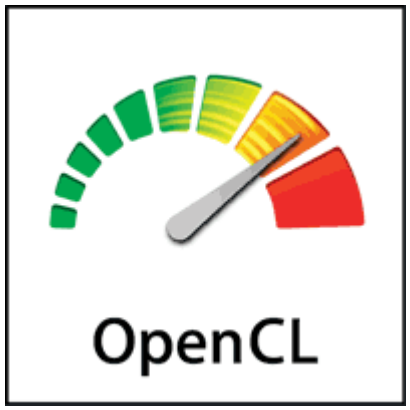

Laboratory of Information Technologies

OpenCL

Computation on HybriLIT

Brief introduction and getting started

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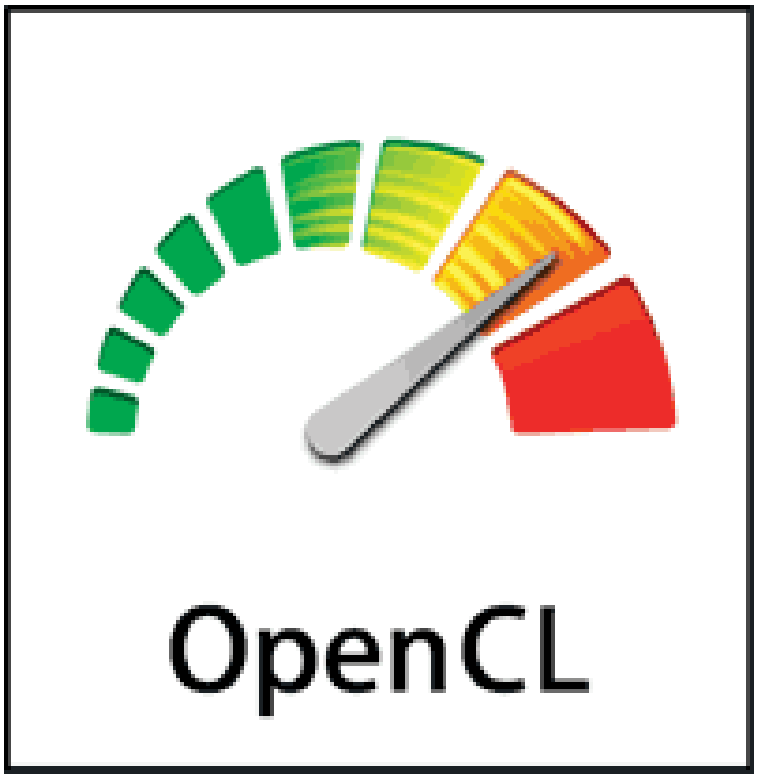
Lattice QCD, Hadron Structure andHadronic Matter
JINR, Dubna, 25.08-06.09.2014

What OpenCL is

Open Computing Language (OpenCL) is the first open, royalty-free standard for cross-platform, parallel programming of modern processors found in personal computers, servers and handheld/embedded devices. OpenCL is based on C99.



Credit: https://www.khronos.org/opencl/

OpenCL as a standard

Credit: https://www.khronos.org/

How OpenCL works

OpenCL consists of a kernel programming API used to program a co-processor or GPU and a run-time host API used to coordinate the execution of these kernels and perform other operations such as memory synchronization. The OpenCL programming model is based on the parallel execution of a kernel over many threads to exploit SIMD or/and SIMT architectures.

