OpenCL
A Super(ficial) Introduction

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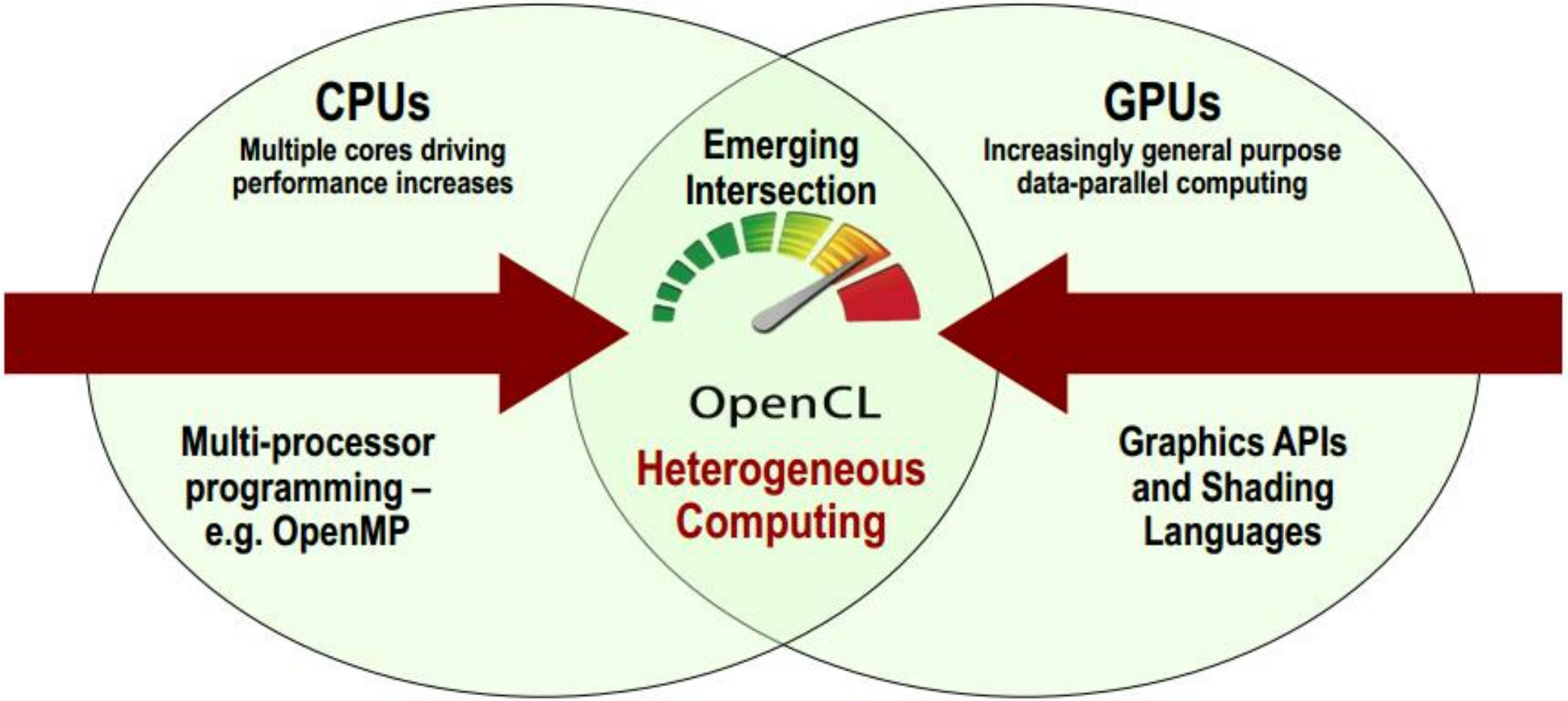
Preliminaries – Disclosures

- The views expressed in this tutorial are those of the people delivering the tutorial.
- We are not speaking for our employers.
- We are not speaking for Khronos.

