
```

Device code:

```
__kernel void main( write_only image2d_t outimg )
{
    int column = get_global_id( 0 );
    int line = get_global_id( 1 );
    float red = get_local_id( 0 ) / 32.;
    float green = get_local_id( 1 ) / 32.;
    float4 color = { red, green, 0, 1 };
    write_imagef( outimg, (int2)(column, line), color );
}
```



Today's Agenda:

- Introduction to GPGPU
- Example: Voronoi Noise
- GPGPU Programming Model
- OpenCL Template

Template

OCL_Lab: The Familiar Template

The OpenCL template is a basic experimentation framework for OpenCL.
Game::Tick implements the following functionality:

1. Set arguments for the OpenCL kernel;
2. Execute the OpenCL kernel (which stores output in an OpenGL texture);
3. Draw a full-screen quad using a shader.

You can find the OpenCL code in program.cl;
The shader is defined in vignette.frag.

/INFOMOV/

END of “GPGPU (1)”

next lecture: “GPGPU (2)”