Lab 1: A Gentle Introduction to CUDA

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After previous year slides of Rasmus Fonseca!

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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 gpu01-diku-apl`
- Password:
- Add the following to your `.bashrc` file:
  - `$ export PATH=/usr/local/cuda-6.0/bin:$PATH`
  - `$ export LD_LIBRARY_PATH=/usr/local/cuda-6.0/lib64:$LD_LIBRARY_PATH`
- And you are ready to go:
  `$ nvcc ...`

Setting up No-Password SSH

On your local machine, add an entry in `.ssh/config` for each gpu01..4:

```
Host gpu01-diku-apl
ProxyCommand ssh -q <user-name>@ssh-diku-apl.science.ku.dk nc -q0
gpu01-diku-apl 22

user <user-name>
```

On each gpu server copy-past your local-machine `id_rsa.pub` into the `.ssh/authorized_keys` file.

Now you should be able to log in from your local machine with:

```
$ ssh gpu01-diku-apl
```

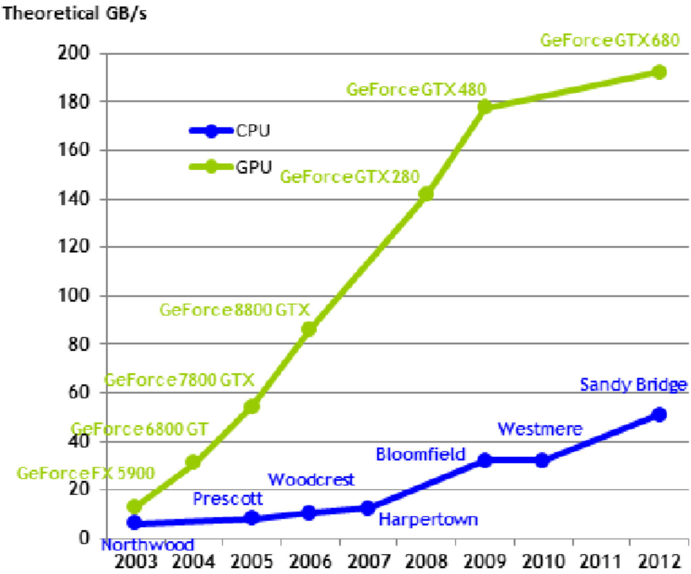
Let's Try it Out:

```
$ ssh gpu01

$ cp -r /usr/local/cuda-6.0/samples .

$ cd samples/1_Utilities/deviceQuery

$ make

$ ./deviceQuery
```

