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The Relevance of OpenCL to HPC

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Announced Abstract

Today's high performance computing **programs** are **evolving** to be **increasingly more parallel,** increasingly more **wait-free,** increasingly **deployed** on many different kinds of hardware including general purpose CPUs, GPGPUs, FPGAs, other custom specific-purpose hardware, etc. The OpenCL standards are platforms providing interfaces that enable deployment of programs to **virtually any heterogeneous computing device**. The OpenCL standard defines a **highly-vectorizable programming language,** OpenCL C, which enables the deployment of programming logic to arbitrary hardware without requiring low-level, "machine-coding" knowledge of such. The OpenCL standard is a **critical component of exascale initiatives** given that it is **hardware neutral**, with **significant support** and participation from all the **major processor vendors**. Unfortunately the main source of information about OpenCL is in the form of its final specifications so there is a lot of misinformation about it. This talk will explain the **relevance** of the OpenCL standard to the HPC community, and offer a **glimpse** into what high-level abstractions for OpenCL, under development by software engineers, might look like.

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Presentation Overview

1. HPC and OpenCL
2. The Relevance Of OpenCL To HPC
3. A Glimpse Into Possible High-Level Abstractions
4. The Future and Discussion
5. References

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What is HPC?

High Performance Computing (HPC) is the use of **parallel computation** to solve problems **efficiently** and **reliably**.

Some organizations and meta-organizations that **provide access to HPC resources and services** to researchers at academic institutions are:

- SHARCNET
- Compute Ontario (SciNET, HPCVL, and SHARCNET)
- Compute Canada (ACEnet, Calcul Québec, Compute Ontario, WestGrid)

What is OpenCL?

Open Computing Language (OpenCL):

- is **open** and **royalty-free** standard
- for use with CPUs, GPUs, and any other computational hardware
- provides **portable efficient heterogeneous hardware access** via a subset of ISO C99 (with parallel extensions)
- uses **programming abstractions** that **transparently** leverage SIMD and/or threading parallelism on the back-end
    - N.B. Through the Khronos Group, all hardware vendors decide on the abstractions used.
- inter-operates with **graphics APIs** (e.g., OpenGL)
- with **WebCL** can be used over the Internet (e.g., via a web browser)

[6, §1], [8, §1], [9, §1], [10, §1], [11, §1]

What is OpenCL? (con't)

OpenCL enables heterogeneous platform computations by enabling one to:

- **discover** the **computational hardware components** of a system,
- **query hardware characteristics** to select proper code and/or to exploit unique hardware features,
- **compile programs** and **extract functions** to run (i.e., “kernels”) and **asynchronously call those kernels** on the target hardware, and,
- **control the ordering** of kernel executions and **memory operations** on desired hardware components.

[12, §1.1]

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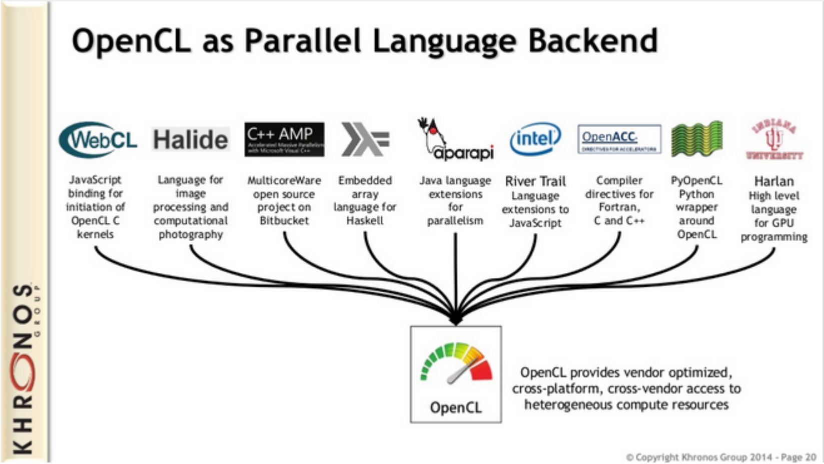
What is OpenCL? (con't)



[13, Slide 20]

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What is OpenCL C?

OpenCL C:

- is used to create **kernels** that are executed on OpenCL devices
- is a programming language **based on C99** (i.e., ISO/IEC 9899:1999)
  - only a **subset of C99** is supported
  - but, for example, adds **vector** types, **atomic** operations, some new types
  - **no recursion**, and **no function pointers**
  - restrictions on pointers, **no** struct bit-fields, many C Standard Library functions are **not** available,
- **memory consistency** model is **based on §7.17 in C11** (i.e., ISO/IEC 9899:2011)

[5, §6, §6.9, §6.13.11]

What is OpenCL C++? (NEW)

OpenCL C++:

- is currently a provisional specification
- is used to create **kernels** that are executed on OpenCL devices
- is a programming language **based on C++14**
  - N.B. The provisional spec cites ISO/IEC JTC1 SC22 WG21 N3690 —not ISO/IEC 14882:2015.
  - only a **subset of C++14** is supported
- C++14 features not supported are:
  - **`dynamic_cast`**, type identification, recursive function calls, **`new`** and **`delete`**, **`noexcept`**, **`goto`**, **`register`**, **`thread_local`**, **`virtual`**, function pointers, exception handling, C++ Standard Library
- Supports **templates** and **metaprogramming.**

[4, §1, §18]

What is SPIR?

