Advanced OpenCL Programming

Pangfeng Liu
National Taiwan University

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Multiple Devices

- We have been using one device for computation.
- Now we will use multiple device to solve a problem.
- We will use matrix multiplication as an example.

Partition

- Since we are very poor and cannot afford four GPUs, we will partition the data by rows (not by block) among devices.
- We will partition matrix by rows, so that the memory assigned to a device is contiguous.
- Each kernel will run on a device, and compute part of the answers.

Partition

- We will partition A and C by rows, and do *not* partition B.
- For example, if we use two devices, then the first kernel will compute the top half of C, and another kernel will compute the bottom half of C.
- The reason for not partitioning B is that all kernels need the entire B.

Constants

- `MAXLOG` is the maximum number of bytes for storing compilation log. More on this later.
- The number of device is `DEVICENUM`. We will use 2 in our humble installation.
- `ITEMPERDEVICE` is the number of work item in `NDRange` of a kernel.

Constants

Example 1: (matrixMul-time-copy-local-multidevice.c)

```
2  #define CL_USE_DEPRECATED_OPENCL_2_0_APIS
3  #include <stdio.h>
4  #include <assert.h>
5  #include <CL/cl.h>
6
7  #define N 1024
8  #define Blk 64
9  #define BSIDE (N / Blk)
10 #define MAXGPU 10
11 #define MAXK 1024
12 #define MAXLOG 4096
13 #define DEVICENUM 2
14 #define ITEMPERDEVICE (N * N / DEVICENUM)
15 #define NANO2SECOND 1000000000.0
16
17 cl_uint A[N][N], B[N][N], C[N][N];
```

Discussion

- If N is 1024, and the number of device is 2, then how many works items are there in a kernel?

Select Devices

- We will select the first `DEVICENUM` GPU device from our humble installation.
- The code is similar to those earlier version, except that now we need to make sure that the number of GPUs found is at least `DEVICENUM`.

Devices

Example 2: (matrixMul-time-copy-local-multidevice.c)

```
30  cl_device_id GPU[MAXGPU];
31  cl_uint GPU_id_got;
32  status =
33    clGetDeviceIDs(platform_id, CL_DEVICE_TYPE_GPU,
34                   MAXGPU, GPU, &GPU_id_got);
35  assert(status == CL_SUCCESS &&
36         GPU_id_got >= DEVICENUM);
37  printf("There are %d GPU devices\n", GPU_id_got);
```

Context

- Since a context can consist of multiple devices, we need only one context.
- Here we include the first `DEVICENUM` GPUs in the context.

Context

Example 3: (matrixMul-time-copy-local-multidevice.c)

```
39    cl_context context =
40      clCreateContext(NULL, DEVICENUM, GPU, NULL, NULL,
41                      &status);
42    assert(status == CL_SUCCESS);
```

Multiple Queue

- Recall that a command queue connects to a device.
- Since we have multiple devices, we need multiple command queues.
- We put the command queues in the `commandQueue` array.
- Note that we set the `CL_QUEUE_PROFILING_ENABLE` to enable profiling.

Command Queue

Example 4: (matrixMul-time-copy-local-multidevice.c)

```
44  cl_command_queue commandQueue[DEVICENUM];
45  for (int device = 0; device < DEVICENUM; device++) {
46    commandQueue[device] =
47      clCreateCommandQueue(context, GPU[device],
48                           CL_QUEUE_PROFILING_ENABLE,
49                           &status);
50    assert(status == CL_SUCCESS);
51  }
```

One Context, Multiple Devices

- Up to this point, we can image there is only one context, which has multiple devices.
- Within this context we will have one command queue to connect to each device.
- Later we will send commands to these devices. The command sent into a command queue will run on the device this command queue connects to.

Discussion

- What will be sent into these command queues as commands?

Program

- The kernel will be sent into the command queue as commands.
- Before this can happen we need to compile the kernel.
- Recall that the "kernel" at this point is only a set of strings, which need to be compiled.

Build Program

- We call `clBuildProgram` to build executable.
- Note that we pass *all* devices we want to use as parameters, so OpenCL will build executable for all our `DEVICENUM` devices.

