Lab 1: A Gentle Introduction to CUDA

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After previous year slides of Rasmus Fonseca!

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September 2021 PMPH Lab Slides

Get CUDA Up and Running

Option 1: Personal computer

- https://developer.nvidia.com/cuda-downloads
- Don't do this now!

Get CUDA Up and Running

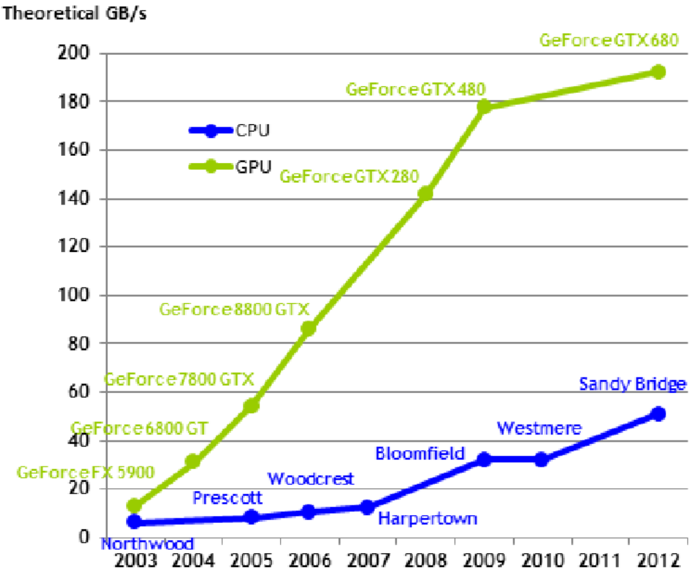
Option 2: Using gpu-servers:

- `$ ssh -l <username> ssh-diku-apl.science.ku.dk`
- Password:
- `$ ssh gpu02-diku-apl`
- Password:
- Add the following to your `.bashrc` file:
  - `$ export PATH=/usr/local/cuda/bin:$PATH`
  - `$ export LD_LIBRARY_PATH=/usr/local/cuda/lib64:$LD_LIBRARY_PATH`
  - `$ export LIBRARY_PATH=$LD_LIBRARY_PATH:$LIBRARY_PATH`
- And you are ready to go:
  `$ nvcc ...`

Let's Try it Out:

```
$ ssh gpu02

$ cp -r /usr/local/cuda/samples .

$ cd samples/1_Utilities/deviceQuery

$ make

$ ./deviceQuery
```

