NVIDIA TECHNOLOGY

Mark Ebersole

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- ACM Tech Packs on top current computing topics: Annotated Bibliographies compiled by subject experts
- Popular video tutorials/keynotes from ACM Digital Library, A.M. Turing Centenary talks/panels
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- Submit questions and comments via Twitter to @acmeducation – we're reading them!

NVIDIA®

Founded in 1993

Jen-Hsun Huang is co-founder and CEO

Listed with NASDAQ under the symbol NVDA in 1999

Invented the GPU in 1999;
shipped more than 1 billion to date

FY13: $4.3 billion in revenue

8,500 employees worldwide

6,400 patent assets

Headquartered in Santa Clara, Calif.

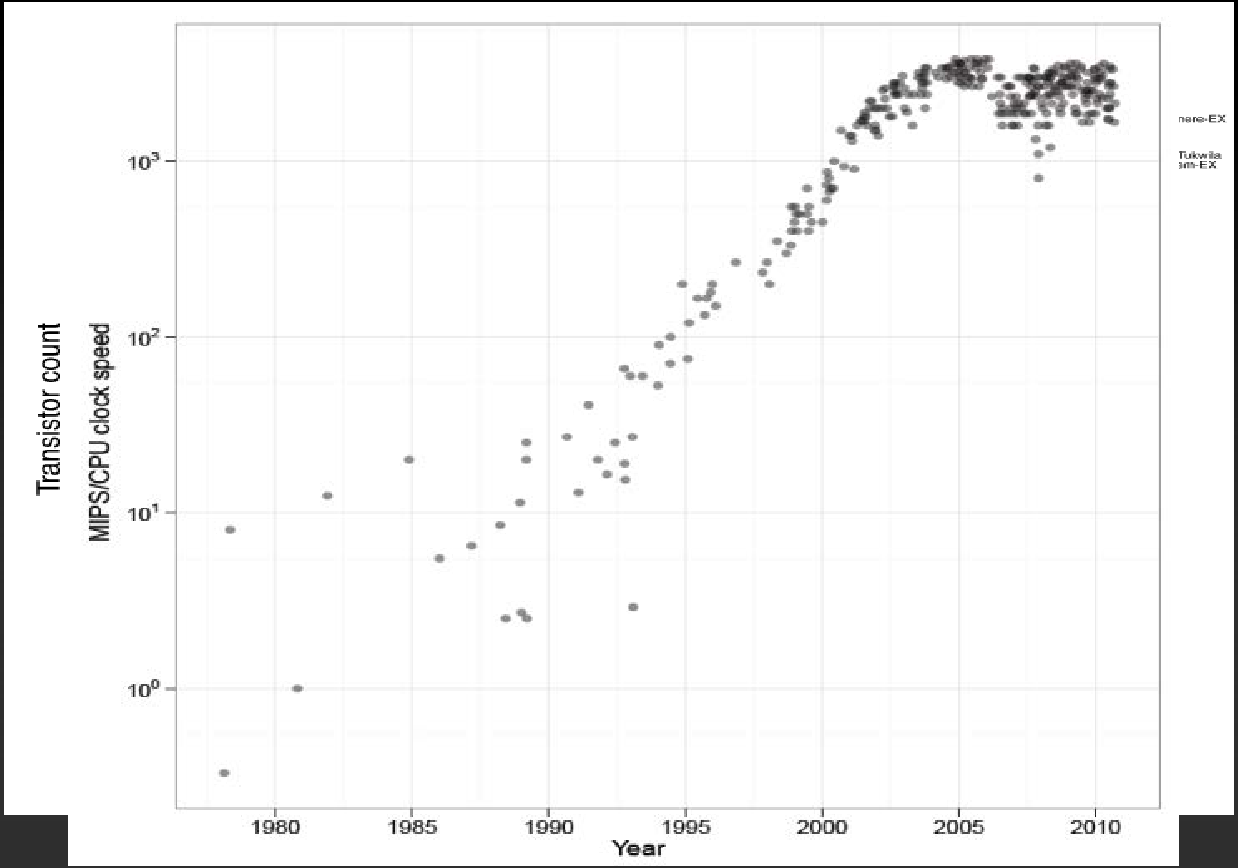
My Three Points

1. What is Accelerated Computing?

2. The Why and How of GPUs

3. Resources

Moore's Law


Transistor count
MIPS/CPU clock speed
10^3
10^2
10^1
10^0
1980
1985
1990
1995
2000
2005
2010
Year
Tukwila

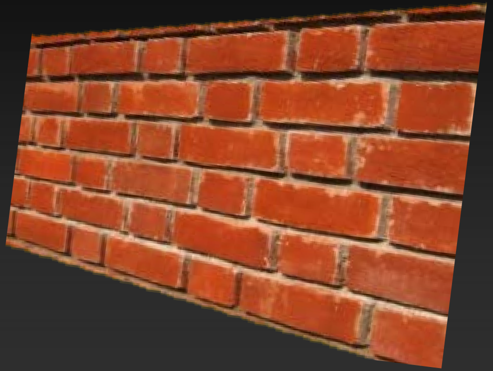
What makes up the brick wall?