Compilation Log

- The kernel source is compiled when an OpenCL program runs.
- It is very inconvenient because when we run an OpenCL program the execution will not display compilation errors of the kernel.
- We will use `clGetProgramBuildInfo` to show the error message if the compilation of the kernel fails.

Prototype 5: clGetProgramBuildInfo.h

```
1  cl_int clGetProgramBuildInfo(cl_program program,
2                               cl_device_id device,
3                               cl_program_build_info param_name,
4                               size_t param_value_size,
5                               void *param_value,
6                               size_t *param_value_size_ret);
```

Parameters

`program` The compiled program.

`device` The device you want to query.

`param_name` The information you want to query.

`param_value_size` The length of `param_value` in bytes.

`param_value` The location for the query answer.

`param_value_size_ret` The number of bytes returned from the query.

Error

- When there is an error in `clBuildProgram`, we will call `clGetProgramBuildInfo` to find out.
- Since we are not sure about which device causes the compilation error, we list the information from all of them.
- We query with `CL_PROGRAM_BUILD_LOG` for the compilation log, and place it into the `log` buffer we prepared.

Build Program

Example 6: (matrixMul-time-copy-local-multidevice.c)

```
65    status =
66      clBuildProgram(program, DEVICENUM, GPU, NULL,
67                     NULL, NULL);
68    if (status != CL_SUCCESS) {
69      char log[MAXLOG];
70      size_t logLength;
71      for (int device = 0; device < DEVICENUM; device++) {
72        clGetProgramBuildInfo(program, GPU[device],
73                              CL_PROGRAM_BUILD_LOG,
74                              MAXLOG, log, &logLength);
75        puts(log);
76      }
77      exit(-1);
78    }
79    printf("Build program completes\n");
```

Discussion

- What is the type of the compilation log?
- What does `puts` do?

Partition

- Now we are ready to partition host buffers A, B and C.
- We will create `DEVICENUM` buffers for A, and each of which will be given to a kernel as a parameter for computations.
- We partition A into sub-matrix of `N / DEVICENUM` rows of A each, and assign each partition to an OpenCL buffer.

Buffer A

- `ITEMPERDEVICE` means the number of items per device.
- The index `device` determines the starting position of a buffer, i.e., where the matrix A will be partitioned.

Buffer for A

Example 7: (matrixMul-time-copy-local-multidevice.c)

```
91   cl_mem bufferA[DEVICENUM];
92   for (int device = 0; device < DEVICENUM; device++) {
93     bufferA[device] =
94       clCreateBuffer(context,
95         CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR,
96         ITEMPERDEVICE * sizeof(cl_uint),
97         ((cl_uint *)A) + device * ITEMPERDEVICE,
98         &status);
99     assert(status == CL_SUCCESS);
100  }
```

Buffer B

- We do not need to partition B because it will be used by all kernels.

Buffer for B

Example 8: (matrixMul-time-copy-local-multidevice.c)

```
102   cl_mem bufferB =
103     clCreateBuffer(context,
104       CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR,
105       N * N * sizeof(cl_uint), B, &status);
106   assert(status == CL_SUCCESS);
```

Buffer C

- Buffers for C are similarly built as for A.
- Unlike A and B that will copy host buffers to device buffers, C will use host memory directly.

Buffer for C

Example 9: (matrixMul-time-copy-local-multidevice.c)

```
108   cl_mem bufferC[DEVICENUM];
109   for (int device = 0; device < DEVICENUM; device++) {
110     bufferC[device] =
111       clCreateBuffer(context,
112         CL_MEM_WRITE_ONLY | CL_MEM_USE_HOST_PTR,
113         ITEMPERDEVICE * sizeof(cl_uint),
114         ((cl_uint *) C) + device * ITEMPERDEVICE,
115         &status);
116     assert(status == CL_SUCCESS);
117   }
118   printf("Build buffers completes\n");
```

Discussion

- Make sure that you understand the offset calculation in A and C.

NDRange

- According to our partition we declare `NDRange` as a two dimension array with `N / DEVICENUM` rows and `N` columns.
- This is consistent with C, where each work item will compute an element of C.
- The work group is still `BSIDE` by `BSIDE` since we will use the previous local memory algorithm.
- We will have `DEVICENUM` kernels, so we will need `DEVICENUM` events for synchronization and profiling.