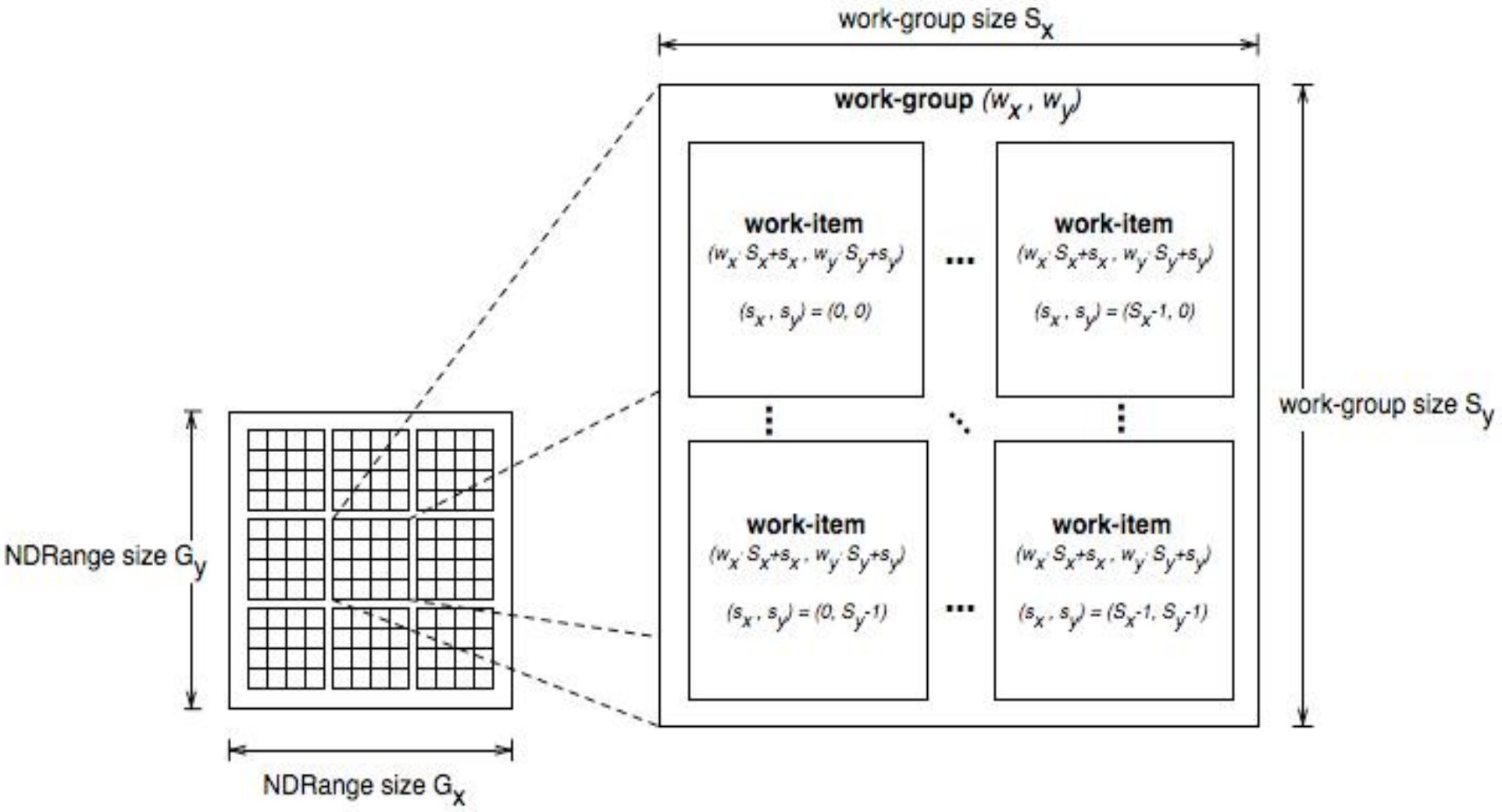
SIMD - **S**ingle **I**nstruction, **M**ultiple **D**ata
SIMT - **S**ingle **I**nstruction, **M**ultiple **T**hreads

Single Instruction is realized in a kernel.
Multiple Data is hosted in data massives.
Multiple Threads parallely execute a kernel.

The **same code** is executed in parallel mode by a **different thread**, and each thread executes the code with **different data**.

http://www.parallella.org/

OpenCL Programming model (1)



Credit: http://opencl.codeplex.com/

OpenCL Programming model (2)

