



# CSE 746 - Parallel and High Performance Computing

## Lecture 5 - Dynamic parallelism with CUDA

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# Dynamic parallelism

- new feature available since late 2012, in GPUs with CC (Compute Capability) 3.5 or higher
- code with dynamic parallelism will not compile for devices with lower than 3.5 Compute Capability
- only some of recent NVIDIA GPU cards support CC 3.5, it is not universal

# Dynamic parallelism

- permits kernel launches from inside kernels
- kernels no longer have to be launched exclusively from host
- relaxing this restriction permits more independence of GPU code from the CPU host, less device/host synchronization required
- opens possibilities for clearer, less complicated code
- true kernel recursion is now possible
- allows much more efficient parallelization for some problems
- without this GPUs lacked a feature which has been available on CPUs for decades, making GPUs harder to program compared to CPUs

# Calling kernel inside kernel has same syntax as calling on host

```
__global void Kernel1(){
    ... //kernel code
}

__global__ void Kernel2(){
    ... //kernel code
    Kernel1<<<N,M>>>() // call kernel inside kernel
    ... //more kernel code
}

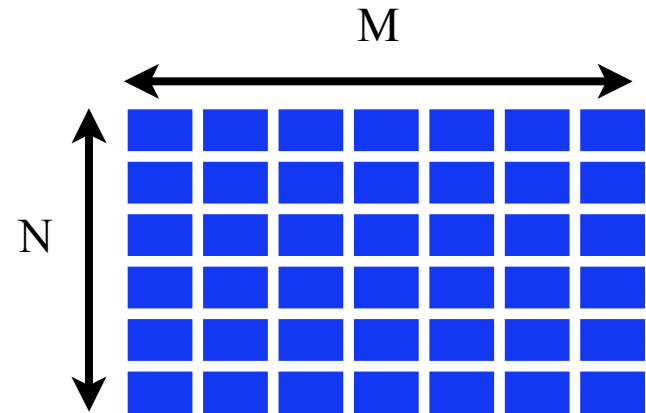
int main(){
    ... //host code
    Kernel2<<<K,J>>>() // call kernel from host
    ... //more host code
}
```

- in this example, Kernel2 launches  $K \cdot J$  threads when called in the main function
- each thread in Kernel2 that calls Kernel1 will launch  $N \cdot M$  new threads
- up to  $K \cdot J \cdot N \cdot M$  threads in total can be launched in this case

# Program easy to write as an efficient GPU kernel

```
for (int i=0; i<N){  
  for (int j=0; j<M;j++){  
    some_convolution_function(i,j);  
  }  
}
```

- perfect target for 2D thread decomposition
- $N*M$  threads will be launched
- all threads call the same function



# Program harder to write as an efficient GPU kernel

```
for (int i=0; i<N){  
    for (int j=0; j<M[i];j++){  
        some_convolution_function(i,j);  
    }  
}
```

- the  $i,j$  values no longer fit a regular grid
- cannot decompose straightforwardly into 2D array of threads
- can consider a series of bad options

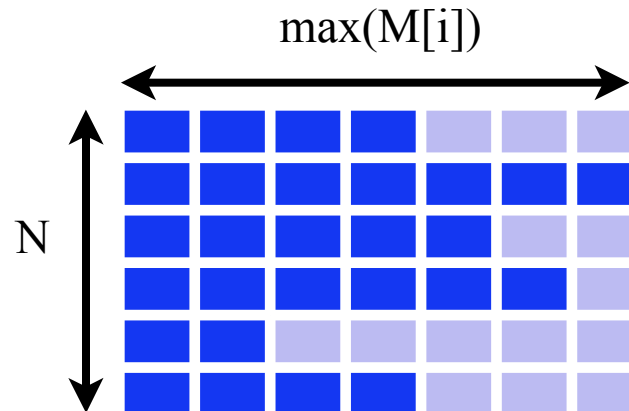
## More threads?

```

__global oversubscribed_kernel(){
  i=threadIdx.x + blockDim.x * blockIdx.x;
  j=threadIdx.y + blockDim.y * blockIdx.y;
  if(j<M[i]){
    some_convolution_function(i,j);
  }
}

```

- could try oversubscription, have  $N \cdot \max(M[i])$  threads, some do no work
- this is wasteful, threads which do nothing have to be created



