CMPSCI 691AD – General Purpose Computation on the GPU

Spring 2009

Lecture 1: Introduction

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Terms you should know...

- CPU: Central Processing Unit
- GPU: Graphics Processing Unit
- GPGPU: General Purpose computation on the GPU
- FLOPS: Floating point Operations Per Second
- GFLOPS: Giga-FLOPS
- CUDA: Compute Unified Device Architecture
- HPC: High Performance Computing

Motivation

- Modern GPUs are massively parallel platform for general-purpose computation.

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- Modern GPUs are massively parallel platform for general-purpose computation.
- The trend of modern microprocessor design:
  - Increase in clock frequency limited by power consumption issues.
  - Virtually all CPU vendors have switched to multi-core and many-core models.
  - Impacts in software development: sequential vs. data-parallel programming.

Parallel Computing

- Moore's Law
  - Transistor count doubles every two years.
  - Increase in transistor count is also a rough measure of computer processing speed.
  - Has been given to everything that changes exponentially.
- New Moore's Law
  - Microprocessors no longer get faster, just wider.

The Ox vs. Chicken Analogy

- Seymour Cray: *If you were plowing a field, which would you rather use: Two strong oxen or 1024 chickens?*

The Ox vs. Chicken Analogy

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- Chicken is winning these days:
  - For many applications, you can run many cores at lower freq and come ahead at the speed game.
  - For example: decrease freq by 20% → 50% cut in power → can add one more dumb core (chicken) → power budget stays the same but with increased performance!

Parallel Computing is *not* New

- High-performance computing community has been developing parallel algorithms for decades.

  However,

- Require exotic, large-scale expensive supercomputers.
- Practice and impact of parallel programming limited.
- Massively parallel machines replaced by clusters of affordable commodity microprocessors

