CUDA 5 and Beyond

Mark Harris
Chief Technologist, GPU Computing

CUDA By the Numbers:

>375,000,000	CUDA-Capable GPUs
>1,000,000	Toolkit Downloads
>120,000	Active Developers
>500	Universities Teaching CUDA

CUDA By the Numbers:

1 download

every 60 seconds

Inspiration for CUDA

CUDA Spotlights

CUDA Fellows

Takayuki Aoki
Tokyo Tech

Lorena Barba
Boston University

Mike Giles
Oxford University

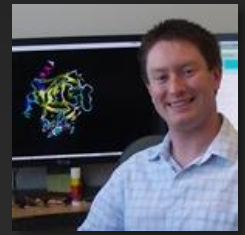
Scott LeGrand
Amazon

PJ Narayanan
IIIT, Hyderabad

Dan Negrut
University of Wisconsin

John Stone
UIUC

Manuel Ujaldon
University of Malaga



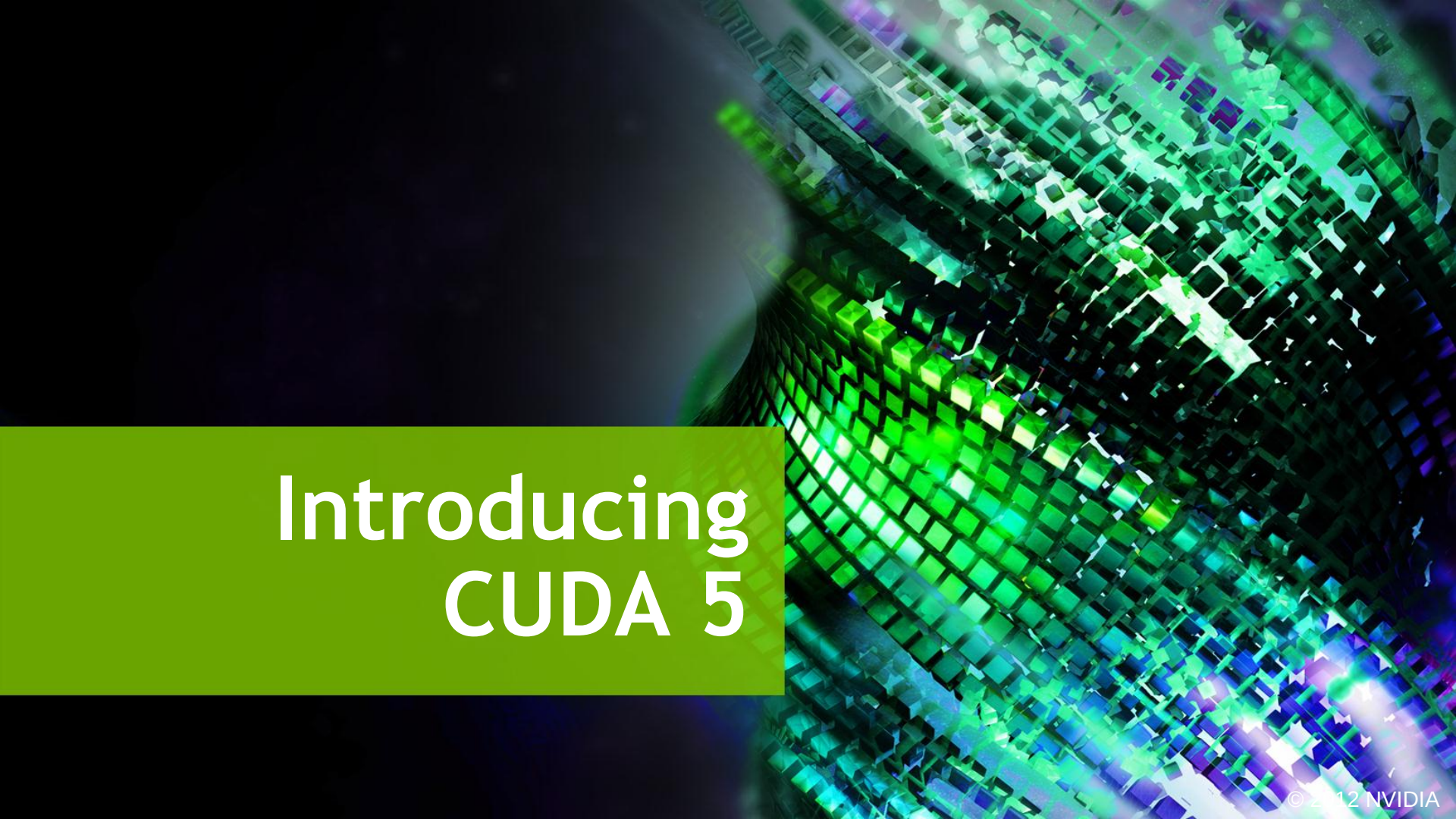
Ross Walker
SDSC

The Soul of CUDA

The Platform for High Performance Parallel Computing

Accessible High Performance

Enable Computing Ecosystem



CUDA 5

Application Acceleration Made Easier

Dynamic Parallelism

Spawn new parallel work from within GPU code on GK110

GPU Object Linking

Libraries and plug-ins for GPU code

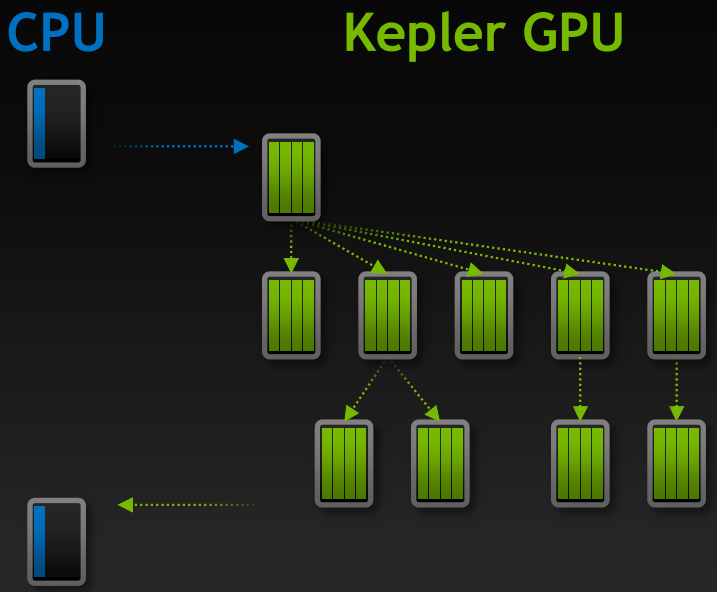
New Nsight™ Eclipse Edition

Develop, Debug, and Optimize… All in one tool!