Power Wall

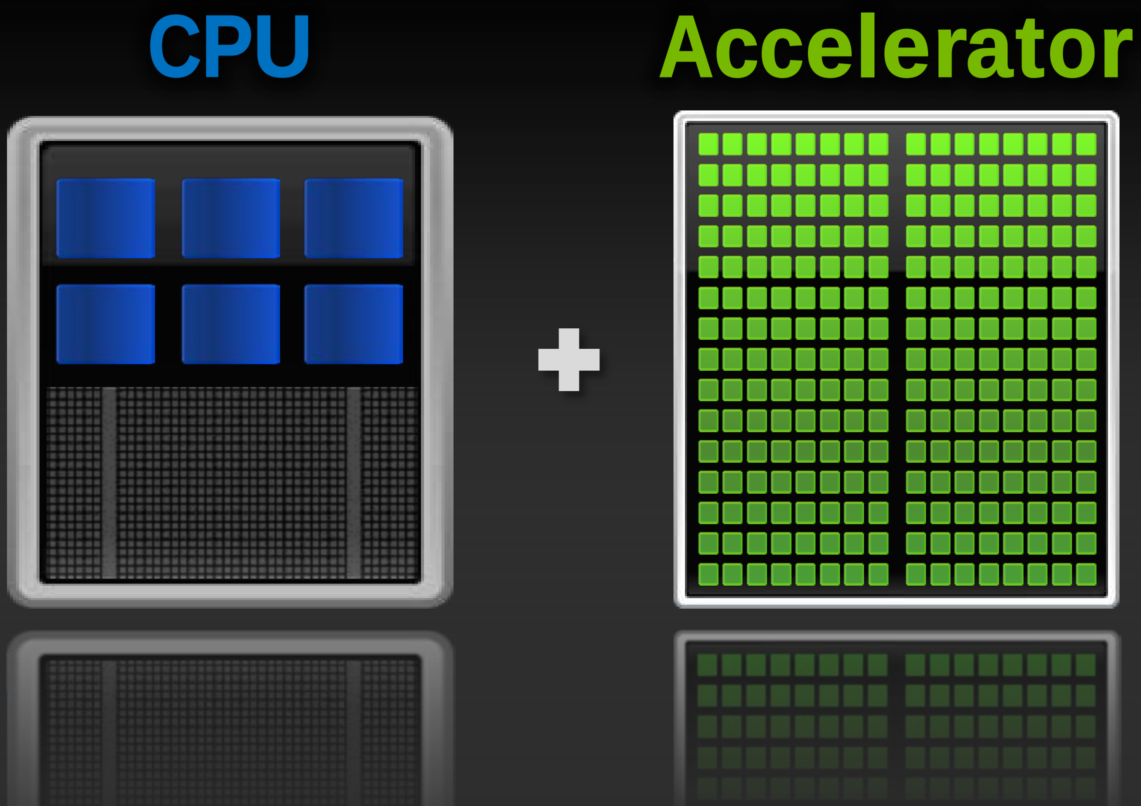
Memory Wall

\+ ILP Wall

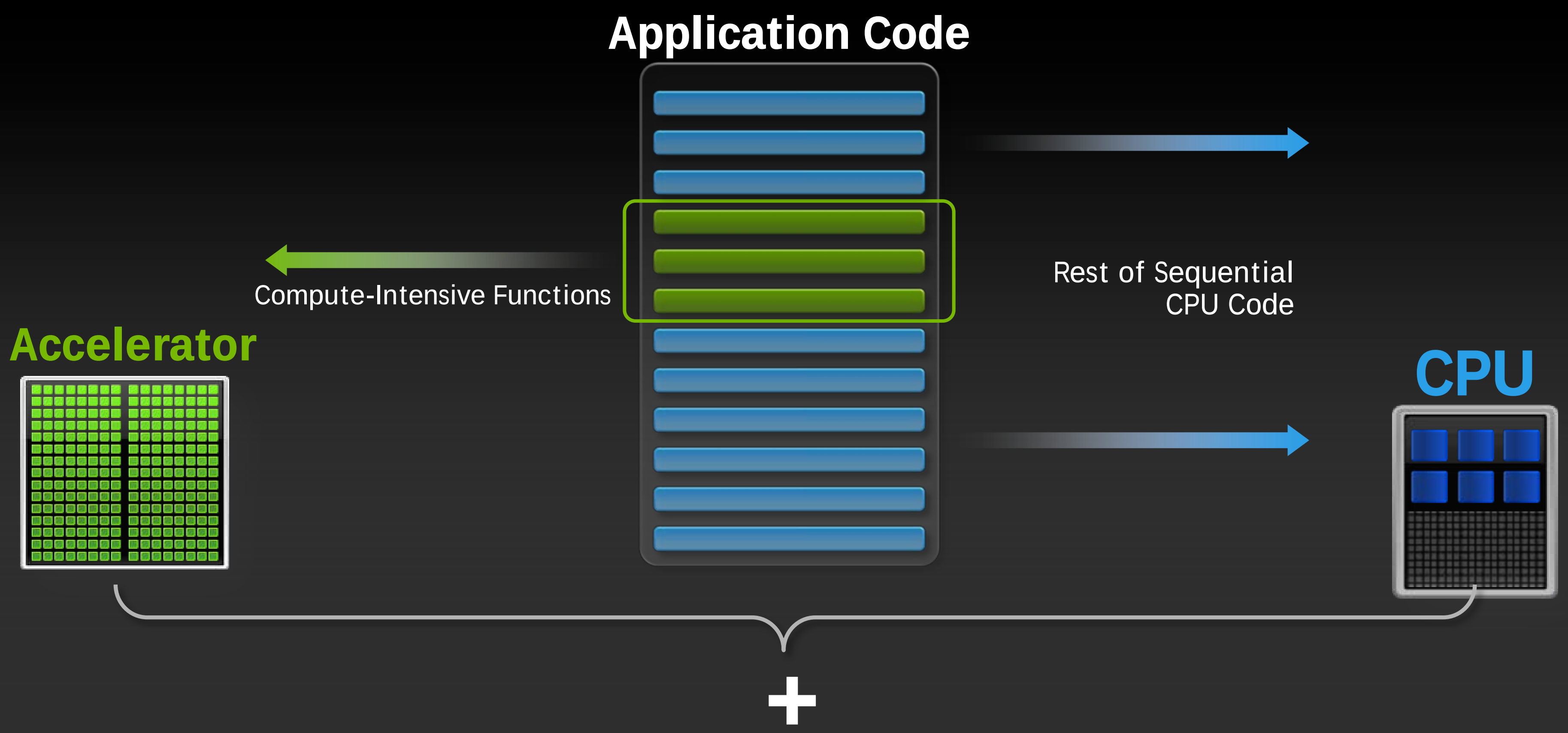
= Brick Wall



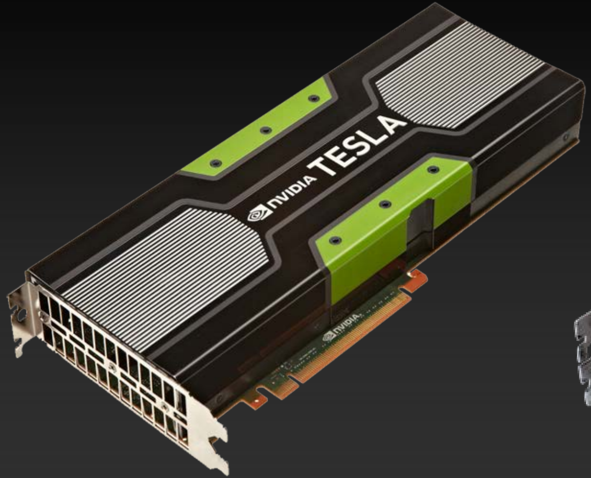
Heterogeneous Computing



The basic idea



Three Major Accelerators

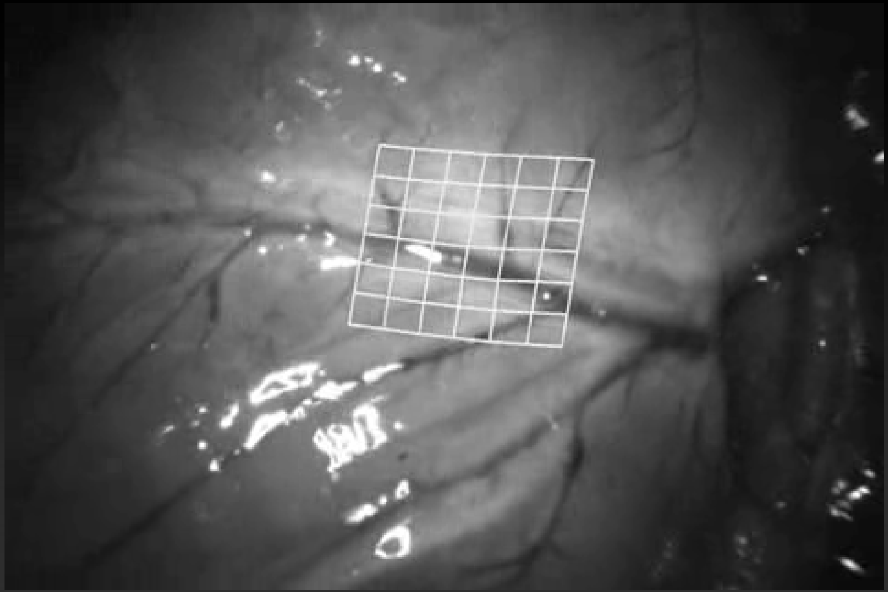


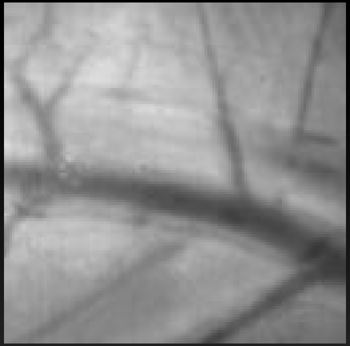
From Phones to Cars

DIAGNOSTIC IMAGING PERFORMANCE

Real-Time Image Reconstruction with GPUs.

