CUDA Parallel Programming Tutorial

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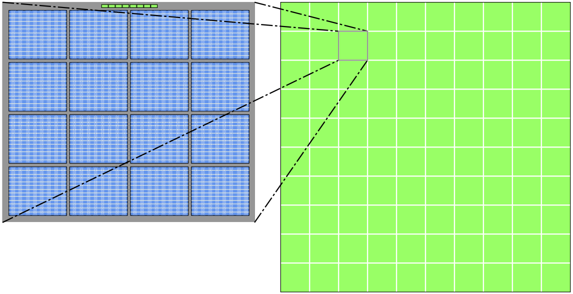
Outline

- Tasks for CUDA
- CUDA programming model
- Getting started
- Example codes

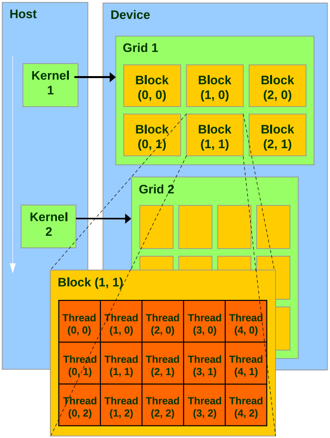
Tasks for CUDA

- Provide ability to run code on GPU
- Manage resources
- Partition data to fit on cores
- Schedule blocks to cores



Data Partitioning

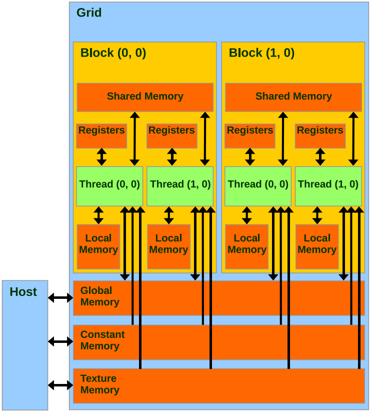
- Partition data in smaller blocks that can be processed by one core
- Up to 512 threads in one block
- All blocks define the grid
- All blocks execute same program (kernel)
- Independent blocks
- Only ONE kernel at a time



Memory Hierarchy

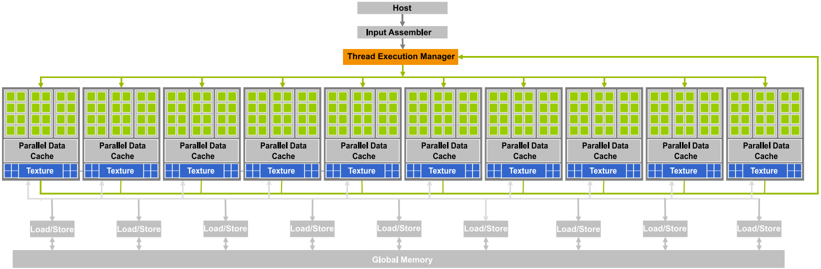
Memory types (fastest memory first):

- Registers
- Shared memory
- Device memory (texture, constant, local, global)



Tesla Architecture

- 30 cores, 240 ALUs (1 mul-add)
- (1 mul-add + 1 mul): 240 * (2+1) * 1.3 GHz = 936 GFLOPS
- 4.0 GB GDDR3, 102 GB/s Mem BW, 4GB/s PCIe BW to CPU



CUDA: Extended C

- Function qualifiers
- Variable qualifiers
- Built-in keywords
- Intrinsics
- Function calls

Function Qualifiers

- Functions: __device__, __global__, __host__

```
__global__ void filter(int *in, int *out) {
    ...
}
```

  - Default: __host__
  - No function pointers
  - No recursion
  - No static variables
  - No variable number of arguments
  - No return value

Variable Qualifiers

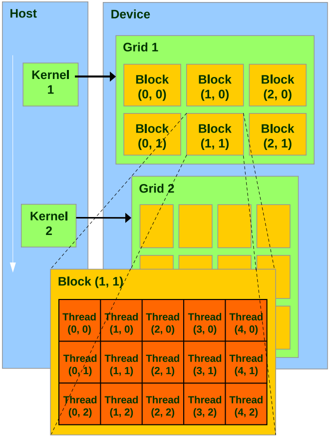
- Variables: __device__, __constant__, __shared__

```
__constant__ float matrix[10] = {1.0f, ...};
__shared__ int [32][2];
```