GPUDirect™

RDMA between GPUs and PCIe devices

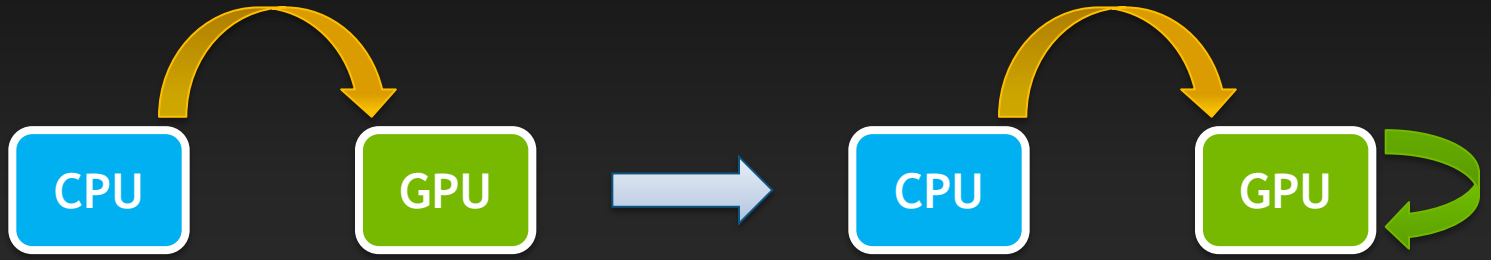
Dynamic Parallelism



What is CUDA Dynamic Parallelism?

