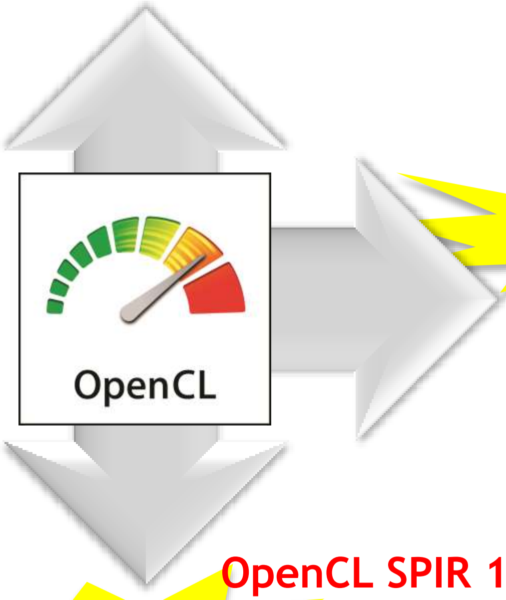
OpenCL BOF

SIGGRAPH 2013

OpenCL Roadmap

OpenCL-HLM (High Level Model)
High-level programming model, unifying host and device execution environments through language syntax for increased usability and broader optimization opportunities



OpenCL 2.0 Provisional released!

OpenCL 2.0
Significant enhancements to memory and execution models to expose emerging hardware capabilities and provide increased flexibility, functionality and performance to developers

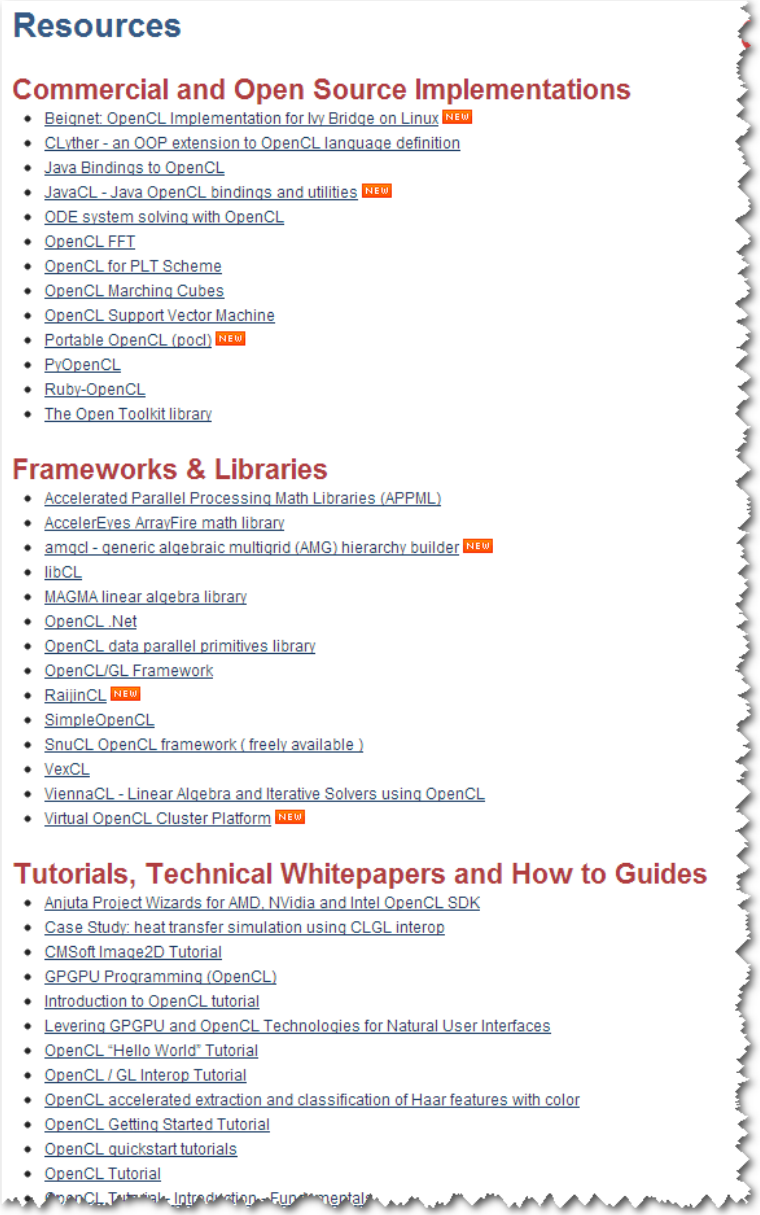
OpenCL SPIR 1.2 Provisional released!

