Practical Course: GPU Programming in Computer Vision

CUDA Miscellaneous

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Summer Semester 2018
September 17 - October 15

Outline

1 Atomics

2 Streams and Events

3 Multi-GPU Programming

4 Third-party Libraries

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4 Third-party Libraries

Communication Through Memory

- Question:

```
__global__ void race()
{
  __shared__ int my_shared_variable;
  my_shared_variable = threadIdx.x;

  // what is the value of my_shared_variable?
}
```

Communication Through Memory

- This is a race condition
- The result is undefined
- The order in which threads access the variable is undefined without explicit coordination
- Use atomic operations (e.g., `atomicAdd`) to enforce well-defined semantics

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Atomics

- Use atomic operations to ensure exclusive access to a variable

```
// assume *p_result is initialized to 0
__global__ void sum(int *input, int *p_result)
{
  atomicAdd(p_result, input[threadIdx.x]);

  // after this kernel exits, the value of
  // *p_result will be the sum of the inputs
}
```

Atomics Imply Serialization

- Atomic operations are costly!
- They imply serialized access to a variable
- $\Rightarrow$ use them only if there is no other better way to achieve your task

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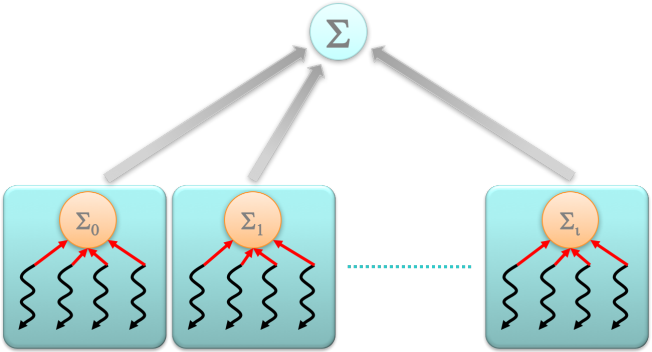
```
__global__ void sum(int *input, int *p_result)
{
  atomicAdd(p_result, input[threadIdx.x]);
}

// how many threads will contend
// for exclusive access to p_result?
sum <<<10,128>>> (input,p_result);
```

Atomics: Hierarchical Summation



Divide & Conquer:

- `__shared__` partial sums: `atomicAdd` per thread
- global total sum: atomicAdd per block

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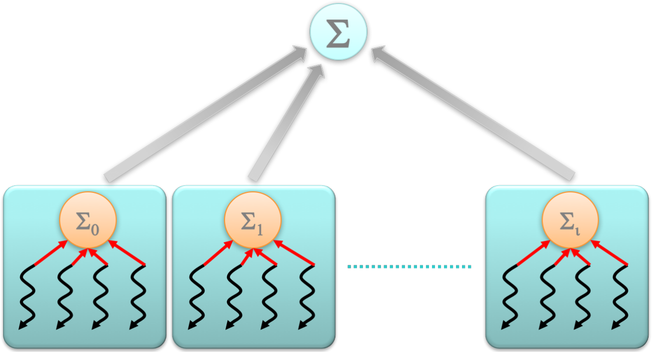

Divide & Conquer:

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Atomics: Hierarchical Summation

```
__global__ void sum(int *input, int *result)
{
  __shared__ int partial_sum;

  // thread 0 is responsible for initializing partial_sum
  if(threadIdx.x == 0) partial_sum = 0;
  __syncthreads();

  // each thread updates the partial sum
  atomicAdd(&partial_sum, input[threadIdx.x]);
  __syncthreads();

  // thread 0 updates the total sum
  if(threadIdx.x == 0) atomicAdd(result, partial_sum);
}
```

Advice: Shared Memory and Atomics

- Always use barriers such as `__syncthreads();` to wait until `__shared__` data is ready
- Prefer barriers to atomics when data access patterns are regular or predictable
- Prefer atomics to barriers when data access patterns are sparse or unpredictable
- Atomics to `__shared__` variables are much faster than atomics to global variables

Advice: Shared Memory and Atomics

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Streams

- Concurrency is handled through `streams`
  - overlap kernel execution with another kernel execution
  - overlap kernel execution with a memcpy
  - overlap memcpy with another memcpy
  - wait for certains kernels, but not for others
- `Stream` = sequence of commands executed in order
  - different `streams` may execute concurrently, but not guaranteed
  - depends on hardware and the kind of operations executed in the streams
  - `default stream` is 0: if no stream specified
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Streams

```
cudaStream_t stream1; cudaStream_t stream2;
cudaStreamCreate(&stream1); cudaStreamCreate(&stream2);
float *h_ptr; cudaMallocHost(&h_ptr, size);

// (potentially) overlapping execution
cudaMemcpyAsync(h_ptr, d_ptr, size, dir, stream1);
kernel <<<grid,block,0,stream2>>> (...);

// check whether memcpy has finished
cudaError_t res = cudaStreamQuery(stream1);
if (res==cudaSuccess) { ... }

// or: wait for completion:
cudaStreamSynchronize(stream1); // will only wait for the memcpy
cudaStreamSynchronize(stream2); // will only wait for the kernel

cudaStreamDestroy(&stream1); cudaStreamDestroy(&stream2);
```

