GeForce 8800 & NVIDIA CUDA

A New Architecture for Computing on the GPU

Stunning Graphics Realism

Lush, Rich Worlds

Crysis © 2006 Crytek / Electronic Arts

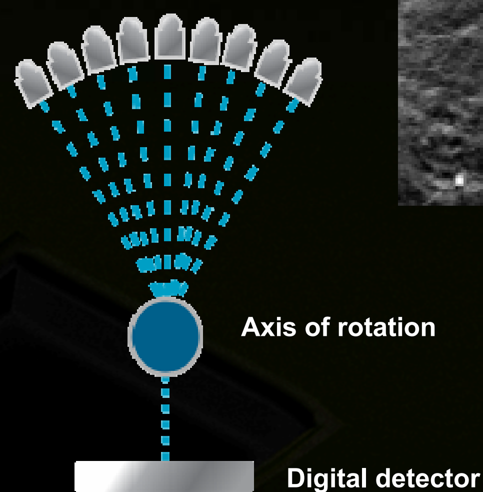
Incredible Physics Effects

Core of the Definitive Gaming Platform

Digital Tomosynthesis: Signal Processing

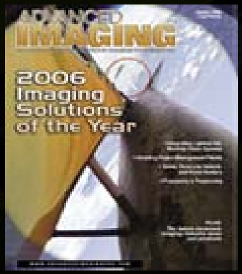
Pioneering work at Massachusetts General Hospital

- 100X speed-up with NVIDIA GPU
  - 32 node server takes 5 hours
  - 1 GPU takes 5 minutes
- Improved diagnostic value
  - Clearer images
  - Fewer obstructions
  - Earlier detection



Low-dose X-ray Projections
Computationally Intense Reconstruction

Advanced Imaging Solution of the Year

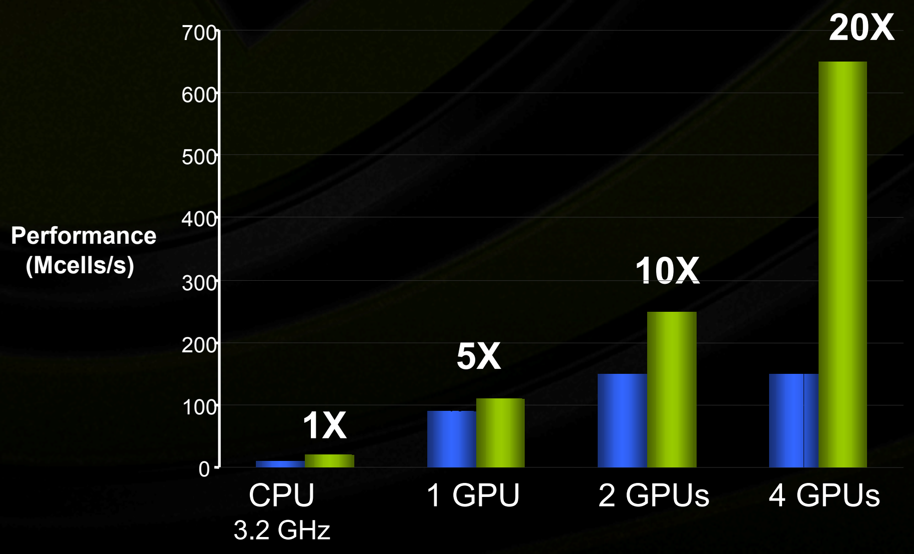


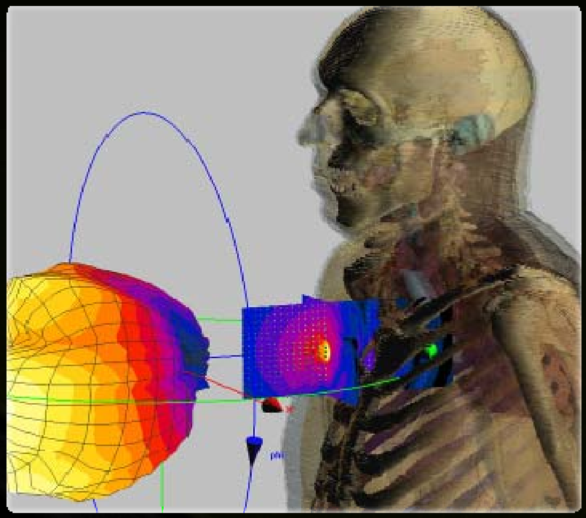
"reduced reconstruction time from 5 hours to 5 minutes"

Electromagnetic Simulation

Acceleware FDTD acceleration technology for the GPU

- 3D Finite-Difference and Finite-Element
- Modeling of:
  - Cell phone irradiation
  - MRI Design / Modeling
  - Printed Circuit Boards
  - Radar Cross Section (Military)
- Large speedups with NVIDIA GPUs

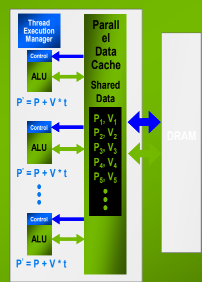




Pacemaker with Transmit Antenna

CUDA & GPU Computing

New Architecture for Computing



Standard C Programming

```
dim3   DimGrid(100, 50);    // 5000 thread blocks
dim3   DimBlock(4, 8, 8);   // 256 threads per block
size_t SharedMemBytes = 64; // 64 bytes of shared memory
KernelFunc<<< DimGrid, DimBlock, SharedMemBytes >>>(...);
```

