Lecture 13

OpenCL

GPU computing with GLSL

OpenGL Compute shaders

Lecture questions

1) What kind of devices will OpenCL run on?

2) What does an OpenCL work group correspond to in CUDA?

3) What geometry is typically used for shader-based GPU computing?

4) What are the main advantages of using OpenGL Compute Shaders?

Just one more thing…

Extensions to CUDA

Libraries: cuFFT, cuBLAS...

Thrust

and others

Thrust

Template library

Templates for common operations

Can simplify your code

Data Structures

- `thrust::device_vector`
- `thrust::host_vector`
- `thrust::device_ptr`
- Etc.

Algorithms

- `thrust::sort`
- `thrust::reduce`
- `thrust::exclusive_scan`
- Etc.

```
#include <thrust/host_vector.h>
#include <thrust/device_vector.h>
#include <thrust/generate.h>
#include <thrust/sort.h>
#include <thrust/copy.h>
#include <cstdlib>

int main(void)
{
    // generate 32M random numbers on the host
    thrust::host_vector<int> h_vec(32 << 20);
    thrust::generate(h_vec.begin(), h_vec.end(), rand);

    // transfer data to the device
    thrust::device_vector<int> d_vec = h_vec;

    // sort data on the device (846M keys per second on GeForce GTX 480)
    thrust::sort(d_vec.begin(), d_vec.end());

    // transfer data back to host
    thrust::copy(d_vec.begin(), d_vec.end(), h_vec.begin());

    return 0;
}
```

Get pre-optimized implementations for critical standard operations

Performance analysis

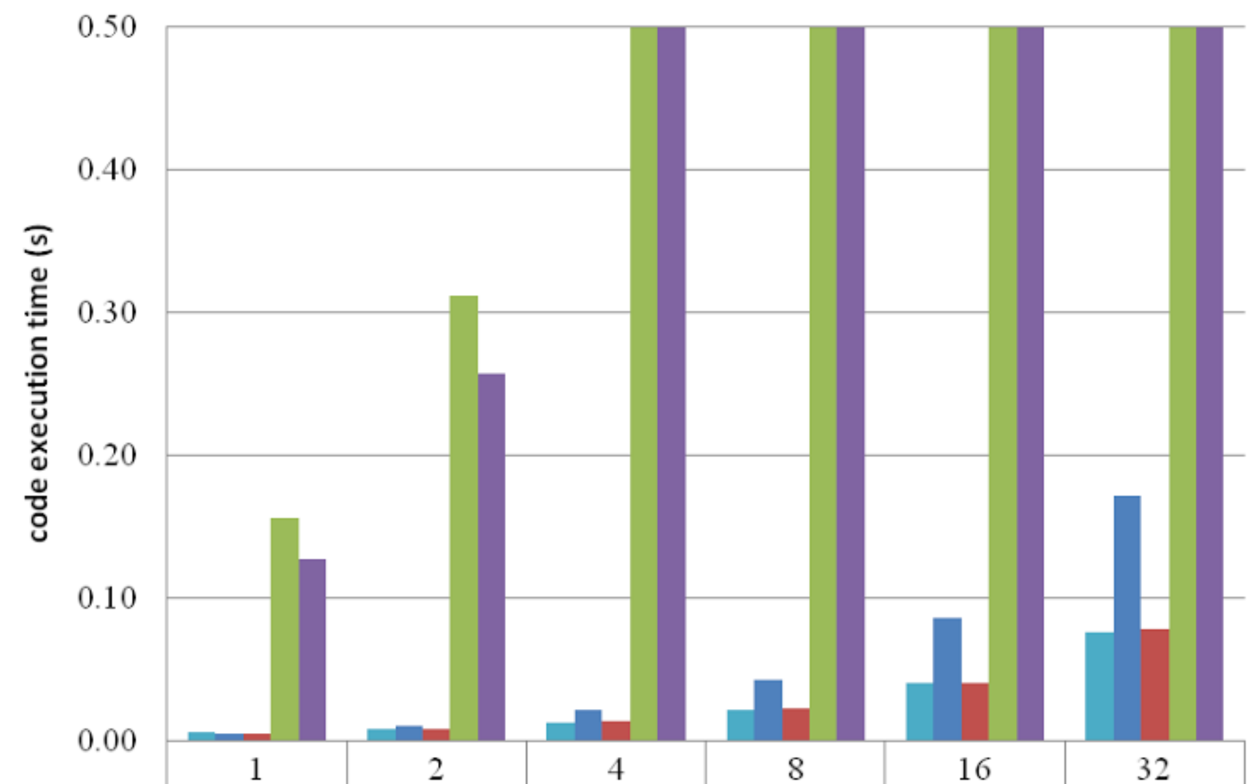
Highly serial summation pararellized by reduction - not a "GPU perfect" case!

