OpenCL: Portable programming at the right or the wrong level?

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OpenCL

- Standard for heterogeneous computing, set by the Khronos Group

..and many more

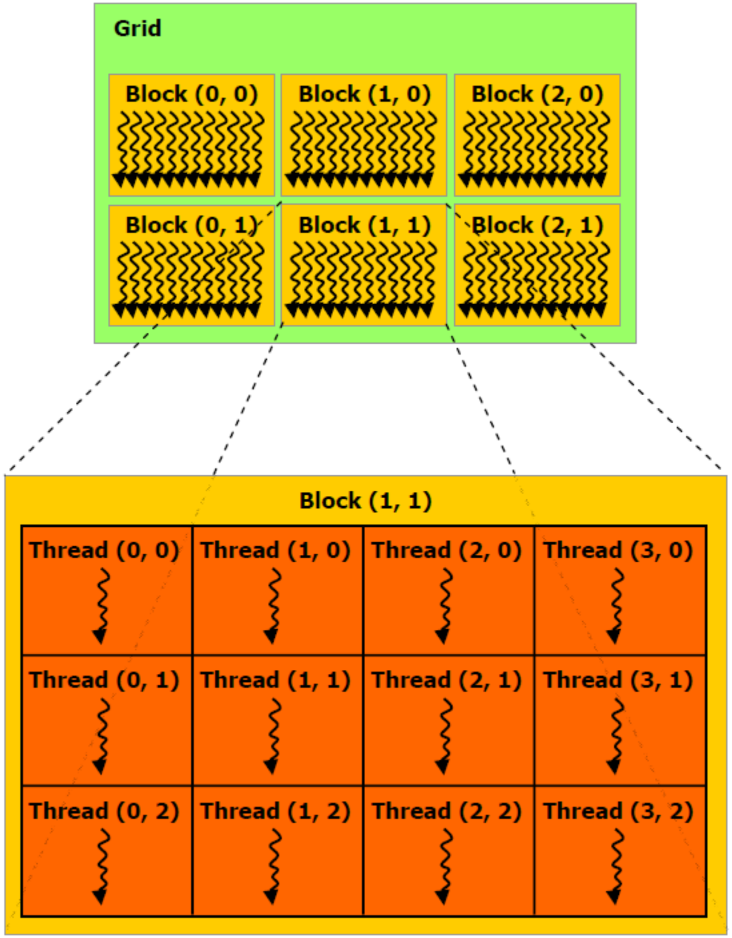
OpenCL

- Idea: implicit data-parallel code executed in «kernels», portable across different devices/vendors

```
void evaluatePdfGaussian(const double mu, const double sigma, const double* data,
  double* results, const int N)
{
  #pragma omp parallel for
  for(int i = 0; i < N; i++)
  {
    double temp = (data[i]-mu)/sigma;
    temp *= temp;
    results[i] = exp(-0.5*temp);
  }
}
```

```
__kernel void evaluatePdfGaussian(__const double mu, __const double sigma, __global
 const double *data, __global double *results, __const int N)
{
  int i = get_global_id(0);
  if (i >= N) return;
  double x = data[i];
  double temp = (x-mu)/sigma;
  temp *= temp;
  results[i] = exp(-0.5*temp);
}
```

- A kernel represents a parallel execution on a grid of threads



(Illustration borrowed from NVIDIAs OpenCL programming guide)

http://www.nvidia.com/content/cudazone/download/OpenCL/NVIDIA_OpenCL_ProgrammingGuide.pdf

OpenCL

- Goal: *To use this both for CPUs and GPUs with the same kernel code, and that this is performant*
- Paradigm suitable for GPU execution
- CPUs and GPUs differ largely in hardware implementation
- Strictly C (or a superset of), no C++ here
- Cannot call «host code» from OpenCL code, and vice versa
- A lot of compute intensive programs are written in C++
- Will this work (and be performant) on CPUs as well?