Agenda

- **Introduction**
- Importance
- Current Support State
- Building OpenCL
- Running OpenCL
- Debugging OpenCL
- OpenCL Performance
- A Look Into the Future

Motivation


CPUs
Multiple cores driving performance increases
Emerging Intersection
GPUs
Increasingly general purpose data-parallel computing
OpenCL
Heterogeneous Computing
Multi-processor programming – e.g. OpenMP
Graphics APIs and Shading Languages

History

- Thus in 2008 OpenCL appeared as the “brainchild” of several tech corporations
- It is developed by the Khronos Group*
- Releases:
  - OpenCL 1.0 – 2008
  - OpenCL 1.1 – 2010
  - OpenCL 1.2 – 2011
  - OpenCL 2.0 – 2013

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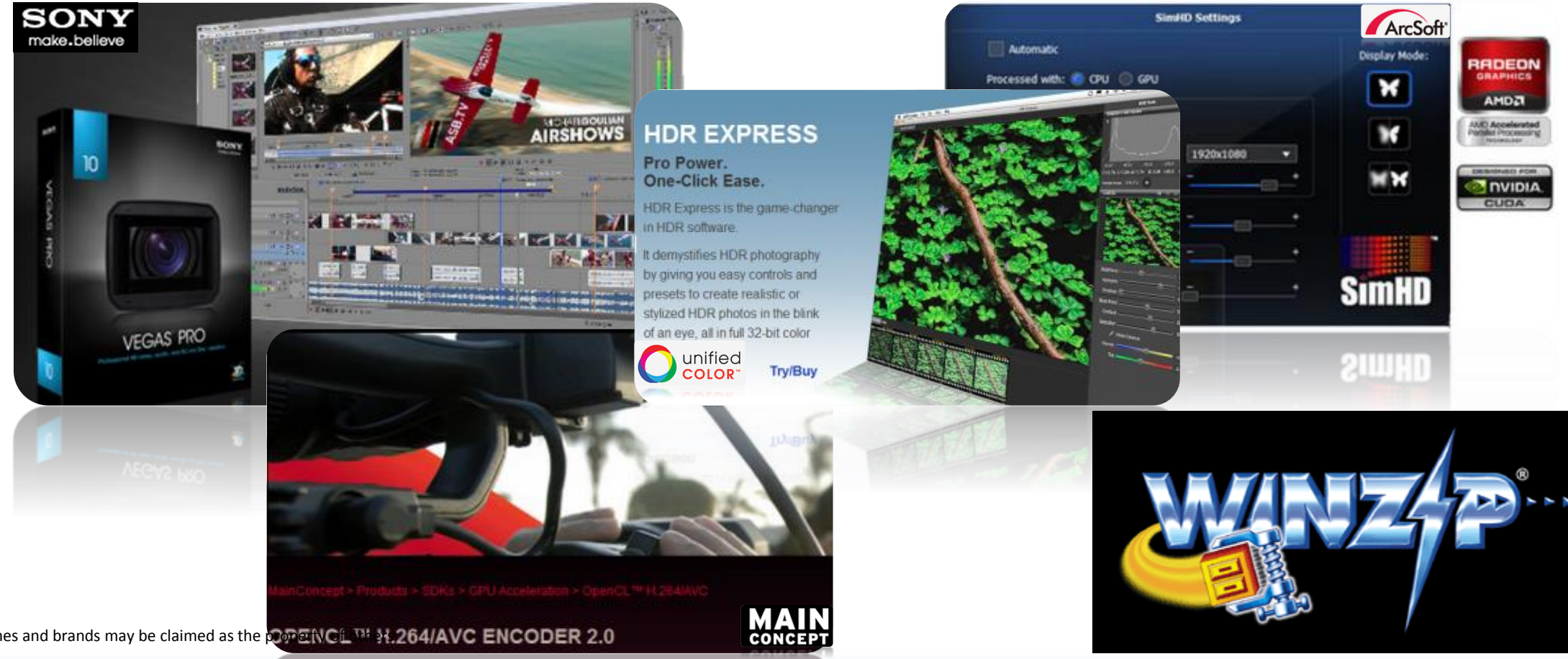
Enabling Heterogeneous Computing

- Advantages of using OpenCL
  - It’s free!
  - Portable language
  - Continuous development
  - Works with OpenGL
  - Can be used on embedded platforms as well as in Web applications
  - Both open source and proprietary implementations
- Disadvantages
  - Not as mature as other technologies
  - Hard to get top performance on all platforms

Usages – Client – Video/Image Encoding



*Other names and brands may be claimed as the property of others.