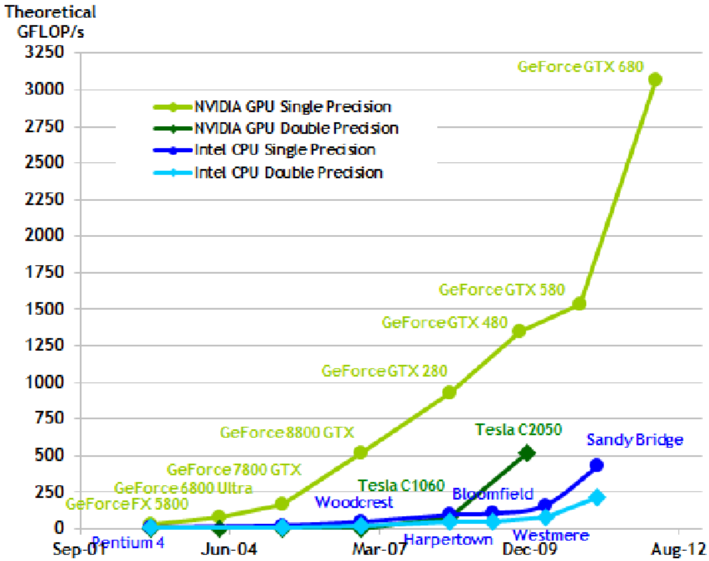
GPU Programming Online Courses

www.udacity.com/course/cs344

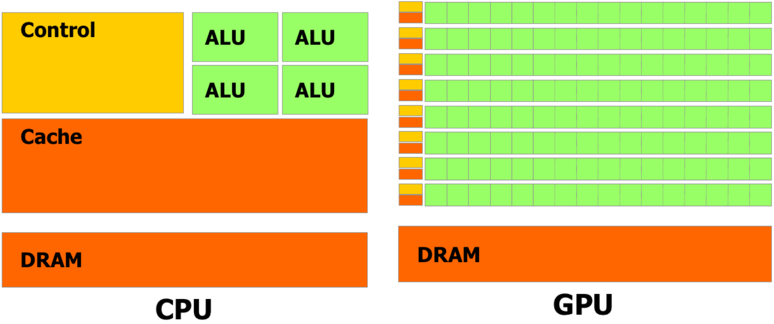
Motivation for Using GPGPUs



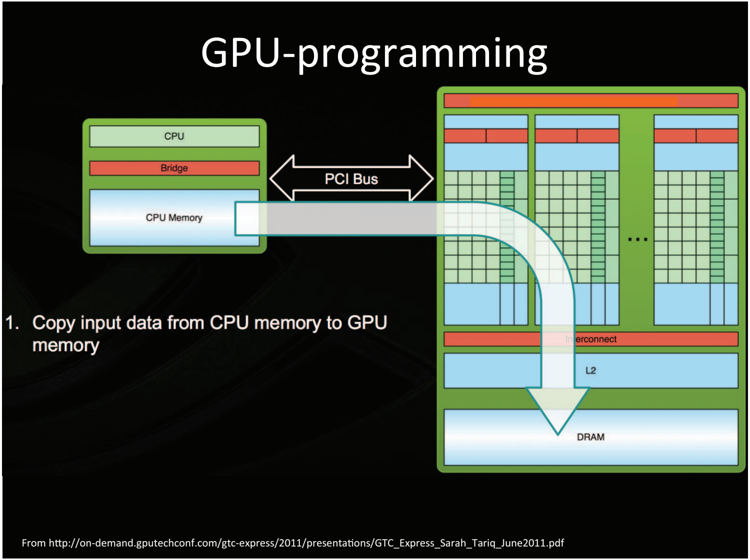
Motivation for Using GPGPUs



Difficulties in Programming GPGPUs



GPGPU programming

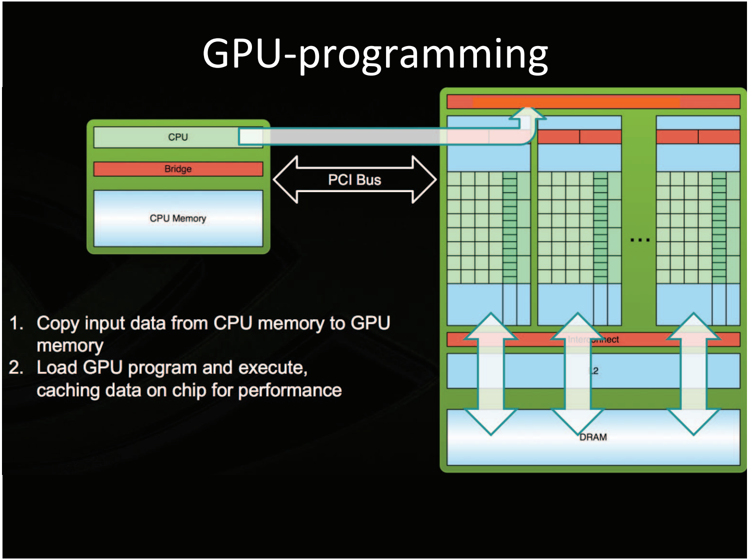


GPU-programming

1. Copy input data from CPU memory to GPU memory

From http://on-demand.gputechconf.com/gtc-express/2011/presentations/GTC_Express_Sarah_Tariq_June2011.pdf

