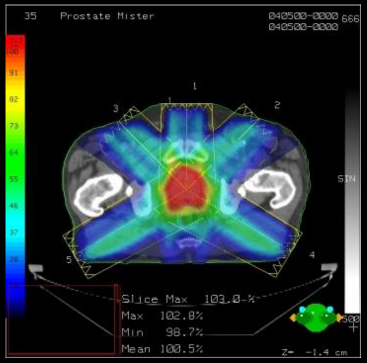
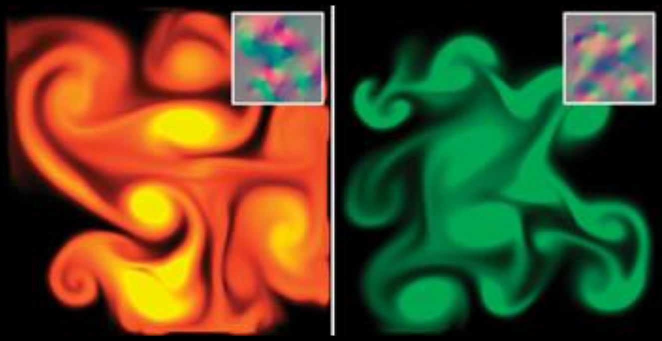
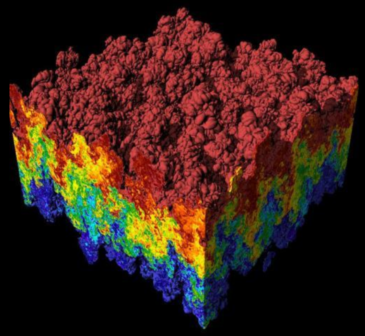
CS 179: GPU Programming

Lecture 1: Introduction







Images: http://en.wikipedia.org
http://www.pcper.com
http://northdallasradiationoncology.com/

Administration

Covered topics:
- (GP)GPU computing/parallelization
- C++ CUDA (parallel computing platform)

TAs:
- cs179.ta@gmail.com for set submission and extension requests
- Aadyot Bhatnagar(abhatnag@caltech.edu)
- Tyler Port (tport@caltech.edu)

Website:
- http://courses.cms.caltech.edu/cs179/

Overseeing Instructor:
- Al Barr (barr@cs.caltech.edu)

Class time:
- ANB 107, MWF 3:00 PM
  - Recitations on Fridays

Course Requirements

Fill out this survey: https://goo.gl/forms/RZiUFBGYs2GKYEFA2

Fill out this when2meet for office hours ASAP: https://www.when2meet.com/?6806202-GXLXT

Homework:

- 6 weekly assignments
- Each worth 10% of grade

Final project:

- 4-week project
- 40% of grade total

P/F Students must receive at least 60% on every assignment AND the final project

Homework

Due on Wednesdays before class (3PM)

First set out April 4th, due April 11th

Collaboration policy:

- Discuss ideas and strategies freely, but all code must be your own
- Do not look up prior years solutions or reference solution code from github without prior TA approval

Office Hours: Located in ANB 104

- Times: TBA (will be announced before first set is out)

Extensions

- Ask a TA for one if you have a valid reason

Projects

Topic of your choice

- We will also provide many options

Teams of up to 2 people

- 2-person teams will be held to higher expectations

Requirements

- Project Proposal
- Progress report(s) and Final Presentation
- More info later…

Machines

Primary GPU machines available

- Currently being setup. You will receive a user account after emailing cs179.ta@gmail.com
- Titan: titan.cms.caltech.edu (SSH and Mosh available)
- Haru: haru.cms.caltech.edu
- Maki: maki.caltech.edu

Secondary machines

- mx.cms.caltech.edu
- minuteman.cms.caltech.edu
- These use your CMS login
- NOTE: Not all assignments work on these machines

Change your password from the temp one we send you

- Use *passwd* command

Machines

Alternative: Use your own machine:

- Must have an NVIDIA CUDA-capable GPU
- Virtual machines won't work
  - Exception: Machines with I/O MMU virtualization and certain GPUs
- Special requirements for:
  - Hybrid/optimus systems
  - Mac/OS X

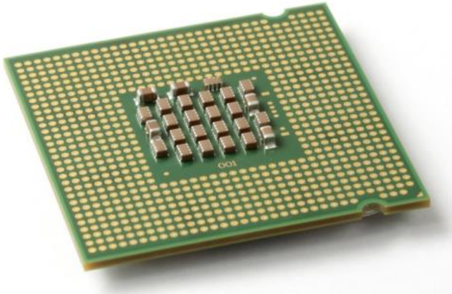
Setup guide on the website is outdated. Do not follow 2016 instructions

