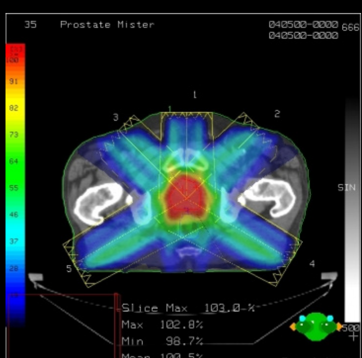
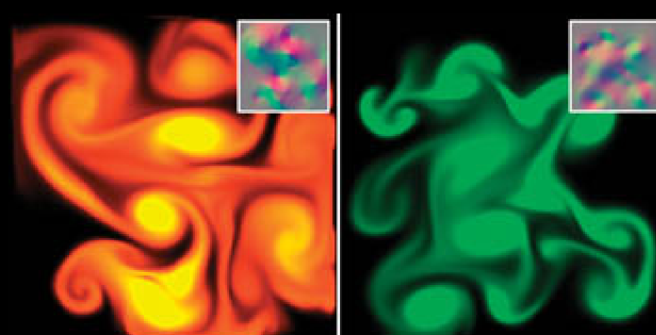
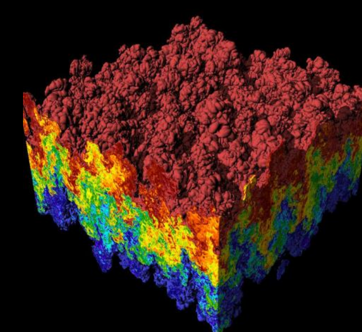
CS 179:
Introduction to GPU Programming.

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:

- George Stathopoulos (gstathop@caltech.edu)
- Ethan Jaszewski (ejaszews@caltech.edu)
- Alden Rogers (abrogers@caltech.edu)

Primary Website (still being updated):

- http://courses.cms.caltech.edu/cs179/
- http://www.piazza.com/caltech/spring2020/cs179
  - Piazza is the primary forum for the course! Make sure you're enrolled!
- Also perhaps information on Moodle. See link on main webpage.

Overseeing Instructor:

- Al Barr (barr@cs.caltech.edu)

Class time:

- Course is ONLINE. No real-time classes. Everything should be on the Primary Website, plus Piazza. TA office hours through Zoom.

Course Requirements

Fill out survey on Piazza about the HW submission day.
Also fill out when2meet link on Piazza for desired office hours

Homework:

- 6 assignments, perhaps in 5 weeks due to COVID-19
- Each worth 10% of grade
- ***Also "enough" work before Add Day****, to pass!*

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 nominal class time (3PM)

First set is out April 6th, due Wed April 15th unless survey differs

- Upcoming sets will use survey's due date
- Use zip on remote GPU computer at Caltech to submit HW.

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
- Make your github repository *Private*!

Office Hours: Will be interactive, through Zoom.

- Times: TBA, based on survey. Survey timezone is in PDT.

Extensions

- Ask a TA for one if you have a valid reason
- See main website for details.

Your GPU Project

Project can be a 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…

Caltech Machine and your accounts now available.

The Primary GPU machine is now set up and available

- You should have received a user account in email.
- Please test access and change your password.
- GPU-enabled machine is on the Caltech campus.
- Let us know if you have problems. You'll be submitting HW on this computer.

Secondary CMS GPU machines are no longer operational.

Alternative GPU Machines

Alternative: Use your own machine.

You will still have to submit HW on the Caltech GPU machine.

- Must have an NVIDIA CUDA-capable GPU
  - At least Compute 3.0
- Virtual machines generally won't work
  - Exception: Machines with I/O MMU virtualization and certain GPUs
- Special requirements for:
  - Hybrid/Optimus systems (laptops)
  - Mac/OS X

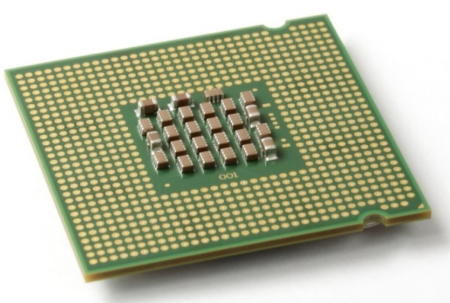
Setup guide on the website is likely outdated. Can follow NVIDIA's posted 2019 installation instructions (linked on page). Ubuntu 20.04 will be easiest to install!

