hiCL:
An OpenCL Abstraction Layer for Scientific Computing, Application to Depth Imaging on GPU and APU

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Scientific computing

CPU platforms are the reference

Scientific applications

implement

Programming languages: Fortran, C/C++, ...

optimize
build
deploy

OpenMP
MPI

CPU platforms
Scientific computing
Leveraging hardware accelerators (HWAs)

Scientific applications

Programming languages: Fortran, C/C++, ...

implement
optimize
build
deploy

Hardware accelerators (HWAs)

GPU                        FPGA                        Xeon Phi                        APU

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Scientific computing
Leveraging hardware accelerators (HWAs)

Scientific applications

Programming languages: Fortran, C/C++, ...
implement
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GPU
FPGA
Xeon Phi
APU

Hardware accelerators (HWAs)
OpenCL: a standard for HPC

- Portable programming model (Khronos)
- Host code + kernels (compiled at runtime) executed on HWAs
OpenCL: a standard for HPC

Typical programming steps

- Query the platform
- Select the devices
- Create a context
- Create command queues
- Create buffer objects
- Transfer data to device
- Create/build programs
- Extract kernels
- Launch kernels (on the device, the most important step)
- Transfer results to host
- Release buffers, kernels and the context
OpenCL: a standard for HPC

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too verbose for scientific computing
OpenCL: a standard for HPC

Managing memory objects

- HWAs are evolving very quickly
- Different memory subsystems are emerging:
  - Integrated HWA sharing memory with the CPU
  - Software manipulations are needed to take advantage of new designs
  - Example: the AMD Accelerated Processing Unit (APU)
OpenCL: a standard for HPC
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  - Example: the AMD Accelerated Processing Unit (APU)

might be a tedious task for scientists
What is an APU?

CPU+discrete GPU

- CPU0
  - L1
  - WC
  - L2
- CPU_{n-1}
  - L1
  - WC
  - L2

Quad-core CPU module

- CPU0
  - L1
  - WC
  - L2
- CPU1
  - L1
  - WC
  - L2
- CPU2
  - L1
  - WC
  - L2
- CPU3
  - L1
  - WC
  - L2

UNB

GARLIC

Integrated GPU module

- CU0
  - Register file
  - PE
  - Local memory
  - TEX L1
- CU1
  - Register file
  - PE
  - Local memory
  - TEX L1
- CU_{N-1}
  - Register file
  - PE
  - Local memory
  - TEX L1

GPU main memory

- PCI Express Bus

CPU+discrete GPU

Accelerated Processing Unit (APU)

- System memory
What is an APU?

**Strengths**
1. No PCI Express bus
2. Integrated GPUs can address the entire memory
3. Low power processors (≈ 95 W TDP at most):
   - CPU ≈ 150 W TDP at most
   - GPU ≈ 250 W at most

**Weaknesses**
1. Low compute power as compared to GPUs:
   - APU up to 25 GB/s memory bandwidth
   - GPU ≈ 300 GB/s
2. Complex memory system:
   - explicit-copy
   - zero-copy

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Motivations and context

Quest for a tool that helps:

- Shortening the OpenCL host code
- Plugging HWAs code into legacy code (target: CPU, APU and GPU)
- Transparently manage memory objects on the different HWAs
- Programmers focus on optimizing kernels
- Spend less time on software engineering
- Spend more time on the domain of expertise
Outline