Motivation for Using GPGPUs



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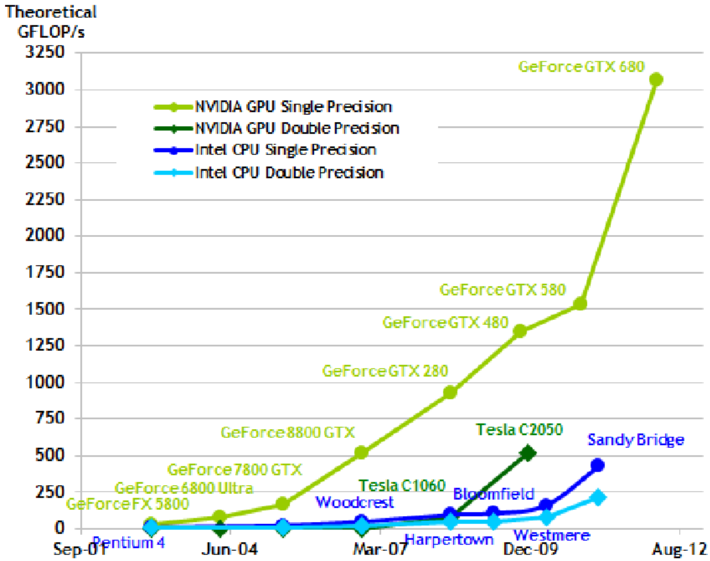
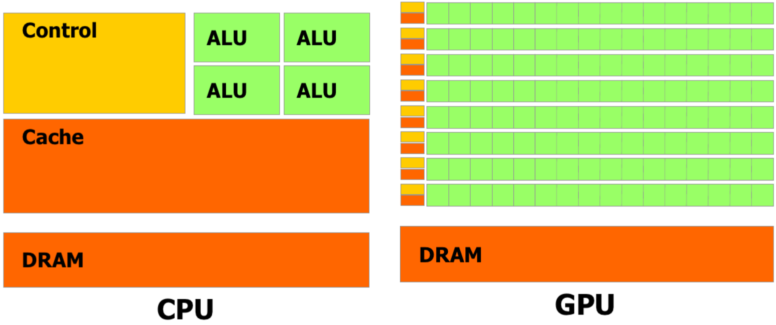
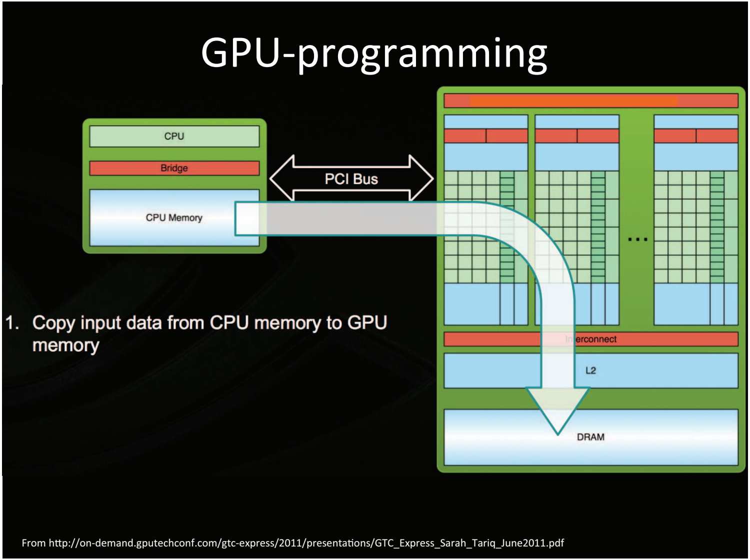