The ability for any GPU thread to launch a parallel GPU kernel

- Dynamically
- Simultaneously
- Independently

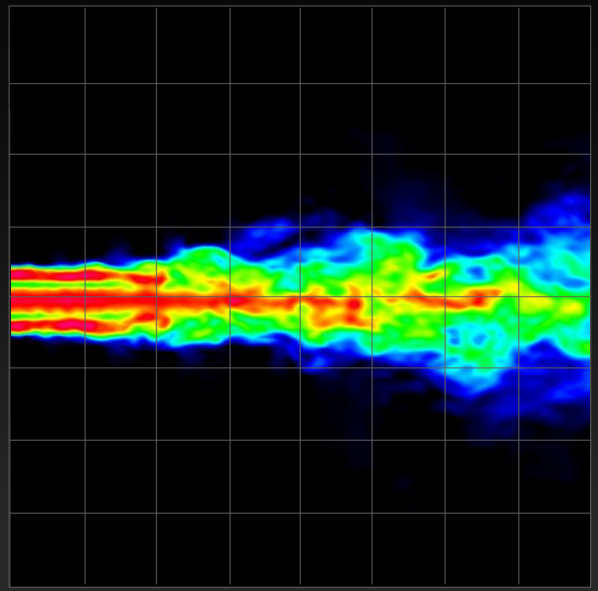


Fermi: Only CPU can generate GPU work

Kepler: GPU can generate work for itself

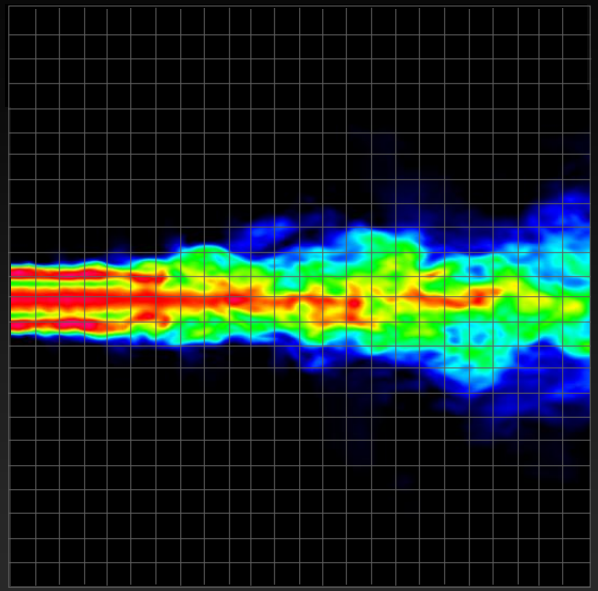
Dynamic Work Generation

Coarse grid



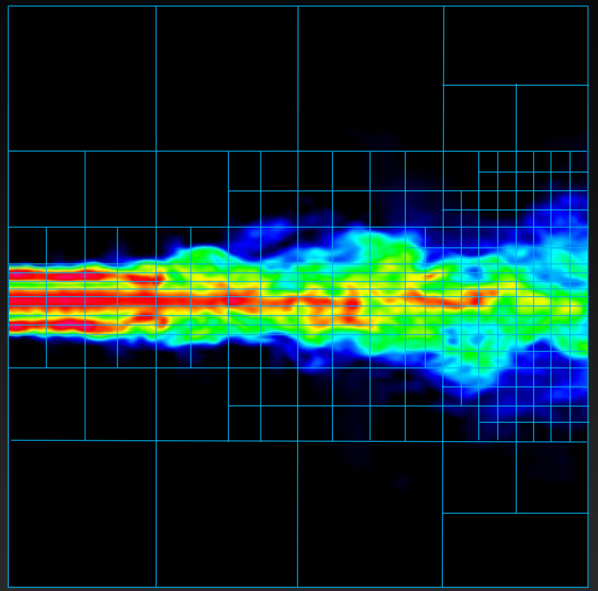
Higher Performance
Lower Accuracy

Fine grid



Lower Performance
Higher Accuracy

Dynamic grid

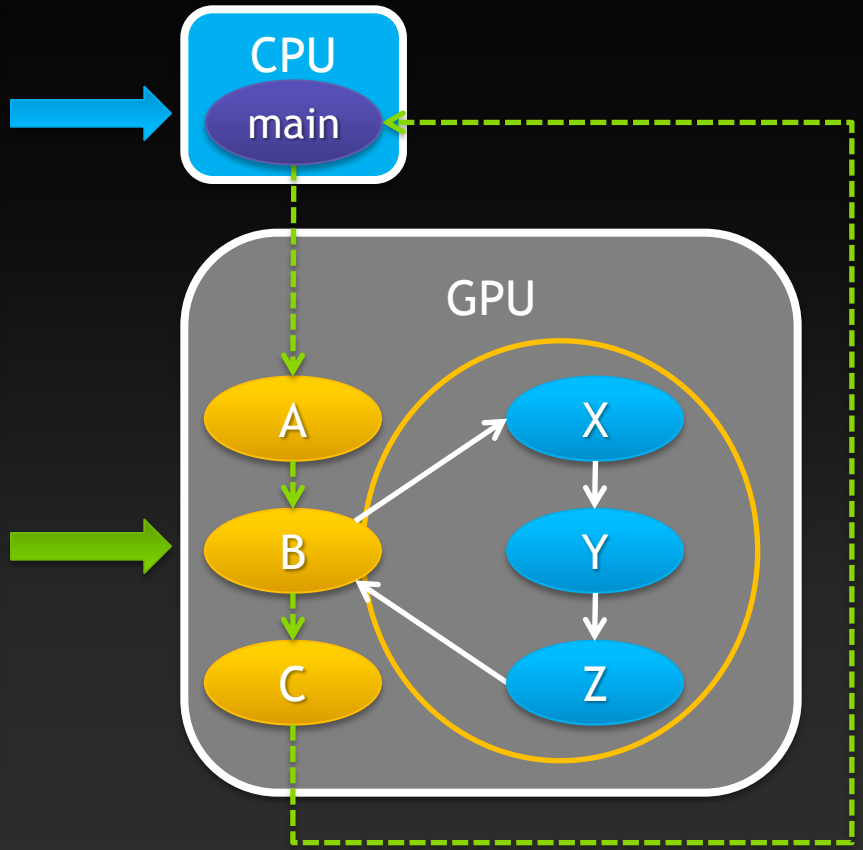


Target performance where accuracy is required

Familiar Syntax and Programming Model

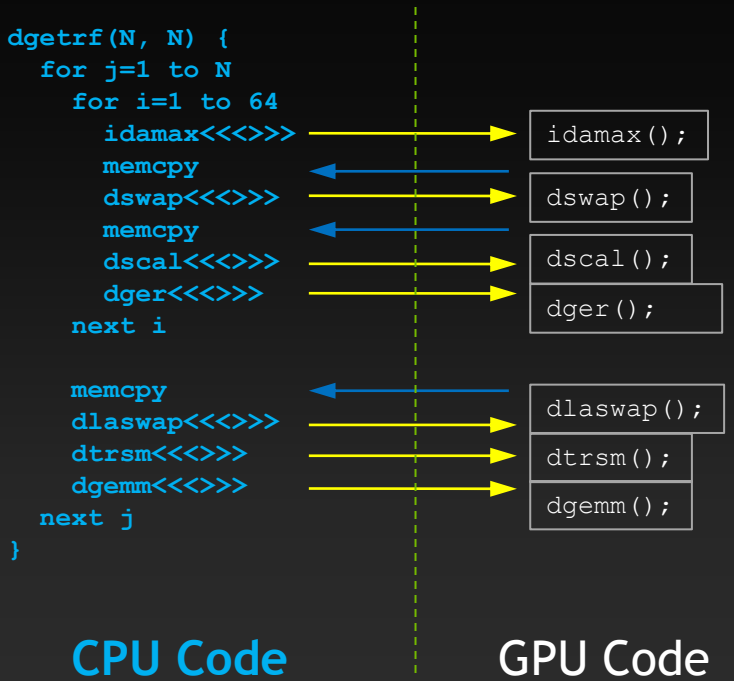
```
int main() {
    float *data;
    setup(data);

    A <<< ... >>> (data);
    B <<< ... >>> (data);
    C <<< ... >>> (data);

    cudaDeviceSynchronize();
    return 0;
}
```

```
__global__ void B(float *data)
{
    do_stuff(data);

    X <<< ... >>> (data);
    Y <<< ... >>> (data);
    Z <<< ... >>> (data);
    cudaDeviceSynchronize();

    do_more_stuff(data);
}
```

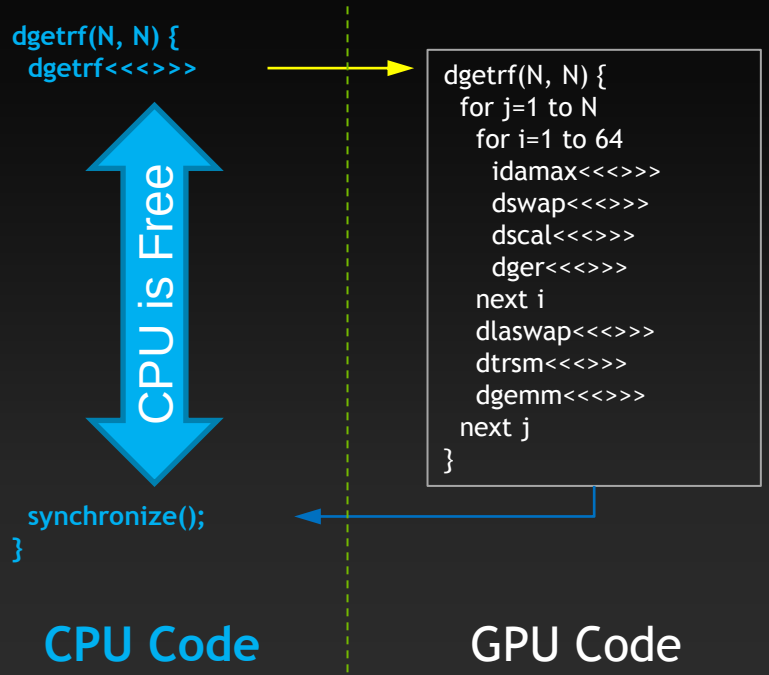


Simpler Code: LU Example

LU decomposition (Fermi)



LU decomposition (Kepler)



