GPU Computing: The Democratization of Parallel Computing

David Luebke
NVIDIA Research

Parallel Computing's Golden Age

- 1980s, early `90s: a golden age for parallel computing
  - Particularly data-parallel computing
- Architectures
  - Connection Machine, MasPar, Cray
  - True supercomputers: incredibly exotic, powerful, expensive
- Algorithms, languages, & programming models
  - Solved a wide variety of problems
  - Various parallel algorithmic models developed
  - P-RAM, V-RAM, circuit, hypercube, etc.

Parallel Computing's Dark Age

- But…impact of data-parallel computing limited
  - Thinking Machines sold 7 CM-1s (100s of systems total)
  - MasPar sold ~200 systems

- Commercial and research activity subsided
  - Massively-parallel machines replaced by clusters of ever-more powerful commodity microprocessors
  - Beowulf, Legion, grid computing, …

Massively parallel computing lost momentum to the inexorable advance of commodity technology

Enter the GPU

- GPU = *Graphics Processing Unit*
  - Chip in computer video cards, PlayStation 3, Xbox, etc.
  - Two major vendors: NVIDIA and ATI (now AMD)

Enter the GPU

- GPUs are massively multithreaded manycore chips
  - NVIDIA Tesla products have up to 128 scalar processors
  - Over 12,000 concurrent threads in flight
  - Over 470 GFLOPS sustained performance
- Users across science & engineering disciplines are achieving 100x or better speedups on GPUs
- CS researchers can use GPUs as a research platform for manycore computing: arch, PL, numeric, …

Enter CUDA

- *CUDA* is a scalable parallel programming model and a software environment for parallel computing
  - Minimal extensions to familiar C/C++ environment
  - Heterogeneous serial-parallel programming model

- NVIDIA's *TESLA* GPU architecture accelerates CUDA
  - Expose the computational horsepower of NVIDIA GPUs
  - Enable general-purpose *GPU computing*

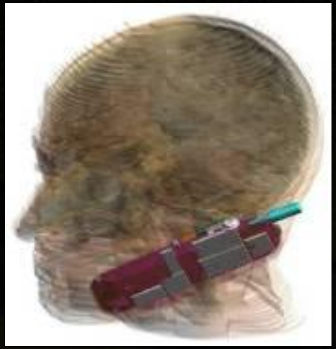
- CUDA also maps well to multicore CPUs!

The Democratization of Parallel Computing

- GPU Computing with CUDA brings data-parallel computing to the masses
  - Over 46,000,000 CUDA-capable GPUs sold
  - A “developer kit” costs ~$200 (for 500 GFLOPS)
- Data-parallel supercomputers are everywhere!
  - CUDA makes this power accessible
  - We’re already seeing innovations in data-parallel computing

Massively parallel computing has become a commodity technology!

GPU Computing: Motivation



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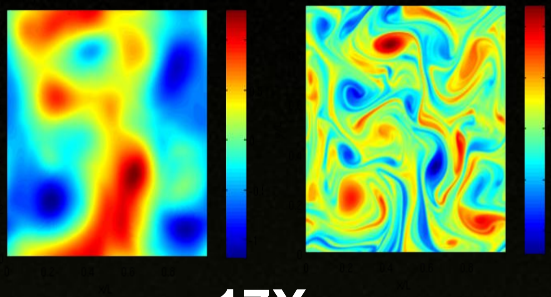

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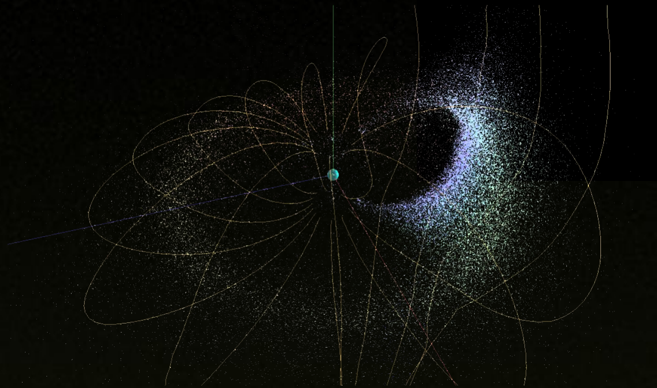

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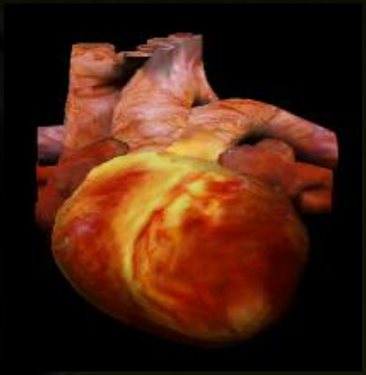