Related work

hiCL presentation

Reverse Time Migration on GPU and APU using hiCL

Conclusions and perspectives
Outline

Related work

hiCL presentation

Reverse Time Migration on GPU and APU using hiCL

Conclusions and perspectives
Related work

Quest for performance with less verbosity
Related work

Quest for performance with less verbosity
Related work

Quest for performance with less verbosity

SimpleOpenCL
cf4ocl
oclkit
Boost.Compute
VirtCL
fortrancl
Outline

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hiCL presentation

In a nutshell

hiCL

- Yet another OpenCL wrapper that eases scientific programming
- Abstracts the memory manipulation complexity on HWAs
- Features:
  - A simple C interface
  - C++ compatible (header guards)
  - A Fortran interface (ISO_C_BINDING Fortran 2003)
Example: matrix multiplication

```c
// allocate the matrices
float *a=(float*)malloc(N*N*sizeof(float));
float *b=(float*)malloc(N*N*sizeof(float));
float *c=(float*)malloc(N*N*sizeof(float));
// initialize matrices a, b and c
init(a, b, c);
...
...
...
...
...
// run the matrix multiplication c+=a*b
sgemm(a, b, c, N);
...
...
...
// delete matrices a, b, and c
free(a, b, c);
```
// allocate the matrices
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...
...
...
...
...
// run the matrix multiplication c+=a*b
hicl_run("sgemm", gpu1, a, b, c, N);
hicl_mem_update(c, READ_ONLY);
hicl_release();
...
// delete matrices a, b, and c
free(a, b, c);
### hiCL presentation

**Example: matrix multiplication**

<table>
<thead>
<tr>
<th></th>
<th>standalone OpenCL</th>
<th>with hiCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines of code ¹</td>
<td>525</td>
<td>280</td>
</tr>
<tr>
<td>Execution time ²</td>
<td>0.479 s</td>
<td>0.491 s</td>
</tr>
</tbody>
</table>

¹ Includes hiCL code and the kernel code
² N=4096, gpu1=AMD HD7970
**hiCL presentation**

**A simplified OpenCL compute model**

- Are exposed to the user:
  - OpenCL kernels
  - Selected OpenCL devices

- **hiCL base:**
  - Encompasses the typical OpenCL work-flow

- **hiCL agent:**
  - Lists of the used memory objects
  - Devices/Kernels/Memory interactions
Reducing the OpenCL verbosity

- **hicl_init(flags)**
  - Only one call to initialize the OpenCL environment
  - Only one context is supported
  - One or multiple devices can be selected depending on flags
  - Each device has a pre-defined number of command queues
  - flags determine the user choices
    - Default platform with default device: DEFAULT
    - Choose the vendor: NVIDIA, AMD, ...
    - Choose the device type: NVIDIA | GPU
    - Even more: NVIDIA | GPU | FIRST
    - Rule: what is not specified is default

- **hicl_release()**
  - Releases the OpenCL context
  - Automatically releases the registered memory objects and kernels

- **hicl_info()**
  - Returns informations about the selected OpenCL resources
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Loading kernels

- **hicl_load(file, options)**
  - Load ".cl" files, compile OpenCL programs, extract kernels
  - The hiCL agent register them for clean release afterwards
  - options are passed to the OpenCL compiler
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Data consistency

- \texttt{hicl\_mem\_wrap(hwa\_name, ptr, size, flags)}
  - \texttt{ptr} is a regular pointer allocated by the user
  - an OpenCL buffer is created and registered behind the curtains
    - the buffer is associated to \texttt{ptr}
  - \texttt{size} is the size of the buffer in number of elements
  - \texttt{flags} determine where and how the OpenCL objects are created
flags can combine:

<table>
<thead>
<tr>
<th>hiCL memory flags</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>allocate the data on the system main memory if not already allocated</td>
</tr>
<tr>
<td>HWA</td>
<td>allocate the data on the HWA memory and copy it from the CPU memory</td>
</tr>
<tr>
<td>ZERO_COPY</td>
<td>the data is shared between the CPU and the HWA</td>
</tr>
<tr>
<td>READ_ONLY</td>
<td>the data is read-only</td>
</tr>
<tr>
<td>WRITE_ONLY</td>
<td>the data is write-only</td>
</tr>
<tr>
<td>READ_WRITE</td>
<td>the data is read-write</td>
</tr>
<tr>
<td>FLOAT, DOUBLE, INT ...</td>
<td>determine the data type</td>
</tr>
</tbody>
</table>

DEFAULT = HWA | READ_WRITE | FLOAT
In order to ensure data consistence between the host and the HWA:

- \texttt{hicl\_mem\_update(ptr, flag)}
- Prior to altering any hiCL memory (positions a dirty bit)
- Keep track of the changes issued by the host on the data
- \texttt{flag} can be:
  - \texttt{READ\_ONLY}: the host reads only the data
  - \texttt{WRITE\_ONLY}: the host modifies the data
  - \texttt{READ\_WRITE}: the host reads and then modifies the data
- The dirty bit is positioned if the flag is \texttt{WRITE\_ONLY} or \texttt{READ\_WRITE}
- If the bit is already positioned the data is updated from the HWA
- **hicl_run**("kernel name", hwa_name, arg1, arg2, arg3 ...)  

