Concurrent Kernels and Multiple GPUs

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Introduction to Supercomputing
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Concurrent Kernels and Multiple GPUs

page locked or pinned memory

In contrast to regular pageable host memory, the runtime provides functions to allocate (and free) *page locked* memory.

Another name for memory that is page locked is *pinned*.

Using page locked memory has several benefits:

- Copies between page locked memory and device memory can be performed concurrently with kernel execution.
- Page locked host memory can be mapped into the address space of the device, eliminating the need to copy, we say *zero copy*.
- Bandwidth between page locked host memory and device may be higher.

Page locked host memory is a scarce resource.

The NVIDIA CUDA Best Practices Guide assigns a low priority to zero-copy operations (i.e.: mapping host memory to the device).

allocating and mapping pinned host memory

To allocate page locked memory, we use `cudaHostAlloc()` and to free the memory, we call `cudaFreeHost()`.

To map host memory on the device:

- The flag `cudaHostAllocMapped` must be given to `cudaHostAlloc()` when allocating host memory.
- A call to `cudaHostGetDevicePointer()` maps the host memory to the device.

If all goes well, then no copies from host to device memory and from device to host memory are needed.

Not all devices support pinned memory, it is recommended practice to check the device properties (see the `deviceQuery` in the SDK).

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using pinned memory

```
$ /tmp/pinnedmemoryuse
Tesla K20c supports mapping host memory.

The error code of cudeHostAlloc : 0

Squaring 32 numbers 1 2 3 4 5 6 7 8 9 10 11 12 13 \
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32...


The fail code of cudaHostGetDevicePointer : 0

After squaring 32 numbers 1 4 9 16 25 36 49 64 81 \
100 121 144 169 196 225 256 289 324 361 400 441 484 \
529 576 625 676 729 784 841 900 961 1024...

$
```

the program `pinnedmemoryuse.cu`

```
/* This program illustrates pinned (page locked) memory. */

#include <stdio.h>

int checkDeviceProp ( cudaDeviceProp p );
/*
 * Returns 0 if the device does not support mapping
 * host memory, returns 1 otherwise. */
```

checking the device

```
int checkDeviceProp ( cudaDeviceProp p )
{
    int support = p.canMapHostMemory;

    if(support == 0)
        printf("%s does not support mapping host memory.\n",
                p.name);
    else
        printf("%s supports mapping host memory.\n",p.name);

    return support;
}
```

a simple kernel

```
__global__ void Square ( float *x )
/*
 * A kernel where the i-th thread squares x[i]
 * and stores the result in x[i]. */
{
   int i = blockIdx.x*blockDim.x + threadIdx.x;
   x[i] = x[i]*x[i];
}
```

the main program

```
void square_with_pinned_memory ( int n );
/*
 * Illustrates the use of pinned memory to square
 * a sequence of n numbers. */

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

   cudaGetDeviceProperties(&dev,0);

   int success = checkDeviceProp(dev);

   if(success != 0)
      square_with_pinned_memory(32);

   return 0;
}
```

allocating pinned memory

```
void square_with_pinned_memory ( int n )
{
   float *xhost;
   size_t sz = n*sizeof(float);
   int error = cudaHostAlloc((void**)&xhost,
                  sz,cudaHostAllocMapped);
   printf("\nThe error code of cudeHostAlloc : %d\n",
          error);

   for(int i=0; i<n; i++) xhost[i] = (float) (i+1);
   printf("\nSquaring %d numbers",n);
   for(int i=0; i<n; i++) printf(" %d",(int) xhost[i]);
   printf("...\n\n");
```

mapping host memory

```
float *xdevice;

int fail = cudaHostGetDevicePointer
              ((void**)&xdevice,(void*)xhost,0);
printf("\nThe fail code of cudaHostGetDevicePointer : \
      %d\n",fail);

Square<<<1,n>>>(xdevice);

cudaDeviceSynchronize();

printf("\nAfter squaring %d numbers",n);
for(int i=0; i<n; i++) printf(" %d",(int) xhost[i]);
printf("...\n\n");

cudaFreeHost(xhost);
}
```