OpenCL-SPIR (Standard Parallel Intermediate Representation)
Exploring LLVM-based, low-level Intermediate Representation for IP Protection and as target back-end for alternative high-level languages

OpenCL Ecosystem

- **Multiple conformant implementations shipping on desktop and mobile**
  - For CPUs and GPUs on multiple OS
- **Open Resources Area**
  - Community submitted resources
  - http://www.khronos.org/opencl/resources
- **OpenCL training courses available**

http://www.accelereyes.com/services/training



Resources

Commercial and Open Source Implementations

- Beignet: OpenCL Implementation for Ivy Bridge on Linux NEW
- CLyther - an OOP extension to OpenCL language definition
- Java Bindings to OpenCL
- JavaCL - Java OpenCL bindings and utilities NEW
- ODE system solving with OpenCL
- OpenCL FFT
- OpenCL for PLT Scheme
- OpenCL Marching Cubes
- OpenCL Support Vector Machine
- Portable OpenCL (pocl) NEW
- PyOpenCL
- Ruby-OpenCL
- The Open Toolkit library

Frameworks & Libraries

- Accelerated Parallel Processing Math Libraries (APPML)
- AccelerEyes ArrayFire math library
- amgcl - generic algebraic multigrid (AMG) hierarchy builder NEW
- libCL
- MAGMA linear algebra library
- OpenCL .Net
- OpenCL data parallel primitives library
- OpenCL/GL Framework
- RaijinCL NEW
- SimpleOpenCL
- SnuCL OpenCL framework (freely available)
- VexCL
- ViennaCL - Linear Algebra and Iterative Solvers using OpenCL
- Virtual OpenCL Cluster Platform NEW

Tutorials, Technical Whitepapers and How to Guides

- Anjuta Project Wizards for AMD, NVidia and Intel OpenCL SDK
- Case Study: heat transfer simulation using CLGL interop
- CMSoft Image2D Tutorial
- GPGPU Programming (OpenCL)
- Introduction to OpenCL tutorial
- Levering GPGPU and OpenCL Technologies for Natural User Interfaces
- OpenCL "Hello World" Tutorial
- OpenCL / GL Interop Tutorial
- OpenCL accelerated extraction and classification of Haar features with color
- OpenCL Getting Started Tutorial
- OpenCL quickstart tutorials
- OpenCL Tutorial
- OpenCL Tutorial- Introduction- Fundamentals

Mobile OpenCL Shipping

- **Android ICD extension released in latest extension specification**
  - OpenCL implementations can be discovered and loaded as a shared object
- **Multiple implementations shipping in Android NDK**
  - ARM, Imagination, Vivante, Qualcomm, Samsung …