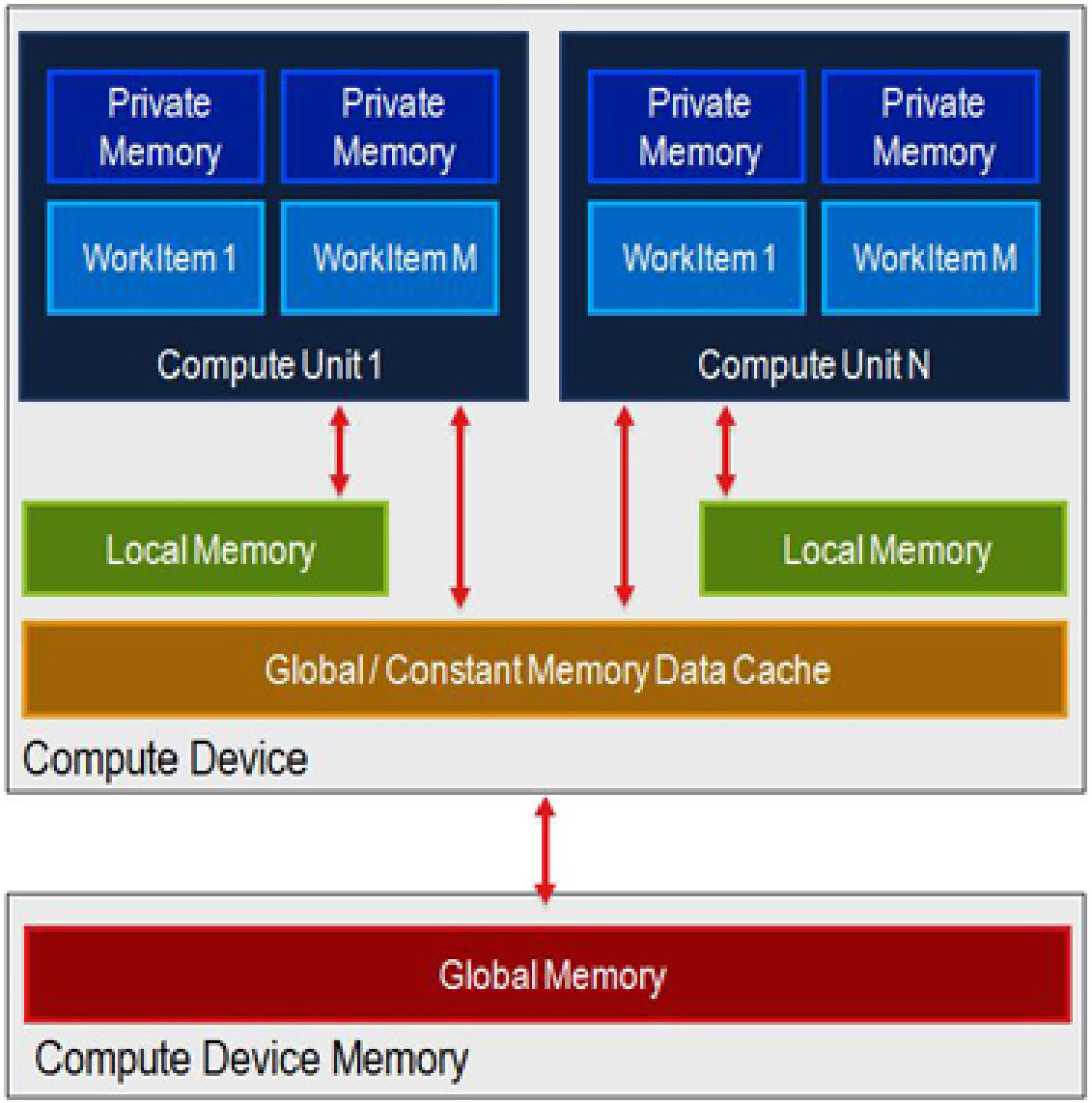
The **work-items** are the smallest execution entity (equivalent to the CUDA threads). Every time a kernel is launched, lots of work-items (a number specified by the programmer) are launched executing the same code. Each work-item has an **ID**, which is accessible from a kernel, and which is used to distinguish the data to be processed by each work-item.

The **work-groups** exist to allow communication and cooperation between work-items (equivalent to CUDA thread blocks). They reflect how work-items are organized (it's a N-dimensional grid of work-groups, with N = 1, 2 or 3). Work-groups also have an unique ID that can be refereed from a kernel.

The ND-Range is the next organization level, specifying how work-groups are organized (again, as a N-dimensional grid of work-groups, N = 1, 2 or 3);

http://opencl.codeplex.com/

OpenCL Memory Hierarchy (1)



OpenCL	CUDA
Global	Global
Local	Shared
Private	Register

Rob Farber, http://www.codeproject.com

OpenCL Memory Hierarchy (2)

Following are the OpenCL address qualifiers (which are distinct from access qualifiers):

- **`__global`**: memory allocated from global address space
- **`__constant`**: a region of read-only memory
- **`__local`**: memory shared by work-group
- **`__private`**: private per work-item memory

Note: kernel arguments have to be **`__global`**, **`__constant`** or **`__local`**. Pointers that are cast using different address qualifiers are undefined.