Unprecedented Performance

New Applications

GPU Computing Model

GPGPU Programming Model

OpenGL Program to Add A and B

↓

Vertex Program

↓

Rasterization

↓

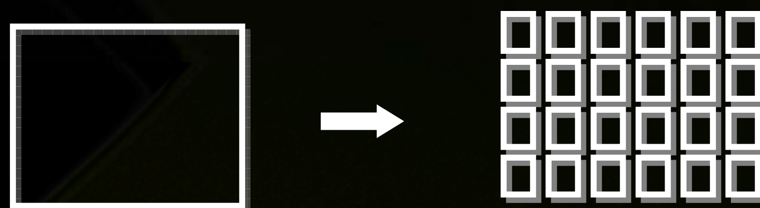
Fragment Program

↓

CPU Reads Texture Memory for Results

Start by creating a quad

“Programs” created with raster operation



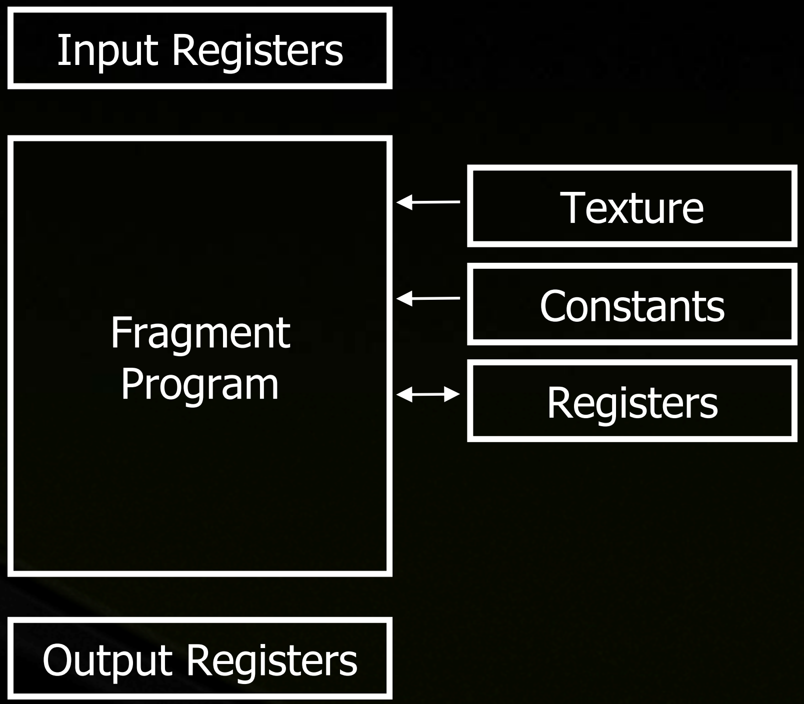
Read textures as input **to OpenGL shader program**

Write answer to texture memory as a “color”

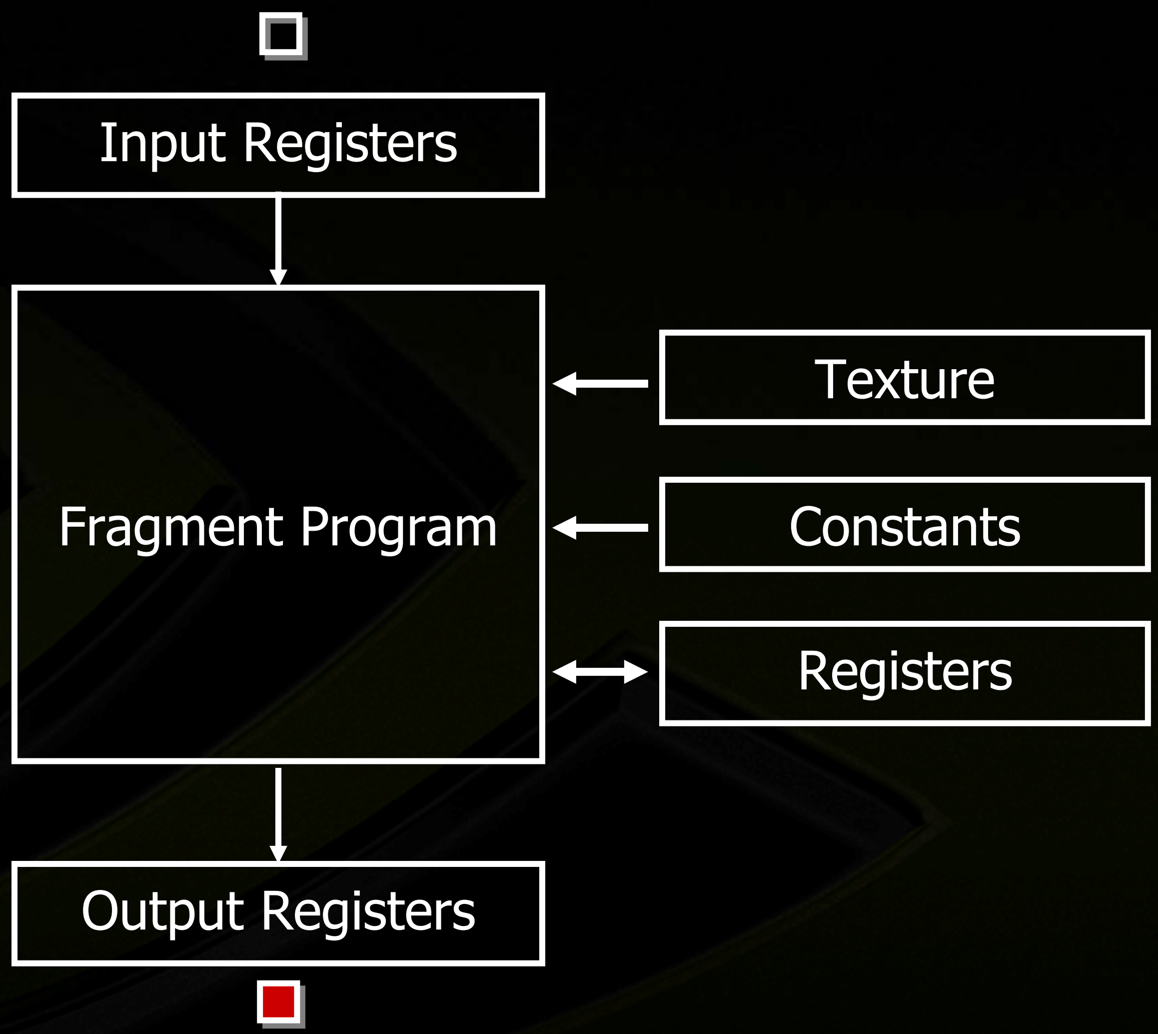
All this just to do A + B

Current Constraints

- Graphics API
- Addressing modes
  - Limited texture size/dimension
- Shader capabilities
  - Limited outputs
- Instruction sets
  - Integer & bit ops
- Communication limited
  - Between pixels
  - Scatter a[i] = p