NDRange

Example 10: (matrixMul-time-copy-local-multidevice.c)

```
120   size_t globalThreads[] =
121     {(size_t)(N / DEVICENUM), (size_t)N};
122   size_t localThreads[] = {BSIDE, BSIDE};
123   cl_event events[DEVICENUM];
```

Set Argument

- We will launch `DEVICENUM` kernels. Each of them will compute `N / DEVICENUM` rows and `N` columns of C.
- We loop through all devices, and assign the argument order as A, B, and C.
- Note that we need to supply the correct A and C since there are `DEVICENUM` of them.

Set Arguments

Example 11: (matrixMul-time-copy-local-multidevice.c)

```
125   for (int device = 0; device < DEVICENUM; device++) {
126     status = clSetKernelArg(kernel, 0, sizeof(cl_mem),
127                             (void*)(&bufferA[device]));
128     assert(status == CL_SUCCESS);
129     status = clSetKernelArg(kernel, 1, sizeof(cl_mem),
130                             (void*)&bufferB);
131     assert(status == CL_SUCCESS);
132     status = clSetKernelArg(kernel, 2, sizeof(cl_mem),
133                             (void*)(&bufferC[device]));
134     assert(status == CL_SUCCESS);
135     printf("Set kernel arguments completes\n");
```

Kernel

- Now we are ready to launch kernel.
- Note that we need to supply the command queue to the device as a parameters.
- The same kernel is launched again and again for `DEVICENUM` times. The only difference is the buffers A and C used in launching the kernel.
- We associate an event with each kernel launching.

Start Kernel

Example 12: (matrixMul-time-copy-local-multidevice.c)

```
137     status =
138       clEnqueueNDRangeKernel(commandQueue[device],
139                              kernel, 2, NULL,
140                              globalThreads, localThreads,
141                              0, NULL, &(events[device]));
142     assert(status == CL_SUCCESS);
143   }
```

Wait for Completion

- Since kernel launching is non-blocking. we need to wait for them to complete.
- We simply use `clWaitForEvents`, and wait for all events to complete.

Wait for Kernels

Example 13: (matrixMul-time-copy-local-multidevice.c)

```
145   clWaitForEvents(DEVICENUM, events);
146   printf("Kernel execution completes.\n");
```

Discussion

- How many events do we need to wait for the whole thing to complete?

Kernel

- The kernel function is very similar to the previous local memory version.
- We also use the constant `DEVICENUM` to denote the number of devices.

Kernel

Example 14: (mul-local-multidevice-kernel.cl)

```
2 #define N 1024
3 #define Blk 64
4 #define DEVICENUM 2
5 #define BSIDE (N / Blk)
```

Kernel

Example 15: (mul-local-multidevice-kernel.cl)

```
7  __kernel void mul(__global int A[N/DEVICENUM][N],
8                    __global int B[N][N],
9                    __global int C[N/DEVICENUM][N])
10 {
11   int globalRow = get_global_id(0);
12   int globalCol = get_global_id(1);
13   int localRow = get_local_id(0);
14   int localCol = get_local_id(1);
15
16   __local int ALocal[BSIDE][BSIDE];
17   __local int BLocal[BSIDE][BSIDE];
```

NDRange

- We declare A and C as `N / DEVICENUM` by `N` arrays, because the domain is partitioned among devices.
- The rest of the code is *not* changed at all!

Reason

- The reason for this "no need to change" is that a kernel function is acting from a local view, i.e., it is a work item within a work group, so all the operations are still the same.
- The kernel still thinks from the point of view of blocks, and the related operations are done in local indices.
- We only need the global index while accessing A, B, and C.
- Since the kernel is given the corresponding parts of A and B, so the operation is correct.

Discussion

- Convince yourself that the code is correct.

Timing

- We would like to know the detailed timing of the kernels.
- In particular we would like to prove the two kernel runs *in parallel*.
- To do so we need the absolute time of the events from all devices.

Base

- The time returned by the event is difficult to interpret.
- We would like to establish a relative time for inspection.
- We choose the time the first kernel entering the queue as the base time, and report the relative time to it for ease understanding.