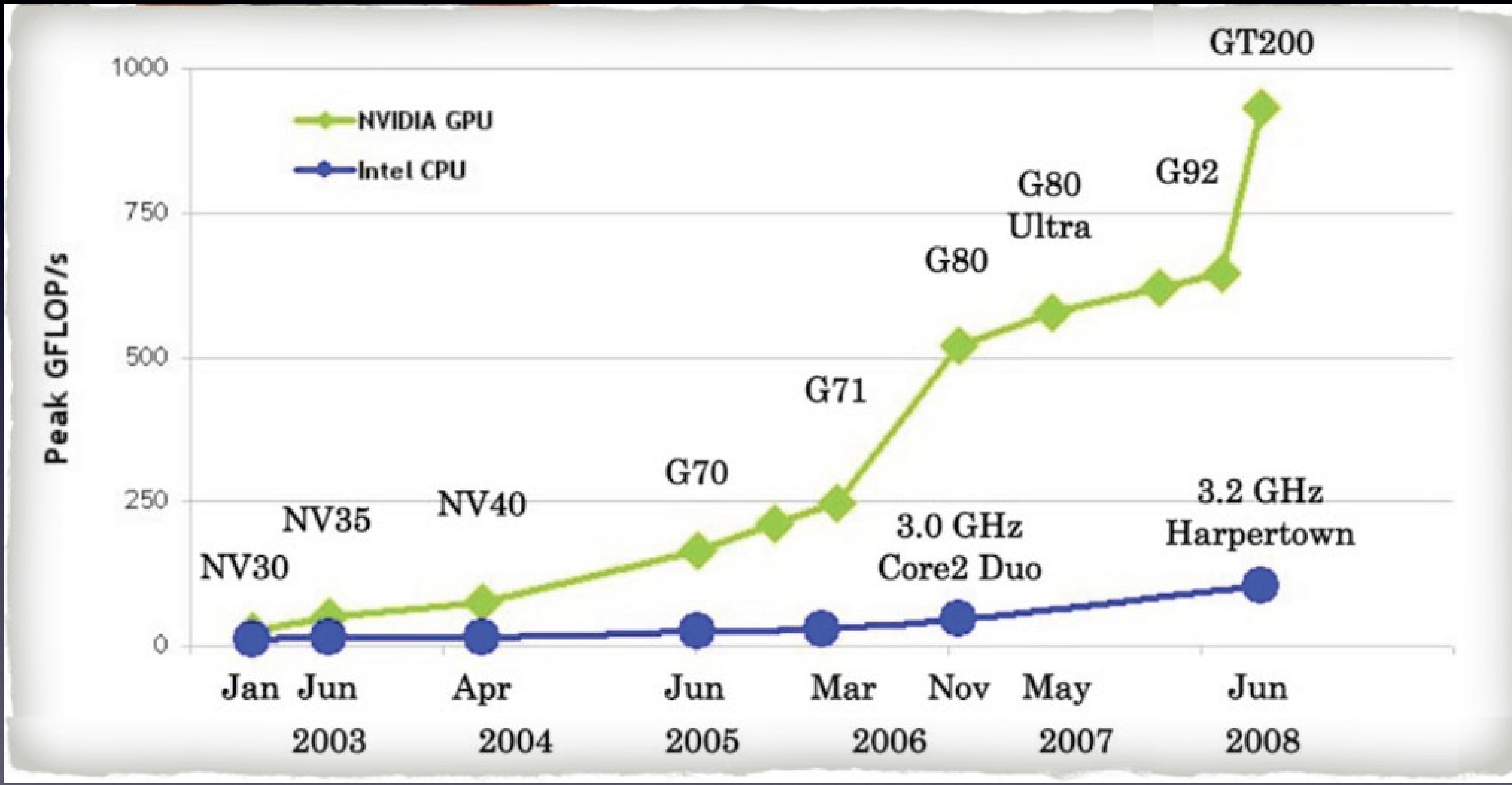
GPUs as Parallel Computers

- GPU = Graphics Processing Unit
  - Video cards, game consoles, mobile phones etc.
  - Two major vendors: NVIDIA and ATI (now AMD)

GPUs as Parallel Computers

- Many-core, High raw computation speed
  - NVIDIA 285 GTX has 240 cores, 1 TFLOPS
  - This compares to modern multi-core CPUs which has 2-8 cores, ~100 GFLOPS

GPU vs. CPU

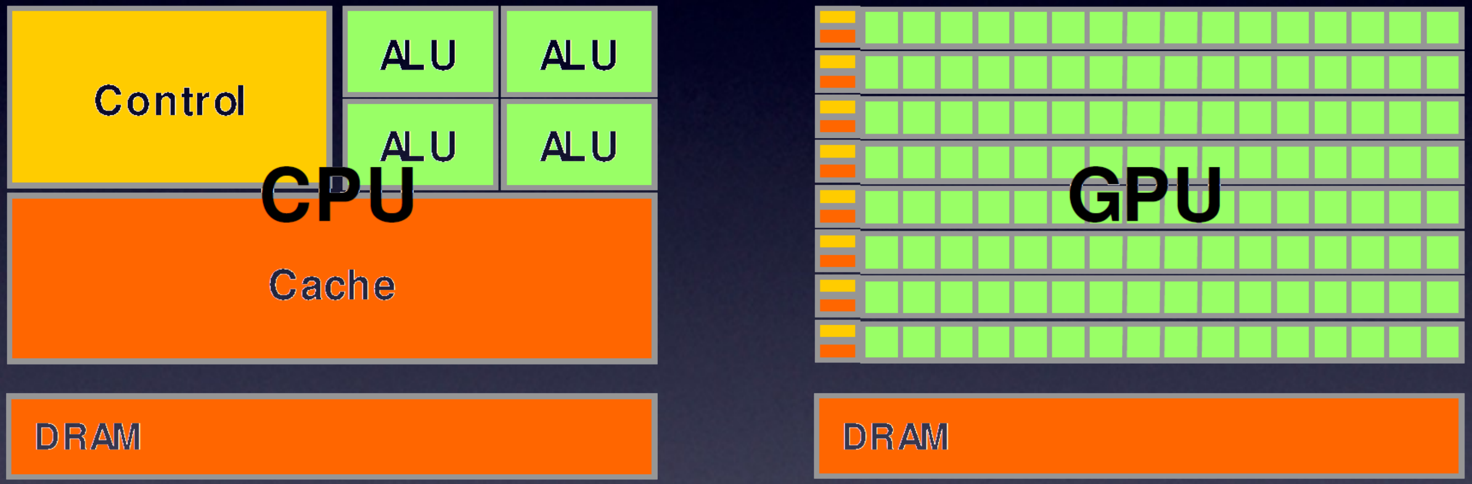

Peak GFLOP/s
1000
750
500
250
0
NVIDIA GPU
Intel CPU
GT200
G92
G80
Ultra
G80
G71
G70
NV40
NV35
NV30
3.2 GHz
Harpertown
3.0 GHz
Core2 Duo
Jan Jun
Apr
Jun
Mar
Nov
May
Jun
2003
2004
2005
2006
2007
2008