The CPU

The "Central Processing Unit"

Traditionally, applications use CPU for primary calculations

- General-purpose capabilities
- Established technology
- Usually equipped with 8 or less powerful cores
- Optimal for concurrent processes but not large scale parallel computations



Wikimedia commons: Intel_CPU_Pentium_4_640_Prescott_bottom.jpg

The GPU

The "Graphics Processing Unit"

Relatively new technology designed for parallelizable problems

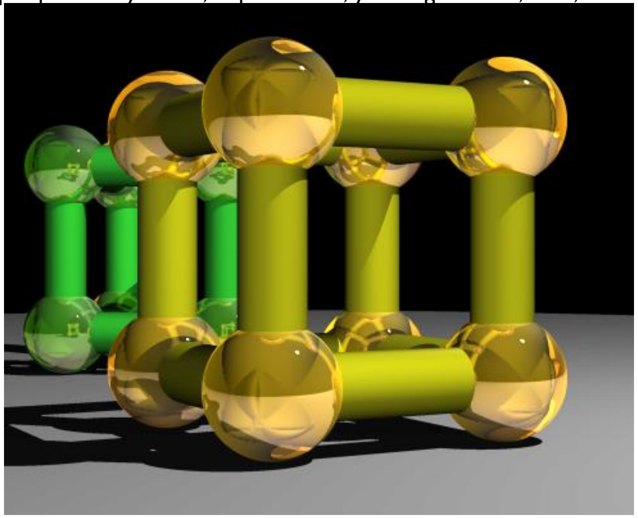
- Initially created specifically for graphics
- Became more capable of general computations

GPUs – The Motivation

Raytracing:

```
for all pixels (i,j):
    Calculate ray point and direction in 3d space
    if ray intersects object:
      calculate lighting at closest object
      store color of (i,j)
```

Superquadric Cylinders, exponent 0.1, yellow glass balls, Barr, 1981



EXAMPLE

Add two arrays

- A[ ] + B[ ] -> C[ ]

On the CPU:

```
float *C = malloc(N * sizeof(float));
for (int i = 0; i < N; i++)
C[i] = A[i] + B[i];
return C;
```

This operates sequentially… can we do better?

A simple problem…

- On the CPU (multi-threaded, pseudocode):

```
(allocate memory for C)
Create # of threads equal to number of cores on processor
(around 2, 4, perhaps 8)
(Indicate portions of A, B, C to each thread...)

...

In each thread,
For (i from beginning region of thread)
C[i] <- A[i] + B[i]
//lots of waiting involved for memory reads, writes, ...
Wait for threads to synchronize...
```

This is slightly faster – 2-8x (slightly more with other tricks)

A simple problem…

- How many threads? How does performance scale?
- Context switching:
  - The action of switching which thread is being processed
  - High penalty on the CPU
  - Not an issue on the GPU

A simple problem…

- On the GPU:

```
(allocate memory for A, B, C on GPU)
Create the “kernel” – each thread will perform one (or a few)
additions
    Specify the following kernel operation:

    For all i‘s (indices) assigned to this thread:
            C[i] <- A[i] + B[i]

Start ~20000 (!) threads
Wait for threads to synchronize...
```

GPU: Strengths Revealed

- Emphasis on parallelism means we have lots of cores
- This allows us to run many threads simultaneously with no context switches

GPU Computing: Step by Step

- Setup inputs on the host (CPU-accessible memory)
- Allocate memory for outputs on the host
- Allocate memory for inputs on the GPU
- Allocate memory for outputs on the GPU
- Copy inputs from host to GPU
- Start GPU kernel (function that executed on gpu)
- Copy output from GPU to host

NOTE: Copying can be asynchronous, and unified memory management is available

The Kernel

- Our “parallel” function
- Given to each thread
- Simple implementation:

```
__global__ void
cudaAddVectorsKernel(float * a, float * b, float * c) {
    //Decide an index somehow
    c[index] = a[index] + b[index];
}
```

Indexing

```
__global__ void
cudaAddVectorsKernel(float * a, float * b, float * c) {
    unsigned int index = blockIdx.x * blockDim.x + threadIdx.x;
    c[index] = a[index] + b[index];
}
```

https://cs.calvin.edu/courses/cs/374/CUDA/CUDA-Thread-Indexing-Cheatsheet.pdf
https://en.wikipedia.org/wiki/Thread_block