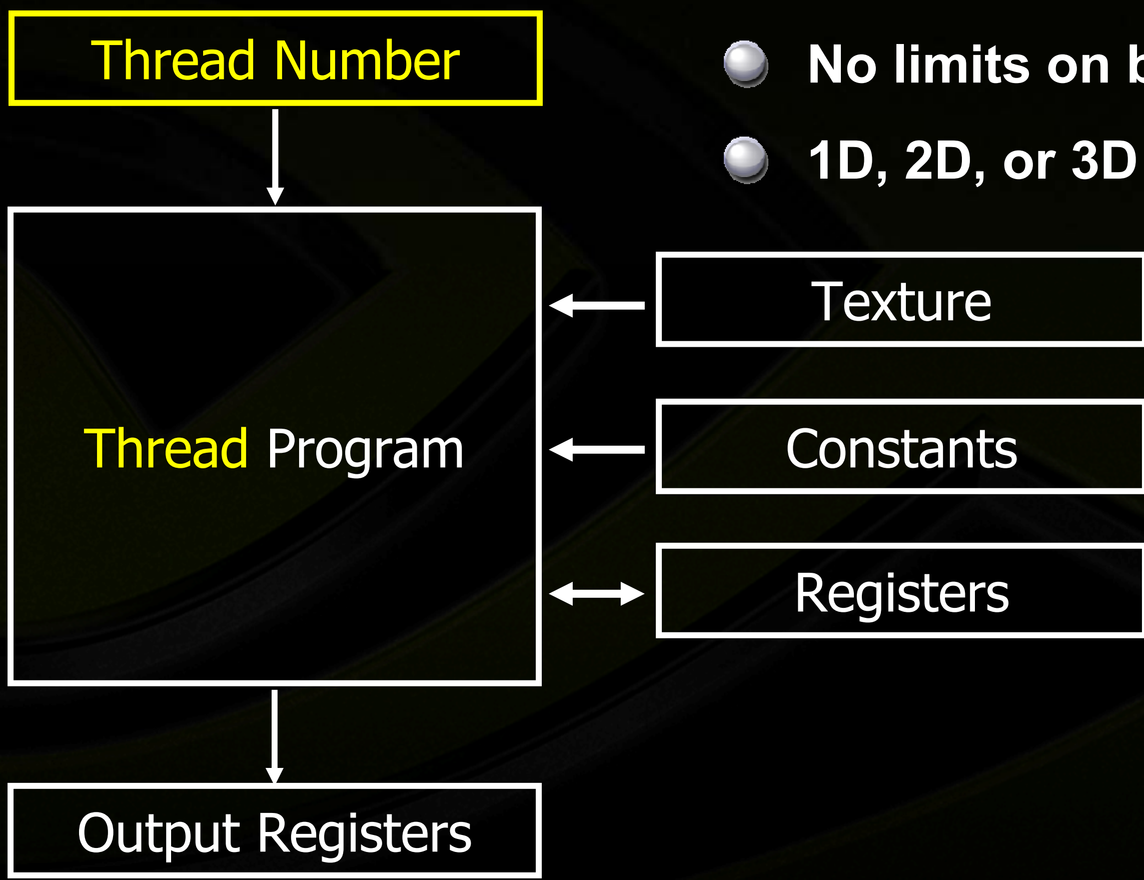
GeForce 7800 Pixel



Thread Programs

Features

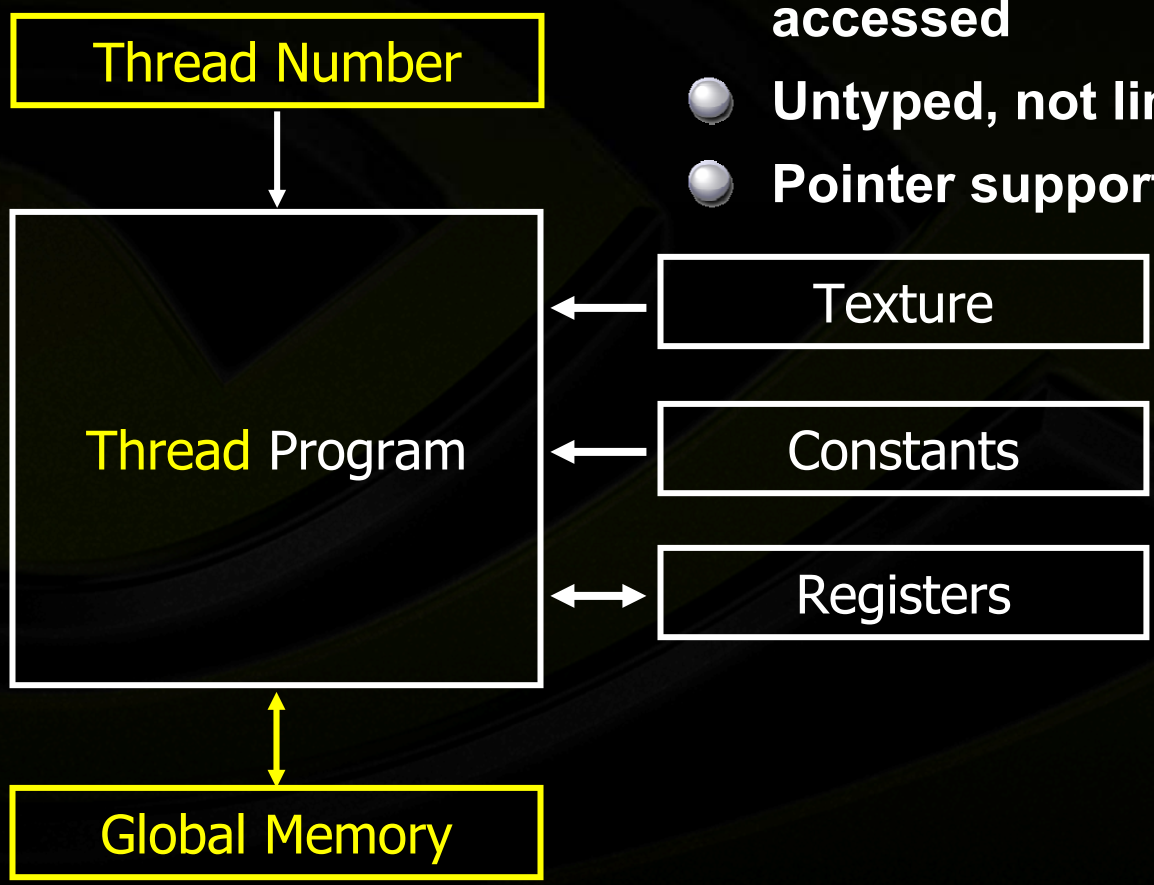
- Millions of instructions
- Full Integer and Bit instructions
- No limits on branching, looping
- 1D, 2D, or 3D thread ID allocation