Operating on a Beating Heart





Only 2% of surgeons will operate on a beating heart

Patient stands to lose 1 point of IQ every10 min with heart stopped

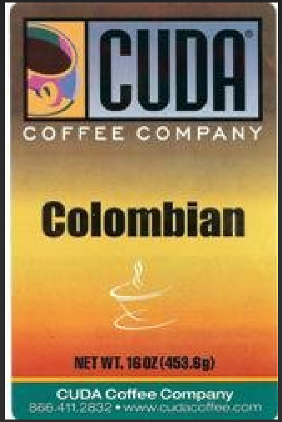
GPU enables real-time motion compensation to virtually stop beating heart for surgeons

Courtesy Laboratoire d'Informatique de Robotique et de Microelectronique de Montpellier

How do I use GPUs?

What is CUDA?

- Programming language?
- Compiler?
- Classic car?
- Beer?
- Wine?
- Coffee?



CUDA Parallel Computing Platform

www.nvidia.com/getcuda

Programming Approaches

Libraries	Directives	Programming Languages
"Drop-in" Acceleration	Easily Accelerate Apps	Maximum Flexibility

Development Environment

Nsight IDE
Linux, Mac and Windows
GPU Debugging and Profiling

CUDA-GDB debugger
NVIDIA Visual Profiler

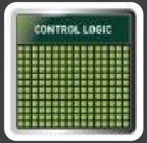
Open Compiler Tool Chain

LLVM COMPILER INFRASTRUCTURE

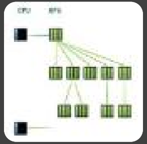
Enables compiling new languages to CUDA platform, and CUDA languages to other architectures

Hardware Capabilities

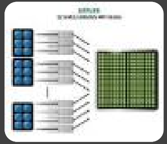
SMX



Dynamic Parallelism



HyperQ



GPUDirect

Growth of GPU Computing

100M
CUDA –Capable GPUs

150K
CUDA Downloads

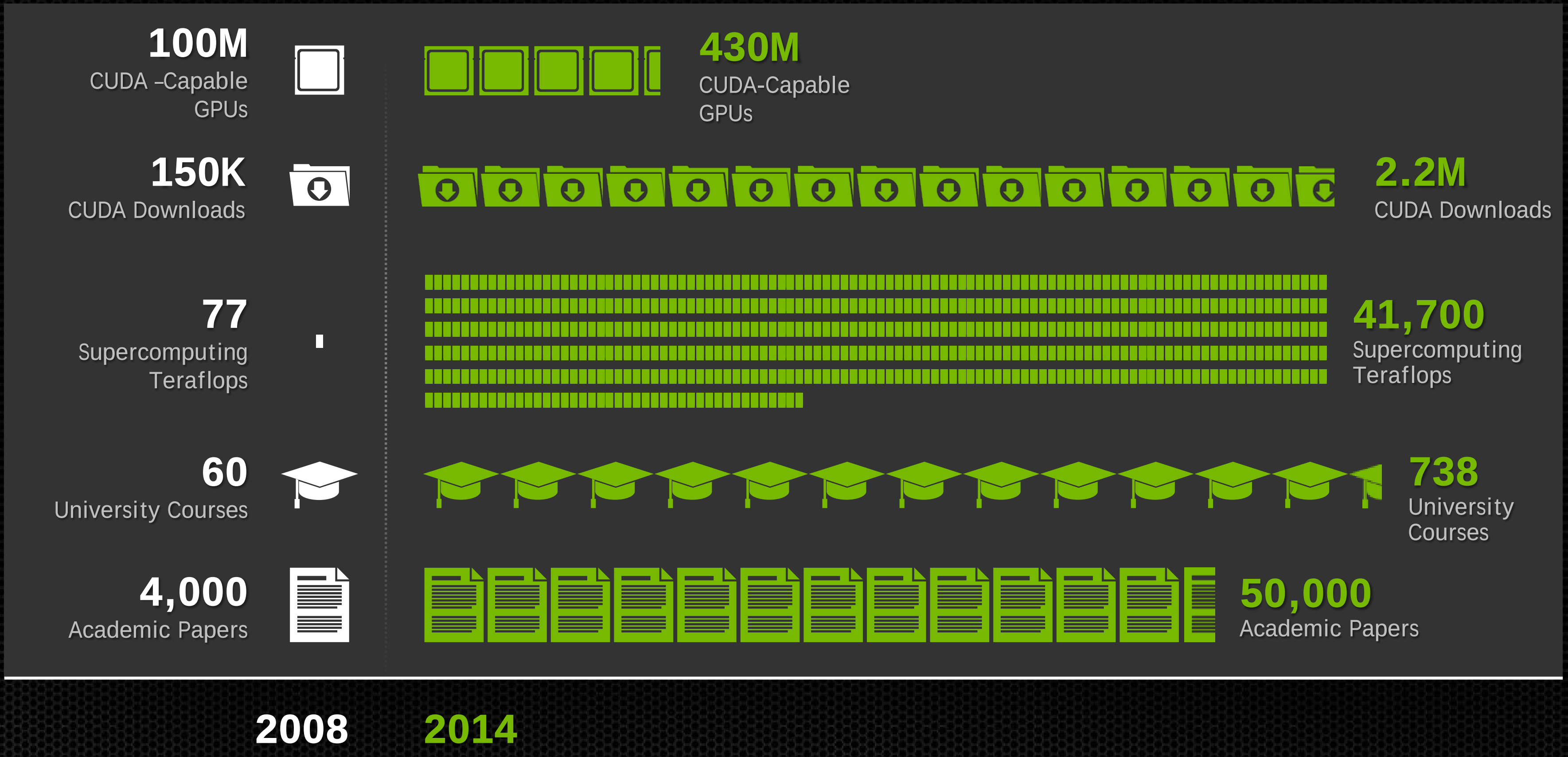
77
Supercomputing Teraflops

60
University Courses

4,000
Academic Papers

2008

Growth of GPU Computing



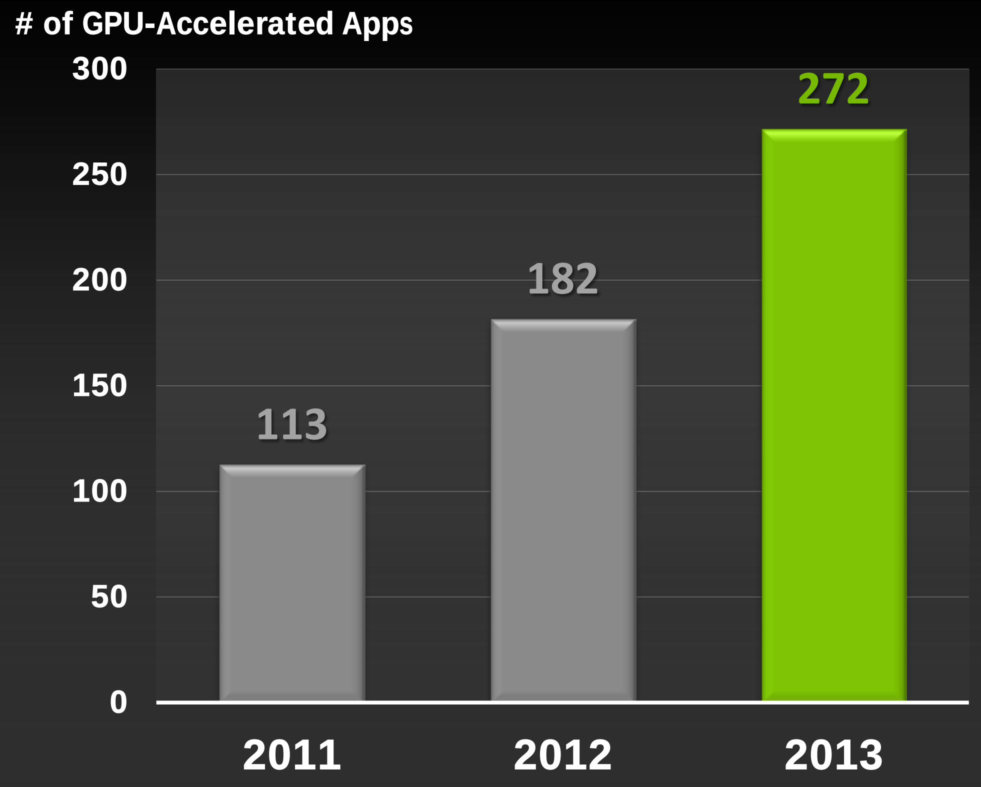
3 Ways to Accelerate Applications

NVIDIA

Applications

Libraries	Directives	Programming Languages
"Drop-in" Acceleration	Easily Accelerate Applications	Maximum Flexibility