GPUs as Parallel Computers

- Many-core, High raw computation speed
  - NVIDIA 285 GTX has 240 cores, 1 TFLOPS
  - This compares to modern multi-core CPUs which has 2-8 cores, ~100 GFLOPS
- High memory bandwidth
  - More than 100GB/s on GPU vs. 10GB/s on CPU
- Users across science and engineering descriplines are achieving 100x or better speedups on GPUs

GPUs as Parallel Computers

- Why such a large performance gap?



- Fundamental differences in design philosophy.

GPUs as Parallel Computers

- GPU design philosophy:
  - Dedicate transistors to maximize FP calculations
  - Simple memory model to maximize bandwidth
  - In contrast, CPUs dedicate large chip area for control logic and memory hierarchies to support complex applications and maximize sequential code performance.
- GPU design driven by the fast growing video game industry.

GPUs as Parallel Computers

- Performance is not the only determining factor.
  - GPUs are becoming popular as parallel processors because they already have a large market share!
  - Over 100 million CUDA-enabled GPUs sold.
  - Relatively low-cost (~$200-400), small form factor

- First time that massively parallel computing is part of a mass-market product.

GPU vs. CPU

- A visual and funny demonstration about the benefits of massively parallel processing on modern GPUs
  - Shown at NVISION 08 by the MythBusters guys

Programming Language Support

- Programs used to be implemented through graphics API → inflexible, and lots of limitations.
- Situation fundamentally changed with the arrival of CUDA → does not go through graphics interface at all.

```
// Sequential Code

void vecAdd(float *v1, float *v2, float *out, int n)
{
    for (int i = 0; i < n; i ++) {

        out[i] = v1[i] + v2[i];

    }

    return;
}
```

Programming Language Support

```
// CUDA Code

__global__ void vecAdd(float *v1, float *v2, float *out, int n)
{
    // get thread index
    int i = blockIdx.x * blockDim.x + threadIdx.x;

    if (i >= n)  return;

    out[i] = v1[i] + v2[i];
}

void main()
{
    vecAdd<<< n/256, 256>>>(v1, v2, out, n);
}
```