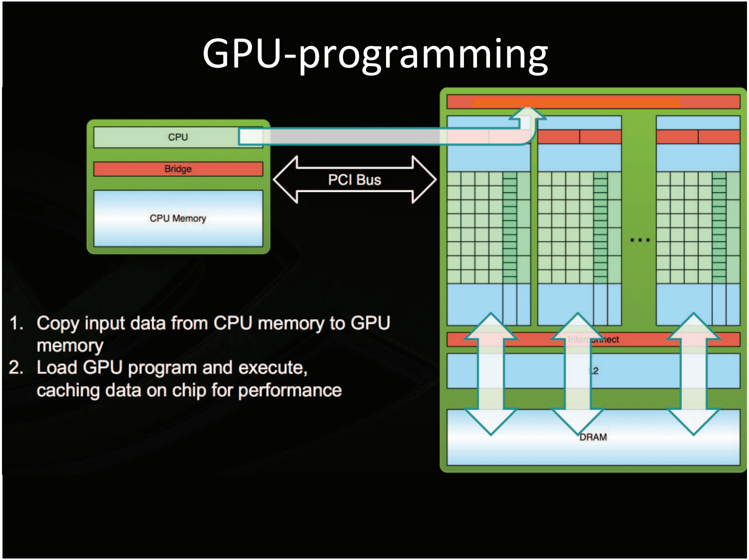
Difficulties in Programming GPGPUs



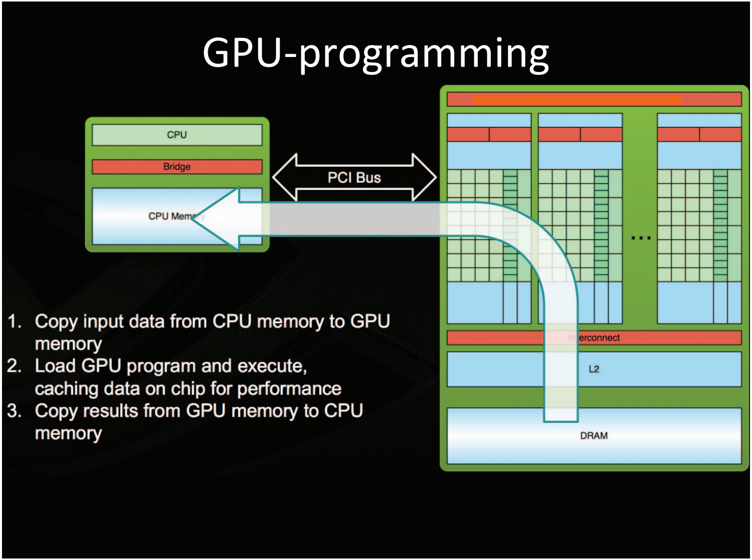
GPGPU programming



GPGPU programming



GPGPU programming



GPGPU programming

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <math.h>

#include <cuda_runtime.h>

__global__ void squareKernel(float *d_in, float *d_out)
{
    const unsigned int tid = threadIdx.x; // access thread id
    d_out[tid] = d_in[tid]*d_in[tid];     // do computation
}

int main(int argc, char **argv)
{
    unsigned int num_threads = 32;
    unsigned int mem_size = sizeof(float) * num_threads;

    // allocate host memory
    float *h_in = (float *)malloc(mem_size);
    float *h_out = (float *) malloc(mem_size);

    // initalize the memory
    for (unsigned int i = 0; i < num_threads; ++i){
        h_in[i] = (float) i;
    }

    // allocate device memory
    float *d_in;
    float *d_out;
    cudaMalloc((void **) &d_in, mem_size);
    cudaMalloc((void **) &d_out, mem_size);

    // copy host memory to device
    cudaMemcpy(d_in, h_in, mem_size, cudaMemcpyHostToDevice);

    // execute the kernel
    squareKernel<<< 1, num_threads >>>(d_in, d_out);

    // copy result from device to host
    cudaMemcpy(h_out, d_out, sizeof(float) * num_threads, cudaMemcpyDeviceToHost);

    for (unsigned int i=0;i<num_threads; ++i){
        printf("%.1f\n",h_out[i]);
    }

    // cleanup memory
    free(h_in);
    free(h_out);
    cudaFree(d_in);
    cudaFree(d_out);

    return 0;
}
```

A Simple CUDA Program

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <math.h>
#include <cuda_runtime.h>

__global__ void squareKernel(float* d_in, float *d_out) {
    const unsigned int lid = threadIdx.x; // local id inside a block
    const unsigned int gid = blockIdx.x*blockDim.x + lid; // global id
    d_out[gid] = d_in[gid]*d_in[gid];     // do computation
}

int main(int argc, char** argv) {
    unsigned int N = 32;
    unsigned int mem_size = N*sizeof(float);

    // allocate host memory
    float* h_in  = (float*) malloc(mem_size);
    float* h_out = (float*) malloc(mem_size);

    // initialize the memory
    for(unsigned int i=0; i<N; ++i){
        h_in[i] = (float)i;
    }
```

A Simple CUDA Program (continuation)

```
    // allocate device memory
    float* d_in;
    float* d_out;
    cudaMalloc((void**)&d_in,  mem_size);
    cudaMalloc((void**)&d_out, mem_size);

    // copy host memory to device
    cudaMemcpy(d_in, h_in, mem_size, cudaMemcpyHostToDevice);

    // execute the kernel
    squareKernel<<< 1, N>>>(d_in, d_out);

    // copy result from ddevice to host
    cudaMemcpy(h_out, d_out, mem_size, cudaMemcpyDeviceToHost);

    // print result
    for(unsigned int i=0; i<N; ++i) printf("%.6f\n", h_out[i]);

    // clean-up memory
    free(h_in);        free(h_out);
    cudaFree(d_in);    cudaFree(d_out);
}
```