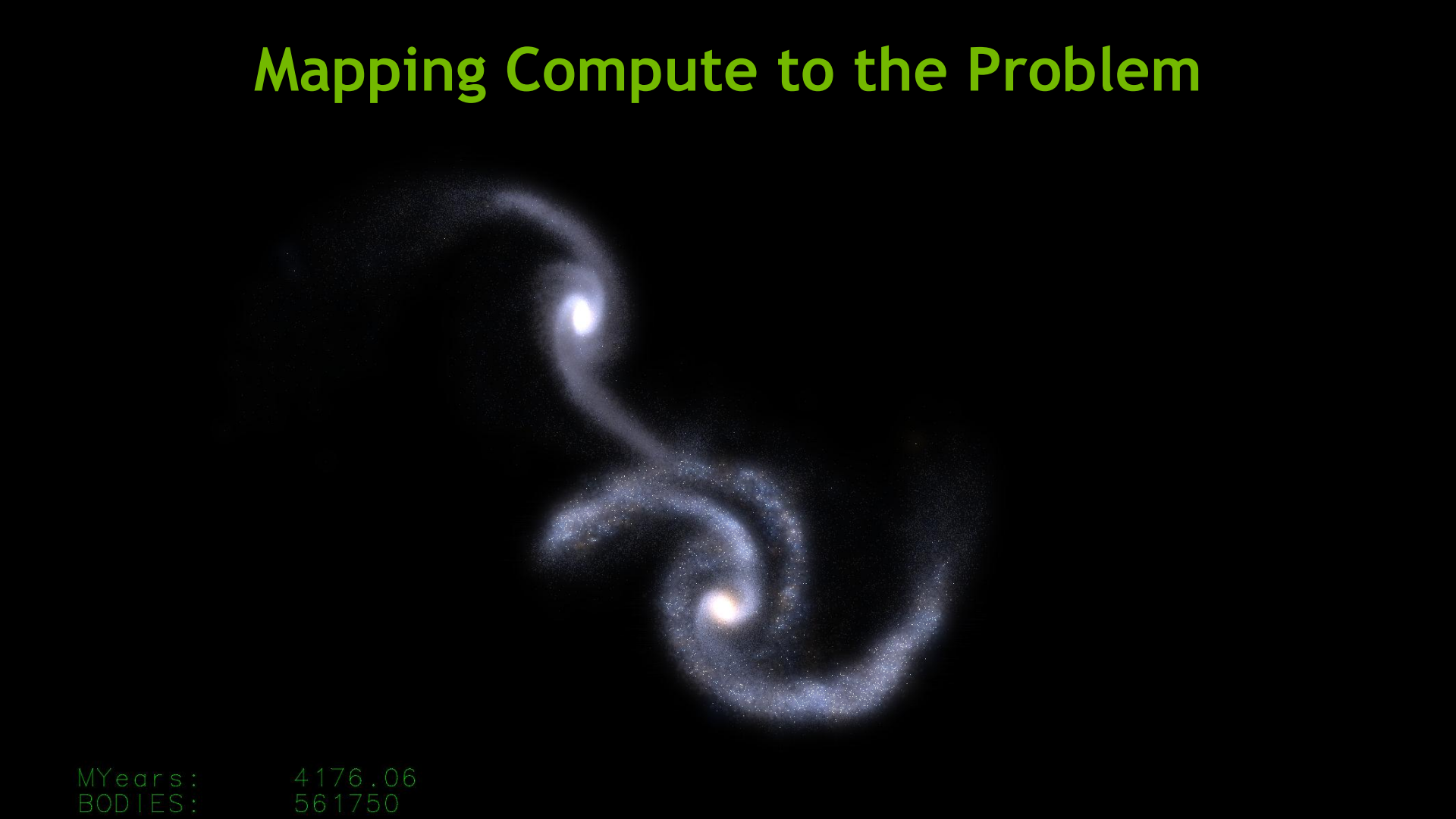
Bonsai GPU Tree-Code

Journal of Computational Physics,
231:2825-2839, April 2012

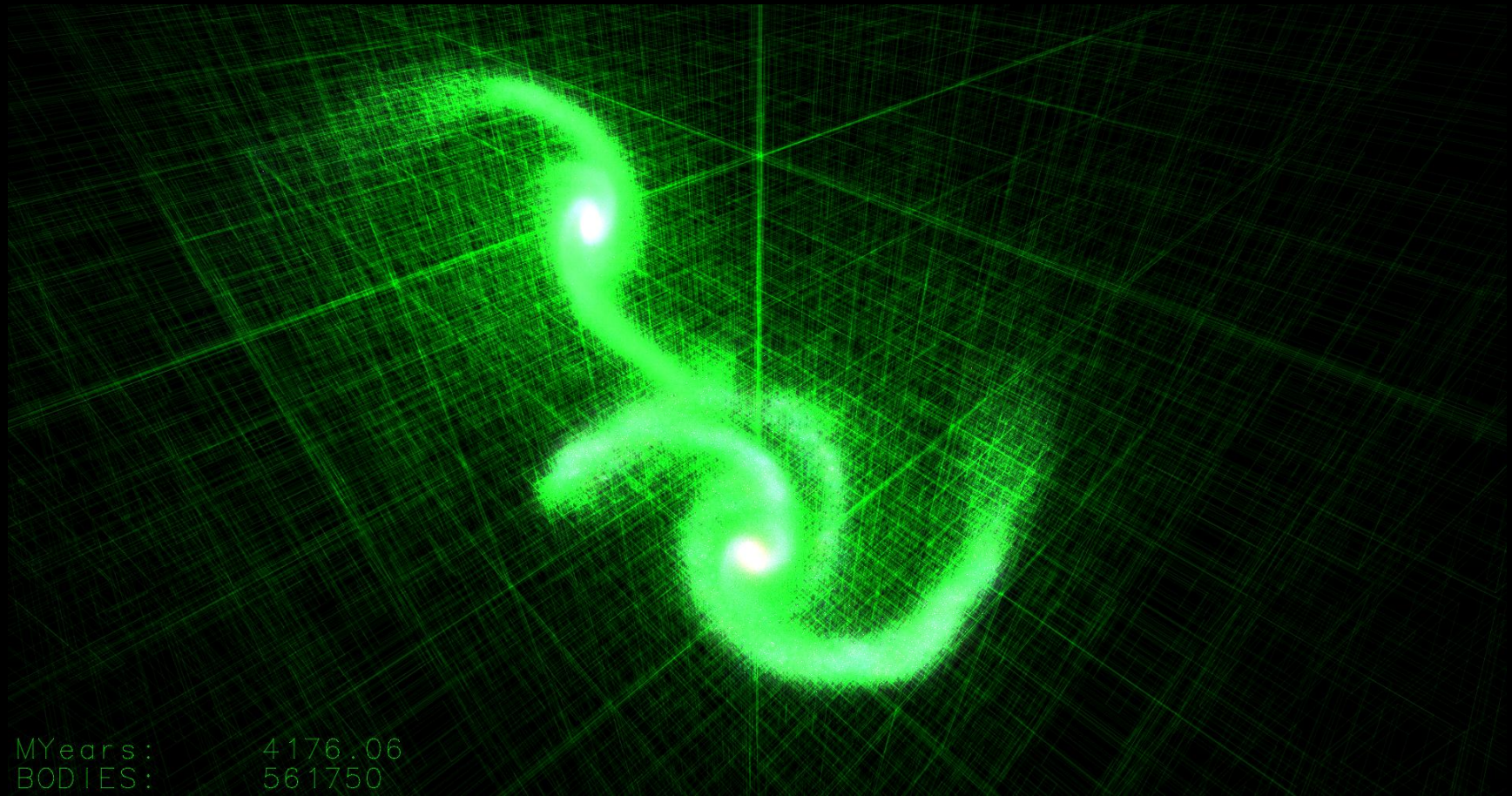
- Jeroen Bédorf, Simon Portegies Zwart
  - Leiden Observatory, The Netherlands
- Evghenii Gaburov
  - CIERA @ Northwestern U.
  - SARA, The Netherlands

- Galaxies generated with:
  Galatics
  Widrow L. M., Dubinksi J., 2005,
  Astrophysical Journal, 631 838