Performance analysis

GPU code: Thrust as fast as optimized CUDA code, but simpler!

CPU code: Don't touch Thrust for this!

(But this was 5 years back - things do change.)



	1	2	4	8	16	32
GPU Time	0.0062	0.0081	0.0131	0.0221	0.0406	0.0763
CPU Time	0.0055	0.0107	0.0216	0.0432	0.0864	0.1721
GPU thrust	0.0057	0.0081	0.0137	0.0226	0.0405	0.0782
CPU thrust	0.1564	0.3114	0.6271	1.2450	2.4941	4.9853
CPU "	0.1277	0.2576	0.5140	1.0236	2.0534	4.0991

And that is just *one* alternative way to access one particular API...

So let's have a look at the alternative APIs as well!

Introduction to OpenCL

Open Compute Language


Zlatan efter nya succén:
VI ÄR REDO FÖR CL

- **Motivation**
- **Overview**
- **Examples**
- **Performance comparison**

Origins of OpenCL

Initiated by Apple

Managed by Khronos group

Many supporting parties

Many providers


KHRONOS
GROUP
Over 100 companies creating
authoring and acceleration standards
Board of Promoters

Why?

- The market could not let CUDA rule the world
- Support for other platforms
- Open standard
- Similarity with OpenGL

For programming ”all” parallel architectures

Supported architectures (not complete!)

GPU

Intel compatible CPUs

ARM

FPGA

CELL

Intel Xeon Phi

Who decides? Any company making its own OpenCL implementation!

”Open”?

Means *open specification*

Like OpenGL

Many providers making their own implementation

There is not *one* OpenCL library.

No free lunch

Model does not fit all architectures

One size fits all - platform dependent optimizations hard to do

OpenCL for GPU Computing

Mostly similar to CUDA both in architecture and performance!

Messy setup - but you get used to it

Kernels similar to CUDA

Easier for NVidia to be first with new features

OpenCL vs CUDA terminology

OpenCL	CUDA
compute unit	multiprocessor (SM)
work item	thread
work group	block
local memory	shared memory
private memory	registers

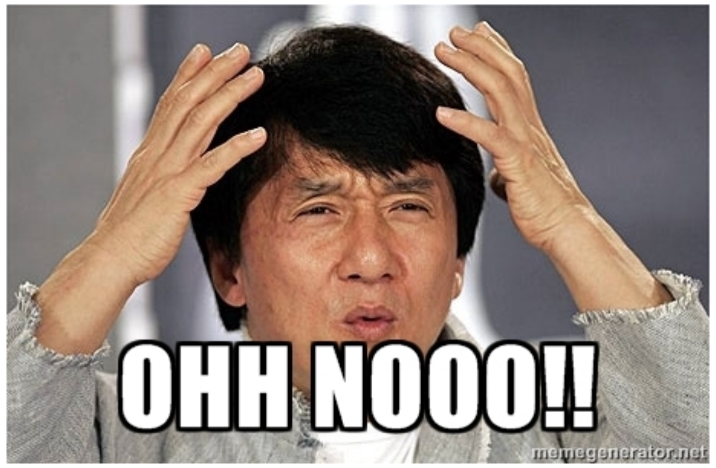
And CUDA local memory =?
OpenCL local memory (= CUDA shared memory)

Oh, that "local memory"...