Solid Growth of GPU Accelerated Apps



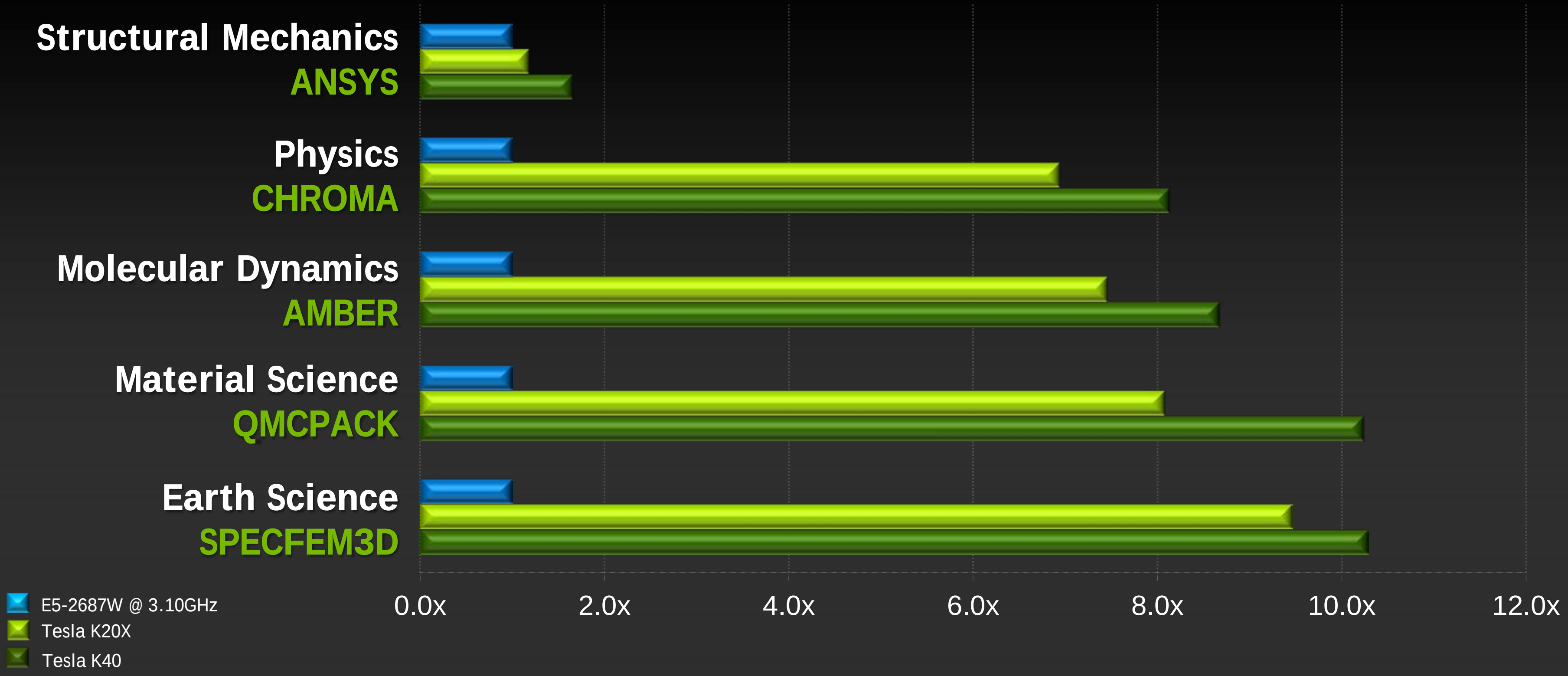
Top HPC Applications

Molecular Dynamics	AMBER CHARMM DESMOND	GROMACS LAMMPS NAMD
Quantum Chemistry	Abinit Gaussian	GAMESS NWChem
Material Science	CP2K QMCPACK	Quantum Espresso VASP
Weather & Climate	COSMO GEOS-5 HOMME	CAM-SE NEMO NIM WRF
Lattice QCD	Chroma	MILC
Plasma Physics	GTC	GTS
Structural Mechanics	ANSYS Mechanical LS-DYNA Implicit MSC Nastran	OptiStruct Abaqus/Standard
Fluid Dynamics	ANSYS Fluent	Culises (OpenFOAM)

Accelerated, In Development


NVIDIA
POPULAR GPU-ACCELERATED APPLICATIONS
Research: Higher Education and Supercomputing
COMPUTATIONAL CHEMISTRY AND BIOLOGY
Bioinformatics
Molecular Dynamics
Defense and Intelligence
Computational Finance
Manufacturing: CAD and CAE
Media and Entertainment
Oil and Gas
02 Research: Higher Education and Supercomputing
06 Defense and Intelligence
07 Computational Finance
08 Manufacturing: CAD and CAE
10 Media and Entertainment
14 Oil and Gas
NVIDIA
270+ GPU-Accelerated Applications
www.nvidia.com/appscatalog

Performance on Leading Scientific Applications



3 Ways to Accelerate Applications

Applications

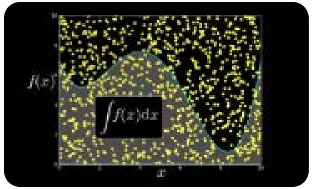
Libraries	Directives	Programming Languages
"Drop-in" Acceleration	Easily Accelerate Applications	Maximum Flexibility

Programming with CUDA

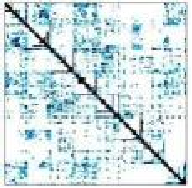
GPU Accelerated Libraries

“Drop-in” Acceleration for your Applications

NVIDIA cuBLAS



NVIDIA cuRAND



NVIDIA cuSPARSE

NVIDIA NPP

GPU VSIPL

Vector Signal Image Processing

CULA tools

GPU Accelerated Linear Algebra

MAGMA

Matrix Algebra on GPU and Multicore

open source initiative

NVIDIA cuFFT

ROGUE WAVE SOFTWARE

IMSL Library

ArrayFire Matrix Computations

CUSP

Sparse Linear Algebra

open source initiative

Thrust

C++ STL Features for CUDA

open source initiative

Thrust C++ Template Library

Serial C++ Code

with STL and Boost

```
int N = 1<<20;
std::vector<float> x(N), y(N);

...




// Perform SAXPY on 1M elements
std::transform(x.begin(), x.end(),
               y.begin(), y.end(),
                2.0f * _1 + _2);
```