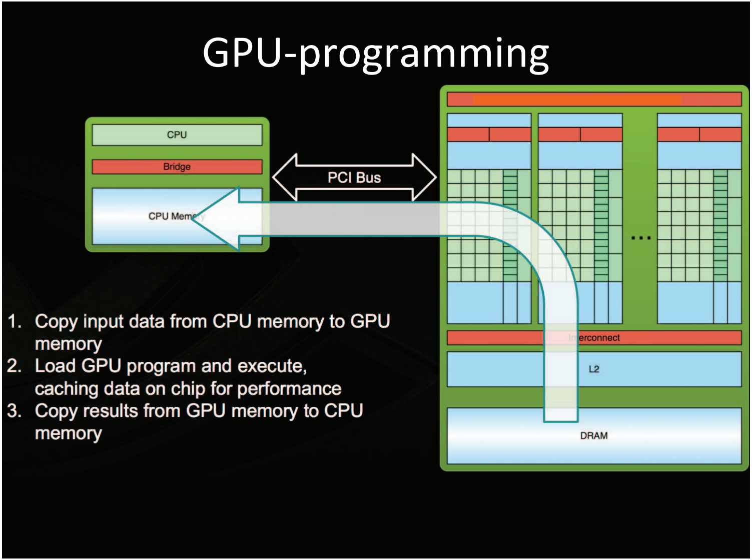
GPGPU programming



GPU-programming

1. Copy input data from CPU memory to GPU memory
2. Load GPU program and execute, caching data on chip for performance

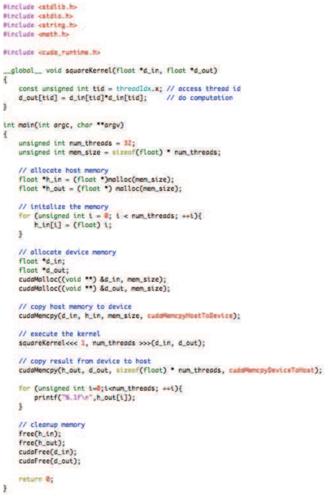
GPGPU programming



GPU-programming

1. Copy input data from CPU memory to GPU memory
2. Load GPU program and execute, caching data on chip for performance
3. Copy results from GPU memory to CPU memory

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 num_threads = 32;
    unsigned int mem_size    = num_threads*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<num_threads; ++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, num_threads>>>(d_in, d_out);

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

    // print result
    for(unsigned int i=0; i<num_threads; ++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);
}
int main() { ...
    unsigned long int elapsed;
    struct timeval t_start, t_end, t_diff;
    gettimeofday(&t_start, NULL);

    // execute the kernel
    squareKernel<<< 1, num_threads>>>(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;
    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))^6` *to the array* `[0,1,..., 32756]` *and writes the result to a file*

This shouldn't be a problem given the shown program (just adapt the kernel a bit), except that:

- except that CUDA won't accept a block of size 32757
  - a *CUDA warp* is formed by 32 threads that execute in SIMD fashion.
  - a *CUDA block* contains a multiple of 32 number of threads (and less than 1024). Synchronization is possible inside a CUDA block by means of barrier.
  - Barrier synchronization is not possible outside the CUDA block (only by finishing the kernel)!
- furthermore if the size of the computation does not exactly matches a multiple of block size, then you need to spawn extra threads, but add an `if` inside the kernel so that the extra threads do no work!

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)

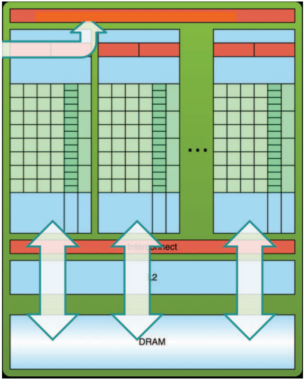
```
From deviceQuery:
 Total amount of global memory:                 3072 MBytes
```

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

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

...

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