Usages – Computer Aided Engineering

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Usages – HPC

- Medical imaging
- Weather forecasting
- Molecular modeling
- Cryptanalysis
- Bitcoin mining

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Operating Systems

- OpenCL is supported by most modern operating systems
  - Microsoft Windows
  - Linux
  - Mac OS/OS X
  - Chrome OS
  - Tizen
  - Near Future: Android

Hardware

- All major hardware vendors support OpenCL
  - Intel
  - AMD/ATI
  - NVIDIA
  - QUALCOMM
  - ARM
  - Texas Instruments
  - Imagination Technologies
  - IBM

Virtualization and Other Software

- OpenCL can run in virtual and distributed environments, making it an important asset for GPGPU computing in the cloud
- Virtual solutions that can run OpenCL are supported by VMware and MOSIX (Virtual OpenCL)

- OpenCL support can be compiled into other frameworks such as OpenCV or Intel Integrated Performance Primitives (IPP)

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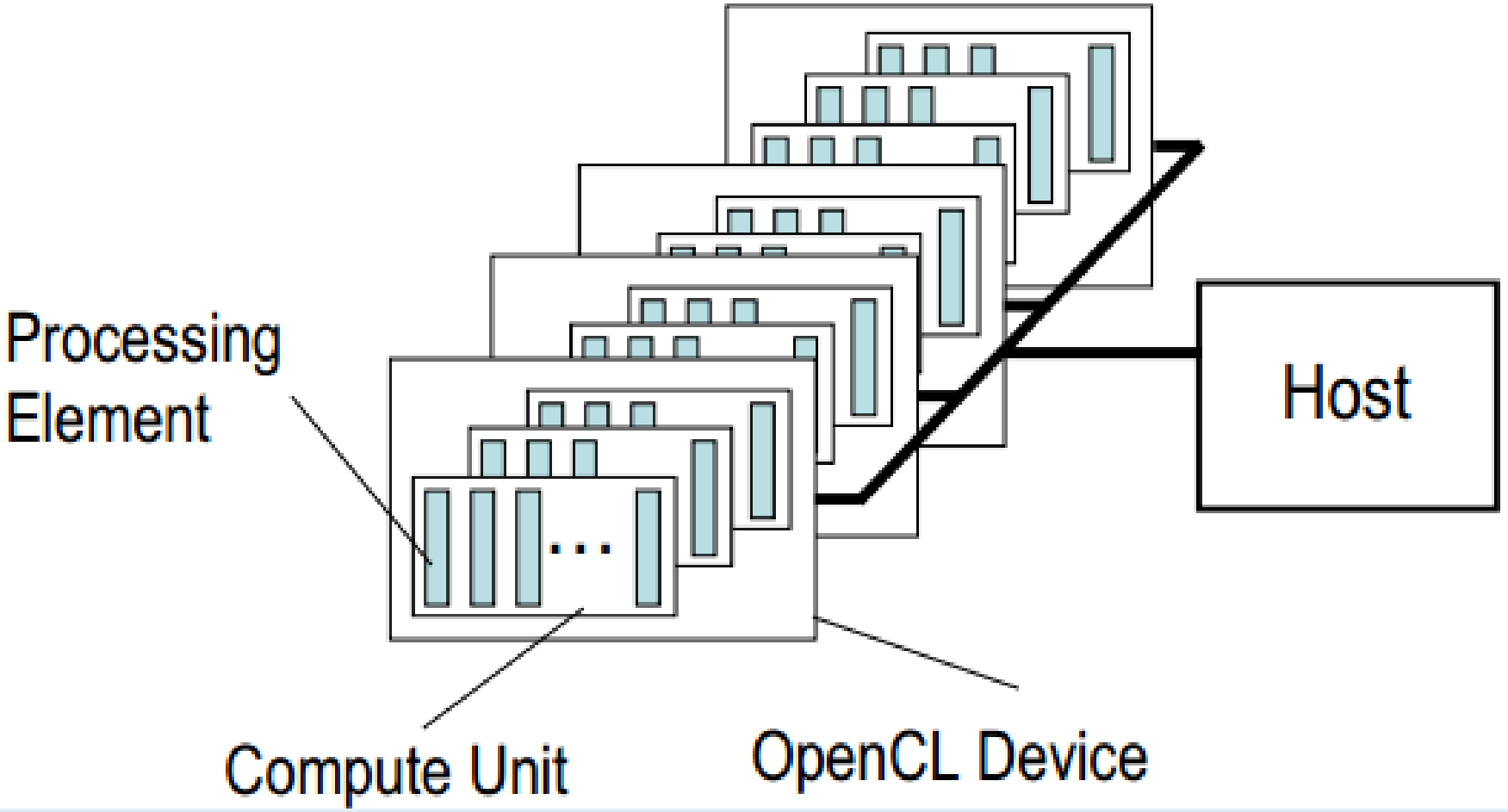
OpenCL Platform Model