Standard Portable Intermediate Representation (SPIR):

- is a **partially compiled, binary OpenCL interchange format**
  - i.e., it efficiently maps OpenCL C into LLVM IR [14]
- is **vendor-neutral** but is **not** OpenCL C source code
- is designed to be a **compiler target format** for programming languages
- is designed to **support vendor extensions**
- is designed to be **efficiently loaded** by an OpenCL implementation
- is an **extension** to the OpenCL standard

[7, §1]

What is SPIR-V? (NEW)

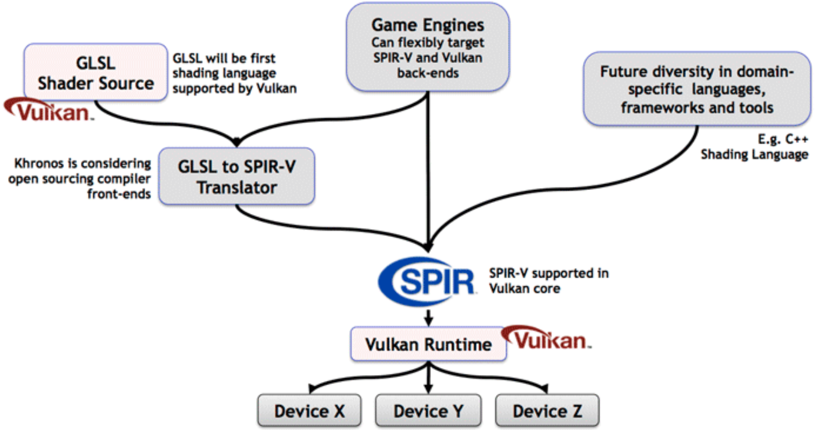
SPIR-V:

- is currently a provisional specification
- is an **intermediate language (IL)** for graphical shaders and compute kernels
- is **only** conceptually similar to SPIR in that it is an IR language
- is **distinct** from SPIR as it does **not** rely on or require the LLVM IR in any way

[2]

SPIR-V is a **“single, common language for multiple languages feeding multiple drivers.”** [1, p.2]

What is SPIR-V? (NEW) (con't)



[3, Slide from announcement]

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Why Does OpenCL Matter To Me?

OpenCL matters to **you** because your OpenCL programs:

- can be run on/across many **different devices** without re-designing, re-factoring, or re-writing it
- are **compiled** and **deployed** using **standard, non-proprietary** API calls, OpenCL C/C++, and/or SPIR/SPIR-V
- have the ability to **query** and **exploit device-specific abilities** while being able to remain non-proprietary

Why Does OpenCL Matter To HPC?

OpenCL matters to **HPC** because:

- **heterogeneous computing** is the future
  - traditional, exascale, big data, digital humanities, etc. have **different** kinds of computing hardware needs
- **power is very costly** —power savings is essential
  - e.g., OpenCL deploys to FPGAs —not just GPUs and CPUs
- **maximizing parallel performance is crucial**
  - OpenCL's C, C++, SPIR, and SPIR-V are **highly vectorizable**
- OpenCL enables programs to be able to be **deployed** on and still **exploit future hardware designs**
- OpenCL has **major traction and support with hardware vendors**

Programming With OpenCL

Each OpenCL standard should be seen as a **distinct release**.

Vendors will **release** OpenCL implementations **compliant** with **specific** OpenCL standards.

Newer standards are **not** necessarily better or worse —they are **different**.

Programming With OpenCL (con't)

In terms of deploying your OpenCL code on any devices:

- Think of OpenCL C as **very high-level, heterogeneous, portable, and human-readable "parallel assembly languages".**
- Think of SPIR and SPIR-V as **heterogeneous and portable machine codes.**

Programming With OpenCL (con't)

Beyond the near-term, an OpenCL user **does not** want to write **raw OpenCL code** when developing software.

- Using abstractions, libraries, middleware, and tools **will be preferred**.
- The latter is well-suited for computer scientists and software engineers.