OpenCL device abstractions

- Different hardware/SDKs/drivers are represented by different «platform» objects
- A platform object can have a range of devices (you must have them physically, of course)

An example

```
cl_platform platform;
cl_device device;
cl_context context;
cl_command_queue queue;
cl_int status;

clGetPlatformIDs(1, &platform, NULL);
clGetDeviceIDs(platform, CL_DEVICE_TYPE_GPU, 1, &device, NULL);
context = clCreateContext(NULL, 1, &device, NULL, NULL, &status);
queue = clCreateCommandQueue(context, device, 0, &status);
```

Kernel declaration/execution

❑ The Gaussian kernel, revisited

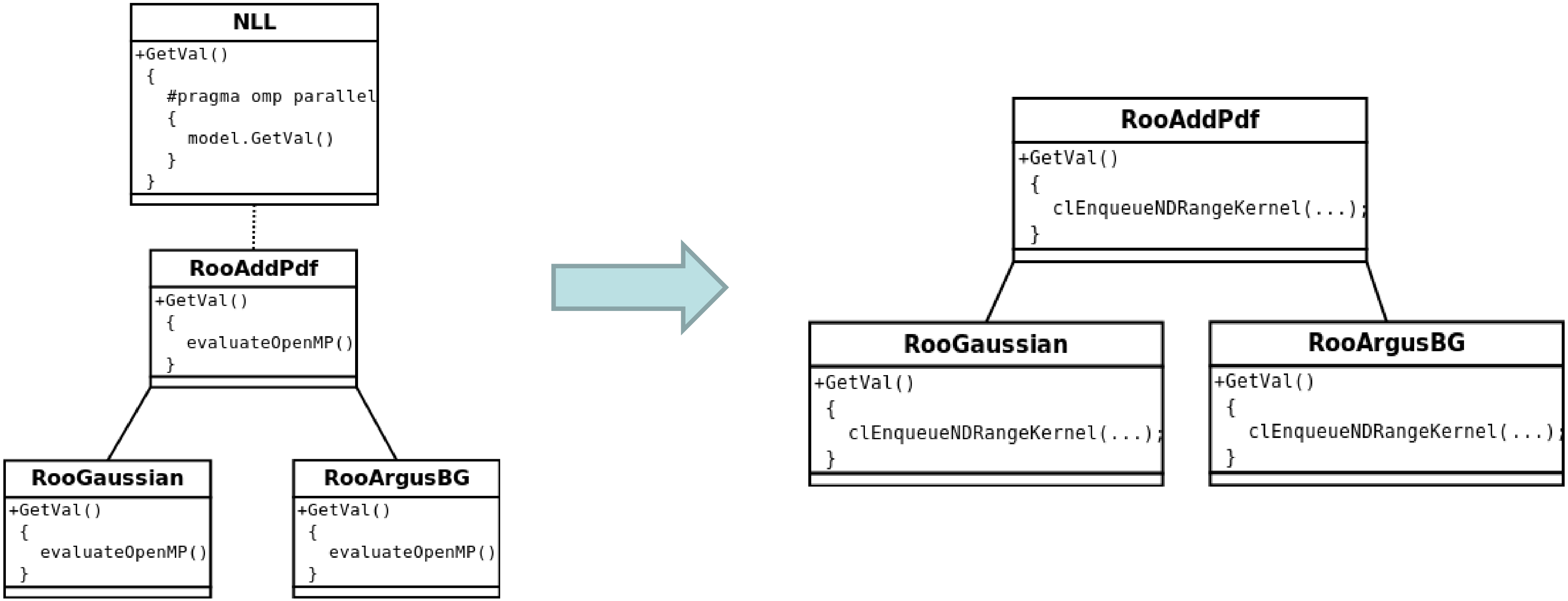
```
__kernel void evaluatePdfGaussian(__const double mu, __const double sigma, __global const double *data,
__global double *results, __const int N)
{
   int i = get_global_id(0);
   if (i >= N) return;
   double x = data[i];
   double temp = (x-mu)/sigma;
   temp *= temp;
   results[i] = exp(-0.5*temp);
}
```

❑ Executing a computational kernel

```
//Assume we have the required arguments and a kernel object for the Gaussian kernel above
clSetKernelArg(evaluatePdfGaussian, 0, sizeof(float), (void*)&mu);
clSetKernelArg(evaluatePdfGaussian, 1, sizeof(float), (void*)&sigma);
clSetKernelArg(evaluatePdfGaussian, 2, sizeof(cl_mem), (void*)&data);
clSetKernelArg(evaluatePdfGaussian, 3, sizeof(cl_mem), (void*)&results);
clSetKernelArg(evaluatePdfGaussian, 4, sizeof(int), (void*)&N);
size_t workGroupSize = 128;  //e.g.
size_t numWorkGroups = N % workGroupSize == 0 ? N/workGroupSize : N/workGroupSize + 1;
size_t total = workGroupSize * numWorkGroups;
clEnqueueNDRangeKernel(queue, evaluatePdfGaussian, 1, NULL, &total, &workGroupSize, 0, NULL, NULL);
```

An implementation example (RooFit)

- With OpenMP, each thread can evaluate a tree of PDFs top-down directly in fully parallel. Using OpenCL requires an explicit call to a kernel inside each PDF (see 2nd illustration), suggesting lower parallel efficiency.