Calling the Kernel

```
void cudaAddVectors(const float* a, const float* b, float* c, size){
    //For now, suppose a and b were created before calling this function

    // dev_a, dev_b (for inputs) and dev_c (for outputs) will be
    // arrays on the GPU.

    float * dev_a;
    float * dev_b;

    float * dev_c;

    // Allocate memory on the GPU for our inputs:
    cudaMalloc((void **) &dev_a, size*sizeof(float));
    cudaMemcpy(dev_a, a, size*sizeof(float), cudaMemcpyHostToDevice);

    cudaMalloc((void **) &dev_b, size*sizeof(float)); // and dev_b
    cudaMemcpy(dev_b, b, size*sizeof(float), cudaMemcpyHostToDevice);


    // Allocate memory on the GPu for our outputs:
    cudaMalloc((void **) &dev_c, size*sizeof(float));
```

Calling the Kernel (2)

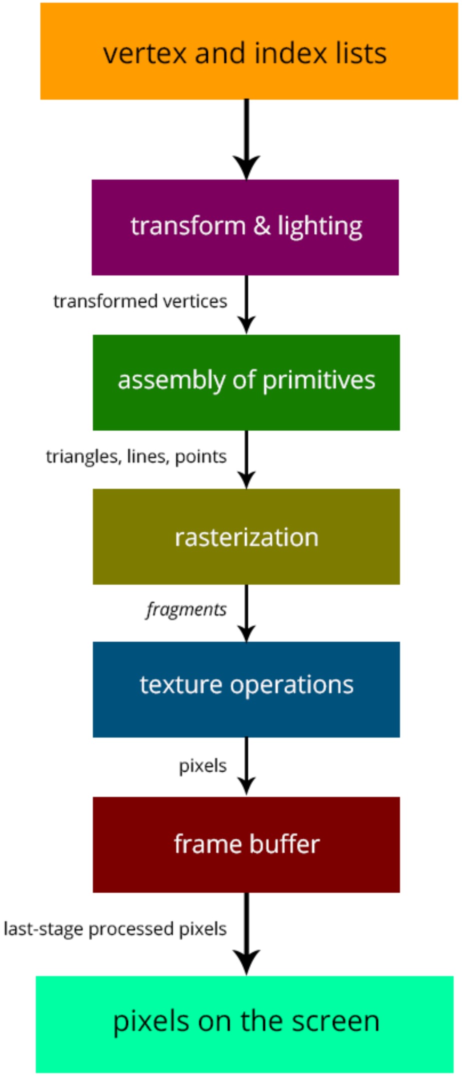
```
    //At lowest, should be 32
    //Limit of 512 (Tesla), 1024 (newer)
    const unsigned int threadsPerBlock = 512;

    //How many blocks we'll end up needing
    const unsigned int blocks = ceil(size/float(threadsPerBlock));

    //Call the kernel!
    cudaAddVectorsKernel<<<blocks, threadsPerBlock>>>
        (dev_a, dev_b, dev_c);

    //Copy output from device to host (assume here that host memory
    //for the output has been calculated)

    cudaMemcpy(c, dev_c, size*sizeof(float), cudaMemcpyDeviceToHost);

    //Free GPU memory
    cudaFree(dev_a);
    cudaFree(dev_b);
    cudaFree(dev_c);
}
```

Questions?

GPUs – Brief History

- Initially based on graphics focused fixed-function pipelines
  - Pre-set functions, limited options

http://gamedevelopment.tutsplus.com/articles/the-end-of-fixed-function-rendering-pipelines-and-how-to-move-on--cms-21469
Source: Super Mario 64, by Nintendo



GPUs – Brief History

- Shaders
  - Could implement one's own functions!
  - GLSL (C-like language)
  - Could "sneak in" general-purpose programming!
  - Vulkan/OpenCL is the modern multiplatform general purpose GPU compute system, but we won't be covering it in this course

http://minecraftsix.com/glsl-shaders-mod/

GPUs – Brief History

"General-purpose computing on GPUs" (GPGPU)

- Hardware has gotten good enough to a point where it's basically having a mini-supercomputer

CUDA (Compute Unified Device Architecture)

- General-purpose parallel computing platform for NVIDIA GPUs

Vulkan/OpenCL (Open Computing Language)

- General heterogenous computing framework

Both are accessible as extensions to various languages

- If you're into python, checkout Theano, pyCUDA.