Events

- Monitor device's progress
- Asynchronously record events at any point in the program
- Event recorded when all commands in stream completed
  - measure elapsed time for CUDA calls (clock cycle precision)
  - query the status of an asynchronous CUDA call
  - block CPU until CUDA calls prior to the event are completed

```
cudaEvent_t start; cudaEvent_t stop;
cudaEventCreate(&start); cudaEventCreate(&stop);
cudaEventRecord(start,0);   // default stream
kernel <<<grid,block>>> (...);
cudaEventRecord(stop,0);    // default stream
cudaEventSynchronize(stop); // block until "stop" recorded
float t; cudaEventElapsedTime(&t, start, stop);
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Multi-GPU Programming

- There may be more than one GPU installed
- Host can query and select GPU devices
  - `cudaGetDeviceCount(int *count);`
  - `cudaSetDevice(int device);`
  - `cudaGetDevice(int *current_device);`
  - `cudaGetDeviceProperties(cudaDeviceProp *prop, int device);`
- Multi-GPU setting: device 0 is used by default

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- Everything happens on the current device:
  - `cudaMalloc(...)` allocates on the cur. dev. only
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  - Kernels execute only on the cur. dev.
  - `cudaDeviceSynchronize()` waits only for cur. dev.
- GPUs are independent: kernels run in parallel

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cudaSetDevice(0); mykernel1 <<<grid1,block1>>> (d0_a, n0_a);
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Multi-GPU Programming

- Data exchange between GPUs
  `cudaMemcpyPeer(ptr_to, dev_to, ptr_from, dev_from, size);`
- From CC$\geq$2.0: Direct access between GPUs
- Kernel on device x can read memory on device y
  - memcopies are done automatically
  - utilizes unified virtual addressing
  - must be explicitly enabled:
  - `cudaDeviceEnablePeerAccess(dev_peer, 0);`
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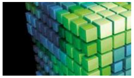
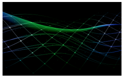
Linear Algebra and Math Libraries



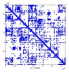
cuBLAS

GPU-accelerated standard BLAS library



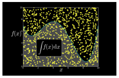
CUDA Math Library

GPU-accelerated standard mathematical function library



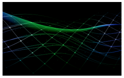
cuSPARSE

GPU-accelerated BLAS for sparse matrices



cuRAND

GPU-accelerated random number generation (RNG)



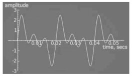
cuSOLVER

Dense and sparse direct solvers for Computer Vision, CFD, Computational Chemistry, and Linear Optimization applications

AmgX

GPU accelerated linear solvers for simulations and implicit unstructured methods

Image Processing, Algorithms and Deep Learning



cuFFT

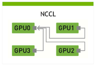
GPU-accelerated library for Fast Fourier Transforms

NVIDIA Performance Primitives

GPU-accelerated library for image and signal processing

NVIDIA Codec SDK

High-performance APIs and tools for hardware accelerated video encode and decode



NCCL

Collective Communications Library for scaling apps across multiple GPUs and nodes

nvGRAPH

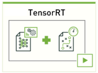
GPU-accelerated library for graph analytics

Thrust

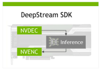
GPU-accelerated library of parallel algorithms and data structures

cuDNN

GPU-accelerated library of primitives for deep neural networks



GPU-accelerated neural network inference library for building deep learning applications



Advanced GPU-accelerated video inference library

… and much more!

OpenCV	FFmpeg	{A} ArrayFire
GPU-accelerated open-source library for computer vision, image processing and machine learning, now supporting real-time operation	Open-source multi-media framework with a library of plugins for audio and video processing	GPU-accelerated open source library for matrix, signal, and image processing
MAGMA	IMSL RogueWave SOFTWARE	GUNROCK GPU GRAPH ANALYTICS FRAMEWORK AT UC DAVIS
GPU-accelerated linear algebra routines for heterogeneous architectures, by Magma	GPU-accelerated open-source Fortran library with functions for math, signal and image processing, statistics, by RogueWave	Library for graph-processing designed specifically for the GPU
SuiteSparse CHOLMOD	CULA|tools	[HiPLAR]
GPU-accelerated functions for sparse direct solvers, included in SuiteSparse linear algebra package authored by Prof.	GPU-accelerated linear algebra library by EM Photonics	GPU-accelerated linear algebra (LA) routines for the R platform for statistical computing supporting heterogeneous
gPP Geometry Performance Primitives	PARALUTION	Sundog Software
GPU-accelerated computational geometry engine for advanced GIS, EDA, computer vision, and motion planning, by Fixstars	GPU-accelerated library for sparse iterative methods by Paralution	Real-time visual simulation of oceans, water bodies in games, simulation, and training applications, by Triton

`https://developer.nvidia.com/gpu-accelerated-libraries`

Further Reading

CUDA Programming Guide (linked on course page)

- Appendix B.12 (atomics)
- Chapter 3, section 3.2.5 (streams & events)
- Appendix J (unified memory programming)