Global Memory

Features

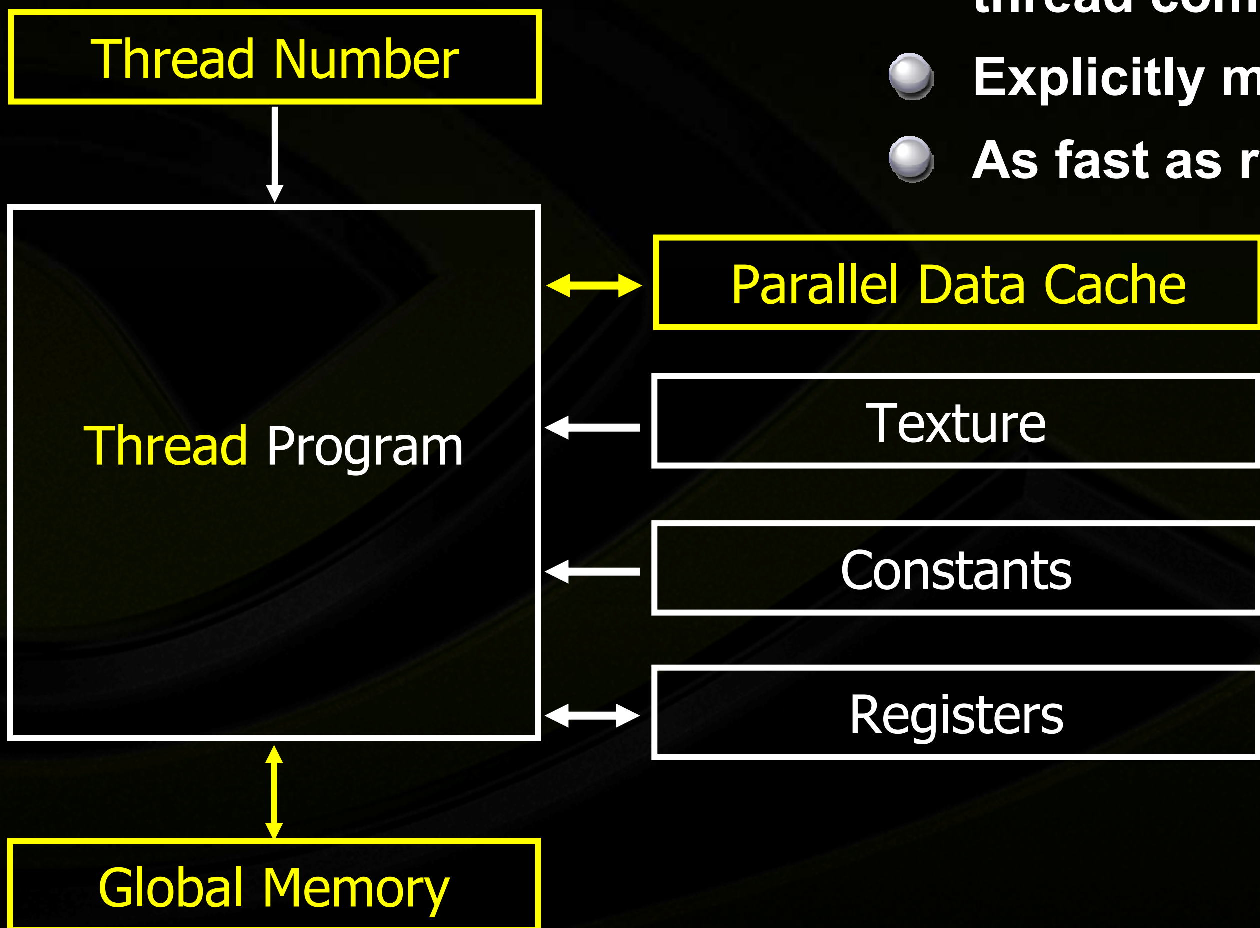
- Fully general load/store to GPU memory: Scatter/Gather
- Programmer flexibility on how memory is accessed
- Untyped, not limited to fixed texture types
- Pointer support



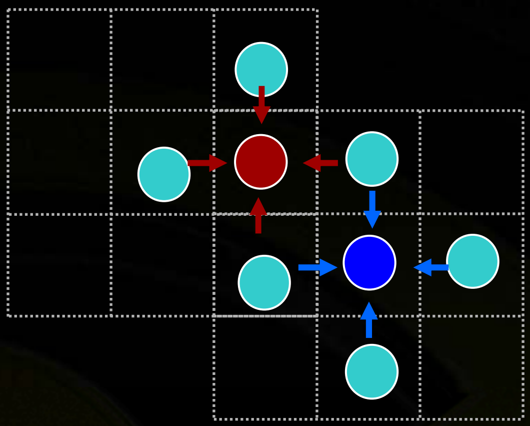
Parallel Data Cache

Features

- Dedicated on-chip memory
- Shared between threads for inter-thread communication
- Explicitly managed
- As fast as registers