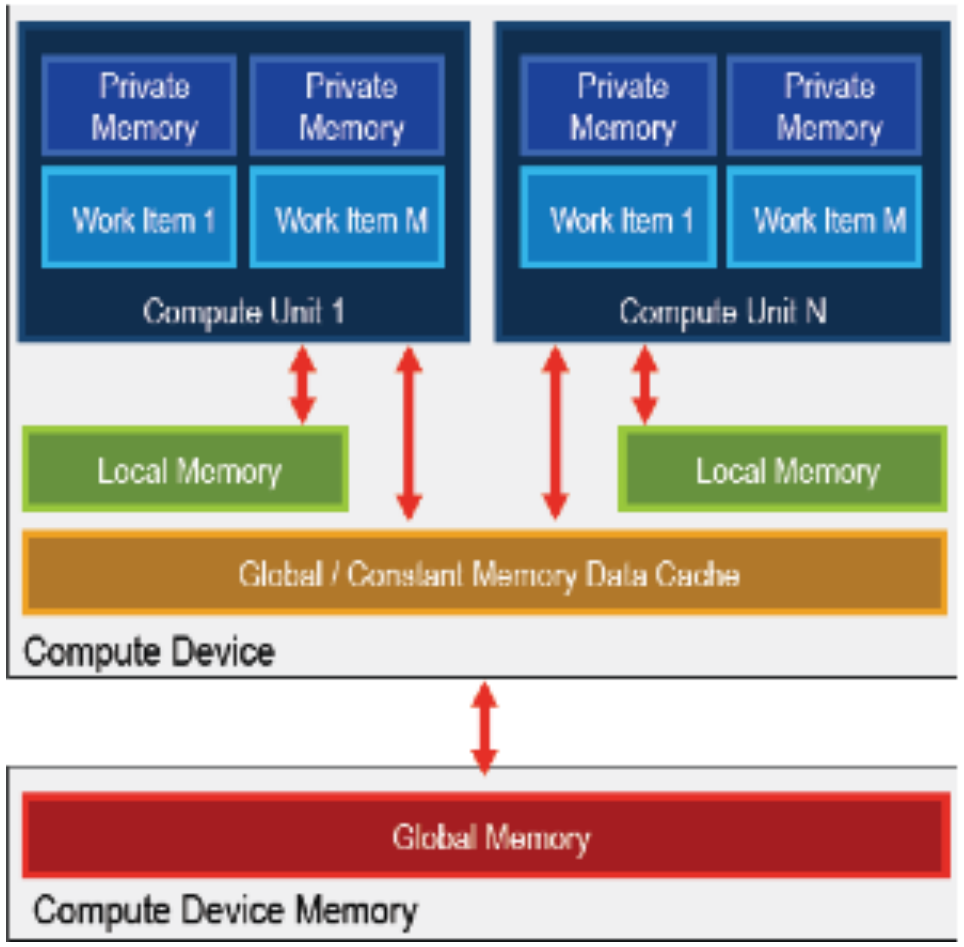
CUDA local memory = global memory accessible *only by one thread* (like registers but slower)

CUDA shared memory = OpenCL local memory = memory local inside the SM, shared within block

Anyone else who thinks this makes sense?