Concurrent Kernels and Multiple GPUs

streams and concurrency

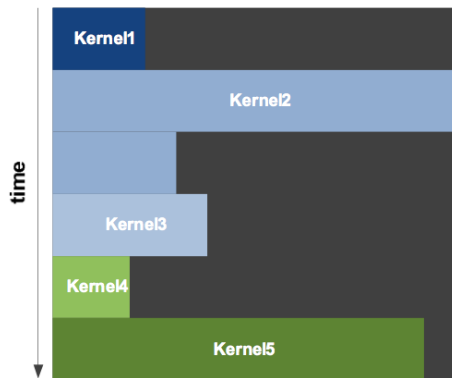The Fermi architecture supports the simultaneous execution of kernels.

Benefits:

- Simultaneous execution of small kernels utilize whole GPU.
- Overlapping kernel execution with device to host memory copy.

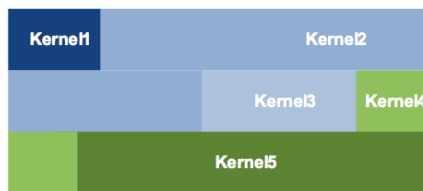A *stream* is a sequence of commands that execute in order.

Different streams may execute concurrently.

The maximum number of kernel launches that a device can execute concurrently is four.

concurrent kernel execution

Serial Kernel Execution

Concurrent Kernel Execution

from the NVIDIA Fermi Compute Architecture Whitepaper

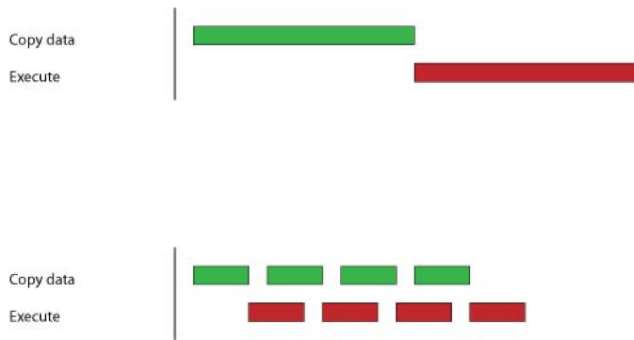# concurrent copy and kernel execution (4 streams)

Figure 3.1   Timeline Comparison for Sequential (top) and Concurrent (bottom) Copy and Kernel Execution

from the NVIDIA CUDA Best Practices Guide

Concurrent Kernels and Multiple GPUs

squaring numbers

```
$ /tmp/concurrent
Tesla K20c supports concurrent kernels
  compute capability : 3.5
  number of multiprocessors : 13

Launching 4 kernels on 16 numbers 1 2 3 4 5 6 7 8 9 10 \
11 12 13 14 15 16...

the 16 squared numbers are 1 4 9 16 25 36 49 64 81 100 \
121 144 169 196 225 256
$
```

a simple kernel

```
__global__ void Square ( float *x, float *y )
/*
 * A kernel where the i-th thread squares x[i]
 * and stores the result in y[i]. */
{
   int i = blockIdx.x*blockDim.x + threadIdx.x;
   y[i] = x[i]*x[i];
}
```

checking if concurrency is supported

```
int checkDeviceProp ( cudaDeviceProp p )
{
   int support = p.concurrentKernels;

   if(support == 0)
      printf("%s does not support concurrent kernels\n",
             p.name);
   else
      printf("%s supports concurrent kernels\n",p.name);

   printf("  compute capability : %d.%d \n",
          p.major,p.minor);
   printf("  number of multiprocessors : %d \n",
          p.multiProcessorCount);

   return support;
}
```