## Fewer threads?

```
__global void fewer_threads_kernel(){
    i=threadIdx.x + blockDim.x * blockIdx.x;
    for (int j=0; j<M[i];j++){
        some_convolution_function(i,j);
    }
}
```

- could have just  $N$  threads
- in this case all threads would do work, but  $N$  might be too small to create enough threads for efficient use of GPU
- different threads would likely have very different amounts of work to do



## Multiple kernels from host

```
__global void multi_kernel(i){  
    j=threadIdx.x + blockDim.x * blockIdx.x;  
    some_convolution_function(i,j);  
}  
  
//on host  
...  
for(i=0;i<N;i++){  
    multi_kernel<<<(enough threads to handle M[i] evaluations)>>>(i)  
}
```

- could call kernel from host N times
- there is overhead to calling a kernel, if N is large, overhead will be significant
- default kernels execute in series, previous must finish before next one starts, even if independent
- could use streams to avoid this, but number of streams working asynchronously is limited

# New option with CC 3.5: more kernels from GPU

```
__global void convolution_kernel(int i,int j){
    some_convolution_function(i,j);
}
__global void dynamic_parallelism_kernel(int *M){

    for(j=0;j<M[blockIdx.x];j++){
        convolution_kernel<<1,1>>(blockIdx.x,j);
    }
}
//on host

...
dynamic_parallelism_kernel<<<N,1>>>(M)
```

- first kernel call creates N blocks with 1 thread each, so N threads
- each thread i of the N threads launches M[i] kernels, each containing one thread
- another possibility: have each thread i launch a kernel with M[i] threads, but work done by each kernel not equal

# New option with CC 3.5: more kernels from GPU

```
__global void convolution_kernel(int i,int j){
    some_convolution_function(i,j);
}

__global void dynamic_parallelism_kernel(int *M){
    for(j=0;j<M[blockIdx.x];j++){
        convolution_kernel<<1,1>>(blockIdx.x,j);
    }
}
//on host
...
dynamic_parallelism_kernel<<<N,1>>>(M)
```

- overhead of launching kernels on GPU much lower than on host
- these kernels will execute asynchronously, as they are launched by different threads

# Synchronization is an issue, just like on host

```
__global__ void Kernel2(){  
... //kernel code  
    Kernel1<<<N,M>>>(); // thread will launch kernel and keep going  
    cudaDeviceSynchronize(); // make thread wait for Kernel1 to complete  
... //code that needs data generated by Kernel1  
}
```

- threads will launch kernels and keep on going, just like the host
- if you need for the thread to wait until Kernel1 is finished before continuing, use `cudaDeviceSynchronize` just like on host
- in this case `cudaDeviceSynchronize` ensures synchronization only within that 1 GPU thread (!!)

# Synchronization is an issue, just like on host

```
__global__ void Kernel2(){
... //kernel code
  if(threadIdx.x==0){
    Kernel1<<<N,M>>>(); // thread will launch kernel and keep going
    cudaDeviceSynchronize(); // make thread wait for Kernel1 to complete
  }
  __syncthreads(); // if all threads in block need Kernel1 to complete
... //code that needs data generated by Kernel1
}
```

- `cudaDeviceSynchronize` will not synchronize threads in a block, it only works within thread when inside kernel
- if you want all threads in a block to wait for kernel to finish, used `cudaDeviceSynchronize()` followed by `__syncthreads`

# CC 3.5+ GPU cards now available at SHARCNET

available on machines: [angel.sharcnet.ca](http://angel.sharcnet.ca), [mosaic.sharcnet.ca](http://mosaic.sharcnet.ca)

Compile with (change to sm\_50 on angel):

```
nvcc -arch=sm_35 --relocatable-device-code true -lcudadevrt -O2  
program.cu
```

On angel:

```
sqsub -q gpu -n 1 --gpp=2 -r 3h -o sleep.out sleep 180m
```

then find with “sqjobs” which node your job is using and login

You will now see the GPUs since the running job is granting you permission

# Exercise - enhance binary reduction code from Lecture 4 using dynamic parallelism

Start code can be found in:

`/home/ppomorsk/CSE746_lec5/reduction`

Goal is to implement 3 level binary reduction using just one kernel function, and have that function called on host only once (with following kernel calls inside the kernel)

Proceed in stages, following instructions in comments at the start of each stage of the process