The CPU

The "Central Processing Unit"

Traditionally, applications use CPU for primary calculations

- General-purpose capabilities, mostly sequential operations
- Established technology
- Usually equipped with 8 or fewer, powerful cores
- Optimal for some types of 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
- Very fast and powerful, computationally
- Uses lots of electrical power

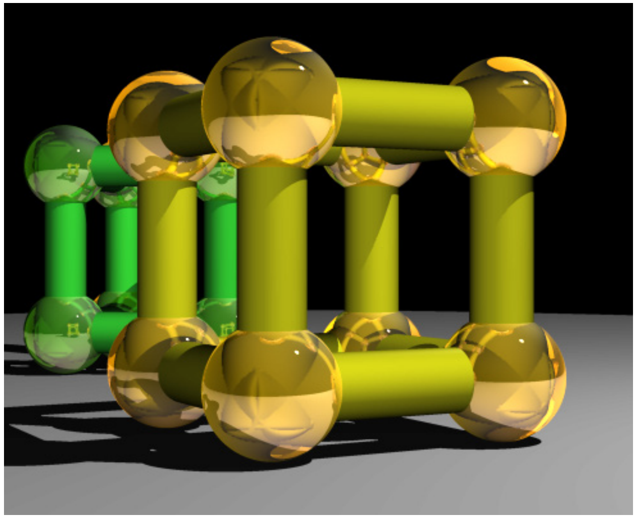
GPUs – The Motivation

Raytracing:

```
for all pixels (i,j) in image:
    From camera eye point,
      calculate ray point and direction in 3d space
    if ray intersects object:
      calculate lighting at closest object point
      store color of (i,j)
Assemble into image file
```

Each pixel could be computed simultaneously, with enough parallelism!

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



SIMPLE 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;
```

*On CPUs the above code operates **sequentially**, but can we do better on CPUs?*

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 are available on the CPUs? How can the performance scale with thread count?

- Context switching:
  - The action of switching which thread is being processed
  - **High penalty** on the CPU (main computer)
  - Not a big 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 all at the same time!
Wait for threads to synchronize...
```

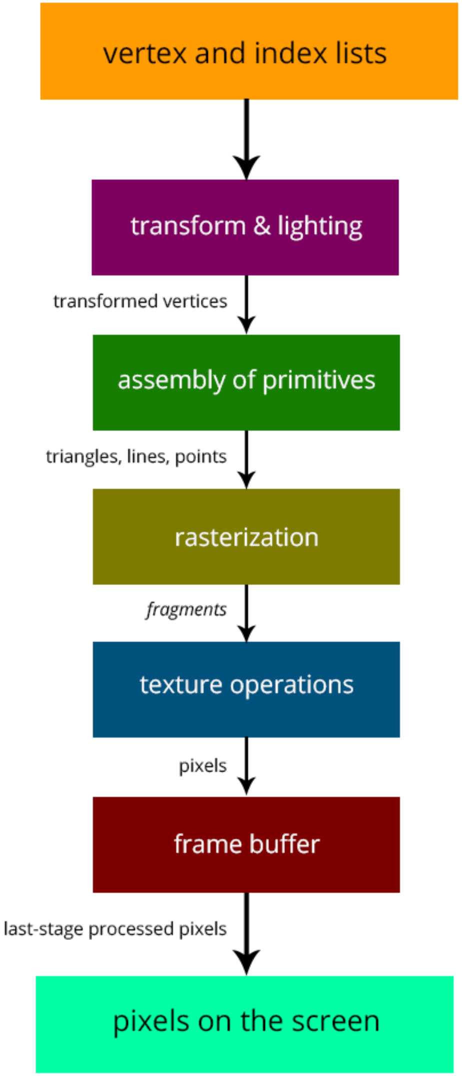
GPU: Strengths Revealed

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

GPUs – Brief History

- Initially based on graphics focused fixed-function pipelines (history)
  - Pre-set pixel/vertex 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
  - Can implement one's own functions using graphics routines.
  - GLSL(C-like language), discussed in CS 171
  - Can "sneak in" general-purpose programming! Uses pixel and vertex operations instead of general purpose code. Very crude.
  - 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/

Using GPUs as “supercomputers”

“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.

Upcoming GPU programming environment: Julia Language

GPU Computing: Step by Step

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

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

The Kernel

- This is our "parallel" function
- Given to each thread
- Simple example, 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);
}
```

GPU Computing Examples

- Solving PDEs on GPUs
- GPU vs CPU fluid mechanics
- Ray Traced Quaternion fractals and Julia Sets
- Deep Learning and GPUs
- Real-Time Signal Processing with GPUs

Questions can be live and interactive, on Zoom during office hours. Also can be posted on Piazza.