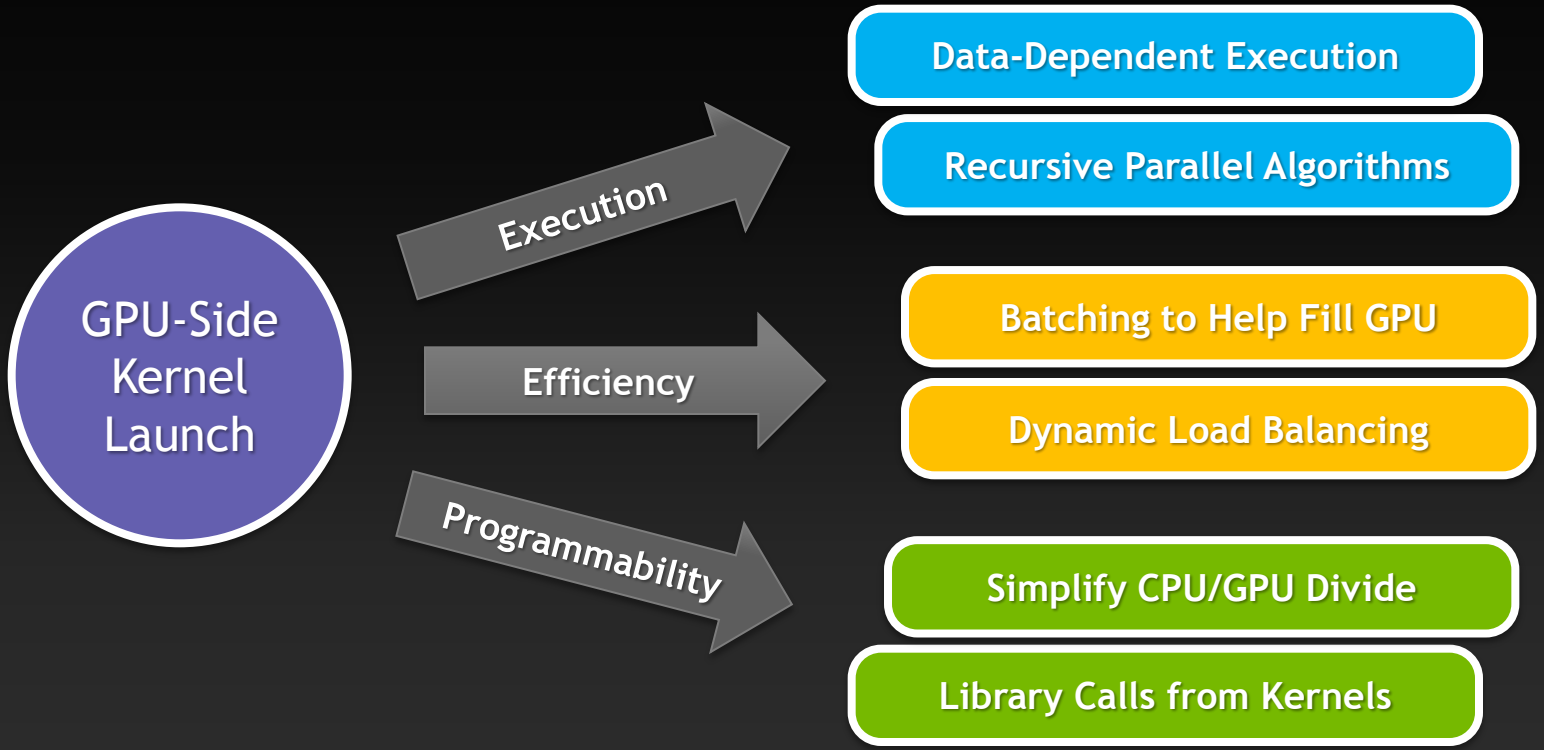
Mapping Compute to the Problem



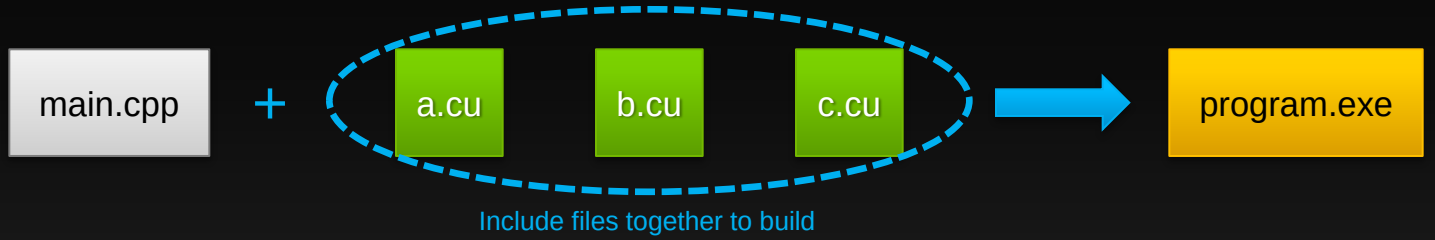
Mapping Compute to the Problem



CUDA Dynamic Parallelism



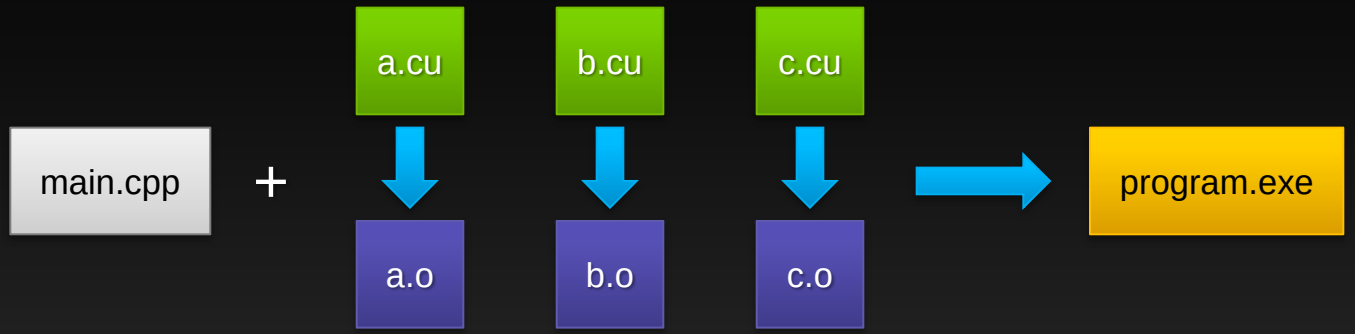
CUDA 4: Whole-Program Compilation & Linking