OpenCL Program Structure (1)

1. Get a platform information

```
clGetPlatformIDs(1, &platform_id, &num_platforms);
```

2. Get information about devices

```
clGetDeviceIDs(platform_id, CL_DEVICE_TYPE_GPU, 1, &device_id,
&num_devices);
```

3. Create an OpenCL context

```
context = clCreateContext(NULL, CL_DEVICE_TYPE_GPU, &device_id,
                          NULL, NULL, NULL);
```

4. Create a command queue

```
queue = clCreateCommandQueue(context, device_id, 0, NULL);
```

OpenCL Program Structure (2)

5. Create a program from the kernel source and build it

```
program = clCreateProgramWithSource(context, 1,
    (const char**)&source_str, (const size_t*)&source_size, NULL);
clBuildProgram(program, 1, &device_id, NULL, NULL, NULL);
```

where `source_str` consists of kernel program (kernel source)

```
char *source_str = {
"__kernel void hello_world(__global int *A) { \n"
"// Get the index the current work-item       \n"
"int i = get_global_id(0);                     \n"
"// Write this number in data massive          \n"
"A[i] = i;                                     \n"
"}                                             \n"};
```

```
// The kernel file "helloWorld_kernel.cl"
__kernel void hello_world(__global int *A)
{
    // Get the index the current work-item
    int i = get_global_id(0);
    // Write this number in data massive
    A[i] = i;
}
```

OpenCL Program Structure (3)

6. Create an OpenCL kernel

```
kernel = clCreateKernel(program, "hello_world", NULL);
```

7. Create device memory buffer and copy the vector A from the host

```
cl_mem a_mem_obj = clCreateBuffer(context, CL_MEM_COPY_HOST_PTR,
                                  nVector*sizeof(int), A, NULL);
```

8. Set the kernel arguments

```
clSetKernelArg(kernel, 0, sizeof(cl_mem), (void*)&a_mem_obj);
```

9. Execute the OpenCL kernel

```
size_t global_item_size = nVector; // Number of work-items (threads)
size_t local_item_size = 64; // Size of work-groups
clEnqueueNDRangeKernel(queue, kernel, 1, NULL, &global_item_size,
                       &local_item_size, 0, NULL, NULL);
```

10. Get back data, copy buffer `a_mem_obj` to the local variable `A`

```
clEnqueueReadBuffer(queue, a_mem_obj, CL_TRUE, 0,
                    nVector*sizeof(int), A, 0, NULL, NULL);
```

How to Get Device Properties (1)

```
//   Get list of available platforms
     cl_platform_id platform_id = NULL;
     clGetPlatformIDs(1, &platform_id, NULL);

//   Get information about available platforms
     clGetPlatformInfo(platform_id, CL_PLATFORM_NAME, MAX_NAME_SIZE, name, NULL);
     clGetPlatformInfo(platform_id, CL_PLATFORM_VERSION, MAX_NAME_SIZE, name, NULL);

//   Get list of available devices on platforms
     clGetDeviceIDs(platform_id, CL_DEVICE_TYPE_ALL, MAX_NUM_DEVICES, devices, &nDevices);

//   Get information about devices
     for(int iDevices = 0; iDevices < nDevices; ++iDevices)
     {
          clGetDeviceInfo(devices[iDevices], CL_DEVICE_NAME, MAX_NAME_SIZE, name, NULL);
          clGetDeviceInfo(devices[iDevices], CL_DRIVER_VERSION, MAX_NAME_SIZE, name, NULL);
          clGetDeviceInfo(devices[iDevices], CL_DEVICE_GLOBAL_MEM_SIZE,
                                                  sizeof(cl_ulong),&entries, NULL);
          clGetDeviceInfo(devices[iDevices], CL_DEVICE_GLOBAL_MEM_CACHE_SIZE,
                                                  sizeof(cl_ulong),&entries, NULL);
          clGetDeviceInfo(devices[iDevices], CL_DEVICE_MAX_CLOCK_FREQUENCY,
                                                  sizeof(cl_ulong),&entries, NULL);
          clGetDeviceInfo(devices[iDevices], CL_DEVICE_MAX_WORK_GROUP_SIZE,
                                                  sizeof(size_t),&p_size, NULL);
     }
```

How to Get Device Properties (2)

```
-bash-4.1:~/OpenCL/Tutorial/FindDevice$ nvcc findDevice.c -o findDevice -l OpenCL
-bash-4.1:~/OpenCL/Tutorial/FindDevice$ srun findDevice
CL_PLATFORM_NAME = NVIDIA CUDA
CL_PLATFORM_VERSION = OpenCL 1.1 CUDA 4.2.1
Found 1 devices
Device name = GeForce GT 635M
    Driver version = 319.60
    Global Memory (MB):     2047
    Local Memory (KB):      32
    Max clock (MHz) :       950
    Max Work Group Size:    1024
-bash-4.1:~/OpenCL/Tutorial/FindDevice$
```

Notebook ASUS: Intel Core $i7$, nVidia GeForce GT 635M (2GB)