- An OpenCL application is composed of **Host** and **Device** code
- Host code sets-up the OpenCL environment and selects the hardware on which the application will run as well as its parameters – extensions, optimizations, synchronization, etc.
- Host code support is implemented in C, but has bindings in other languages such as C++, Java, C#, Python
- Device code or kernel code runs on the computing end of the machine and it’s very similar to a C99 function

OpenCL Platform Abstraction



Building an OpenCL “Hello World”

```
const char *msg = "Hello World!";
// Get Platform Object
clGetPlatformIDs(1, &platform, NULL);
// Get Device Object
clGetDeviceIDs(platform, CL_DEVICE_TYPE_CPU, 1, &device, NULL);
// Create OpenCL Context
context = clCreateContext(NULL, 1, &device, NULL, NULL, NULL);
// Create OpenCL Program
program = clCreateProgram(context, 1, &kernel_code, NULL, NULL);
// Build Program
clBuildProgram(program, 1, &device, NULL, NULL, NULL);
// Get Kernel Reference
kernel = clCreateKernel(program, "hello_world", NULL);
// Create Command Queue
queue = clCreateCommandQueue(context, device, 0, NULL);
// Create Memory Object
memobj = clCreateBuffer(context, CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR,
strlen(msg) + 1, msg, NULL);
// Set Kernel Argument
clSetKernelArg(kernel, 0, sizeof(memobj), (void*)&memobj);
// Schedule the Kernel for Execution
clEnqueueNDRangeKernel(queue, kernel, 1, NULL, {4, 0, 0}, NULL, 0, NULL,
NULL);
__kernel void hello_world(__global char *msg) {
      int global_id = get_global_id(0);
      printf("%s from %d!\n", msg, global_id);
}
```

Platforms and Devices

- Platform is a synonym for vendor OpenCL implementation. You can have multiple corresponding to a single hardware device (ex: multiple OpenCL drivers installed)
- Each platform has 1 or more devices. Devices are handles for the underlying hardware (CPU, GPU, etc.)
- Device type is important when compiling OpenCL kernel code
- Programs can be created from source or loaded as precompiled binary. They can contain 1 or more kernels and auxiliary functions

Context

- Contexts are used to define the kernel execution environment:
  - Memory management
  - OpenCL object scope (ex: events, kernel objects, queues, programs, etc.)
- Contexts can be made to include one or more devices (especially useful for hybrid implementations)
- With OpenCL 1.2, contexts can partition devices using **clCreateSubDevices**
- For managing objects, OpenCL uses a reference counting model with **clRetain…** and **clRelease…** functions