Example Algorithm - Fluids



Pressure depends on neighbors

Goal: Calculate PRESSURE in a fluid

Pressure = Sum of neighboring pressures

$P_n' = P_1 + P_2 + P_3 + P_4$

So the pressure for each particle is…

$Pressure_1 = P_1 + P_2 + P_3 + P_4$

$Pressure_2 = P_3 + P_4 + P_5 + P_6$

$Pressure_3 = P_5 + P_6 + P_7 + P_8$

$Pressure_4 = P_7 + P_8 + P_9 + P_{10}$

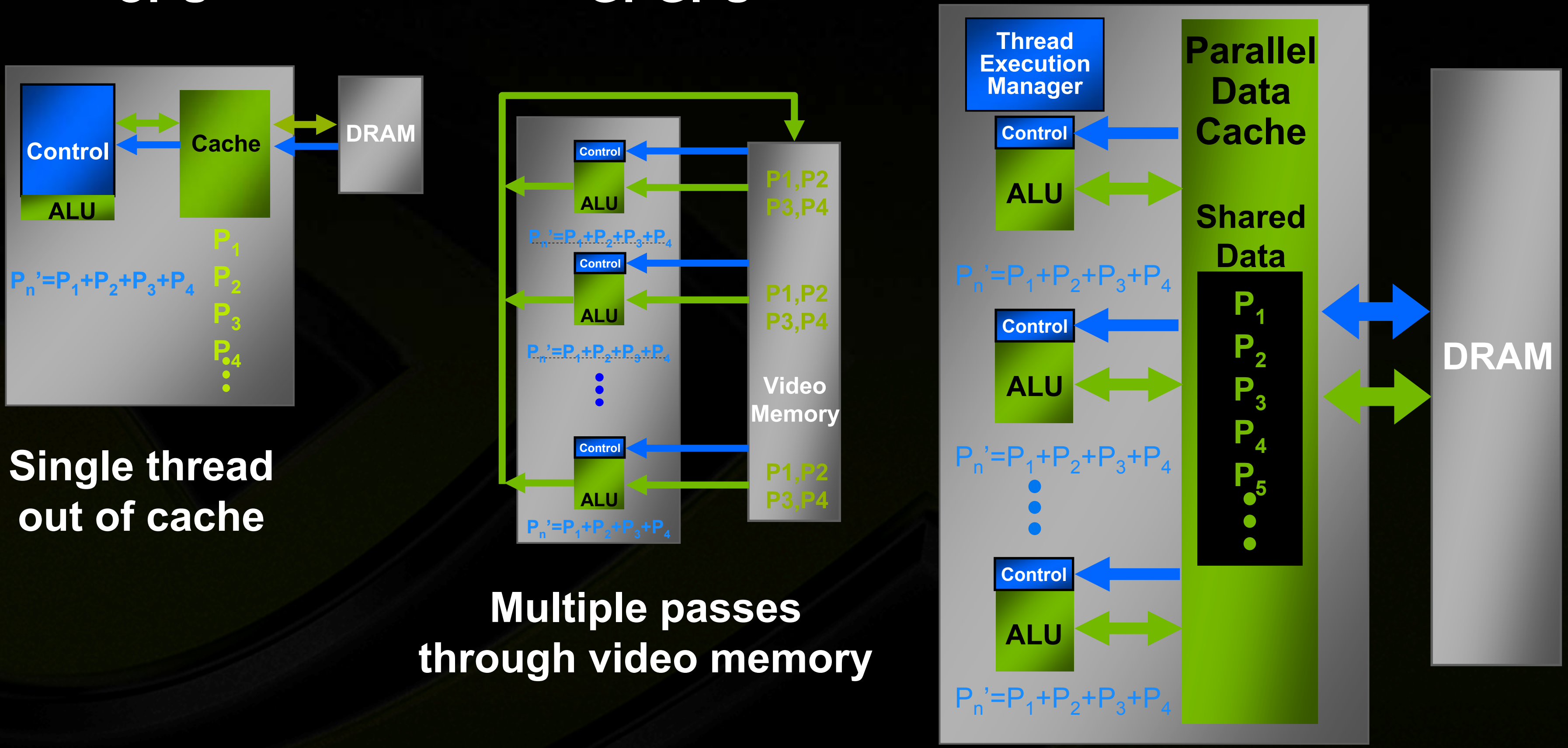
⋮

Example Fluid Algorithm

CUDA GPU Computing

CPU

GPGPU



Single thread out of cache

Multiple passes through video memory

Parallel execution through cache

Data/Computation

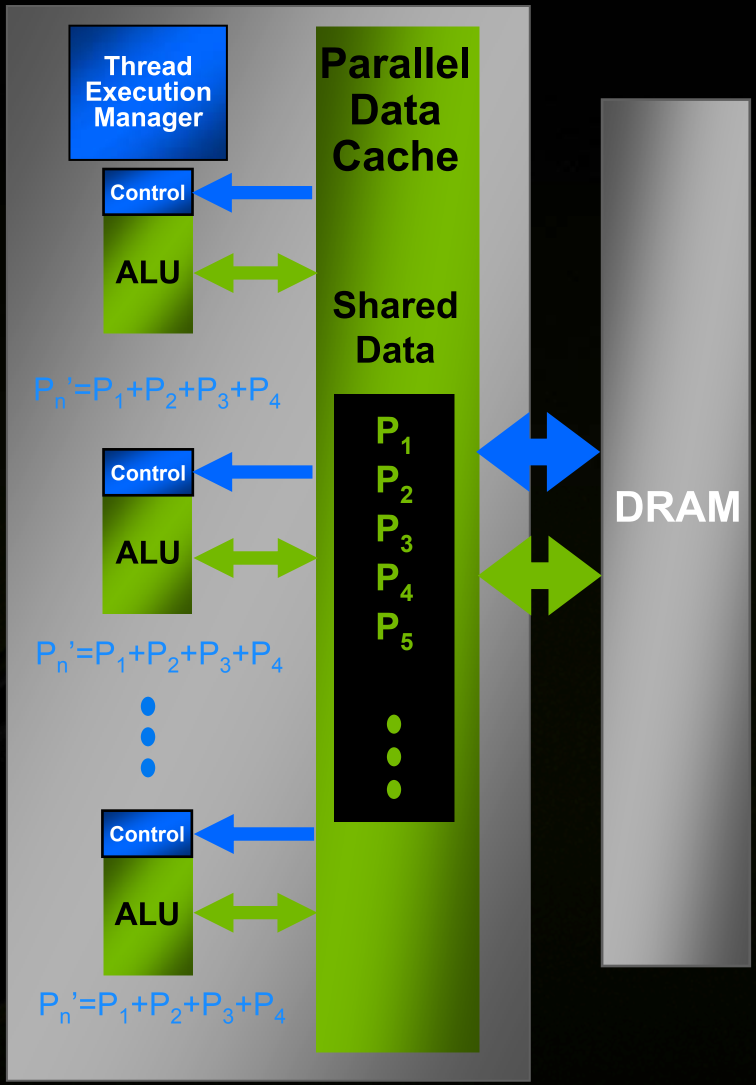
Program/Control

Parallel Data Cache

Addresses a fundamental problem of stream computing

Bring the data closer to the ALU

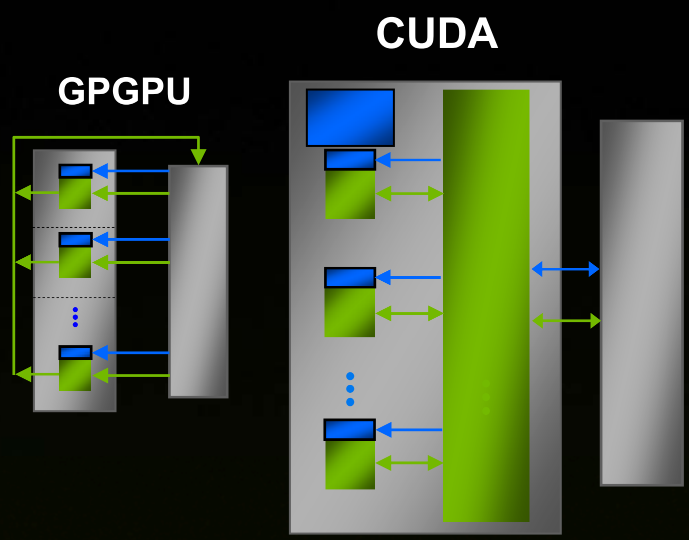
- Stage computation for the parallel data cache
- Minimize trips to external memory
- Share values to minimize overfetch and computation
- Increases arithmetic intensity by keeping data close to the processors
- User managed generic memory, threads read/write arbitrarily