“Hello World” (1)

```
//  Get platform and device information
  clGetPlatformIDs(1,&platform_id,&num_platforms);
  clGetDeviceIDs(platform_id,CL_DEVICE_TYPE_GPU,1,&device_id,&num_devices);
//  Create an OpenCL context
  cl_context context=clCreateContext(NULL,CL_DEVICE_TYPE_GPU,&device_id,NULL,NULL,NULL);
//  Create a command queue
  cl_cmd_queue cmd_queue = clCreateCommandQueue(context,device_id,0,NULL);
//  Create a program from the kernel source
  cl_program program=clCreateProgramWithSource(context,1,(const char**)&source,NULL,NULL);
//  Build the program
  clBuildProgram(program,1,&device_id,NULL,NULL,NULL);
//  Create the OpenCL kernel
  cl_kernel kernel=clCreateKernel(program,"hello_world",NULL);
//  Create memory buffer on the device for vector
  cl_mem a_mem_obj=clCreateBuffer(context,CL_MEM_COPY_HOST_PTR,nVector*sizeof(int),A,NULL);
//  Set the kernel arguments
  clSetKernelArg(kernel,0,sizeof(cl_mem),(void*)&a_mem_obj);
//  Execute the OpenCL kernel
  size_t global_size = nVector; size_t local_size = 64;
  clEnqueueNDRangeKernel(cmd_queue,kernel,1,NULL,&global_size,&local_size,0,NULL,NULL);
//  Copy the memory buffer a_mem_obj on the device to the local variable A
  clEnqueueReadBuffer(cmd_queue,a_mem_obj,CL_TRUE,0,nVector*sizeof(int), A ,0,NULL,NULL);
//  Print the result to the screen
  for(int iVector = 0; iVector < nVector; iVector++)
    printf("Helo World! I am thread number %d.\n", A[iVector]);
```

“Hello World” (2)

```
// The kernel file “helloWorld_kernel.cl”
__kernel void hello_world(__global int *A)
{
    // Get the index the current work-item
    int i = get_global_id(0);
    // Write this number in data massive
    A[i] = i;
}
```

```
-bash-4.1:~/OpenCL/Tutorial/HelloWorld$ nvcc helloWorld.c -o helloWorld -l OpenCL
-bash-4.1:~/OpenCL/Tutorial/HelloWorld$ srun helloWorld
Helo World! I am thread number 0.
Helo World! I am thread number 1.
Helo World! I am thread number 2.
...
Helo World! I am thread number 1021.
Helo World! I am thread number 1022.
Helo World! I am thread number 1023.
-bash-4.1:~/OpenCL/Tutorial/HelloWorld$
```

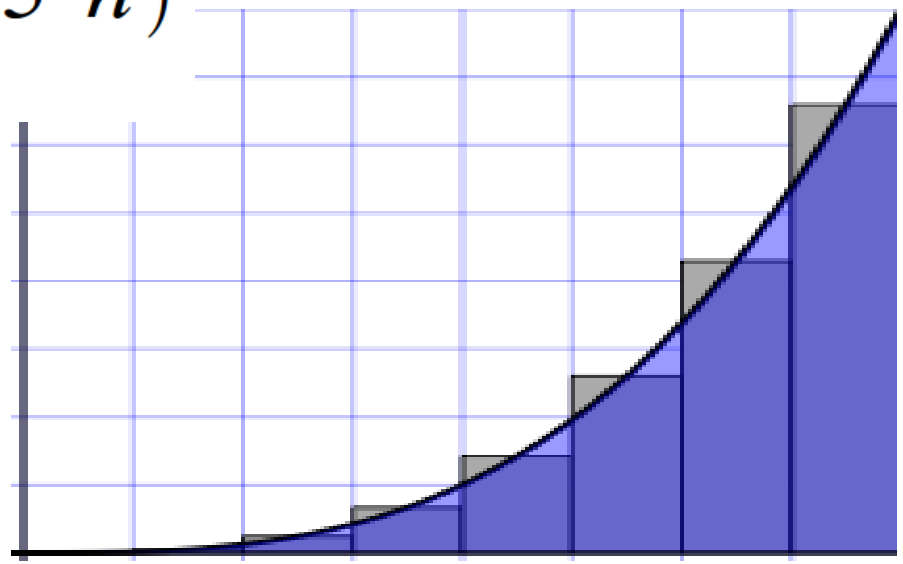
Calculation of Integral (1)

Calculate numerically integral of function $\mathbf{f(x)}$ on the interval $[\mathbf{a,b}]$.