- Leads to larger serial fraction, many kernel calls and in general, stalls
- Remember, no C++ in OpenCL kernels

Experiences

- Introduces more expressive code when setting up environment and e.g. calling kernels.
- Using plain C++ for CPU and OpenCL for GPU, we get duplication of code since we now must use an OpenCL compiler in addition to the C/C++ compiler
- Neither Intel or AMDs x86 implementation (Linux) offers auto-vectorization per 01.07.2011
- Have to use vector types to achieve vectorization. But even then AMDs OpenCL compiler (for CPU) does not vectorize transcendentals for instance

Manual vectorization ☹

```
__kernel void evaluatePdfGaussian(__const double mu, __const double sigma, __global
  const double *data, __global double *results, __const int N)
{
  int i = get_global_id(0);
  if (i >= N) return;
  double x = data[i];
  double temp = (x-mu)/sigma;
  temp *= temp;
  results[i] = exp(-0.5*temp);
}
```

```
__kernel __attribute__((vec_type_hint(double2))) void evaluatePdfGaussian(__const double mu,
    __const double sigma, __global const double *data, __global double *results, __const int N
    )
{
  int i = get_global_id(0);
  if (i >= N/2) return;
  double2 x = vload2(i, data);
  double2 temp = (x-mu)/sigma;
  temp *= temp;
  double2 result = exp(-0.5*temp);
  vstore2(result, i, results);
}
```

Experiences cont.

- Hidden threading overhead. Necessary to do more work per OpenCL thread for performance (goes for both Intel and AMD)
- Have talked to Intel OpenCL expert. He says that Intel will support auto-vectorization in OpenCL
- It would of course be nice to have one piece of code for any device, but that seems like somewhat of a silver bullet so far…
- AMD APP SDK uses LLVM as backend for CPUs

Manual work partitioning ☹☹☹

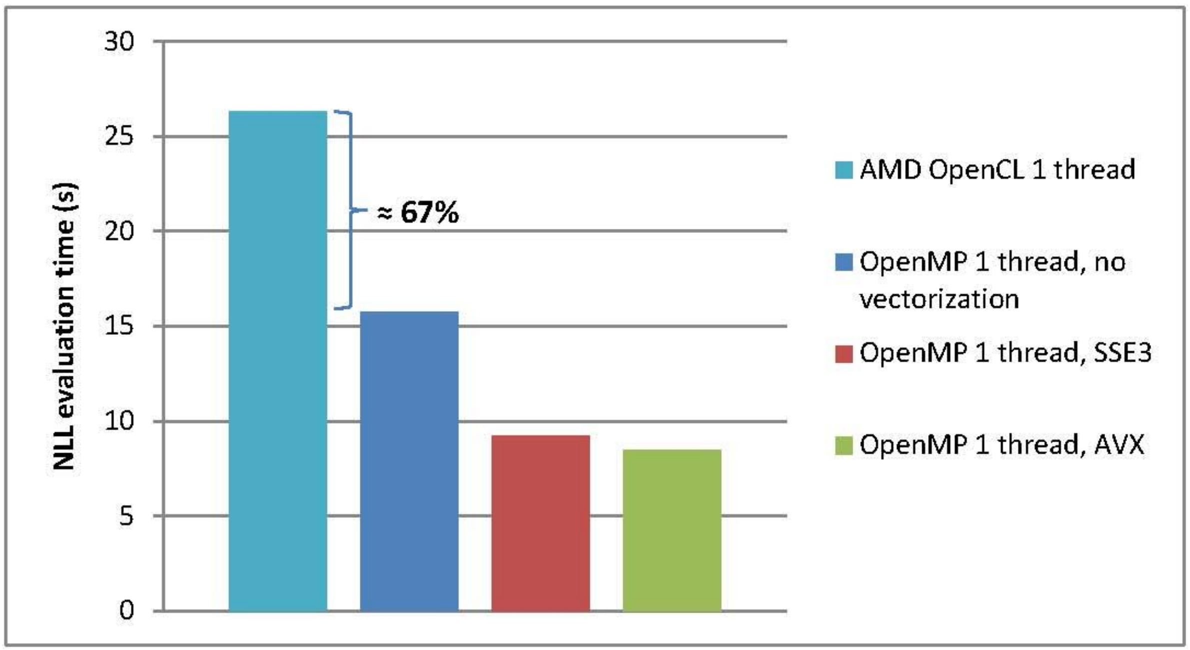
```
__kernel void evaluatePdfGaussian(__const double mu, __const double sigma, __global
 const double *data, __global double *results, __const int N)
{
  int i = get_global_id(0);
  if (i >= N) return;
  double x = data[i];
  double temp = (x-mu)/sigma;
  temp *= temp;
  results[i] = exp(-0.5*temp);
}
```