Parallel execution through cache

Streaming vs. GPU Computing

- Streaming
  - Gather in, Restricted write
  - Memory is far from ALU
  - No inter-element communication
- CUDA
  - More general data parallel model
  - Full Scatter / Gather
  - PDC brings the data closer to the ALU
  - App decides how to decompose the problem across threads
  - Share and communicate between threads to solve problems efficiently



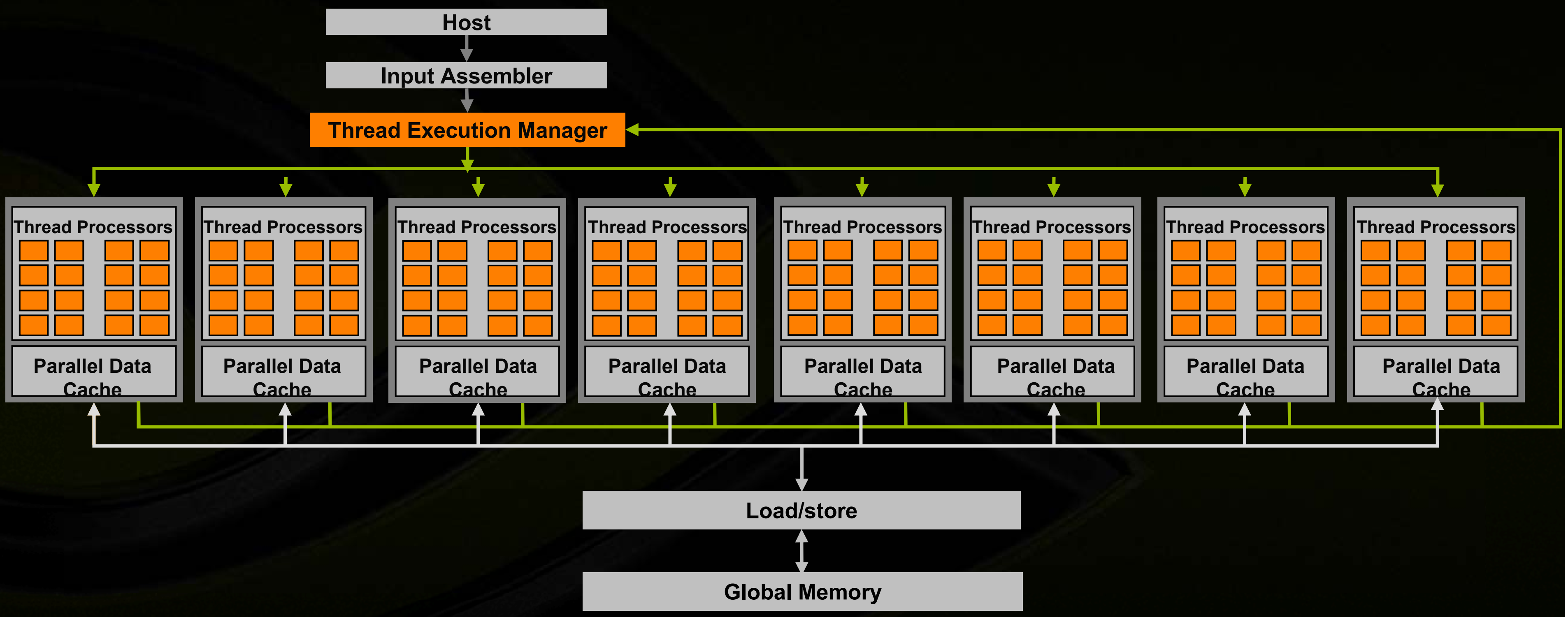
GeForce 8800 GTX Graphics Board

Core	575MHz
Multi-Processors	128
Shader	1350MHz
Memory	900MHz
Memory	768MB GDDR3

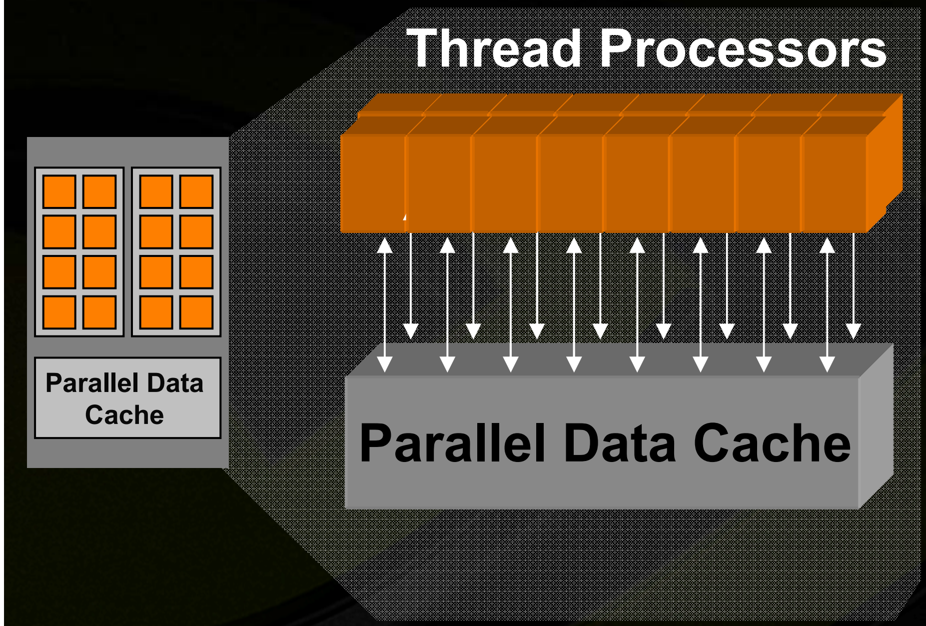
$599 e-tail

GeForce 8800 GPU Computing

- Processors execute computing threads



Thread Processor



- 128, 1.35 GHz processors
- 16KB Parallel Data Cache per cluster
- Scalar architecture
- IEEE 754 Precision
- Full featured instruction set