www.boost.org/libs/lambda

Parallel C++ Code

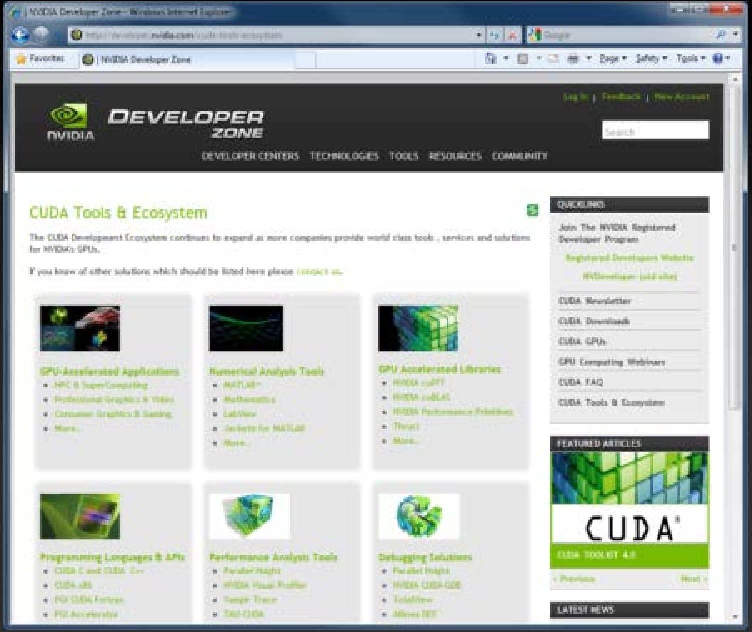
```
int N = 1<<20;
thrust::host_vector<float> x(N), y(N);

...

thrust::device_vector<float> d_x = x;
thrust::device_vector<float> d_y = y;


// Perform SAXPY on 1M elements
thrust::transform(d_x.begin(), d_x.end(),
                  d_y.begin(), d_y.begin(),
                  2.0f * _1 + _2);
```

thrust.github.com

Explore the CUDA (Libraries) Ecosystem

- **CUDA Tools and Ecosystem described in detail on NVIDIA Developer Zone:**

  developer.nvidia.com/cuda-tools-ecosystem

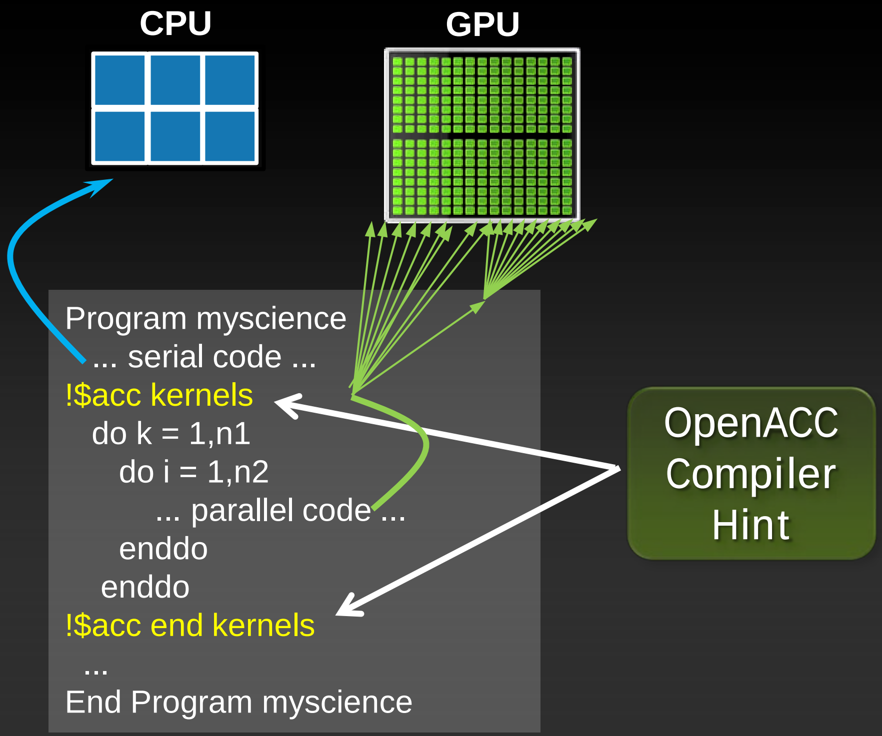


3 Ways to Accelerate Applications

Applications

Libraries	Directives	Programming Languages
"Drop-in" Acceleration	Easily Accelerate Applications	Maximum Flexibility

OpenACC Directives



Your original Fortran or C code

Simple Compiler hints

Compiler Parallelizes code

Works on many-core GPUs & multicore CPUs

SAXPY – OpenACC

SAXPY in C

```
void saxpy(int n,
           float a,
           float *x,
           float *restrict y)
{
#pragma acc parallel loop
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}

...
// Perform SAXPY on N elements
saxpy(N, 3.0, x, y);
...
```

SAXPY in Fortran

```
subroutine saxpy(n, a, x, y)
  real :: x(*), y(*), a
  integer :: n, i
!$acc parallel loop
  do i=1,n
    y(i) = a*x(i)+y(i)
  enddo
!$acc end parallel
end subroutine saxpy

...
! Perform SAXPY on N elements
call saxpy(N, 3.0, x, y)
...
```

SAXPY - OpenMP

SAXPY in C

```
void saxpy(int n,
           float a,
           float *x,
           float *restrict y)
{
#pragma omp parallel for
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}

...
// Perform SAXPY on N elements
saxpy(N, 3.0, x, y);
...
```

SAXPY in Fortran

```
subroutine saxpy(n, a, x, y)
  real :: x(*), y(*), a
  integer :: n, i
!$omp parallel do
  do i=1,n
    y(i) = a*x(i)+y(i)
  enddo
!$omp end parallel do
end subroutine saxpy

...
! Perform SAXPY on N elements
call saxpy(N, 3.0, x, y)
...
```

OpenACC Implementations

OpenACC 2.0
launched
December 2013

OpenACC 2.0
launched
December 2013

OpenACC 2.0
Rolling out from
January 2014

OpenACC 2.0
Targeted for
late 2014/
early 2015

Known academic efforts:

- accULL – U. of La Laguna/EPCC
- Omni – U. of Tsukuba
- OpenARC – ORNL
- OpenUH – U. of Houston

3 Ways to Accelerate Applications

Applications

Libraries	Directives	Programming Languages
"Drop-in" Acceleration	Easily Accelerate Applications	Maximum Flexibility

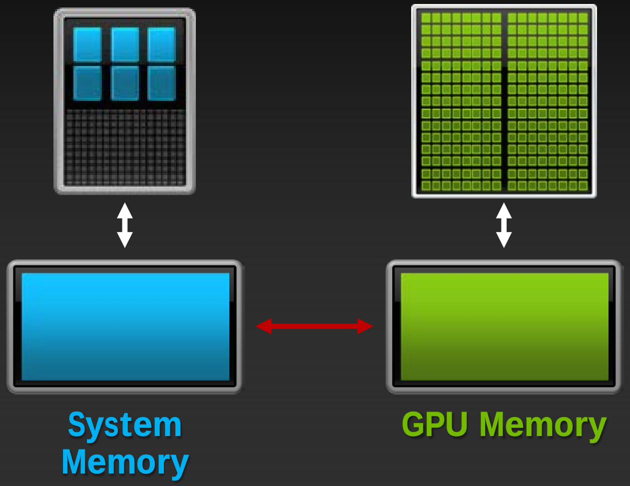
GPU Programming Languages

Numerical analytics	MATLAB, Mathematica, LabVIEW
Fortran	OpenACC, CUDA Fortran
C	OpenACC, CUDA C
C++	Thrust, CUDA C++
Python	CUDA Python, PyCUDA
F#	Alea.cubase

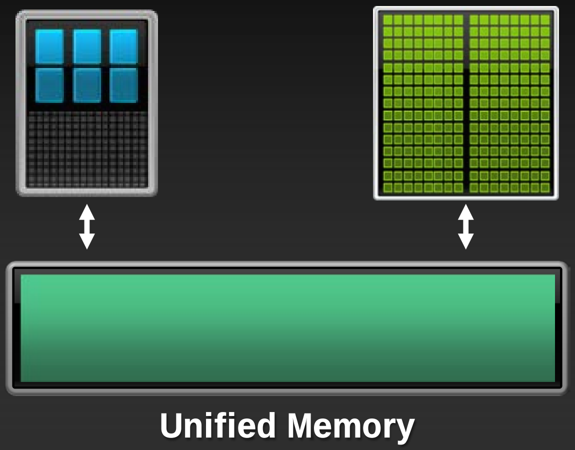
CUDA 6 - Unified Memory

Dramatically Lower Developer Effort

Developer View Today



Developer View With Unified Memory



CUDA 6 Release Candidate available now

Programming a CUDA-enabled Language

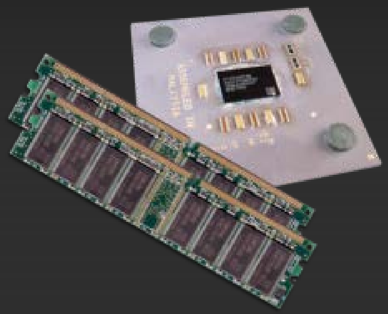
- CUDA C/C++
  - Based on industry-standard C/C++
  - Small set of extensions to enable heterogeneous programming
  - Straightforward APIs to manage devices, memory etc.