Get Time

Example 16: (matrixMul-time-copy-local-multidevice.c)

```
148   cl_ulong base;
149   status =
150     clGetEventProfilingInfo(events[0],
151       CL_PROFILING_COMMAND_QUEUED,
152       sizeof(cl_ulong), &base, NULL);
153   assert(status == CL_SUCCESS);
```

Get Time

- We loop through all devices and get timing information from all of them.
- This part is the same as before.

Get Time

Example 17: (matrixMul-time-copy-local-multidevice.c)

```
155   for (int device = 0; device < DEVICENUM; device++) {
156     cl_ulong timeEnterQueue, timeSubmit, timeStart,
157       timeEnd;
158     status =
159       clGetEventProfilingInfo(events[device],
160         CL_PROFILING_COMMAND_QUEUED,
161         sizeof(cl_ulong), &timeEnterQueue, NULL);
162     assert(status == CL_SUCCESS);
163     status =
164       clGetEventProfilingInfo(events[device],
165         CL_PROFILING_COMMAND_SUBMIT,
166         sizeof(cl_ulong), &timeSubmit, NULL);
167     assert(status == CL_SUCCESS);
```

Get Time

Example 18: (matrixMul-time-copy-local-multidevice.c)

```
169     status =
170       clGetEventProfilingInfo(events[device],
171         CL_PROFILING_COMMAND_START,
172         sizeof(cl_ulong), &timeStart, NULL);
173     assert(status == CL_SUCCESS);
174     status =
175       clGetEventProfilingInfo(events[device],
176         CL_PROFILING_COMMAND_END,
177          sizeof(cl_ulong), &timeEnd, NULL);
178     assert(status == CL_SUCCESS);
```

Relative Time

- In addition to queuing time, submission time, and execution, we also report the relative time when the four events happened.
- The relative time is in nanosecond.

Print Time

Example 19: (matrixMul-time-copy-local-multidevice.c)

```
180     printf("\nkernel entered queue at %f\n",
181             (timeEnterQueue - base) / NANO2SECOND);
182     printf("kernel submitted to device at %f\n",
183             (timeSubmit - base) / NANO2SECOND);
184     printf("kernel started at %f\n",
185             (timeStart - base) / NANO2SECOND);
186     printf("kernel ended  at %f\n",
187             (timeEnd - base) / NANO2SECOND);
188     printf("kernel queued time %f seconds\n",
189             (timeSubmit - timeEnterQueue) / NANO2SECOND);
190     printf("kernel submission time %f seconds\n",
191             (timeStart - timeSubmit) / NANO2SECOND);
192     printf("kernel execution time %f seconds\n",
193          (timeEnd - timeStart) / NANO2SECOND);
194   }
```

Demonstration

- Run the `matrixMul-time-copy-local-multidevice-cl` program.

Discussion

- Does the kernels run in parallel? Observe the results and give your answer.

Dependency

- We may launch multiple kernels into multiple devices.
- Kernels may have dependency, and we need to ensure dependency among kernels.

Example

- In the following example we compute $G = (A + B) + (D + E)$, where all vector has length N.
- We compute $C = A + B$, then $F = D + E$, then we compute $G = C + F$. The last computation must wait for the first two to complete.
- We will use one device for *each* of the three additions.

Constants

- We first declare the constants and variables.

Example 20: (vectorAdd-dependency.c)

```
2  #define CL_USE_DEPRECATED_OPENCL_2_0_APIS
3  #include <stdio.h>
4  #include <assert.h>
5  #include <CL/cl.h>
6  #define N (65536 * 4)
7  #define MAXGPU 10
8  #define MAXK 1024
9  #define MAXLOG 4096
10 #define DEVICENUM 3
11 #define NANO2SECOND 1000000000.0
12
13 cl_uint A[N], B[N], C[N], D[N], E[N], F[N], G[N];
```

Initialization

- We initialize the A, B, D and E vectors.

Example 21: (vectorAdd-dependency.c)

```
82    for (int i = 0; i < N; i++) {
83      A[i] = i;
84      B[i] = N - i;
85      D[i] = i;
86      E[i] = N - i;
87    }
```

Buffers

- We then create buffers for kernel parameters.
- A and B are read only, and need to be copied into device.
- C is both read and write enable.