CUDA 4 required single source file for a single kernel

No linking external device code

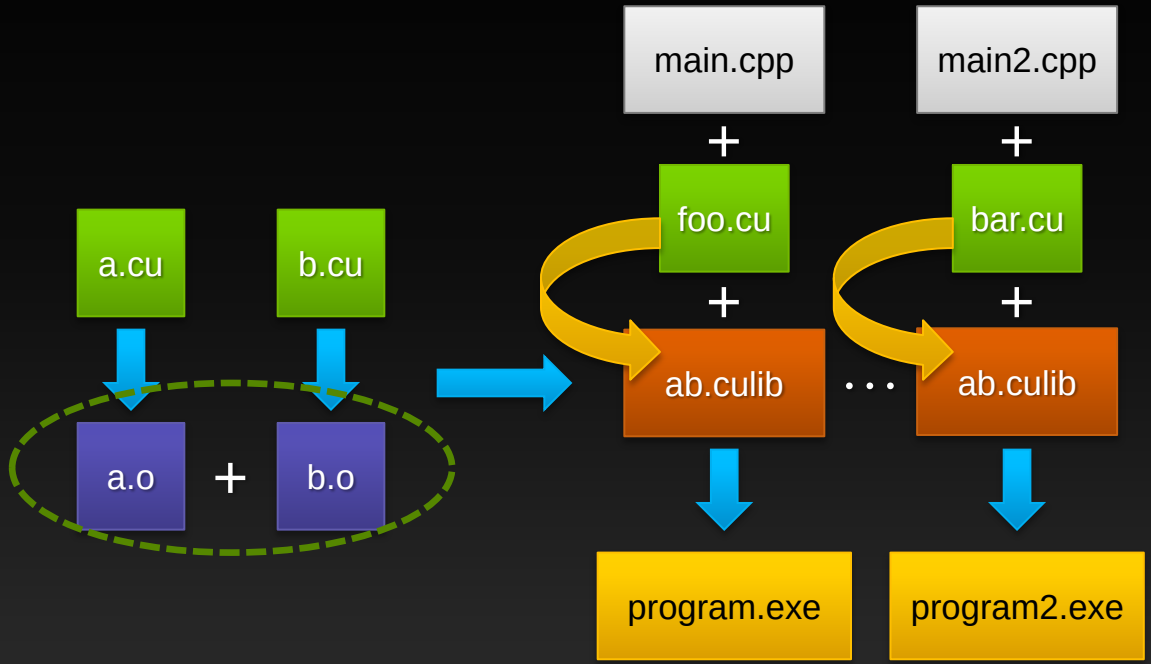
CUDA 5: Separate Compilation & Linking



Separate compilation allows building independent object files

CUDA 5 can link multiple object files into one program

CUDA 5: Separate Compilation & Linking



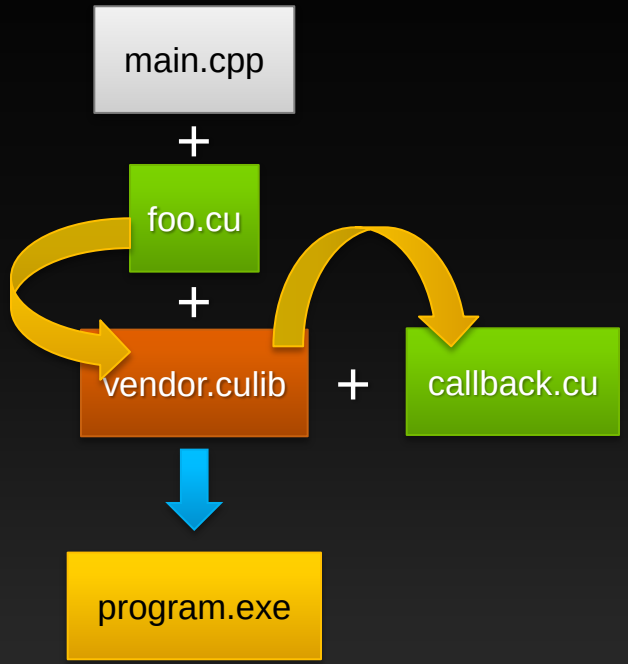
Can also combine object files into static libraries

Link and externally call *device* code

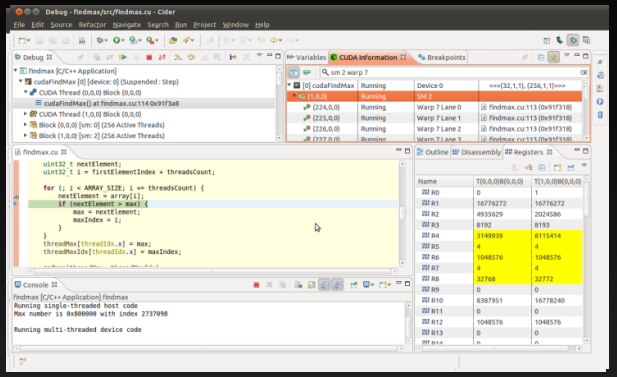
Facilitates code reuse, reduces compile time

CUDA 5: Separate Compilation & Linking

Enables closed-source device libraries to call user-defined device callback functions