  - Run "kernel name" on the device hwa_name  
  - C Variadic functions help passing arguments to the OpenCL kernels  
    - Not yet possible in the Fortran hiCL interface  
  - Related memory objects are:  
    - Automatically updated from the host if they are dirty  
    - Positioned dirty by the HWA if they are WRITE_ONLY or READ_WRITE
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Example: 3D finite difference stencil

// allocate the buffers
float *u=(float*)malloc(N*N*N*sizeof(float));
float *v=(float*)malloc(N*N*N*sizeof(float));

// initialize the buffer u
init(u);
...
...
...
...
...

// run the stencil 10 times
for(int i; i<10; i++)
    fd_stencil(u, v, N, i);
...
...

// perform a snapshot (save to disk)
snapshot(v)
...
...

// delete matrices u, v
free(u, v);
hiCL presentation
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// run the stencil 10 times
for(int i; i<10; i++)
    hicl_run("fd_stencil", gpu1, u, v, N, i);
...
...
// only here a HWA-CPU memory transfer takes place
hicl_mem_update(v, READ_ONLY);
// perform a snapshot (save to disk)
snapshot(v)

hicl_release();
...
...
// delete the buffers
free(u, v);
hiCL presentation

Example: 3D finite difference stencil

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<tr>
<td>Lines of code$^3$</td>
<td>638</td>
<td>328</td>
</tr>
<tr>
<td>Execution time$^4$</td>
<td>1.571 s</td>
<td>1.582 s</td>
</tr>
</tbody>
</table>

$^3$Includes hiCL code and the kernel code

$^4$320×320×320 with 100 iterations on an AMD HD7970 GPU
Use red-black trees to index:
- the hiCL memory objects by the memory addresses (pointers)
- the hiCL kernels by names
- the hiCL devices by cl_device_id

Enhance the memory objects and kernel lookups
Outline

Related work

hiCL presentation

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Conclusions and perspectives
Reverse Time Migration (RTM)

- The reference imaging algorithm in the Oil and Gas industry
- Repositions seismic events into their true location in the subsurface

- Sub-salt and steep dips imaging
- Accurate (two-way wave equation)
- Requires massive compute resources (compute and storage)
Implementing RTM using hiCL

- Use the 3D finite difference stencil kernel to solve the wave equation
- Use the **HWA** flag to run on the GPU and on the APU (explicit-copy)
- Use the **HWA | ZERO_COPY** flags to run on the APU (zero-copy)
- Use the hiCL Fortran interface (initial code is in Fortran)
Implementing RTM using hiCL

Performance results

- Run the same host code while changing the memory flags
- The APU is more efficient than the GPU:
  - Only for high frequencies of data retrieval ($K < 3$)
  - The zero-copy feature enhances the performance for $K < 3$
Outline

Related work

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Reverse Time Migration on GPU and APU using hiCL

Conclusions and perspectives
Conclusions and perspectives

Conclusions

- hiCL is a scientific programming friendly OpenCL wrapper
- Helps integrate OpenCL kernels into existing industrial codes
- Comes with C/C++ and Fortran interfaces
- Its main focus is to simplify the memory management
- Targets cutting-edge accelerators
- Release date (in few weeks on github):
  - for release announcement please subscribe on https://groups.google.com/d/forum/hicl

Perspectives

- Compliance with OpenCL 2.0
- Performance enhancement and overhead reduction
- Support Intel integrated GPU
- Support OpenCL images