Example 22: (vectorAdd-dependency.c)

```
89   cl_mem bufferA =
90     clCreateBuffer(context,
91                    CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR,
92                    N * sizeof(cl_uint), A, &status);
93   assert(status == CL_SUCCESS);
94   cl_mem bufferB =
95     clCreateBuffer(context,
96                    CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR,
97                    N * sizeof(cl_uint), B, &status);
98   assert(status == CL_SUCCESS);
99   cl_mem bufferC =
100    clCreateBuffer(context,
101                   CL_MEM_READ_WRITE,
102                   N * sizeof(cl_uint), NULL, &status);
103  assert(status == CL_SUCCESS);
```

Buffers

- Similarly we create buffers for D, E and F.

Example 23: (vectorAdd-dependency.c)

```
105   cl_mem bufferD =
106     clCreateBuffer(context,
107                    CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR,
108                    N * sizeof(cl_uint), D, &status);
109   assert(status == CL_SUCCESS);
110   cl_mem bufferE =
111     clCreateBuffer(context,
112                    CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR,
113                    N * sizeof(cl_uint), E, &status);
114   assert(status == CL_SUCCESS);
115   cl_mem bufferF =
116     clCreateBuffer(context,
117                    CL_MEM_READ_WRITE,
118                    N * sizeof(cl_uint), NULL, &status);
119   assert(status == CL_SUCCESS);
```

Buffers

- We create buffers for G.
- This buffer is write only and use the host memory directly, so the host can print it directly.

Example 24: (vectorAdd-dependency.c)

```
121   cl_mem bufferG =
122     clCreateBuffer(context,
123                    CL_MEM_WRITE_ONLY | CL_MEM_USE_HOST_PTR,
124                    N * sizeof(cl_uint), G, &status);
125   assert(status == CL_SUCCESS);
126   printf("Build buffers completes\n");
```

Discussion

- What are the characteristic for read only, read and write, and write only buffers respectively?

Buffers

- Both `NDRange` and the work group are one dimensional.
- The size of `NDRange` is N.
- The size of a work group is 256.

Example 25: (vectorAdd-dependency.c)

```
128   size_t globalThreads[] = {(size_t)N};
129   size_t localThreads[] = {256};
```

$C = A + B$

- Now we launch the first kernel for $C = A + B$.
- We have already built three command queues for three devices.
- We use `commandQueue[0]` for the first addition.
- We also declared three events to denote the completion of the three kernels that we will launch.

Example 26: (vectorAdd-dependency.c)

```
131   cl_event events[3];
132   status = clSetKernelArg(kernel, 0, sizeof(cl_mem),
133                           (void*)&bufferA);
134   assert(status == CL_SUCCESS);
135   status = clSetKernelArg(kernel, 1, sizeof(cl_mem),
136                           (void*)&bufferB);
137   assert(status == CL_SUCCESS);
138   status = clSetKernelArg(kernel, 2, sizeof(cl_mem),
139                           (void*)&bufferC);
140   assert(status == CL_SUCCESS);
141
142   status =
143     clEnqueueNDRangeKernel(commandQueue[0], kernel, 1, NULL,
144                            globalThreads, localThreads,
145                            0, NULL, &(events[0]));
146   assert(status == CL_SUCCESS);
```

$F = D + E$

- Similarly we launch the second kernel for $F = D + E$.
- Note that we used `commandQueue[1]` and `events[1]`.

Example 27: (vectorAdd-dependency.c)

```
148   status = clSetKernelArg(kernel, 0, sizeof(cl_mem),
149                           (void*)&bufferD);
150   assert(status == CL_SUCCESS);
151   status = clSetKernelArg(kernel, 1, sizeof(cl_mem),
152                           (void*)&bufferE);
153   assert(status == CL_SUCCESS);
154   status = clSetKernelArg(kernel, 2, sizeof(cl_mem),
155                           (void*)&bufferF);
156   assert(status == CL_SUCCESS);
157   status =
158     clEnqueueNDRangeKernel(commandQueue[1], kernel, 1, NULL,
159                            globalThreads, localThreads,
160                            0, NULL, &(events[1]));
161   assert(status == CL_SUCCESS);
```

$G = C + F$

- Finally we launch the third kernel for $G = C + F$.
- Note that we used `commandQueue[2]` and `events[2]`.