Prerequisites

- You (probably) need experience with C or C++
- You don’t need GPU experience
- You don’t need parallel programming experience
- You don’t need graphics experience

Heterogeneous Computing

- Terminology:
  - *Host* The CPU and its memory (host memory)
  - *Device* The GPU and its memory (device memory)



Host

Device

SAXPY

Standard C Code

```
void saxpy(int n, float a, float *x, float *y)
{
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}

int N = 1<<20;

// Perform SAXPY on 1M elements
saxpy(N, 2.0f, x, y);
```

Parallelism on a GPU – CUDA Blocks

- ...alled a “**kernel**”
- ...on running on the

Grid0

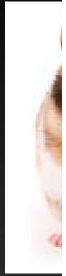
= BLOCK

- A block can identify itself by reading **blockIdx.x**

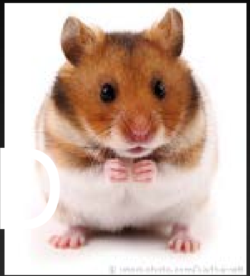
Parallelism on a GPU – CUDA Threads

- ... up into “threads”

Block




= THREAD



t...

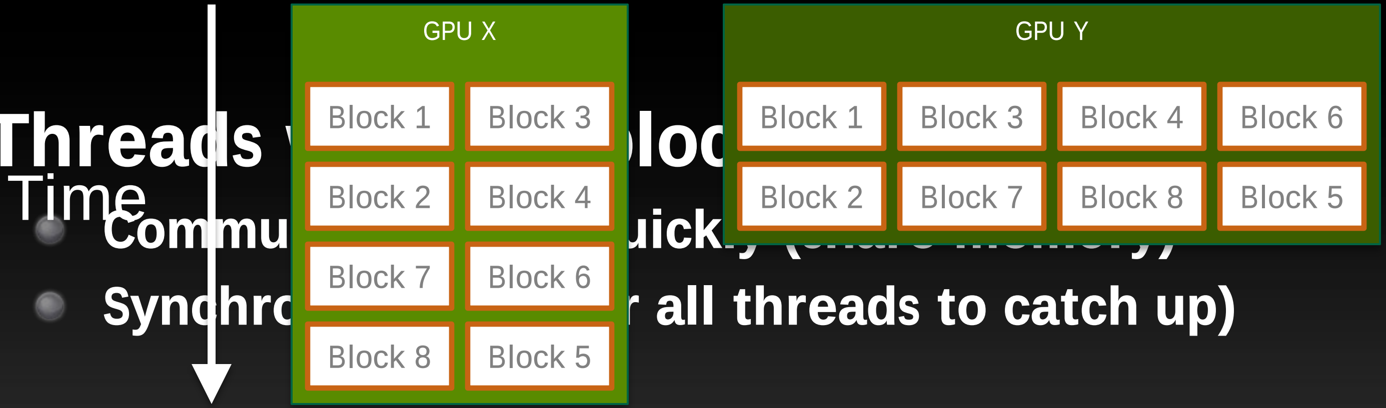
threadIdx.x = 2

threadIdx.x = M - 1

- ... by reading threadIdx.x
- ...s per block can be read ...
  - In the above example blockDim.x = M

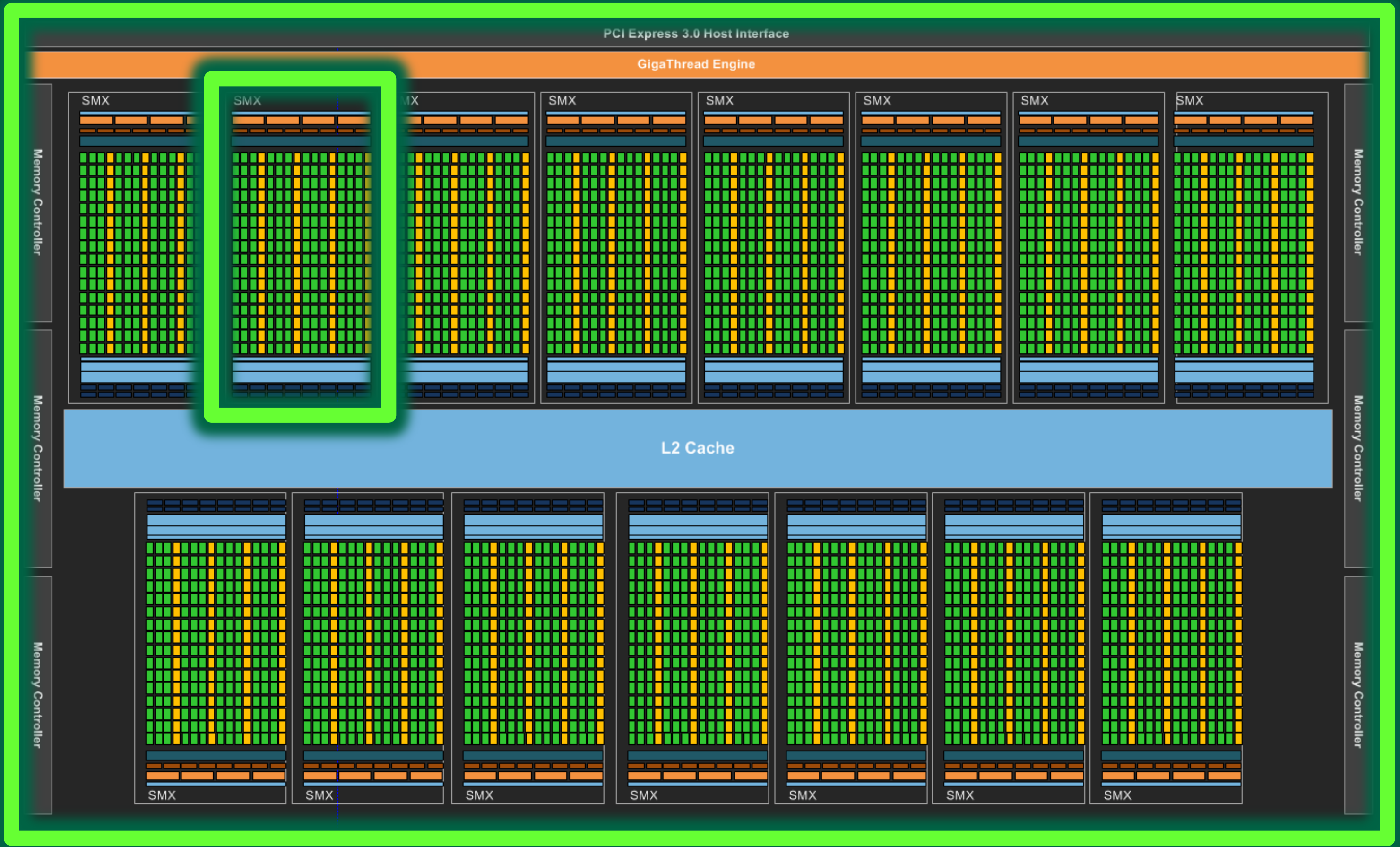
Why threads and blocks?