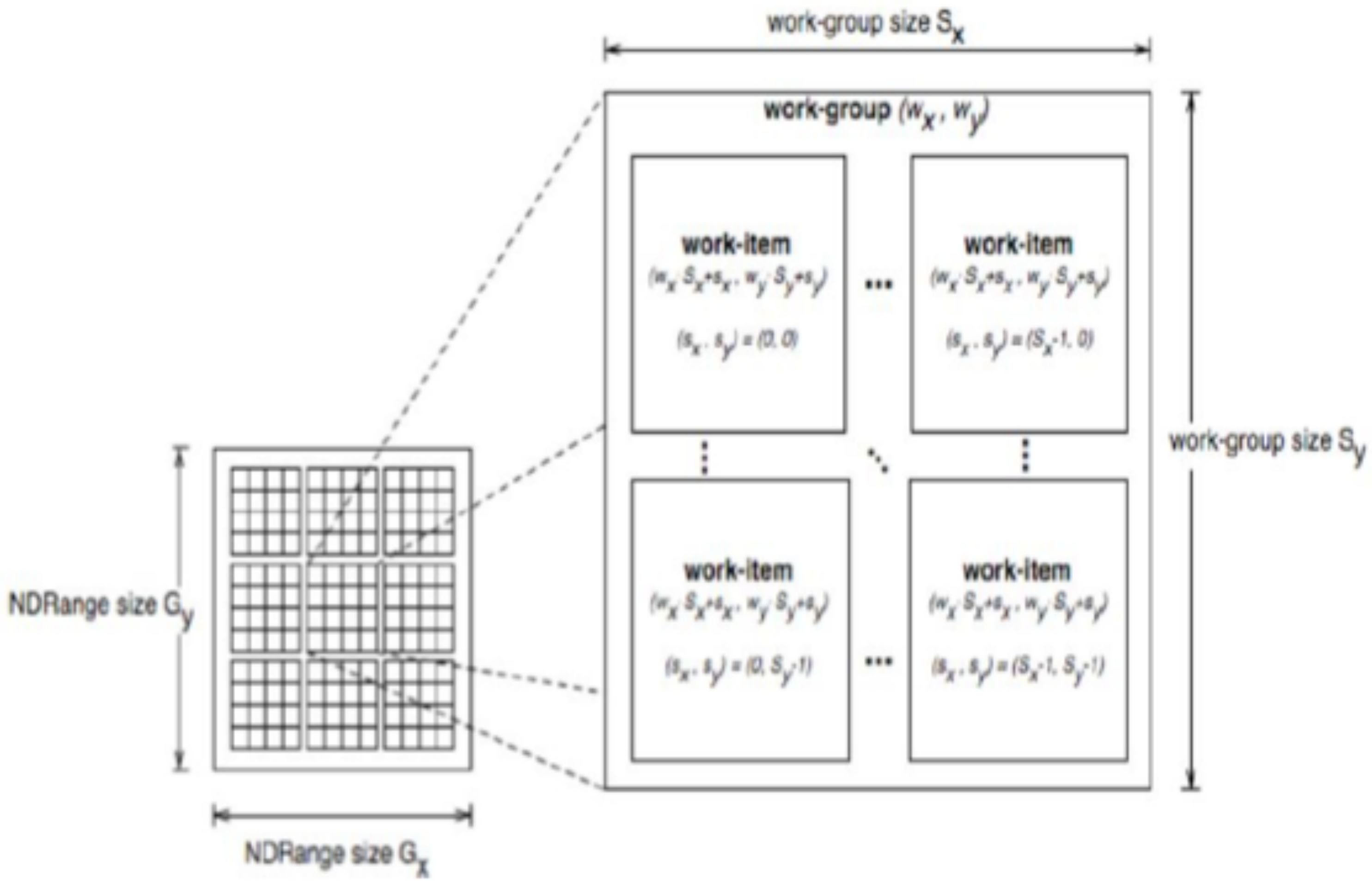


OpenCL memory model



Been there, done that...

OpenCL execution model



Anyone who see ”blocks” and ”threads”?

Synchronization

Kernels can synchronize within a work group:

```
barrier(CLK_LOCAL_MEM_FENCE)
```

No synchronization between work groups. (Do you remember why?)

Synchronizes memory access. You choose which kind of memory access to synchronize (global, local).

Synchronization

The host (CPU) can synchronize on global level:

Available for:

tasks (e.g. clEnqueueNDRangeKernel)

Memory(e.g.clEnqueueReadBuffer)

events (e.g. clWaitforEvents)

Heterogenous

Some differences from CUDA: Designed for heterogenous systems!

Several devices may be active at once

You can specify which device to launch a task to

Query devices and device characteristics

Some overhead compared to CUDA, and the reward is flexibility!

Language

Based on C99, but:

- No function pointers
- No pointers to pointers in function calls
  (=> no multi-dimensional arrays)
- No recursion
- No arrays with dynamical length
- No bitfields
- Also, no possibility to call a kernel from another kernel

Optional:

- Pointers with length <32 bit
- Writing support for 3D images
- Double and half types
- Atomic functions

On the positive side:

- Integrated functions for reading / writing 2D images and reading 3D images
- Converting functions incl. explicit rounding and saturation
- math.h, all functions with different precisions
- Vector support (2-, 3- and 4-dimensional)

Available primitive datatypes:

- Bool,char,int,long,float,size_t,void,+unsigned versions

Mix of OpenCL and OpenGL possible

- Can share data structures and variables (without copying)
- API functions available

How about that setup?