CUDA Programming Model

Programming Model:
A Highly Multi-threaded Coprocessor

- The GPU is viewed as a compute device that:
  - Is a coprocessor to the CPU or host
  - Has its own DRAM (device memory)
  - Runs many threads in parallel

- Data-parallel portions of an application execute on the device as kernels which run many cooperative threads in parallel

- Differences between GPU and CPU threads
  - GPU threads are extremely lightweight
    - Very little creation overhead
  - GPU needs 1000s of threads for full efficiency
    - Multi-core CPU needs only a few

C on the GPU

- A simple, explicit programming language solution
- Extend only where necessary

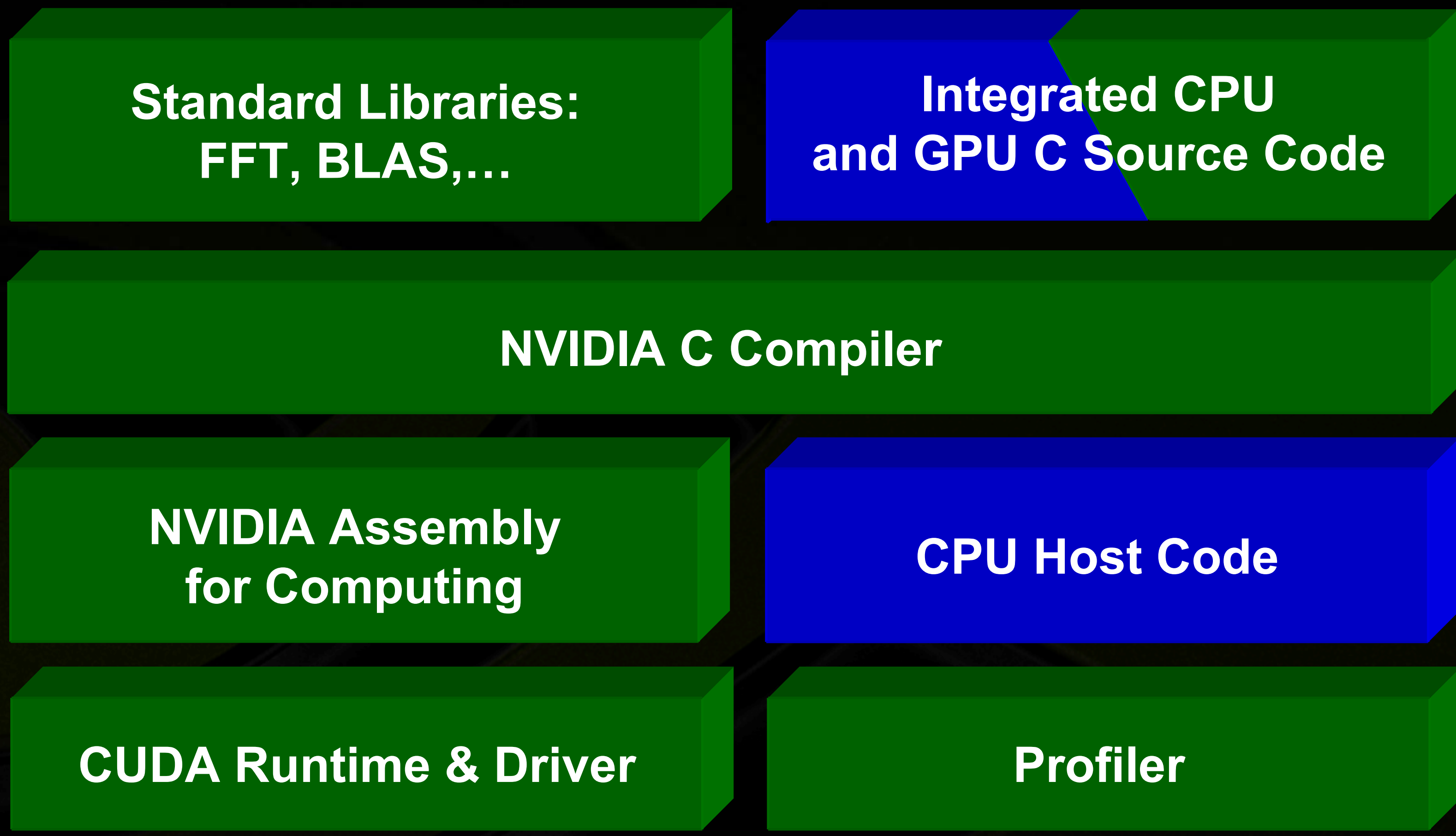
```
__global__ void KernelFunc(...);
__device__ int GlobalVar;
__shared__ int SharedVar;

KernelFunc<<< 500, 128 >>>(...);
```

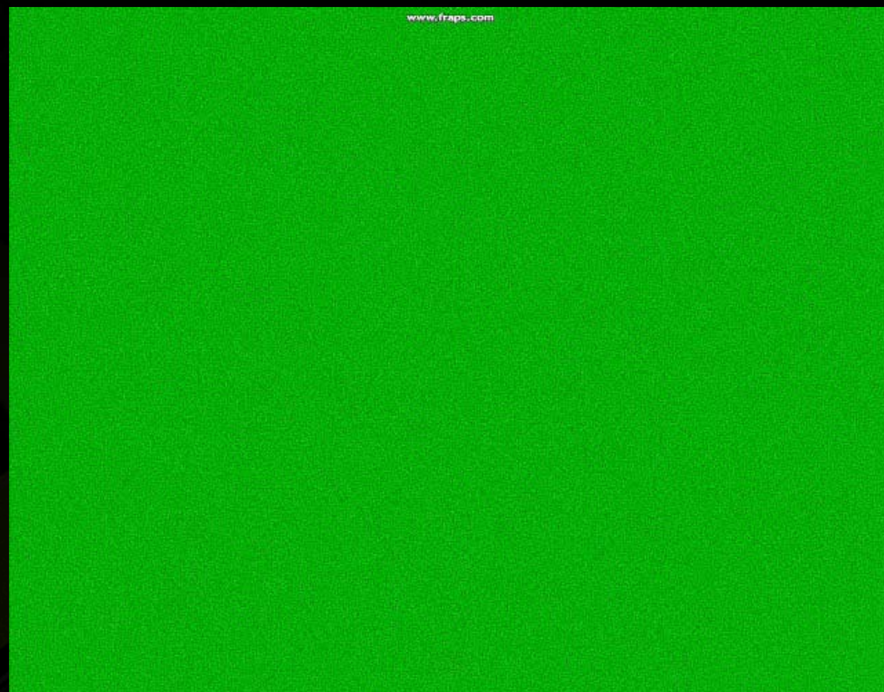
Runtime Component: Memory Management

- Explicit GPU memory allocation
- Returns pointers to GPU memory
- Device memory allocation
  - `cudaMalloc()`, `cudaFree()`
- Memory copy from host to device, device to host, device to device
  - `cudaMemcpy()`, `cudaMemcpy2D()`, ...
  - `cudaGetSymbolAddress()`
- OpenGL & DirectX interoperability
  - `cudaGLMapBufferObject()`