$$I=\int_a^b f(x)\,dx=\int_0^{\frac{\pi}{2}} \sqrt{x}\cdot\left[\sin(x)\cdot\ln(x+1)\right]^{\frac{x}{5}}\,dx$$

The answer is $\mathbf{I\approx 1.18832595716124}$

$$\int_a^b f(x)\,dx\approx h\sum_{i=0}^{i=n-1} f(x_i+0.5\cdot h)$$



The approximation error formula

$$R(x)=\frac{f''(x)}{24}(b-a)h^2$$

Calculation of Integral (2)

```
double func(double x) { return pow( sin(x) * log(x+1.0), x/5.0 ) * pow(x, 0.5); }
int main()
{
    double h = (right - left) / (N - 1);
    for(int i = 0; i < N; i++)
        X[i] = left + i * h;

    double integral = 0.0;
    for(int i = 0; i < N-1; i++)
    {
        Y[i] = h * func(0.5 * (X[i] + X[i+1]));
        integral += Y[i];
    }
    printf("Integral = %e\n", integral);
    return 0;
}
```

```
-bash-4.1:~/OpenCL/Tutorial/HelloWorld$ c++ calcInteg.cpp -o calcInteg -O3
-bash-4.1:~/OpenCL/Tutorial/CalcIntegral$ srun calcInteg
Calculation of the integral on CPU!
Exact answer is 1.18832595716124
Integral = 1.18832595716153
Time = 13.77 sec.
-bash-4.1:~/OpenCL/Tutorial/CalcIntegral$
```

Calculation of Integral (3)

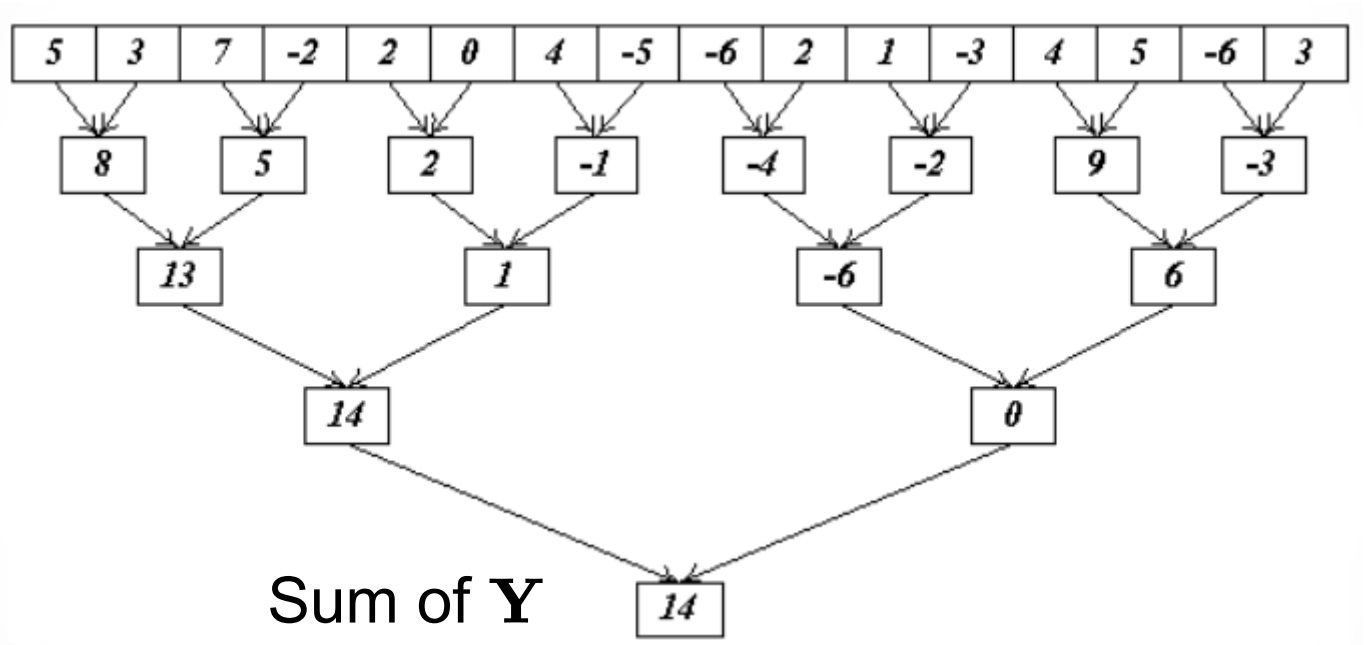
```
#pragma OPENCL EXTENSION cl_khr_fp64: enable
double func(double x) { return pow( sin(x) * log(x+1.0), x/5.0 ) * pow(x, 0.5); }

__kernel void calc_integral(__global double *h, __global double *X, __global double *Y)
{
//   Get the index of the current element
     int i = get_global_id(0);
//   Do the operation
     Y[i] = h[0] * func(0.5 * (X[i] + X[i+1]));
}
```

```
-bash-4.1:~/OpenCL/Tutorial/HelloWorld$ nvcc calcInteg.c -o calcInteg -l OpenCL
-bash-4.1:~/OpenCL/Tutorial/CalcIntegral$ srun calcInteg
Calculation of the integral on GPU!
Exact answer is 1.18832595716124
Integral = 1.18832595716153
Time = 2.88 sec.
-bash-4.1:~/OpenCL/Tutorial/CalcIntegral$
```