VIVANTE

SAMSUNG

OpenCL as Parallel Compute Foundation

C++ AMP
Shevlin Park
Uses Clang and LLVM

OpenCL HLM
C++ syntax/compiler extensions

WebCL
JavaScript binding to OpenCL for initiation of OpenCL C kernels

Aparapi
Java language extensions for parallelism

River Trail
Language extensions to JavaScript

PyOpenCL
Python wrapper around OpenCL

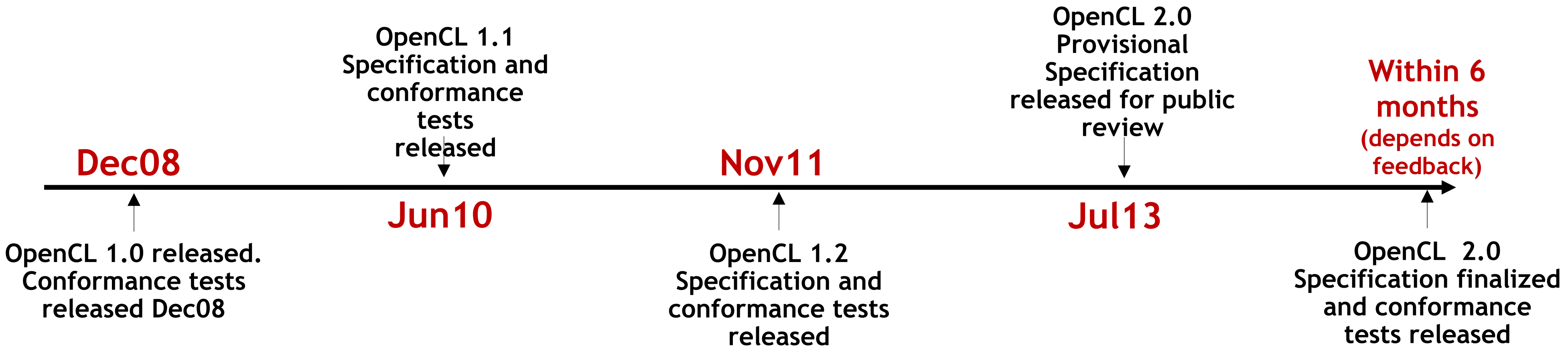
Harlan
High level language for GPU programming

OpenCL

OpenCL provides vendor optimized, cross-platform, cross-vendor access to heterogeneous compute resources

OpenCL Milestones

- **24 month cadence for major OpenCL 2.0 update**
  - Slightly longer than18 month cadence between versions of OpenCL 1.X
- **Provisional Specification enables public review**
  - Warning! The spec may change before final release!



Give us your Feedback on OpenCL 2.0!

- **Full OpenCL 2.0 Documentation available**
  - Provisional Specification
  - Reference Card
  - Online Reference pages
- **Forum and Bugzilla is open for comments**
  - OpenCL Registry contains all specifications
- **All feedback welcome!**
  - www.khronos.org/registry/cl/

The Rest of the BOF!

- **State-of-the-union of the OpenCL Ecosystem**
  - Neil Trevett, OpenCL Working Group Chair, NVIDIA
- **OpenCL 2.0 Overview**
  - Affie Munshi, OpenCL Chair
- **OpenCL SPIR 1.2**
  - Adam Lake, Intel
- **Intel and OpenCL**
  - Adam Lake, Intel
- **OpenCL on mobile demo**
  - Jay Yun, Qualcomm

OpenCL 2.0

Affie Munshi
OpenCL Specification Editor

Goals

- Enable New Programming Patterns
- Performance Improvements
- Well-defined Execution & Memory Model
- Improve CL / GL sharing

Shared Virtual Memory

- **In OpenCL 1.2 buffer objects can only be passed as kernel arguments**
- **Buffer object described as pointer to type in kernel**
- **Restrictions**
  - Pass a pointer + offset as argument value
  - Store pointers in buffer object(s)
- **Why?**
  - Host and OpenCL device may not share the same virtual address space
  - No guarantee that the same virtual address will be used for a kernel argument across multiple enqueues

Shared Virtual Memory

- **clSVMAlloc - allocates a shared virtual memory buffer**
  - Specify size in bytes
  - Specify usage information
  - Optional alignment value
- **SVM pointer can be shared by the host and OpenCL device**
- **Examples**

```
clSVMAlloc(ctx, CL_MEM_READ_WRITE, 1024 * 1024, 0)

clSVMAlloc(ctx, CL_MEM_READ_ONLY, 1024 * 1024, sizeof(cl_float4))
```