Save, Compile, Run

```
$ nvcc -O3 simpleCUDA.cu

$ ./a.out
```

Measuring Runtime

```
#include <sys/time.h>
#include <time.h>
int timeval_subtract(   struct timeval* result,
                        struct timeval* t2,struct timeval* t1) {
    unsigned int resolution=1000000;
    long int diff = (t2->tv_usec + resolution * t2->tv_sec) -
                    (t1->tv_usec + resolution * t1->tv_sec) ;
    result->tv_sec = diff / resolution;   result->tv_usec = diff % resolution;
    return (diff<0);
}
#define GPU_RUNS 100
int main() { ...
    unsigned long int elapsed; struct timeval t_start, t_end, t_diff;
    gettimeofday(&t_start, NULL);

    // execute the kernel
    for(int i=0; i<GPU_RUNS; i++) {
        squareKernel<<< 1, N>>>(d_in, d_out);
    } cudaThreadSynchronize();

    gettimeofday(&t_end, NULL);
    timeval_subtract(&t_diff, &t_end, &t_start);
    elapsed = (t_diff.tv_sec*1e6+t_diff.tv_usec) / GPU_RUNS;
    printf("Took %d microseconds (%.2fms)\n",elapsed,elapsed/1000.0);
...}
```

Trouble Ahead

This week assignment: *Write a CUDA program that maps the function* `(x/(x-2.3))`^{3} *to the array* `[0,1,..., 753411]` *...*

This shouldn't be a problem with our program (adapt the kernel)

- GPU logical threads organized in a grid of blocks, in which the grid and the block can have up to three dimensions.
- However CUDA does not accept a block of size 32757
  - a *CUDA warp* is formed by 32 threads that execute SIMD.
  - a *a CUDA block* may contain up to 1024 threads (included); ideally the block size is a multiple of 32, but not necessarily.
  - Synchronization/communication is possible inside a CUDA block by means of barriers & scratchpad memory (shared memory).
  - Barrier synchronization is not possible across threads in different CUDA blocks, i.e., only by finishing the kernel!

Trouble Ahead

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  - Synchronization/communication is possible inside a CUDA block by means of barriers & scratchpad memory (shared memory).
  - Barrier synchronization is not possible across threads in different CUDA blocks, i.e., only by finishing the kernel!
- Finally if the size of the computation does not matches exactly a multiple of block size, then you need to spawn extra threads, hence you need to add an `if` inside the kernel code, to make the extra threads iddle!

GPGPU in More Detail

- A set of Streaming Multiprocessors (SMs)

```
From deviceQuery:
 (15) Multiprocessors, (192) CUDA Cores/MP:     2880 CUDA Cores
```

- Each SM executes 1 ‘thread block’ at a time.
- Each block has access to
  - Global memory (function arguments)

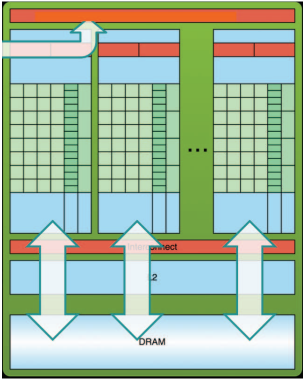
```
From deviceQuery:
 Total amount of global memory:                 3072 MBytes
```

  - Shared memory (`__shared__ int array[512]`)

```
From deviceQuery:
Total amount of shared memory per block:       49152 bytes
```

  - Local memory (local variables)

```
From deviceQuery:
 Total number of registers available per block: 65536
```



Running Multiple Blocks

```
    unsigned int N = 32757;
    unsigned int mem_size    = N*sizeof(float);
    unsigned int block_size  = 256;
    unsigned int num_blocks  = ((N + (block_size - 1)) / block_size);

    // execute the kernel
    squareKernel<<< num_blocks, block_size>>>(d_in, d_out, N);

...

__global__ void squareKernel(float* d_in, float *d_out, int N) {
    const unsigned int lid = threadIdx.x; // local id inside a block
    const unsigned int gid = blockIdx.x*blockDim.x + lid; // global id
    if(gid < N) {
        d_out[gid] = d_in[gid]*d_in[gid];      // do computation
    }
}
```

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