1) Get a list of platforms

2) Choose a platform

3) Get a list of devices

4) Choose a device

5) Create a context

6) Load and compile kernel code

Then we can start working

7) Allocate memory

8) Copy data to device

9) Run kernel

10) Wait for kernel to complete

11) Read data from device

12) Free resources

1-5: Where to run

Simplified here - might fail!

```
cl_platform_id platform;
unsigned int no_plat;
err =  clGetPlatformIDs(1,&platform,&no_plat);

// Where to run
err = clGetDeviceIDs(platform, CL_DEVICE_TYPE_GPU, 1, &device_id, NULL);
if (err != CL_SUCCESS) return -1;
```

Context

```
context = clCreateContext(0, 1, &device_id, NULL, NULL, &err);
if (!context) return -1;
commands = clCreateCommandQueue(context, device_id, 0, &err);
if (!commands) return -1;
```

6: Kernel

```
// What to run
program =
clCreateProgramWithSource(context, 1,
(const char **) & KernelSource, NULL,
&err);
if (!program) return -1;

err = clBuildProgram(program, 0, NULL,
NULL, NULL, NULL);
if (err != CL_SUCCESS) return -1;
kernel = clCreateKernel(program, "hello",
&err);
if (!kernel || err != CL_SUCCESS) return -1;
```

```
const char *KernelSource = "\n" \
"__kernel void hello(              \n" \
"   __global char* a,          \n" \
"   __global char* b,          \n" \
"   __global char* c,          \n" \
"   const unsigned int count)  \n" \
"{                              \n" \
"   int i = get_global_id(0);  \n" \
"   if(i < count)              \n" \
"       c[i] = a[i] + b[i];   \n" \
"}                              \n" \
"\n";
```

Most programs also load kernels from files

7-8: Get the data in there

```
 // Create space for data and copy a and b to device (note that we could also use
clEnqueueWriteBuffer to upload)
 input = clCreateBuffer(context,  CL_MEM_READ_ONLY | CL_MEM_USE_HOST_PTR,
sizeof(char) * DATA_SIZE, a, NULL);
 input2 = clCreateBuffer(context,  CL_MEM_READ_ONLY | CL_MEM_USE_HOST_PTR,
sizeof(char) * DATA_SIZE, b, NULL);
 output = clCreateBuffer(context, CL_MEM_WRITE_ONLY, sizeof(char) * DATA_SIZE,
NULL, NULL);
 if (!input || !output) return -1;

 // Send data
 err  = clSetKernelArg(kernel, 0, sizeof(cl_mem), &input);
 err |= clSetKernelArg(kernel, 1, sizeof(cl_mem), &input2);
 err |= clSetKernelArg(kernel, 2, sizeof(cl_mem), &output);
 err |= clSetKernelArg(kernel, 3, sizeof(unsigned int), &count);
 if (err != CL_SUCCESS) return -1;
```

9-10: Run kernel, wait for completion

```
// Run kernel!
err = clEnqueueNDRangeKernel(commands, kernel, 1, NULL, &global,
&local, 0, NULL, NULL);

if (err != CL_SUCCESS) return -1;

clFinish(commands);
```

11-12: Read back data, release

```
// Read result
err = clEnqueueReadBuffer( commands, output, CL_TRUE, 0, sizeof(char) * count,
c, 0, NULL, NULL );
if (err != CL_SUCCESS) return -1;

// Print result
printf("%s\n", c);

// Clean up
clReleaseMemObject(input);
clReleaseMemObject(output);
clReleaseProgram(program);
clReleaseKernel(kernel);
clReleaseCommandQueue(commands);
clReleaseContext(context);
```

”Platform” vs ”device”

Platform = an OpenCL implementation

Device = a chip which the platform supports

Language freedom… sort of

+ Very easy to call from any language! Anything that can call into a C API can call OpenCL!

- Kernel code is only C-style (although a specific implementation may choose to support more).

Performance

Investigations report remarkably small differences

Our research on FFT so far has CUDA up to 2x faster

Very hard to compare, due to multiple OpenCL implementations

Some report CUDA to be better on NVidia platforms...
some report a draw even there.

Our experience: Usually very close!

Conclusions on OpenCL

Don't fear the complex setup phase! The rest is similar to CUDA.

Performance tend to be on par with CUDA or almost.

Speciality: heterogenous systems!