CUDA SDK

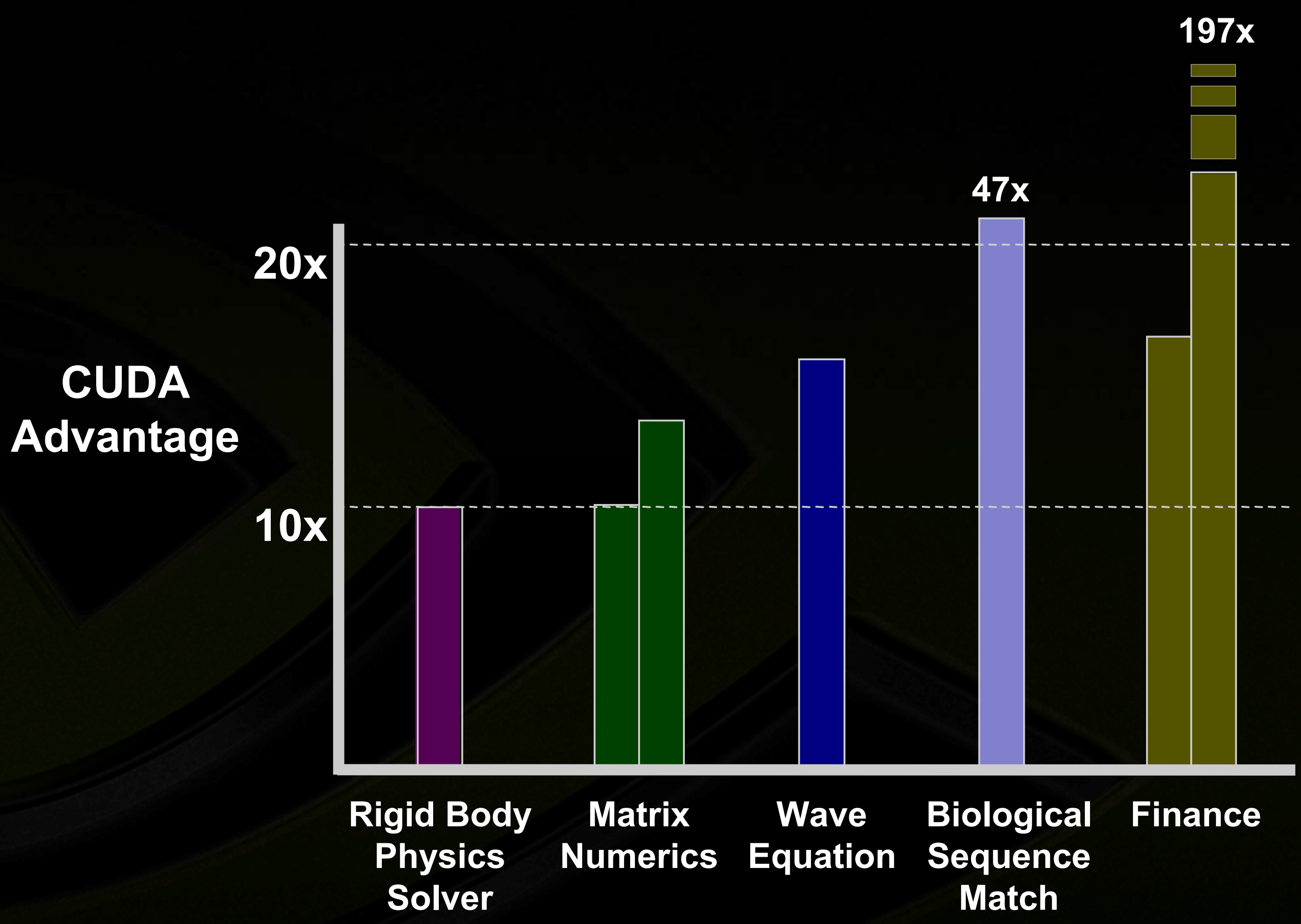

Standard Libraries:
FFT, BLAS,…
Integrated CPU
and GPU C Source Code
NVIDIA C Compiler
NVIDIA Assembly
for Computing
CPU Host Code
CUDA Runtime & Driver
Profiler

CUDA Stable Fluids Demo



CUDA port of:
Jos Stam, "Stable Fluids", In SIGGRAPH 99 Conference Proceedings, Annual Conference Series, August 1999, 121-128.

New Applications Enabled by CUDA



GeForce 8800 vs. 2.66 GHz Core 2 Duo

CUDA Performance Advantages

Performance:

- BLAS1: 60+ GB/sec
- BLAS3: 100+ GFLOPS
- FFT: 52 benchFFT* GFLOPS
- FDTD: 1.2 Gcells/sec
- SSEARCH: 5.2 Gcells/sec
- Black Scholes: 4.7 GOptions/sec

Benefits:

- Leveraging the parallel data cache
- GPU memory bandwidth
- GPU GFLOPS performance
- Custom hardware intrinsics
  - __sinf, __cosf, __expf, __logf, ...

All benchmarks are compiled code!

*GFLOPS as defined by http://www.fftw.org/benchfft

Conclusions

- GPU Computing on GeForce 8800
  - Simple threading model
  - Parallel data cache
  - General global memory access
- CUDA Programming model
  - C on GPUs
  - Tool chain and driver designed for computation
- Libraries optimized for GPU Computing
  - CUFFT, CUBLAS
- Availability
  - Linux and Windows
  - Register for the Beta online

http://developer.nvidia.com/CUDA

Questions?

http://developer.nvidia.com/CUDA