Command Queues

- Queues are used to submit commands to the device:
  - Memory operations
  - Kernel execution
  - Synchronization: waiting for events, barriers
- They support in-order and out-of order execution
- Each command queue points to a single device within a context, but a context can have many command queues and a device can be used by multiple queues
- Command queues are vital when it comes to synchronization
- Command queue functions will start with **clEnqueue…**

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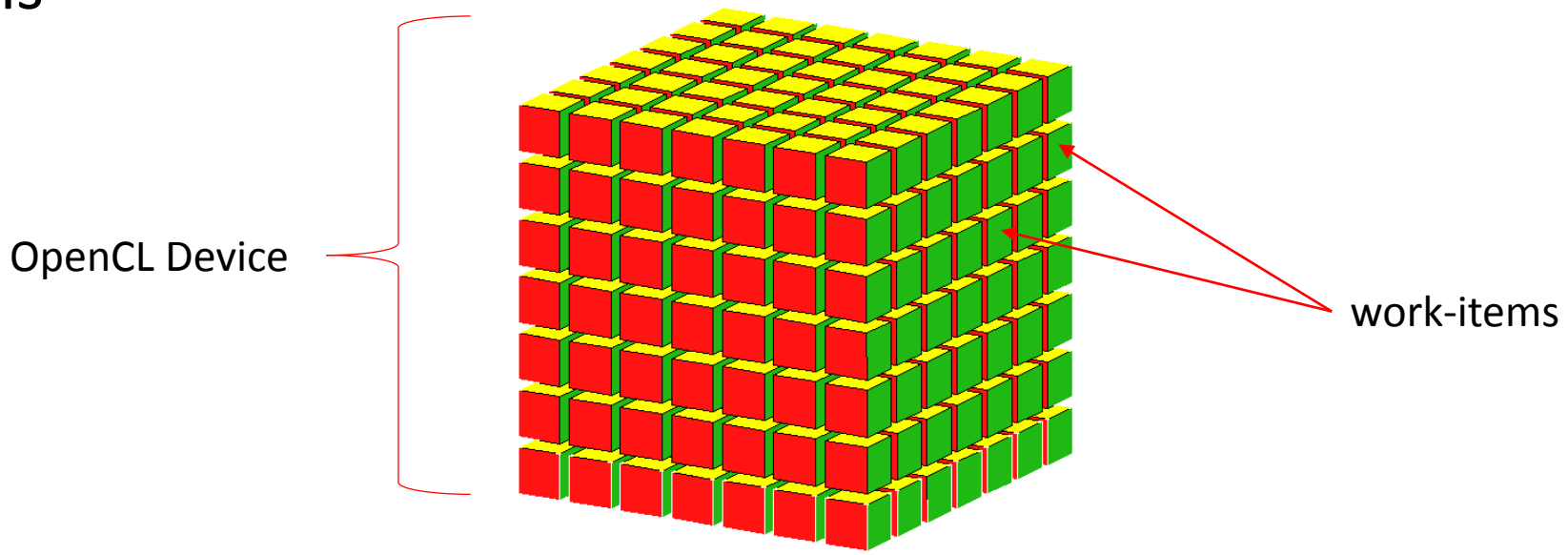
Work-Items

- Work-items are an abstraction used for device compute-cores
- The kernels is a piece of code designed to run in parallel on a group of work-items



clEnqueueNDRangeKernel

- cl_command_queue **command_queue**,
- cl_kernel **kernel**,
- cl_uint **work_dim**,
- const size_t ***global_work_offset**,
- const size_t ***global_work_size**,
- const size_t ***local_work_size**,
- cl_uint **num_events_in_wait_list**,
- const cl_event ***event_wait_list**,
- cl_event ***event**