GPU Programming Languages

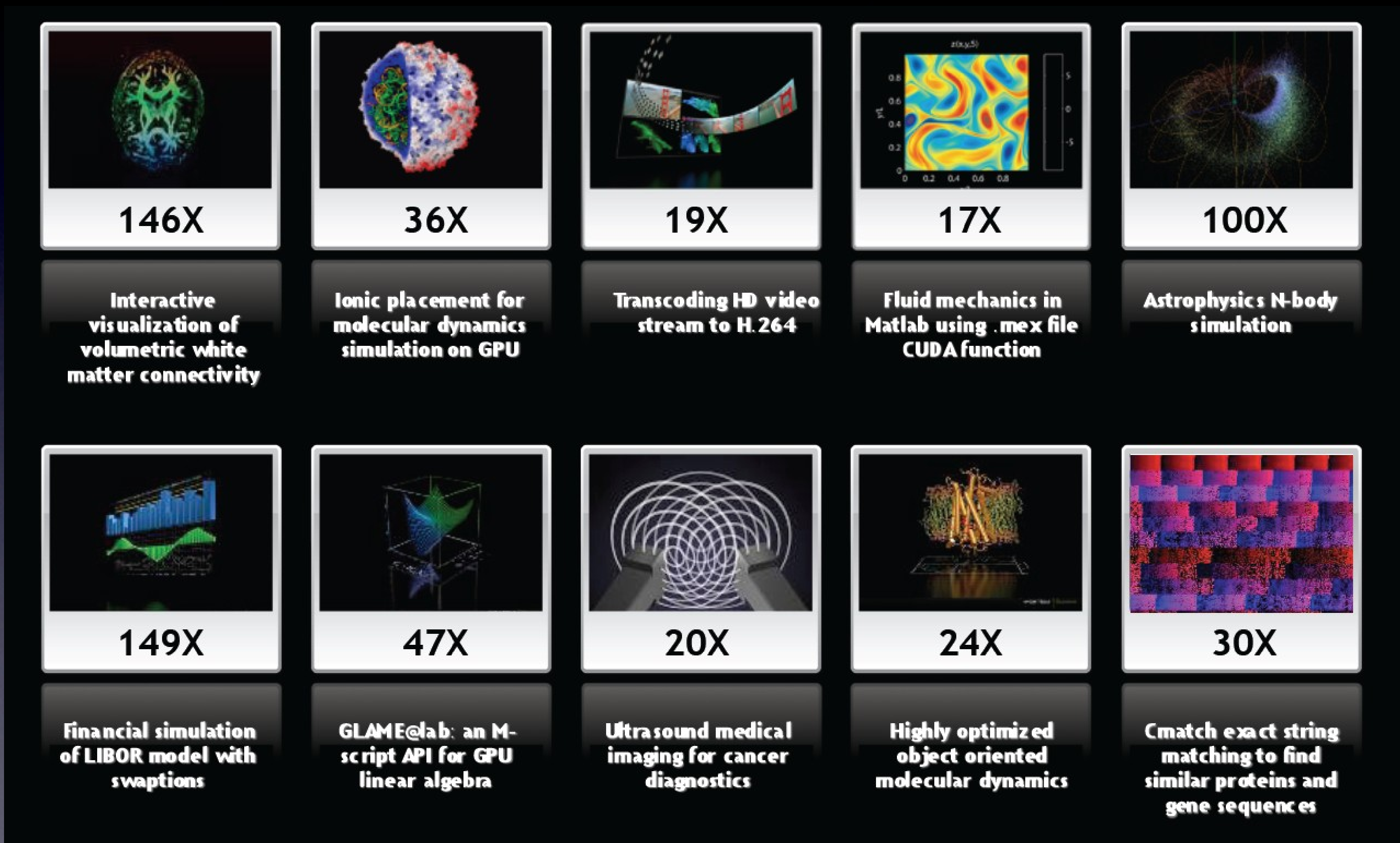
- *Shading Languages*
  - OpenGL shading language (GLSL)
  - DirectX (HLSL)
- *General Purpose*
  - CUDA
  - Brook+
  - OpenCL (Open Computing Language)

Desktop Supercomputing

- *"We've all heard 'desktop supercomputer' claims in the past, but this time it's for real: NVIDIA and its partners will be delivering outstanding performance and broad applicability to the mainstream marketplace."*

Burton Smith, Microsoft
Previously Chief Scientist at Cray

GPGPU Applications



Course Goals

- Learn how to program modern GPUs using CUDA and achieve:
  - High performance
  - Scalability across future generations

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- Learn how to program modern GPUs using CUDA and achieve:
  - High performance
  - Scalability across future generations
- Gain both knowledge and hand-on experience:
  - Programming API, tools, and techniques
  - Principles and patterns for parallel computing
  - Processor architecture features and constraints

Course Schedule

- First Half:
  - Graphics hardware
  - CUDA programming API
  - OpenGL shading language
  - GPGPU optimizations.
- Second Half:
  - Principles, patterns, building blocks for parallel computing
  - Student presentations