- Default: Variables reside in registers

Built-In Variables

- Available inside of kernel code
- Thread index within current block:
  `threadIdx.x` , **`threadIdx.y`** ,
  `threadIdx.z`
- Block index within grid:
  `blockIdx.x` , **`blockIdx.y`**
- Dimension of grid, block:
  `gridDim.x` , **`gridDim.y`**
  `blockDim.x` , **`blockDim.y`** ,
  `blockDim.z`
- Warp size: **`warpSize`**



Intrinsics

- `void __syncthreads();`
- Synchronizes in all thread of current block
- Use in conditional code may lead to deadlocks
- Intrinsics for most mathematical functions exists, e.g.

  `__sinf(x), __cosf(x), __expf(x), ...`
- Texture functions

Function Calls

- Launch parameters:
  - Grid dimension (up to 2D)
  - Block dimension (up to 3D)
  - Optional: stream ID
  - Optional: shared memory size
  - `kernel<<<grid, block, stream, shared_mem>>>();`

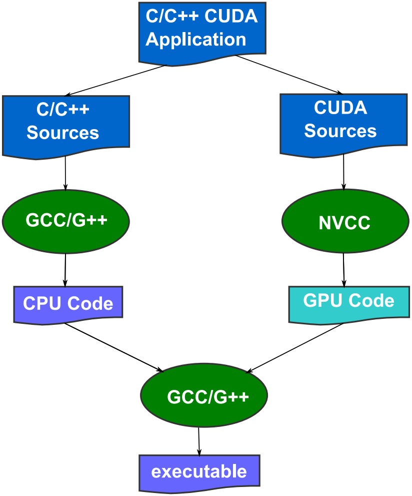
```
__global__ void filter(int *in, int *out);
...
dim3 grid(16, 16);
dim3 block(16, 16);
filter <<< grid, block, 0, 0 >>> (in, out);
filter <<< grid, block >>> (in, out);
```

Getting Started

- Compiler path
- Sample Makefile
- Debugging
- Memory management
- Time measurement

Compiler Path

- gcc/g++ compiler for host code
- nvcc compiler for device code
- gcc/g++ for linking
- icc/icpc works as well



Simple Project Makefile

- Use different files for host and device code
- Compile device/host code with nvcc
- Compile additional code with gcc
- Adjust Makefile from SDK:

```
# Add source files here
EXECUTABLE  := vector_add
# CUDA source files (compiled with cudacc)
CUFILES     := vector_add_host.cu
# CUDA dependency files
CU_DEPS     := \
    vector_add_device.cu \
    defines.h

# C/C++ source files (compiled with gcc / c++)
CCFILES     := \
    vector_add_cpu.cpp

#set directory for common.mk
CUDA_SDK_PATH       ?= /opt/cuda/sdk
ROOTDIR             := $(CUDA_SDK_PATH)/projects
ROOTBINDIR          := bin
ROOTOBJDIR          := obj
include $(CUDA_SDK_PATH)/common/common.mk
```

Building the Program

Makefile offers different options:

- Production mode: make
- Debug mode: make dbg=1
- Emulation mode: make emu=1
- Debug+Emulation mode: make dbg=1 emu=1

Debugging

SDK offers wrappers for function calls:

- For CUDA function calls: `cutilSafeCall(function);`
- For kernel launches (calls internally cudaThreadSynchronize()): `cutilCheckMsg(function);`
- For SDK functions: `cutilCheckError(function);`

Additional tools (recommended):

- CudaVisualProfiler
- valgrind – in emulation mode only, there is no MMU on the GPU!
- gdb – in emulation mode: `#ifdef __DEVICE_EMULATION__`
- real (!) gdb support, for GNU Linux – unfortunately 32bit only :(