the main program

```
void launchKernels ( void );
/*
 * Launches concurrent kernels on arrays of floats. */

int main ( int argc, char* argv[] )
{
   cudaDeviceProp dev;
   cudaGetDeviceProperties(&dev,0);

   int success = checkDeviceProp(dev);
   if(success != 0) launchKernels();

   return 0;
}
```

allocating memories

```
void launchKernels ( void )
{
    const int nbstreams = 4;
    const int chunk = 4;
    const int nbdata = chunk*nbstreams;

    float *xhost;
    size_t sz = nbdata*sizeof(float);

    cudaMallocHost((void**)&xhost,sz);

    for(int i=0; i<nbdata; i++) xhost[i] = (float) (i+1);
    printf("\nLaunching %d kernels on %d numbers",
            nbstreams,nbdata);
    for(int i=0; i<nbdata; i++)
        printf(" %d",(int) xhost[i]);
    printf("...\n\n");
    float *xdevice; cudaMalloc((void**)&xdevice,sz);
    float *ydevice; cudaMalloc((void**)&ydevice,sz);
```

asynchronous concurrent execution

```
cudaStream_t s[nbstreams];
for(int i=0; i<nbstreams; i++) cudaStreamCreate(&s[i]);

for(int i=0; i<nbstreams; i++)
   cudaMemcpyAsync
      (&xdevice[i*chunk],&xhost[i*chunk],
       sz/nbstreams,cudaMemcpyHostToDevice,s[i]);

for(int i=0; i<nbstreams; i++)
   Square<<<1,chunk,0,s[i]>>>
      (&xdevice[i*chunk],&ydevice[i*chunk]);
```

synchronization

```
for(int i=0; i<nbstreams; i++)
   cudaMemcpyAsync
      (&xhost[i*chunk],&ydevice[i*chunk],
       sz/nbstreams,cudaMemcpyDeviceToHost,s[i]);

cudaDeviceSynchronize();

printf("the %d squared numbers are",nbdata);
for(int i=0; i<nbdata; i++)
   printf(" %d",(int) xhost[i]);
printf("\n");

for(int i=0; i<nbstreams; i++) cudaStreamDestroy(s[i]);
cudaFreeHost(xhost);
cudaFree(xdevice); cudaFree(ydevice);
}
```

Concurrent Kernels and Multiple GPUs

enumerating available devices

```
$ /tmp/count_devices
number of devices : 3
graphics card 0 :
  name : Tesla K20c
  number of multiprocessors : 13
graphics card 1 :
  name : GeForce GT 620
  number of multiprocessors : 2
graphics card 2 :
  name : Tesla K20c
  number of multiprocessors : 13
$
```

the program `count_devices.cu`

```
/* This program illustrates counting available devices,
 * compile it with nvcc and note the extension .cu
 * and for a more detailed version, see deviceQuery.cpp
 * of the GPU Computing SDK */

#include <stdio.h>

void printDeviceProp ( cudaDeviceProp p )
/*
 * prints some device properties */
{
   printf("   name : %s \n",p.name);
   printf("   number of multiprocessors : %d \n",
          p.multiProcessorCount);
}
```

the main program

```
int main ( int argc, char* argv[] )
{
   int deviceCount;
   cudaGetDeviceCount(&deviceCount);
   printf("number of devices : %d\n",deviceCount);

   for(int d = 0; d < deviceCount; d++)
   {
      cudaDeviceProp dev;
      cudaGetDeviceProperties(&dev,d);
      printf("graphics card %d :\n",d);
      printDeviceProp(dev);
   }

   return 0;
}
```

Concurrent Kernels and Multiple GPUs

computing with multiple GPUs

Chapter 8 of the NVIDIA CUDA Best Practices Guide describes multi-GPU programming.

To work with *p* GPUs concurrently, the CPU can use

- *p* lightweight threads (Pthreads, OpenMP, etc); or
- *p* heavyweight threads (or processes) with MPI.

The command to select a GPU is `cudaSetDevice()`.

All inter-GPU communication happens through the host.

See the `simpleMultiGPU` of the GPU Computing SDK.