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Example OpenCL C

Example courtesy of AJ Guillon.

```
__kernel sum(
  __global float* out,
  __global float* in1,
  __global float* in2,
  uint64_t length
)
{
  size_t idx = get_global_id(0);

  if (get_global_id(0) >= length)
    return;

  out[idx] = in1[idx] + in2[idx];
}
```

Possible C++ Host Code Example

Example courtesy of AJ Guillon.

```
// Get a collection of devices that support OpenCL
devices my_devices = get_devices();

// Compile a program for the devices
program my_program = compile("sum.cl");

// Extract the kernel we want
kernel sum = my_program.extract("sum");

// Allocate three arrays of values
auto x = allocate_vector<float>(100);
auto y = allocate_vector<float>(100);
auto z = allocate_vector<float>(100);
```

Possible C++ Host Code Example (con't)

```
// Read the values for x, and y
x = file.read("x");
y = file.read("y");

// Do z = x + y on the first device
sum.call(my_devices[0])(z, x, y, x.length() );

// Do y = x + x on the second device
sum.call(my_devices[1])(y, x, x, x.length() );

// Print out the results
std::cout << "Z: " << z << std::endl;

// Print out the results
std::cout << "Y: " << y << std::endl;
```

Possible OpenCL C++ Example

Example courtesy of AJ Guillon.

```
typedef compute_foo_strategy<
  conditional< numeric_limits<double>::supported() &&
               ! numeric_limits<double>::emulated() >,
  double,
  float>,
  hardware_traits::scalar_code_preferred()
  >
  compute_foo_type;


/* Now it is a simple matter to call foo */
long result = compute_foo_type::foo(x, y);
```

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The Future and Discussion

What is next for OpenCL and HPC?

Discussion and **Q&A** with guest: **AJ Guillon**

- AJ is a member of the Khronos OpenCL Standards Committee.

Thank You

Thank you.

References

[1] Khronos Group. *An Introduction to SPIR-V: A Khronos-Defined Intermediate Language for Native Representation of Graphical Shaders and Compute Kernels*. Ed. by J. Kessenich and LunarG. URL: `https://www.khronos.org/registry/spir-v/papers/WhitePaper.pdf` (visited on 03/03/2015) (cit. on p. 13).

[2] Khronos Group. *SPIR-V Specification (Provisional), Version 0.99*. Ed. by J. Kessenich, LunarG, and B. (Ouriel. Revision 29. URL: `https://www.khronos.org/registry/spir-v/specs/1.0/SPIRV.pdf` (visited on 03/03/2015) (cit. on p. 13).

[3] Khronos Group. *Vulkan - Graphics and compute belong together*. URL: `https://www.khronos.org/vulkan` (visited on 03/03/2015) (cit. on p. 14).

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[4] Khronos OpenCL Working Group. *The OpenCL C Specification, Version 1.0*. Ed. by A. Munshi. Revision 8. URL: https://www.khronos.org/registry/cl/specs/opencl-2.1-openclc++.pdf (visited on 03/03/2015) (cit. on p. 11).

[5] Khronos OpenCL Working Group. *The OpenCL C Specification, Version 2.0*. Ed. by A. Munshi. Revision 26. URL: https://www.khronos.org/registry/cl/specs/opencl-2.0-openclc.pdf (visited on 02/21/2015) (cit. on p. 10).

[6] Khronos OpenCL Working Group. *The OpenCL Specification, Version 1.0*. Ed. by A. Munshi. Revision 48. URL: https://www.khronos.org/registry/cl/specs/opencl-1.0.pdf (visited on 02/21/2015) (cit. on p. 7).

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[7] Khronos OpenCL Working Group. *The OpenCL Specification, Version 1.0*. Ed. by A. Munshi. Revision 48. URL: https://www.khronos.org/registry/cl/specs/opencl-1.0.pdf (visited on 02/21/2015) (cit. on p. 12).

[8] Khronos OpenCL Working Group. *The OpenCL Specification, Version 1.1*. Ed. by A. Munshi. Revision 44. URL: https://www.khronos.org/registry/cl/specs/opencl-1.1.pdf (visited on 02/21/2015) (cit. on p. 7).

[9] Khronos OpenCL Working Group. *The OpenCL Specification, Version 1.2*. Ed. by A. Munshi. Revision 19. URL: https://www.khronos.org/registry/cl/specs/opencl-1.2.pdf (visited on 02/21/2015) (cit. on p. 7).

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[10] Khronos OpenCL Working Group. *The OpenCL Specification, Version 2.0*. Ed. by L. Howes and A. Munshi. Revision 26. URL: https://www.khronos.org/registry/cl/specs/opencl-2.0.pdf (visited on 02/21/2015) (cit. on p. 7).

[11] Khronos OpenCL Working Group. *The OpenCL Specification, Version 2.1 (Provisional)*. Ed. by L. Howes and A. Munshi. Revision 8. URL: https://www.khronos.org/registry/cl/specs/opencl-2.1.pdf (visited on 03/03/2015) (cit. on p. 7).

[12] A. Munshi, B. R. Gaster, T. G. Mattson, J. Fung, and D. Ginsburg. *OpenCL Programming Guide*. Upper Saddle River, NJ: Addison-Wesley, 2012 (cit. on p. 8).

References (con't)

[13] N. Trevett. *What's Next in Graphics APIs - SIGGRAPH Asia*. 2014-02. URL: http://www.slideshare.net/NeilTrevett/whats-next-in-graphics-apis-siggraph-asia-dec14 (visited on 02/21/2015) (cit. on p. 9).

[14] University of Illinois. *The LLVM Compiler Infrastructure*. Ed. by C. Lattner. URL: http://llvm.org (visited on 02/21/2015) (cit. on p. 12).