Memory Management

- Host manages GPU memory
  - `cudaMalloc(void **pointer, size_t size);`
  - `cudaMemset(void *pointer, int value, size_t count);`
  - `cudaFree(void *pointer);`
- Memcopy for GPU:
  - `cudaMemcpy(void *dst, void *src, size_t size, cudaMemcpyKind direction`
- cudaMemcpyKind:
  - cudaMemcpyHostToDevice
  - cudaMemcpyDeviceToHost
  - cudaMemcpyDeviceToDevice

Time Measurement

- Initialization biases execution time
- Don't measure first kernel launch!
- SDK provides timer:

```
int timer=0;
cutCreateTimer(&timer);
cutStartTimer(timer);
...
cutStopTimer(timer);
cutGetTimerValue(timer);
cutDeleteTimer(timer);
```

- Use events for asynchronous functions:

```
cudaEvent_t start_event, stop_event;
cutilSafeCall(cudaEventCreate(&start_event));
cutilSafeCall(cudaEventCreate(&stop_event));
cudaEventRecord(start_event, 0);    // record in stream-0, to ensure that all
     previous CUDA calls have completed
...
cudaEventRecord(stop_event, 0);
cudaEventSynchronize(stop_event);   // block until the event is actually
     recorded
cudaEventElapsedTime(&time_memcpy, start_event, stop_event);
```

Example

Vector addition:

- CPU Implementation
- Host code
- Device code

Vector Addition - CPU Implementation

```
void vector_add(float *iA, float *iB, float* oC, int width) {
    int i;

    for (i=0; i<width; i++) {
        oC[i] = iA[i] + iB[i];
    }
}
```

Vector Addition - GPU Initialization

```
// include CUDA and SDK headers - CUDA 2.1
#include <cutil_inline.h>
// include CUDA and SDK headers - CUDA 2.0
#include <cuda.h>
#include <cutil.h>
// include kernels
#include "vector_add_kernel.cu"

int main( int argc, char** argv) {
    int dev;

    // CUDA 2.1
    dev = cutGetMaxGflopsDeviceId();
    cudaSetDevice(dev);

    // CUDA 2.0
    CUT_DEVICE_INIT(argc, argv);
}
```

Vector Addition - Memory Management

```
// allocate device memory
int *device_idata_A, *device_idata_B, *device_odata_C;
cudaMalloc((void**) &device_idata_A, mem_size);
cudaMalloc((void**) &device_idata_B, mem_size);
cudaMalloc((void**) &device_odata_C, mem_size);

// copy host memory to device
cudaMemcpy(device_idata_A, host_idata_A, mem_size,
    cudaMemcpyHostToDevice);
cudaMemcpy(device_idata_B, host_idata_B, mem_size,
    cudaMemcpyHostToDevice);
...

// copy result from device to host
cudaMemcpy(host_odata_C, device_odata_C, mem_size,
    cudaMemcpyDeviceToHost);

// free memory
cudaFree(device_idata_A);
cudaFree(device_idata_B);
cudaFree(device_odata_C);
```

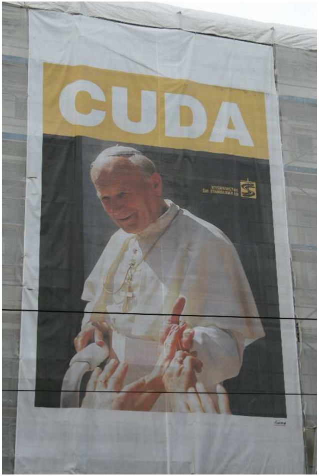
Vector Addition - Launch Kernel

```
// setup execution parameters
dim3 grid(1, 1);
dim3 threads(num_elements, 1);

// execute the kernel
vec_add<<< grid, threads >>>(device_idata_A, device_idata_B,
    device_odata_C);
cudaThreadSynchronize();
```

Vector Addition - Kernel Function

```
__global__ void vector_add(float *iA, float *iB, float* oC) {
    int idx = threadIdx.x + blockDim.x * blockId.x;

    oC[idx] = iA[idx] + iB[idx];
}
```

Questions?



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