- **Free SVM buffers**
  - clEnqueueSVMFree, clSVMFree

Shared Virtual Memory

- clSetKernelArgSVMPointer
  - SVM pointers as kernel arguments
  - A SVM pointer
  - A SVM pointer + offset

```
kernel void
vec_add(float *src, float *dst)
{
    size_t id = get_global_id(0);
    dst[id] += src[id];
}
```

```
// allocating SVM pointers
cl_float *src = (cl_float *)clSVMAlloc(ctx, CL_MEM_READ_ONLY, size, 0);
cl_float *dst = (cl_float *)clSVMAlloc(ctx, CL_MEM_READ_WRITE, size, 0);

// Passing SVM pointers as arguments
clSetKernelArgSVMPointer(vec_add_kernel, 0, src);
clSetKernelArgSVMPointer(vec_add_kernel, 1, dst);

// Passing SVM pointer + offset as arguments
clSetKernelArgSVMPointer(vec_add_kernel, 0, src + offset);
clSetKernelArgSVMPointer(vec_add_kernel, 1, dst + offset);
```

Shared Virtual Memory

- clSetKernelExecInfo
  - Passing SVM pointers in other SVM pointers or buffer objects

```
// allocating SVM pointers
my_info_t *pA = (my_info_t *)clSVMAlloc(ctx,
          CL_MEM_READ_ONLY, sizeof(my_info_t), 0);
pA->pB = (cl_float *)clSVMAlloc(ctx,
          CL_MEM_READ_WRITE, size, 0);

// Passing SVM pointers
clSetKernelArgSVMPointer(my_kernel, 0, pA);

clSetKernelExecInfo(my_kernel,
                    CL_KERNEL_EXEC_INFO_SVM_PTRS,
                    1 * sizeof(void *), &pA->pB);
```

```
typedef struct {
  …
  float *pB;
  …
} my_info_t;

kernel void
my_kernel(global my_info_t *pA, …)
{
   …
   do_stuff(pA->pB, …);
   …
}
```

Shared Virtual Memory

- **Three types of sharing**
  - Coarse-grained buffer sharing
  - Fine-grained buffer sharing
  - System sharing

Shared Virtual Memory - Coarse & Fine Grained

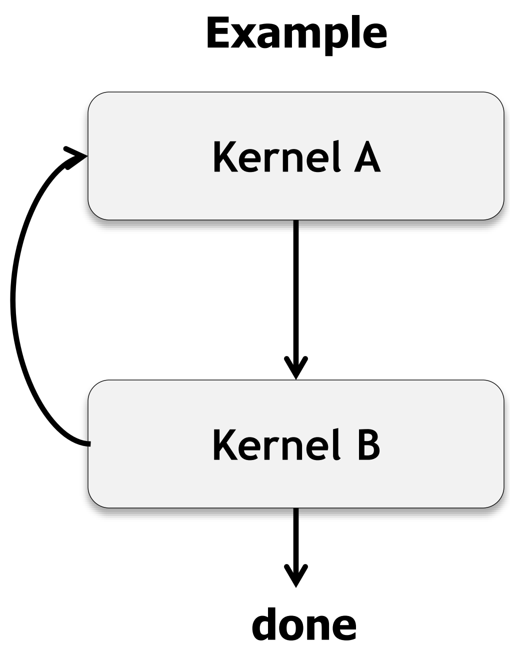
- **SVM buffers allocated using clSVMAlloc**
- **Coarse grained sharing**
  - Memory consistency only guaranteed at synchronization points
  - Host still needs to use synchronization APIs to update data
    - clEnqueueSVMMap / clEnqueueSVMUnmap or event callbacks
    - Memory consistency is at a buffer level
  - Allows sharing of pointers between host and OpenCL device
- **Fine grained sharing**
  - No synchronization needed between host and OpenCL device
    - Host and device can update data in buffer concurrently
    - Memory consistency using C11 atomics and synchronization operations
  - Optional Feature

Shared Virtual Memory - System Sharing

- **Can directly use any pointer allocated on the host**
  - No OpenCL APIs needed to allocate SVM buffers
- **Both host and OpenCL device can update data using C11 atomics and synchronization functions**
- **Optional Feature**

Dynamic Parallelism

- In OpenCL 1.2 only the host can enqueue kernels
- Iterative algorithm example
  - kernel A queues kernel B
  - kernel B decides to queue kernel A again
- Requires host - device interaction and for the host to wait for kernels to finish execution
  - Can use callbacks to avoid waiting for kernels to finish but still overhead
- A very simple but extremely common dynamic parallelism example