- **Threads ... bloc...**
  - **Commu... uick...**
  - **Synchro... r all threads to catch up)**



- **Why break up into blocks?**
  - **Limiting cooperation to a subset of threads enables building a high-performance hardware implementation.**
  - **By requiring all blocks to be independent, programs can scale to larger or smaller GPUs without code changes or even recompilation.**

Kepler Block Diagram



SAXPY CPU

```
void saxpy_cpu(int n, float a, float *x, float *y)
{
    for (int i = 0; i < n; ++i)
        y[i] = a*x[i] + y[i];
}
```

SAXPY kernel

```
__global__ void saxpy_gpu(int n, float a, float *x, float *y)
{
    int i = blockIdx.x*blockDim.x + threadIdx.x;
    if (i < n)
        y[i] = a*x[i] + y[i];
}
```

Block




SAXPY kernel - with data

```
__global__ void saxpy_gpu(int n, float a, float *x, float *y)
{
    int i = blockIdx.x*blockDim.x + threadIdx.x;
    if (i < n)
        y[i] = a*x[i] + y[i];
}
```

10 threads (hamsters)
each with a different i

- Let's work with 30 data elements
  - Broken into 3 blocks, with 10 threads per block
- So, blockDim.x = 10

- For blockIdx.x = 0
  - i = 0 * 10 + threadIdx.x = {0,1,2,3,4,5,6,7,8,9}
- For blockIdx.x = 1
  - i = 1 * 10 + threadIdx.x = {10,11,12,13,14,15,16,17,18,19}
- For blockIdx.x = 2
  - i = 2 * 10 + threadIdx.x = {20,21,22,23,24,25,26,27,28,29}

Calling saxpy_gpu: `main()`

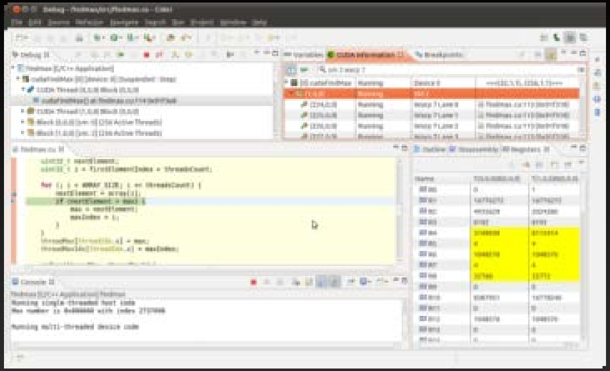
Standard C Code

```
#define N (2048 * 512)
int main(void) {
    float *x, *y;    // host copies
    int size = N * sizeof(float);

    // Alloc space for x & y and
    // setup input values
    x = (float *)malloc(size);
    random_floats(x, N);
    y = (float *)malloc(size);
    random_floats(y, N);

    // Launch saxpy on CPU
    saxpy_cpu(N, 2.0f, x, y);

    // Cleanup
    free(x); free(y);
    return 0;
}
```

Parallel C Code

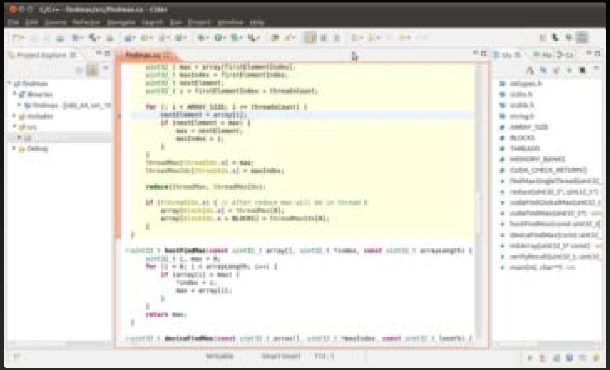
```
#define N (2048 * 512)
int main(void) {
    float *x, *y;    // host copies
    int size = N * sizeof(float);

    // Alloc space for x & y and
    // setup input values
    x = (float *)malloc(size);
    random_floats(x, N);
    y = (float *)malloc(size);
    random_floats(y, N);

    // Launch saxpy on GPU
    saxpy_cpu(N, 2.0f, x, y);

    // Cleanup
    free(x); free(y);
    return 0;
}
```

NVIDIA® Nsight™ Eclipse Edition for Linux and MacOS



CUDA-Aware Editor

- Automated CPU to GPU code refactoring
- Semantic highlighting of CUDA code
- Integrated code samples & docs



Nsight Debugger

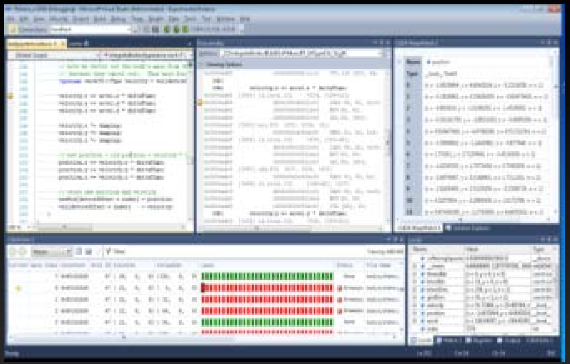
- Simultaneously debug CPU and GPU
- Inspect variables across CUDA threads
- Use breakpoints & single-step debugging

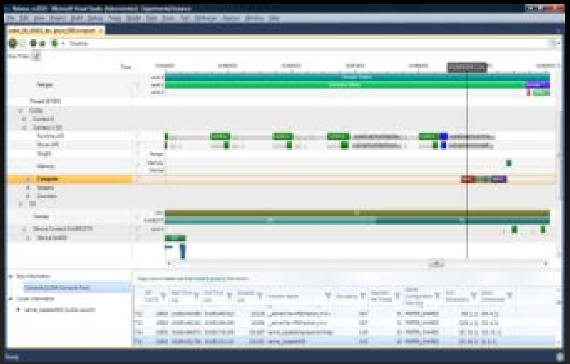
Nsight Profiler

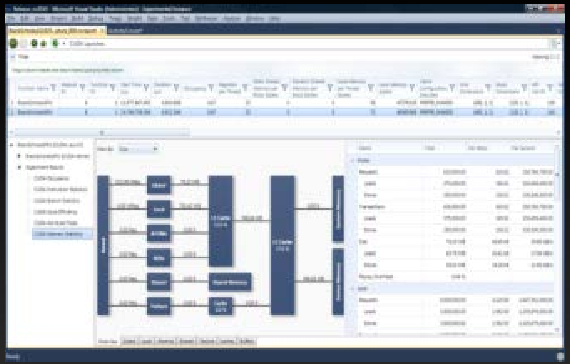
- Quickly identifies performance issues
- Integrated expert system
- Source line correlation

developer.nvidia.com/nsight

NVIDIA® Nsight™, Visual Studio Ed.