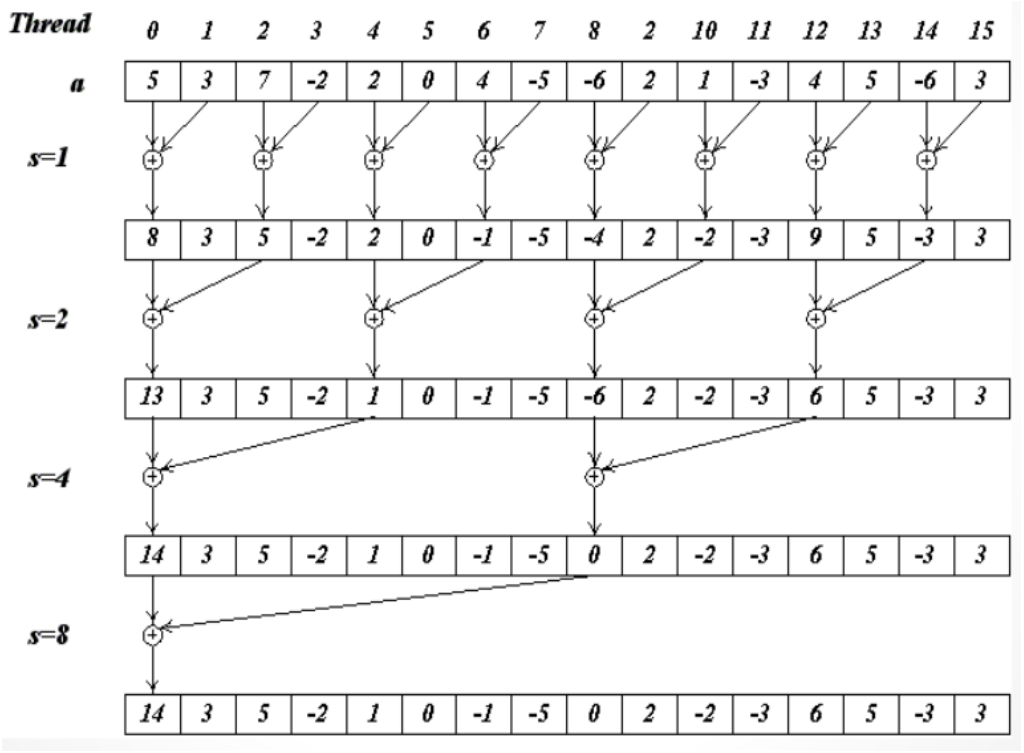
Calculation on GPU is around 5 times faster then on CPU.