Dynamic Parallelism

- **Allow a device to queue kernels to itself**
  - Allow a work-item(s) to queue kernels
- **Use similar approach to how host queues commands**
  - Queues and Events
  - Functions that queue kernels and other commands
  - Event and Profiling functions

Dynamic Parallelism

- Use clang Blocks to describe kernel to queue

```
kernel void my_func(global int *a, global int *b)
{
    …
    void (^my_block_A)(void) =
            ^{
                size_t id = get_global_id(0);
                b[id] += a[id];
             };

  enqueue_kernel(get_default_queue(),
                 CLK_ENQUEUE_FLAGS_WAIT_KERNEL,
                 ndrange_1D(…),
                 my_block_A);
}
```

Dynamic Parallelism

```
int enqueue_kernel(queue_t queue,
                   kernel_enqueue_flags_t flags,
                   const ndrange_t ndrange,
                   void (^block)())

int enqueue_kernel(queue_t queue,
                   kernel_enqueue_flags_t flags,
                   const ndrange_t ndrange,
                   uint num_events_in_wait_list,
                   const clk_event_t *event_wait_list,
                   clk_event_t *event_ret,
                   void (^block)())
```

Dynamic Parallelism

- Queuing kernels with pointers to local address space as arguments

```
int enqueue_kernel(queue_t queue,
                   kernel_enqueue_flags_t flags,
                   const ndrange_t ndrange,
                   void (^block)(local void *, …), uint size0, …)

int enqueue_kernel(queue_t queue,
                   kernel_enqueue_flags_t flags,
                   const ndrange_t ndrange,
                   uint num_events_in_wait_list,
                   const clk_event_t *event_wait_list,
                   clk_event_t *event_ret,
                   void (^block)(local void *, …), uint size0, …)
```

Dynamic Parallelism

- Example showing queuing kernels with local address space arguments

```
void my_func_local_arg (global int *a, local int *lptr, …) { … }

kernel void my_func(global int *a, …)
{
    …
    uint local_mem_size = compute_local_mem_size(…);

    enqueue_kernel(get_default_queue(),
                   CLK_ENQUEUE_FLAGS_WAIT_KERNEL,
                   ndrange_1D(…),
                   ^(local int *p){my_func_local_arg(a, p, …);},
                   local_mem_size);
}
```

Dynamic Parallelism

- **Specify when a child kernel can begin execution**
  - Don't wait on parent
  - Wait for kernel to finish execution
  - Wait for work-group to finish execution
- **A kernel's execution status is complete**
  - when it has finished execution
  - all its child kernels have finished execution

Dynamic Parallelism

- **Other Commands**
  - Queue a marker
- **Query Functions**
  - Get workgroup size for a block
- **Event Functions**
  - Retain & Release events
  - Create user event
  - Set user event status
  - Capture event profiling info
- **Helper Functions**
  - Get default queue
  - Return a 1D, 2D or 3D ND-range descriptor

Generic Address Space

- In OpenCL 1.2, function arguments that are a pointer to a type must declare the address space of the memory region pointed to
- Many examples where developers want to use the same code but with pointers to different address spaces

```
void
my_func (local int *ptr, …)
{
    …
    foo(ptr, …);
    …
}
```

```
void
my_func (global int *ptr, …)
{
    …
    foo(ptr, …);
    …
}
```

- Above example is not supported in OpenCL 1.2
- Results in developers having to duplicate code

Generic Address Space

- OpenCL 2.0 no longer requires an address space qualifier for arguments to a function that are a pointer to a type
  - Except for kernel functions
- Generic address space assumed if no address space is specified
- Makes it really easy to write functions without having to worry about which address space arguments point to

```
void
my_func (int *ptr, …)
{
    …
}

kernel void
foo(global int *g_ptr, local int *l_ptr, …)
{
    …
    my_func(g_ptr, …);
    my_func(l_ptr, …);
}
```

Generic Address Space - Casting Rules

- Implicit casts allowed from named to generic address space
- Explicit casts allowed from generic to named address space
- Cannot cast between constant and generic address spaces

```
kernel void foo()
{
    int *ptr;
    local int *lptr;
    global int *gptr;
    local int val = 55;

    ptr = gptr; // legal
    lptr = ptr; // illegal
    lptr = gptr; // illegal
    ptr = &val; // legal
    lptr = (local int *)ptr; // legal
}
```