Logistics

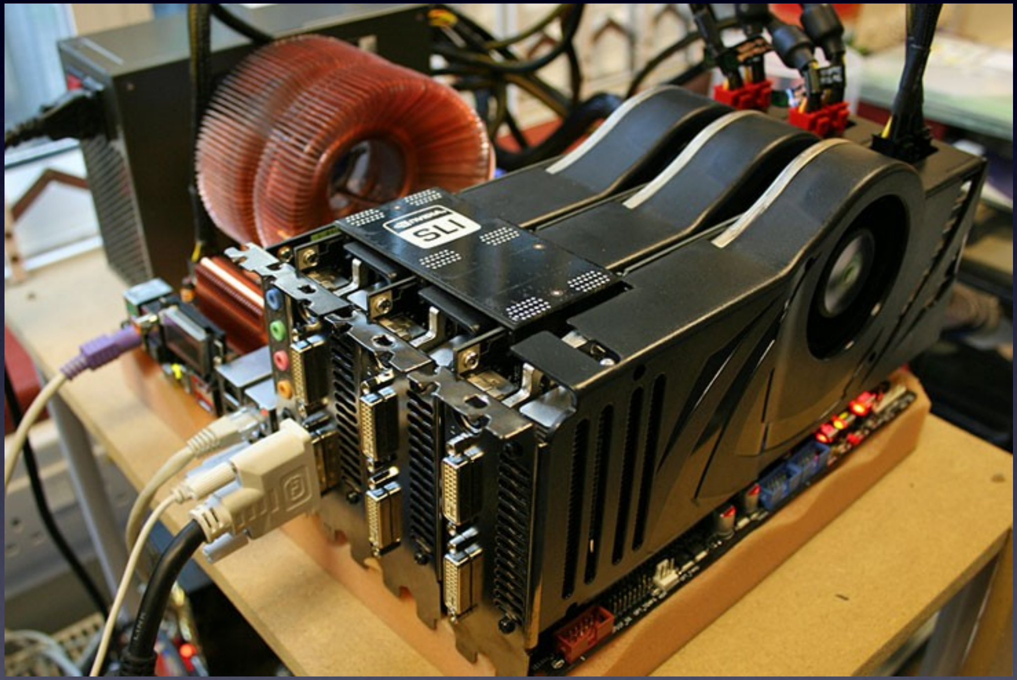
- Time: 2:30—3:45pm TuThu
- Location: LGRT 1322
- Office hours: 4:00—5:00pm TuThu (CS 270)
- Course web page: TWiki
- Course forum: phpBB
- Prerequisites: Familiar with C/C++ programming and data structures

Logistics

- Textbooks: *(Recommended, not required)*
  - NVIDIA CUDA Programming Guide (download)
  - Patterns for Parallel Programming
  - Introduction to Parallel Computing (2nd edition)

Hardware Resources

- List of CUDA-Enabled Hardware



- Linux server: raster.cs.umass.edu (Ubuntu 8.10, 8800 GTS)

Logistics

- Course Workload and Grading:
  - 3 programming assignments: 15% each
  - 1 midterm exam (in-class): 15%
  - 1 final project: 30%
  - Class presentation: 10%
- Final project will be presented in class.

Final Project

- Pick a nontrivial computational problem of your own choice, implement an efficient, GPU-based solution

Final Project

- Pick a nontrivial computational problem of your own choice, implement an efficient, GPU-based solution
- *Computer Vision and Graphics*
  SIFT extraction, object recognition, Kalman filter...
  Ray tracing, photon mapping, volume rendering...
- *Numerical and Physical Simulation*
  Fluid dynamics, heat transfer, Monte Carlo methods,
  Astrophysics, electrodynamics, sparse linear algebra...
- *Life Science, Medical Imaging*
  Molecular dynamics, MRI image registration, segmentation,
  Protein folding, string matching...

Policies

- Assignments may be discussed with classmates, but you must implement your own solutions.
- Final project is to be completed by each student independently. You may discuss with other students, but you may not share code with each other.
- To cope with unforeseen circumstances, you are allowed five late days in total during the entire semester.
- No late day is permitted for final project.

Keep in Mind

- First time this course is offered
  - There will be rough edges
  - Concepts that need more explanations
  - Questions that I don't have immediate answers
- Questions/comments/feedbacks are all welcome and encouraged.

Warm-up Assignment

- Setup CUDA programming environment
  - Install CUDA driver, toolkit, SDK (2.0 or 2.1)
  - (Links on the class webpage)

Warm-up Assignment

- Setup CUDA programming environment
  - Install CUDA driver, toolkit, SDK
- Study CUDA SDK examples
- Compile a few examples, fix problem if any
- Use CUDA template for creating your own project
  - CUDA code is compiled with ***nvcc***

Warm-up Assignment

- *nvcc* basics
  - Code (.cu, .cpp, etc.) is separated into
    - host (CPU) code
    - device (GPU) code
  - Link with necessary libraries
    - cuda, cudart, cutil, cudpp …
  - Supports device emulate mode
    - threads are created and emulated on host side
    - very handy for debugging