Kernel Execution

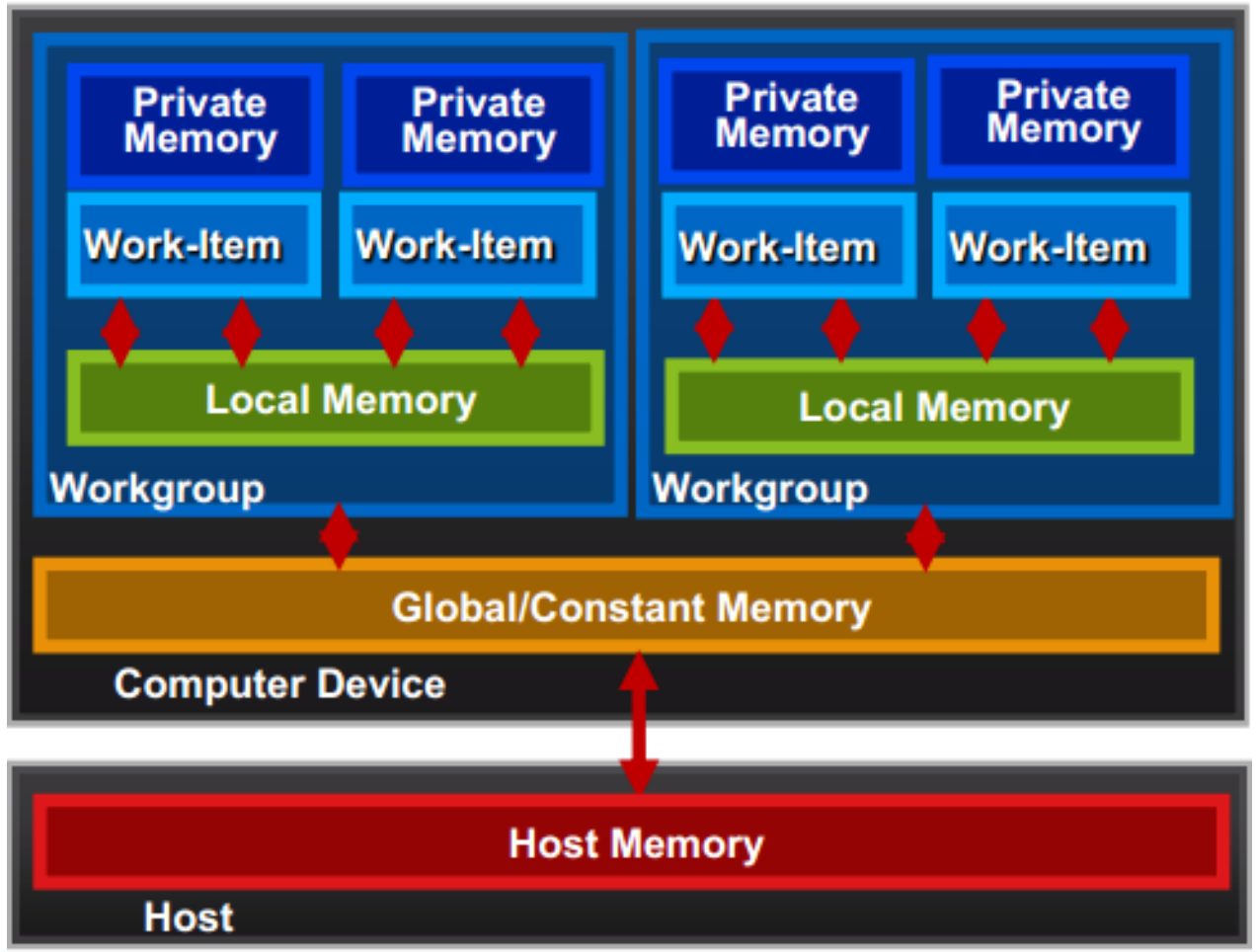
- Kernel functions are designed to replace and parallelize loops in serial programs
- The programmer can set the dimension of the problem when he/she queues the kernel for execution
- Besides the original layout (**global work size**), kernels can be grouped in smaller units called **local work groups**
- Kernel functions have some special API not part of standard C:
  - get_global_id, get_local_id, get_global_size, get_work_dim, get_local_size, get_num_groups, get_group_id