Example 28: (vectorAdd-dependency.c)

```
163   status = clSetKernelArg(kernel, 0, sizeof(cl_mem),
164                           (void*)&bufferC);
165   assert(status == CL_SUCCESS);
166   status = clSetKernelArg(kernel, 1, sizeof(cl_mem),
167                           (void*)&bufferF);
168   assert(status == CL_SUCCESS);
169   status = clSetKernelArg(kernel, 2, sizeof(cl_mem),
170                           (void*)&bufferG);
171   assert(status == CL_SUCCESS);
172   status =
173     clEnqueueNDRangeKernel(commandQueue[2], kernel, 1, NULL,
174                            globalThreads, localThreads,
175                            0, NULL, &(events[2]));
176   assert(status == CL_SUCCESS);
```

Wait for Events

- We wait for all three kernel to finish.

Example 29: (vectorAdd-dependency.c)

```
178   status = clWaitForEvents(DEVICENUM, events);
179   assert(status == CL_SUCCESS);
180   printf("All three kernels complete.\n");
```

Wait for Events

- The rest of the code just prints the timing information, checks for correctness, and releases resources.
- Please refer to previous discussion.

Demonstration

- Run the `vectorAdd-dependency-cl`.

Discussion

- Does the program produce the correct answer?
- If not what is the possible reason?

Problem

- The previous program waits for all three kernels to complete, but the third kernel did *not* wait for the first two.
- We will use the *wait for events* mechanism to launch the third kernel.

Prototype 30: clEnqueueNDRangeKernel.h

```
1  cl_int
2  clEnqueueNDRangeKernel (cl_command_queue command_queue,
3                          cl_kernel kernel,
4                          cl_uint work_dim,
5                          const size_t *global_work_offset,
6                          const size_t *global_work_size,
7                          const size_t *local_work_size,
8                          cl_uint num_events_in_wait_list,
9                          const cl_event *event_wait_list,
10                         cl_event *event);
```

$G = C + F$

- We launch the third kernel and wait for the first two events in the `events` array.
- Set `num_events_in_wait_list` to 2 and `event_wait_list` to `events`.

Example 31: (vectorAdd-dependency-correct.c)

```
163   status = clSetKernelArg(kernel, 0, sizeof(cl_mem),
164                           (void*)&bufferC);
165   assert(status == CL_SUCCESS);
166   status = clSetKernelArg(kernel, 1, sizeof(cl_mem),
167                           (void*)&bufferF);
168   assert(status == CL_SUCCESS);
169   status = clSetKernelArg(kernel, 2, sizeof(cl_mem),
170                           (void*)&bufferG);
171   assert(status == CL_SUCCESS);
172   status =
173     clEnqueueNDRangeKernel(commandQueue[2], kernel, 1, NULL,
174                            globalThreads, localThreads,
175                            2, events, &(events[2]));
176   assert(status == CL_SUCCESS);
```

Demonstration

- Run the `vectorAdd-dependency-correct-cl`.

Discussion

- Does the program produce the correct answer?
- Observe the timing and make sure the first two kernels run in parallel, and the third kernel will wait for the first two.

flFinish

- The host can also explicitly wait for the first two kernels to finish before launching the third kernel by `clFinish`.
- We just need to wait for the command queues to the first two devices to become empty.

Example 32: (vectorAdd-dependency-clfinish.c)

```
163   clFinish(commandQueue[0]);
164   clFinish(commandQueue[1]);
165   status = clSetKernelArg(kernel, 0, sizeof(cl_mem),
166                           (void*)&bufferC);
167   assert(status == CL_SUCCESS);
168   status = clSetKernelArg(kernel, 1, sizeof(cl_mem),
169                           (void*)&bufferF);
170   assert(status == CL_SUCCESS);
171   status = clSetKernelArg(kernel, 2, sizeof(cl_mem),
172                           (void*)&bufferG);
173   assert(status == CL_SUCCESS);
174   status =
175     clEnqueueNDRangeKernel(commandQueue[2], kernel, 1, NULL,
176                            globalThreads, localThreads,
177                            0, NULL, &(events[2]));
178   assert(status == CL_SUCCESS);
```

Demonstration

- Run the `vectorAdd-dependency-clfinish-cl` program.