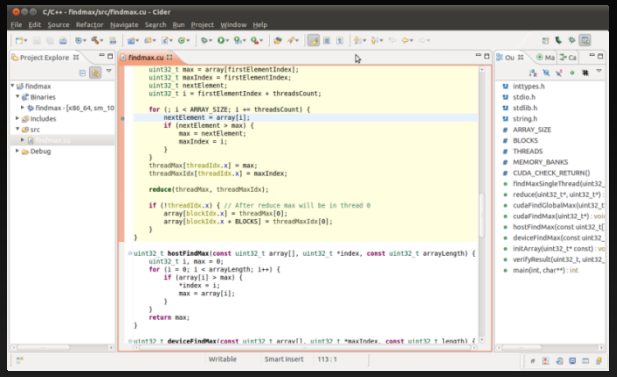


NVIDIA® Nsight™ Eclipse Edition



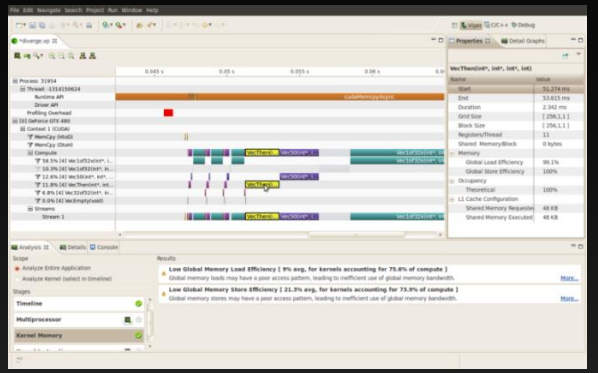
CUDA-Aware Editor

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



Nsight Debugger

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

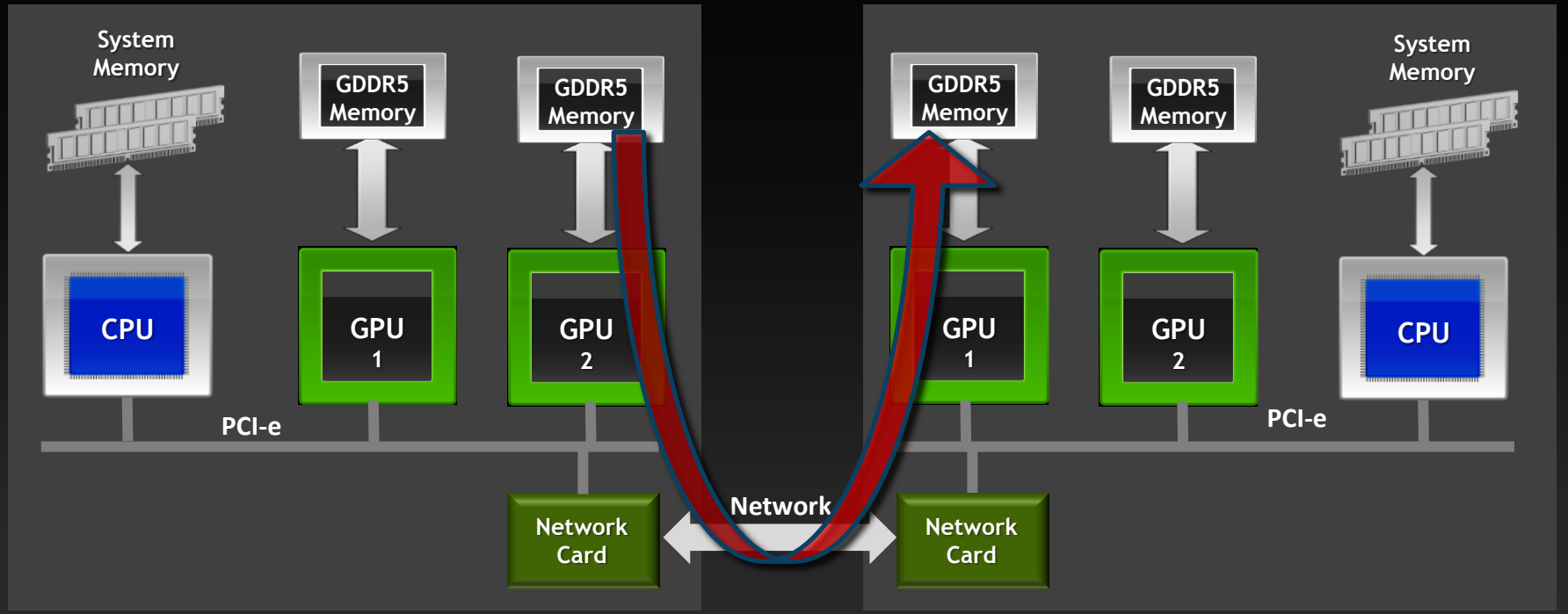


Nsight Profiler

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

Available for Linux and Mac OS

NVIDIA GPUDirect™ now supports RDMA



RDMA: Remote Direct Memory Access between any GPUs in your *cluster*

Other talks on CUDA 5 and Kepler

- S0235 – "Compiling CUDA and Other Languages for GPUs" (LLVM)
  - Vinod Grover and Yuan Lin, Wed 10am
- S0338 – "New Features in the CUDA Programming Model"
  - Stephen Jones, 10am Thursday
- S0642 – "Inside Kepler"
  - Stephen Jones and Lars Nyland, Wed 2pm
- S0419A – "Optimizing Application Performance with CUDA Profiling Tools"
  - David Goodwin, 9am Tuesday

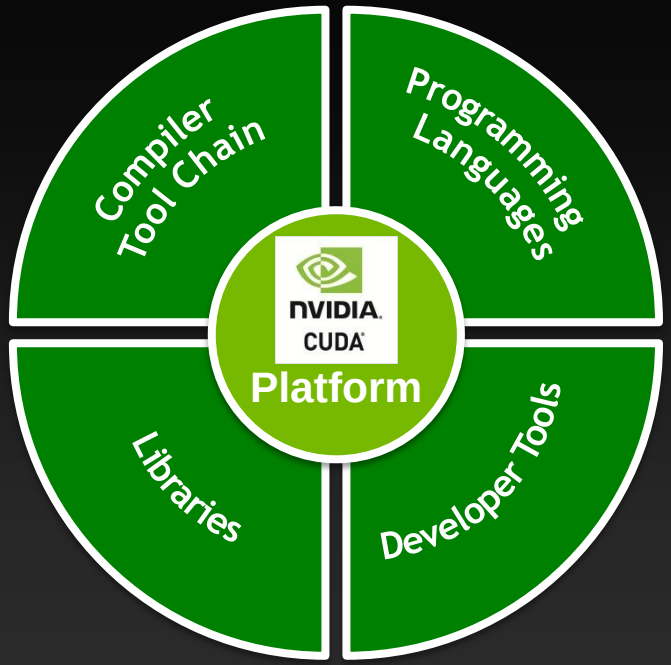
Try out CUDA 5

- CUDA 5.0 Preview (alpha)
  - Become a registered developer and download CUDA 5.0 preview

    http://developer.nvidia.com/user/register
  - Use GPU linking and NSIGHT EE—both work with Fermi & GK104
  - Peruse early documentation and header files for GK110 features
    - SM 3.5 support and Dynamic Parallelism
  - Provide feedback to NVIDIA via CUDA Forums and CUDA_RegDev@nvidia.com
- CUDA 5.0 Release Candidate
  - Later in 2012 (TBD)
  - Full support for all CUDA 5.0 features


Beyond CUDA 5

Platform for Parallel Computing



The CUDA Platform is a foundation that supports a diverse parallel computing ecosystem.

Diversity of Programming Languages

http://www.ohloh.net

Rapid Parallel C++ Development

- Resembles C++ STL
- Open source
- High-level interface
  - Enhances developer productivity
  - Enables performance portability between GPUs and multicore CPUs
- Flexible
  - CUDA, OpenMP, and TBB backends
  - Extensible and customizable
  - Integrates with existing software


```
// generate 32M random numbers on host
thrust::host_vector<int> h_vec(32 << 20);
thrust::generate(h_vec.begin(),
                 h_vec.end(),
                 rand);

// transfer data to device (GPU)
thrust::device_vector<int> d_vec = h_vec;

// sort data on device
thrust::sort(d_vec.begin(), d_vec.end());

// transfer data back to host
thrust::copy(d_vec.begin(),
             d_vec.end(),
             h_vec.begin());
```

http://developer.nvidia.com/thrust or http://thrust.googlecode.com

Expressive Parallel Programming

```
transform(rows, Y,
    [=](uint2 row) {
        return inner_product(
            slice(nonZeros, row.x, row.y),
            gather(X, slice(col, row.x, row.y)));
    });
```