OpenCL C99

- The following section lists most of the differences between C standard and __kernel functions
  - Recursion is not supported
  - Built-in data types: vectors, half floats
  - Built-in mathematical and image processing functions
  - Built-in kernels
  - Cannot dynamically allocate memory inside a kernel – no malloc/free (has to be done from host code)
  - Synchronization functions
  - No function pointers
  - No bit fields and variable size arrays/structures

Kernel Memory Model

- Relaxed consistency
- Memory transfers can take up most of the time



Optimal Execution Model

- A big challenge for anyone writing portable applications for OpenCL is getting the maximum performance on all platforms
- Things to take into consideration when writing portable code:
  - Problem size vs. global/local work sizes
  - Memory transfers between host and device:
    - Bandwidth
    - Unified memory access
  - Platform support – using CPU instead of GPU
  - Device extensions: dx/gl sharing, kernel atomic operations
- Useful information can be obtained using **clGetDeviceInfo**

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Host Code

- Host code can be debugged using regular debuggers
- User can get program build information using **clGetProgramBuildInfo**
- Popular IDEs have plug-ins to support OpenCL developers:
  - Visual Studio
  - Eclipse
  - NetBeans

Printf

- “The best debugging tools are your intuition and printf” (where supported)
- Printf output is flushed after the kernel invocation – there is no synchronization with respect to work-item order
- Differences from normal printf:
  - Vector printing
  - Does not return the number of characters printed (returns 0 on success)
  - “%s” can only be used for literal strings

OpenCL Debuggers

- gDEBugger/AMD CodeXL
  - Real time OpenCL and OpenGL API level debugging
  - Static kernel analysis
    - Build messages
  - Online OpenCL kernel debugging
    - Object vizualization
  - Works on both Linux and Windows
  - GPU profiling
- Intel® SDK for OpenCL Applications - Kernel Builder
  - Syntax checker
  - Cross hardware compilation support
  - Assembly language view
  - Can run kernel code on a device without user having to write host code

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OpenCL Profiling

- Users can attach events to queued commands
- Command queues have be created with CL_QUEUE_PROFILING_ENABLE flag set
- These events can later be interrogated via **clGetEventProfilingInfo**:
  - Queue time (CL_PROFILING_COMMAND_QUEUED)
  - Submit time (CL_PROFILING_COMMAND_SUBMIT)
  - Start (CL_PROFILING_COMMAND_START)
  - Stop (CL_PROFILING_COMMAND_END)
- Devices running OpenCL programs can be profiled using profiling software such as VTune

OpenCL vs. CUDA

- OpenCL is more recent than CUDA but already has support from all major vendors
- CUDA only works on Nvidia
- OpenCL performance may vary across vendor implementations, whereas CUDA tends to be more uniform
- CUDA benefits from better debugging and profiling tools
- Performance comparisons between the 2 APIs usually comes down to hardware and driver performance rather then implementation (there is no neutral ground)

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OpenCL 2.0

- In late 2013 OpenCL 2.0 appeared and brought a new dimension to heterogeneous computing
- Important features include:
  - Shared virtual memory
  - Nested parallelism
  - Generic address space
  - Improved image support
  - C11 atomics for inter-work-item synchronization
  - Android support – enables OpenCL libraries to be discovered and loaded in Android
  - Pipes for kernels
  - Industry support – growing enthusiasm and adoption rate based on passed successes

Vision

- OpenCL drives progress in areas such as Perceptual Computing and Augmented Reality
- Mobile support can enable faster data processing algorithms to be implemented at a reduced cost
- OpenCL has been included in Cloud technologies by Amazon and Adobe and this tendency is likely to grows
- Hybrid implementations can tackle a wider range of problems, surpassing GPGPUs and CPU-offload programs in performance and efficiency

Conclusions

- The “Age of OpenCL” is just beginning
- OpenCL has the potential to bring a new dimension in the field of computing as s whole rather than just HPC or GPGPU
- Samples and documentation is freely available making the initial learning curve less steep
- Continuous development and integration with other APIs will ensure even greater success in the future

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