Discussion

- Does the program produce the correct answer?
- Observe the timing and make sure the first two kernels run in parallel, and the third kernel will wait for the first two.
- Compare the timing results between `vectorAdd-dependency-correct-cl` and `vectorAdd-dependency-clfinish-cl`, especially in when the last kernel joined the command queue.

Group Size

- The previous matrix multiplication program has extremely good performance due to two reasons.
  - It uses local memory to speed up data access.
  - It has a larger group size (256).
- Now we would like to study the effects of group size on performance.

Compute Units

- A device has only a limited number of compute units.
- The work items of a work group will occupy a compute unit.
- For a given number of work items, if the work group size is small, then the number of work groups becomes large, and some work groups will wait for compute unit.
- In other words, a small work group size limits the the number of work items that we can process in parallel.

Classroom

- A school has only a limited number of classrooms.
- The students are divided into group, and one group will occupy a classroom.
- For a given number of students, if the group size is small, then the number of groups becomes large, and some groups will wait for classroom.
- In other words, a small group size limits the the number of students that can study in parallel.

Discussion

- Give your own example of this phenomenon.

Compute Unit Number

- We need only one GPU device.
- We call `clGetDeviceInfo` with `CL_DEVICE_MAX_COMPUTE_UNITS` to get the number of compute units on GPU.
- We need the number of compute units to determine the work group size.

Example 33: (vectorAdd-groupsize.c)

```
24  cl_device_id GPU[MAXGPU];
25  cl_uint GPU_id_got;
26  status =
27    clGetDeviceIDs(platform_id, CL_DEVICE_TYPE_GPU,
28                   MAXGPU, GPU, &GPU_id_got);
29  assert(status == CL_SUCCESS && GPU_id_got >= 1);
30  printf("There are %d GPU devices\n", GPU_id_got);
31  cl_uint unit;
32  status =
33    clGetDeviceInfo(GPU[0], CL_DEVICE_MAX_COMPUTE_UNITS,
34                    sizeof(cl_uint), &unit, NULL);
35  assert(status == CL_SUCCESS);
36  printf("# of compute units is %d\n", unit);
```

Group Size

- We fix the number of work items to N, and vary the size of the work group from 1 to 256.
- We wait for the event before launching the next kernel.
- We will record the timing information into a file `vectorAdd-grouopsize.dat`.

Example 34: (vectorAdd-groupsize.c)

```
109   size_t workItem[] = {(size_t)N};
110   FILE *timefp = fopen("vectorAdd-groupsize.dat", "w");
111   assert(timefp != NULL);
112   for (int groupSize = 1; groupSize <= 256; groupSize *= 2) {
113     cl_event event;
114     size_t localSize[1];
115     localSize[0] = groupSize;
116     status =
117       clEnqueueNDRangeKernel(commandQueue, kernel, 1, NULL,
118                              workItem, localSize,
119                              0, NULL, &event);
120     assert(status == CL_SUCCESS);
121     /* waitforevent */
122     status = clWaitForEvents(1, &event);
123     assert(status == CL_SUCCESS);
124     printf("The kernel with group size %d completes.\n",
125            groupSize);
```

Get Timing Information

- The rest of the code will retrieve timing information from the event.
- We output the group size and the execution time into a file `vectorAdd-grouopsize.dat`.