⇓

```
__kernel __attribute__((vec_type_hint(double2))) void evaluatePdfGaussian(__const double mu,
    __const double sigma, __global const double *data, __global double *results, __const int N,
     __const int numComputeElements)
{
  int i = get_global_id(0);
  if (i >= N) return;
  int part = N/numComputeElements;
  for(int index = i*part; index < (i+1)*part - 1; index+=2)
  {
    double2 x = vload2(index/2, data);
    double2 temp = (x-mu)/sigma;
    temp *= temp;
    double2 result = exp(-0.5*temp);
    vstore2(result, index/2, results);
  }
}
```

Some CPU results

- Benchmark on a desktop system
  - CPU: Intel Sandy Bridge @ 3.40GHz: 4 cores – 8 potential hardware threads
  - Linux 64bit, Intel C++ compiler version 12.1



/Function /Call Stack	CPU Time
__exp_f64	40.4%
__OpenCL_evaluatePdfAdd_stub	12.3%
__OpenCL_normalizeResults_stub	12.2%
__OpenCL_evaluatePdfProd_stub	8.9%
__OpenCL_evaluatePdfPolynomial_stub	7.1%
__log_f64	4.8%
__OpenCL_evaluatePdfArgusBG_stub	3.8%
[libatiocl64.so]	3.0%

VS

/Function /Call Stack	CPU Time
__svml_exp2.N	47.2%
PdfArgusBG::evaluateOpenMP	8.1%
PdfPolynomial::evaluateOpenMP	6.9%
PdfProd::evaluateOpenMP	6.5%
PdfAdd::evaluateOpenMP	6.1%
PdfGaussian::evaluateOpenMP	5.6%
AbsPdf::GetVal	4.7%
__svml_log2.L	3.8%
NLL::GetVal	3.4%
PdfBifurGaussian::evaluateOpenMP	1.9%

On GPUs

- Potential portability problem between NVIDIA and AMD/ATI; VLIW registers
- More difficult for AMD to exploit parallelism
- AMD Radeon series has 4 general stream cores and 1 special functional unit per scalar processor. We cannot use the functional unit (Geforce also has special functional units)
- We use transcendentals and double precision. Peak performance? Dream on...
- So, portability issue will in general arise only if doing simple math and not being memory-bound (typically, linear algebra)
- Of course, optimal work group size will differ between different models
- In our case, we are in general memory (latency) bound, so we don't experience any difference

Conclusion

- Reflect carefully before introducing OpenCL in your code
- Not ideal for CPU computations until code can be written the same way on the CPU as on the GPU and be performant. In essence this means:
  - Automatic vectorization for CPUs (both Intel and AMD supports SSE…)
  - Implicit effective thread-scheduling for most workloads
- No point in mixing OpenCL for CPUs and GPUs today, from a programmer's perspective (me). Atleast if you can play around with the Intel compiler

Conclusion

- OpenCL can be painful in legacy C++ programs. NVIDIA CUDA supports C++, but then we're bound to one specific vendor
- The main positive effect is code reuse between CPU and GPU
- Yes, it is portable, but it is not fully performance portable (there's a bunch of papers that states exactly this, also across GPU vendors)
- We are now focusing on hybrid (balancing) solutions with OpenMP and OpenCL, and they can co-exist fairly well