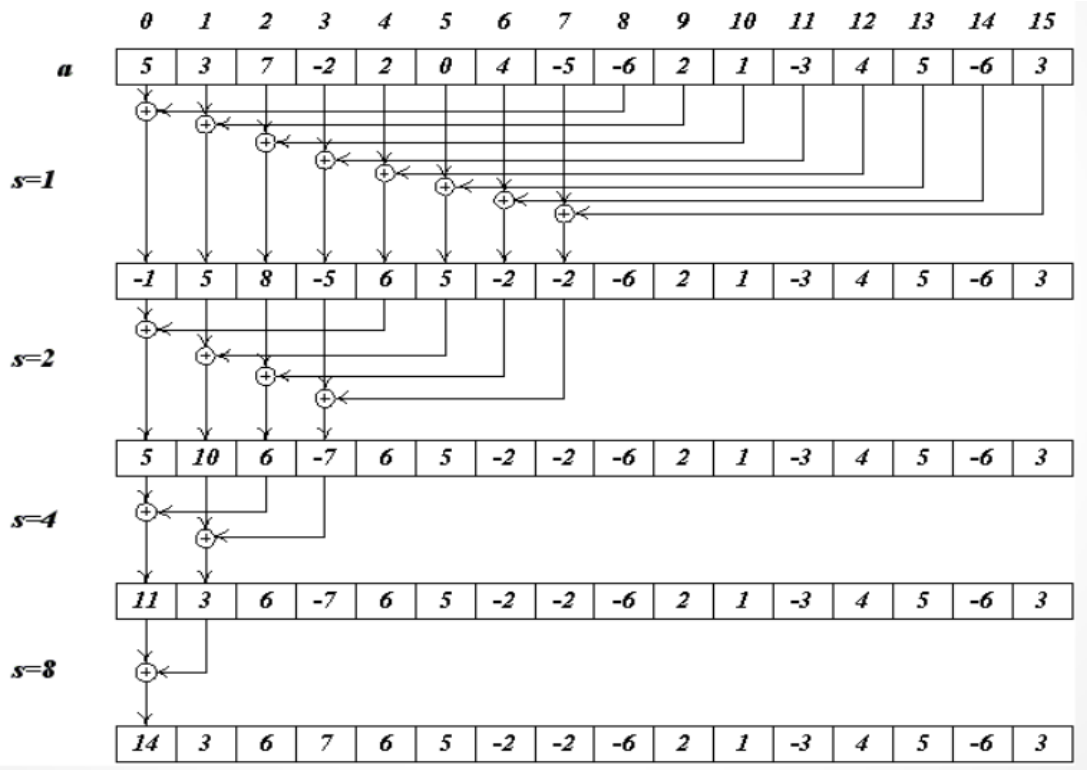
Parallel Reduction Algorithms (1)

A vector $\mathbf{Y}$



Parallel Reduction Algorithms (1)





J. Sanders, E. Kandrot. *CUDA by Example: An Introduction to General-Purpose GPU Programming*

Reduction for Sum Operator (1)

```
__kernel void calc_parallel_sum(__global int *gData, __local int *lData)
{
    int iGlobal = get_global_id(0);
    int iLocal  = get_local_id(0);
    int sizeGroup = get_local_size(0);
    int iGroup = get_group_id(0);

    lData[iLocal] = gData[iGlobal];  // load into shared memory
    barrier(CLK_LOCAL_MEM_FENCE);

    for(unsigned int s=1; s <sizeGroup; s *= 2)
    {
        if(iLocal % (2*s) == 0)
            lData[iLocal] += lData[iLocal + s];
        barrier(CLK_LOCAL_MEM_FENCE);
    }

    if(iLocal == 0)  // write result of block reduction
        gData[iGroup] = lData[0];
}
```

J. Sanders, E. Kandrot. *CUDA by Example: An Introduction to General-Purpose GPU Programming*

Reduction for Sum Operator (2)

```
__kernel void calc_parallel_sum(__global int *gData, __local int *lData)
{
    int iGlobal = get_global_id(0);
    int iLocal  = get_local_id(0);
    int sizeGroup = get_local_size(0);
    int iGroup = get_group_id(0);

    lData[iLocal] = gData[iGlobal];  // load into shared memory
    barrier(CLK_LOCAL_MEM_FENCE);

    for(unsigned int s=1; s <sizeGroup; s *= 2)
    {
        int index = 2 * s * iLocal;
        if(index < sizeGroup)
            lData[iLocal] += lData[iLocal + s];
        barrier(CLK_LOCAL_MEM_FENCE);
    }

    if(iLocal == 0)  // write result of block reduction
        gData[iGroup] = lData[0];
}
```

J. Sanders, E. Kandrot. *CUDA by Example: An Introduction to General-Purpose GPU Programming*

Reduction for Sum Operator (3)

```
__kernel void calc_parallel_sum(__global int *gData, __local int *lData)
{
    int iGlobal = get_global_id(0);
    int iLocal  = get_local_id(0);
    int sizeGroup = get_local_size(0);
    int iGroup = get_group_id(0);

    lData[iLocal] = gData[iGlobal];  // load into shared memory
    barrier(CLK_LOCAL_MEM_FENCE);

    for(unsigned int s = sizeGroup/2; s > 0; s >>= 1)
    {
        if(iLocal < s)
            lData[iLocal] += lData[iLocal + s];
        barrier(CLK_LOCAL_MEM_FENCE);
    }

    if(iLocal == 0)  // write result of block reduction
        gData[iGroup] = lData[0];
}
```

J. Sanders, E. Kandrot. *CUDA by Example: An Introduction to General-Purpose GPU Programming*