Generic Address Space - Built-in Functions

- **bool is_global(const void *)**
  bool is_local(const void *)
  bool is_private(const void *)
  - Returns true if pointer points to the global, local or private address space and false otherwise
- **cl_mem_fence_flags get_fence(const void *ptr)**
  - Returns the memory fence flag value
  - Needed by work_group_barrier and mem_fence functions

C11 Atomics

- **Implements a subset of the C11 atomic and synchronization operations**
  - Enable assignments in one work-item to be visible to others
- **Atomic operations**
  - loads & stores
  - exchange, compare & exchange
  - fetch and modify (add, sub, or, xor, and, min, max)
  - test and set, clear
- **Fence operation**
- **Atomic and Fence operations take**
  - Memory order
  - Memory scope
- **Operations are supported for global and local memory**

C11 Atomics

- **memory_order_relaxed**
  - Atomic operations with this memory order are not synchronization operations
  - Only guarantee atomicity
- **memory_order_acquire, memory_order_release, memory_order_acq_rel**
  - Atomic store in work-item A for variable M is tagged with memory_order_release
  - Atomic load in work-item B for same variable M is tagged with memory_order_acquire
  - Once the atomic load is completed work-item B is guaranteed to see everything work-item A wrote to memory before atomic store
  - Synchronization is only guaranteed between work-items releasing and acquiring the same atomic variable
- **memory_order_seq_cst**
  - Same as memory_order_acq_rel, and
  - A single total order exists in which all work-items observe all modifications

C11 Atomics

- **Memory scope - specifies scope of memory ordering constraints**
  - Work-items in a work-group
  - Work-items of a kernel executing on a device
  - Work-items of a kernel & host threads executing across devices and host
    - For shared virtual memory

C11 Atomics

- Supported Atomic Types
  - atomic_int, atomic_uint
  - atomic_long, atomic_ulong
  - atomic_float
  - atomic_double
  - atomic_intptr_t, atomic_uintptr_t, atomic_ptrdiff_t
  - atomic_size_t
  - atomic_flag
- Atomic types have the same size & representation as the non-atomic types except for atomic_flag
- Atomic functions must be lock-free

Images

- **2D image from buffer**
  - GPUs have dedicated and fast hardware for texture addressing & filtering
  - Accessing a buffer as a 2D image allows us to use this hardware
  - Both buffer and 2D image use the same data storage
- **Reading & writing to an image in a kernel**
  - Declare images with the read_write qualifier
  - Use barrier between writes and reads by work-items to the image
    - work_group_barrier(CLK_IMAGE_MEM_FENCE)
  - Only sampler-less reads are supported

Images

- **Writes to 3D images is now a core feature**
- **New image formats**
  - sRGB
  - Depth
- **Extended list of required image formats**
- **Improvements to CL / GL sharing**
  - Multi-sampled GL textures
  - Mip-mapped GL textures

Pipes

- Memory objects that store data organized as a FIFO
- Kernels can read from or write to a pipe object
- Host can only create pipe objects

Pipes

- **Why introduce a pipe object?**
  - Allow vendors to implement dedicated hardware to support pipes
  - Read from and write to a pipe without requiring atomic operations to global memory
  - Enable producer – consumer relationships between kernels

Pipes - Read & Write Functions

- **Work-item read pipe functions**
  - Read a packet from a pipe
  - Read with reservation
    - Reserve n packets for reading
    - Read individual packets (identified by reservation ID and packet index)
    - Confirm that the reserved packets have been read
- **Work-item write pipe functions**
  - Write a packet to a pipe
  - Write with reservation
- **Work-group pipe functions**
  - Reserve and commit packets for reading / writing

Other 2.0 Features

- Program scope variables
- Flexible work-groups
- New work-item functions
  - get_global_linear_id, get_local_linear_id
- Work-group functions
  - broadcast, reduction, vote (any & all), prefix sum
- Sub-groups
- Sharing with EGL images and events