CUDA Debugger

- Debug CUDA kernels directly on GPU hardware
- Examine thousands of threads executing in parallel
- Use on-target conditional breakpoints to locate errors

CUDA Memory Checker

- Enables precise error detection

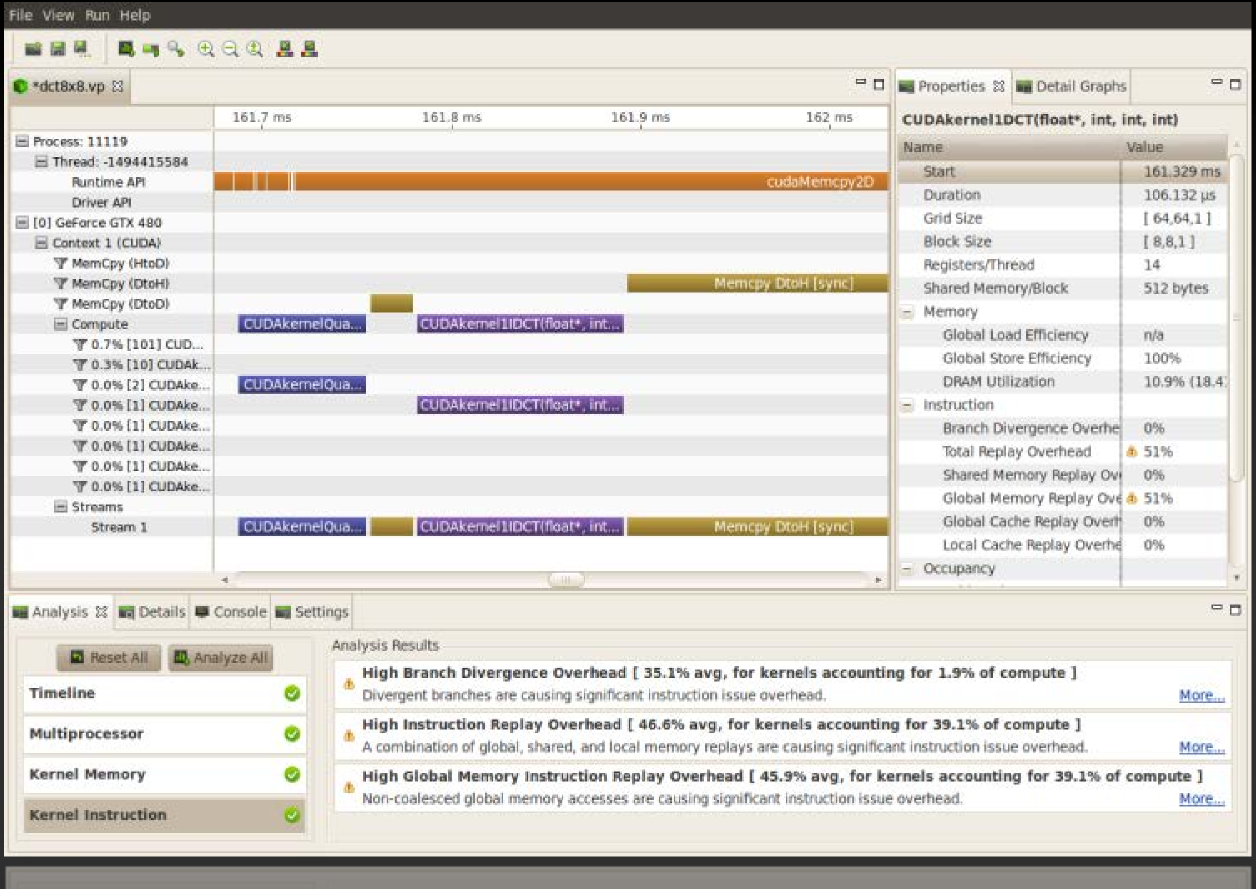
System Trace

- Review CUDA activities across CPU and GPU
- Perform deep kernel analysis to detect factors limiting maximum performance

CUDA Profiler

- Advanced experiments to measure memory utilization, instruction throughput and stalls

NVIDIA Visual Profiler



Beyond HPC
Big Data

Analyzing Twitter — salesforce

Searching Audio — shazam

Visual Shopping — CORTEXICA vision systems, ebay

Real-time Video Delivery — ELEMENTAL, ESPN

With Fricken Laserbeams!

- Created by Intellectual Ventures to help fight malaria in third world countries
- Image detection and targeting is done with NVIDIA GPUs

Resources: developer.nvidia.com/cudazone

- Parallel Forall: devblogs.nvidia.com/parallelforall
  - CUDACasts at bit.ly/cudacasts
    - Short how-to screencasts
- Self-paced labs: nvidia.qwiklab.com
  - 90-minute labs, simply need a supported web browser
- Documentation: docs.nvidia.com
- Technical Questions:
  - NVIDIA Developer forums devtalk.nvidia.com
  - Search or ask on stackoverflow.com/tags/cuda

CUDA Registered Developer Program

- Access to exclusive developer downloads
  - Double-Double Precision Library and Source
  - SIMD within a Word
  - Optimized LINPACK
  - And more…
- Exclusive access to pre-release CUDA Installers
  - Like CUDA 6!
- Submit bugs and features requests to NVIDIA Engineering
- Exclusive activities and special offers
- Membership is free and easy!

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Graphics

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Media & Entertainment

Graphics Virtualization

Mobile App & Game Development

PC Game Development

In-car Infotainment

Getting Started

1. Try out GPU Computing:
   developer.nvidia.com/cuda-education-training
2. Subscribe to Parallel Forall blog
3. Sign up as a Registered Developer
4. Install the CUDA Toolkit
5. Attend GTC 2014 or watch GTC On-Demand

ACM: The Learning Continues…

- Questions about this webcast? learning@acm.org
- ACM Learning Webinars (on-demand archive): http://learning.acm.org/webinar
- ACM Learning Center: http://learning.acm.org
- ACM SIGHPC: http://www.sighpc.org/
- ACM Queue: http://queue.acm.org

BACKUP SLIDES

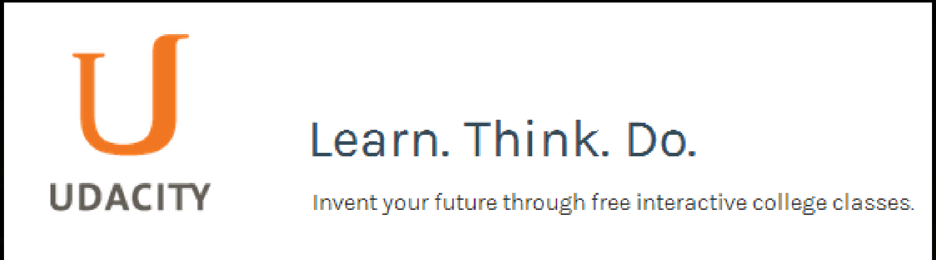
nvidia.qwiklab.com

- 90-minute, online, self-paced GPU Programming labs
- Only requires a browser and network which supports Web Sockets
  - You can verify by going to websocketstest.com and look for:

WebSockets (Port 80)	
Connected	Yes ✓
Data Receive	Yes ✓
Data Send	Yes ✓
Echo Test	Yes ✓
Server time	2014/2/11 19:00:58

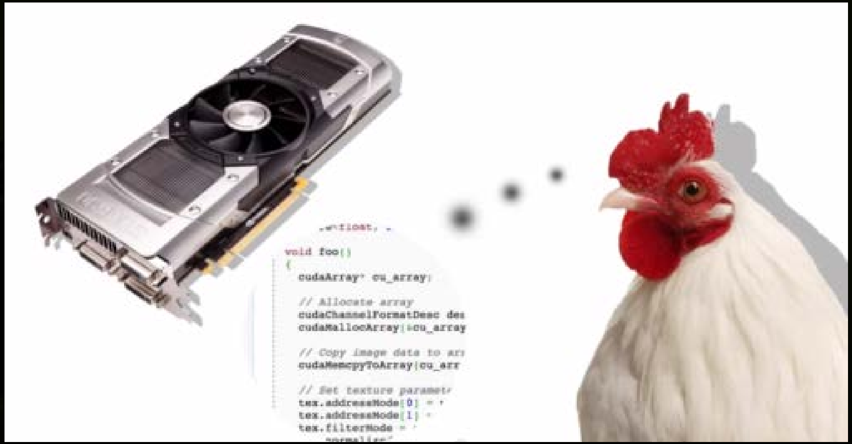
  - Internet Explorer 9 and earlier do NOT support Web Sockets

Udacity Parallel Programming Course



30,000+ Students Already Registered

IT’S FREE!



Udacity.com