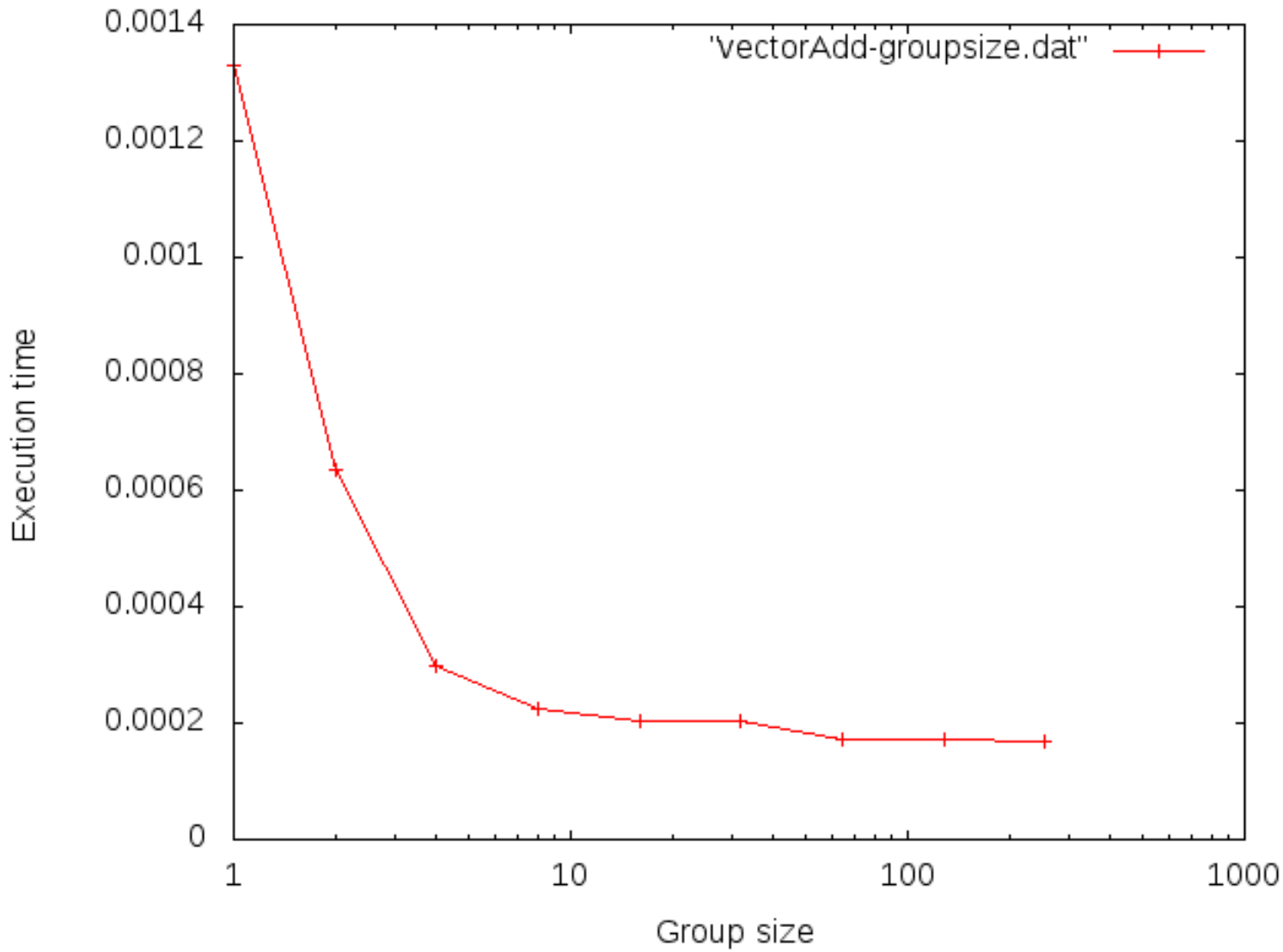
Example 35: (vectorAdd-groupsize.c)

```
158     printf("\nkernel entered queue at %f\n",
159             (timeEnterQueue - base) / NANO2SECOND);
160     printf("kernel submitted to device at %f\n",
161             (timeSubmit - base) / NANO2SECOND);
162     printf("kernel started at %f\n",
163             (timeStart - base) / NANO2SECOND);
164     printf("kernel ended  at %f\n",
165             (timeEnd - base) / NANO2SECOND);
166     printf("kernel queued time %f seconds\n",
167             (timeSubmit - timeEnterQueue) / NANO2SECOND);
168     printf("kernel submission time %f seconds\n",
169             (timeStart - timeSubmit) / NANO2SECOND);
170     printf("kernel execution time %f seconds\n",
171             (timeEnd - timeStart) / NANO2SECOND);
172     fprintf(timefp, "%d %f\n", groupSize,
173              (timeEnd - timeStart) / NANO2SECOND);
174   }
```

Demonstration

- We plot the kernel execution time for different group sizes.
- The x-xis is in log scale.

Execution Time



Discussion

- Observe the execution time and draw you conclusion about the effects of group size on performance.