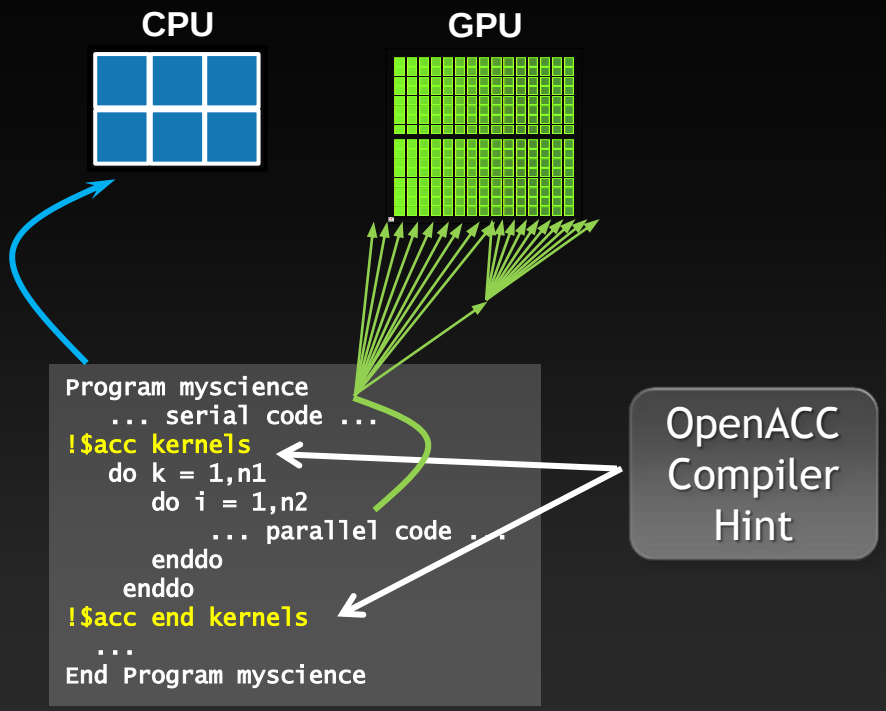
Dynamic Parallel Launches

C++11 Lambda Function

For each row of sparse matrix M
    Y[i] = inner product of
        non-zero elements of row with
        corresponding elements of X

$$Y = \begin{bmatrix} 4 & -1 & \cdots & & 1 \\ -1 & 4 & & & \\ \vdots & & \ddots & & \vdots \\ & 1 & \cdots & 4 & -1 \\ & & & -1 & 4 \end{bmatrix} X$$

OpenACC Directives



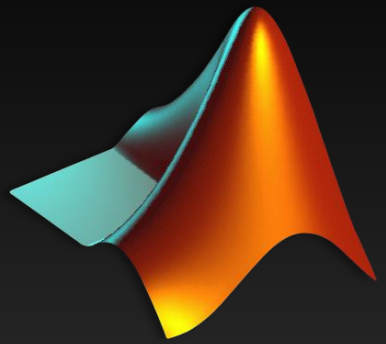
Your original Fortran or C code

Simple Compiler hints

Compiler Parallelizes code

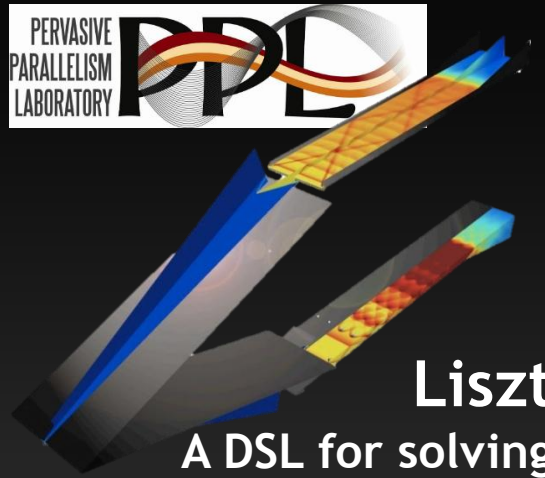
Works on many-core GPUs & multicore CPUs

Domain-specific Languages



MATLAB

R Statistical
Computing Language



Liszt
A DSL for solving
mesh-based PDEs

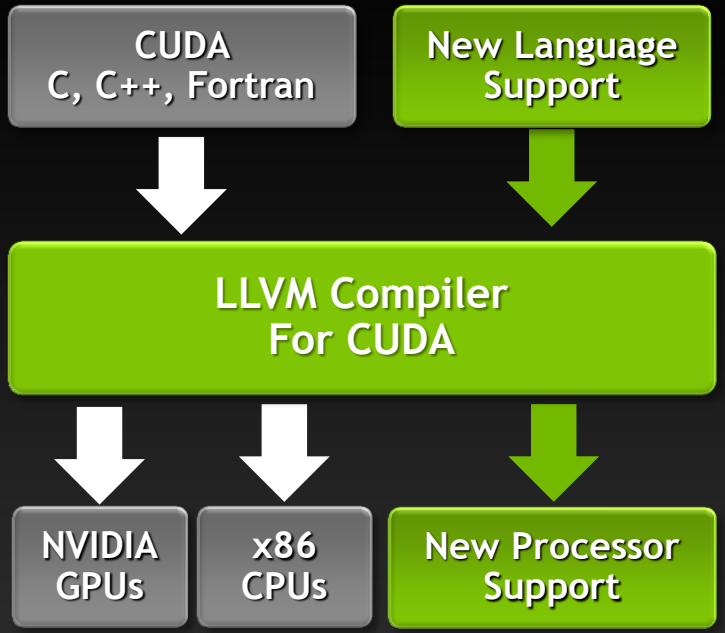
CUDA Compiler Contributed to Open Source LLVM

Developers want to build front-ends for

Java, Python, R, DSLs

Target other processors like

ARM, FPGA, GPUs, x86



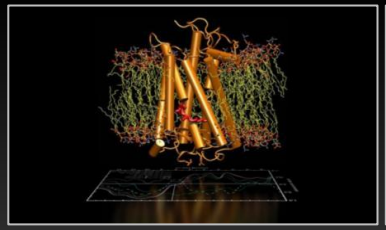
LLVM COMPILER INFRASTRUCTURE

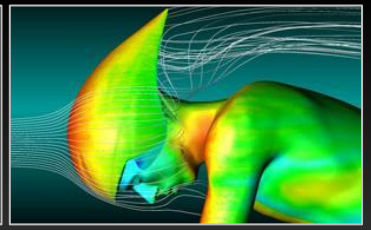
Building A Massively Parallel Future

- The Future is Heterogeneous
- Many solutions build a heterogeneous future
  - General-purpose Languages
  - Directives
  - DSLS

Education & Research

Domain Science





Languages and Compilers

LLVM COMPILER INFRASTRUCTURE

Thrust

Heterogeneous Architectures

CUDA on ARM

Computer Science