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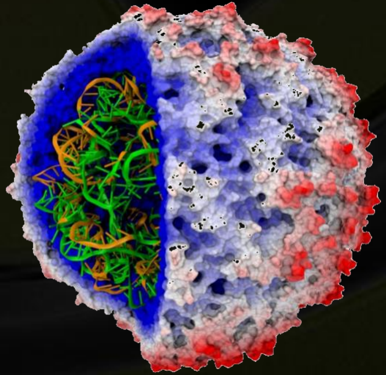

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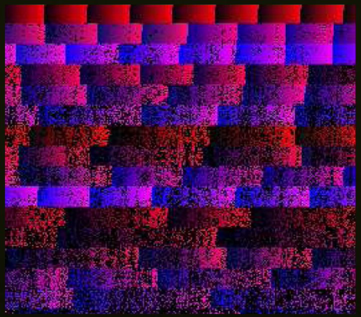
GPU Computing: Motivation



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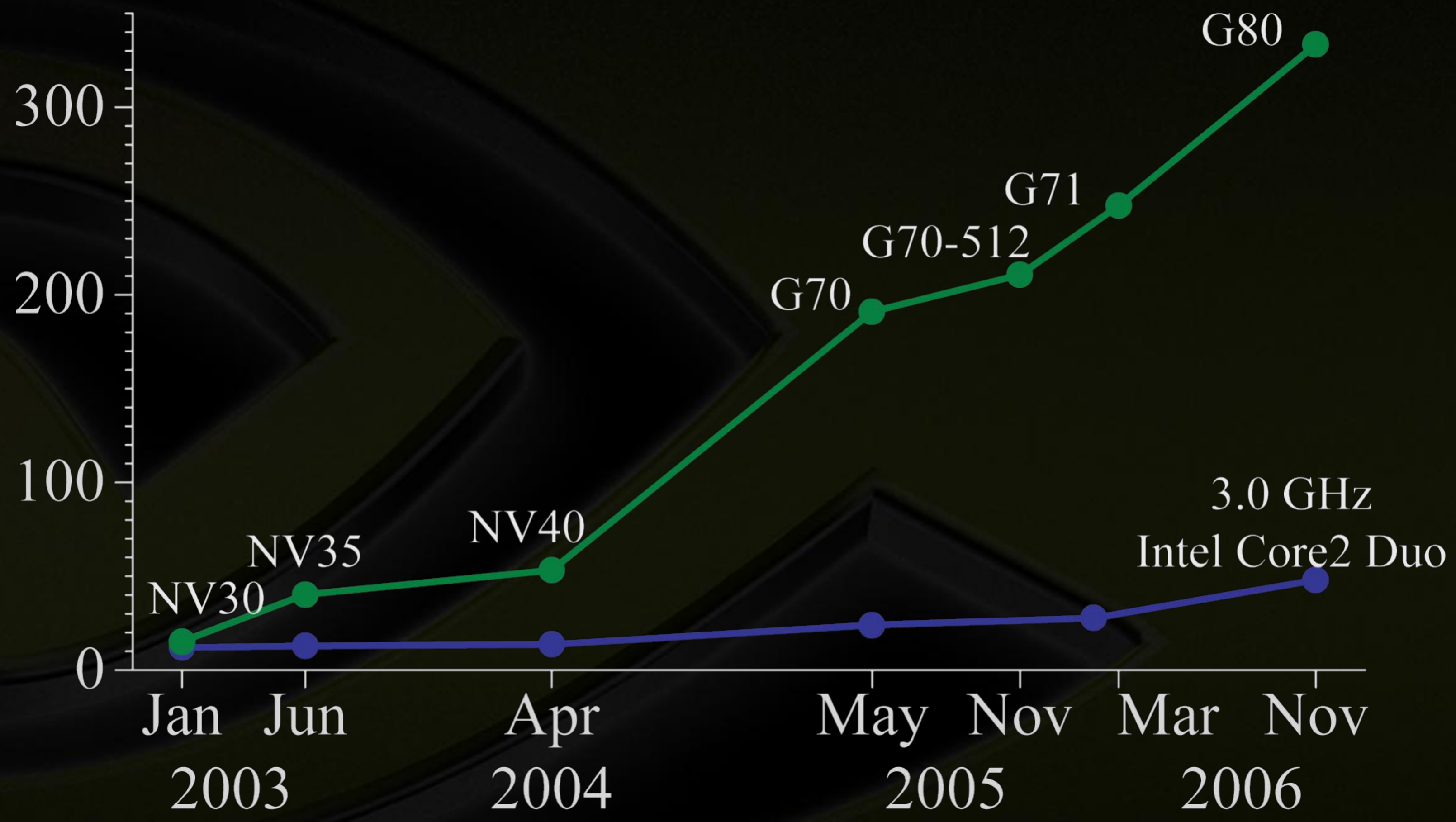
GPUs Are Fast

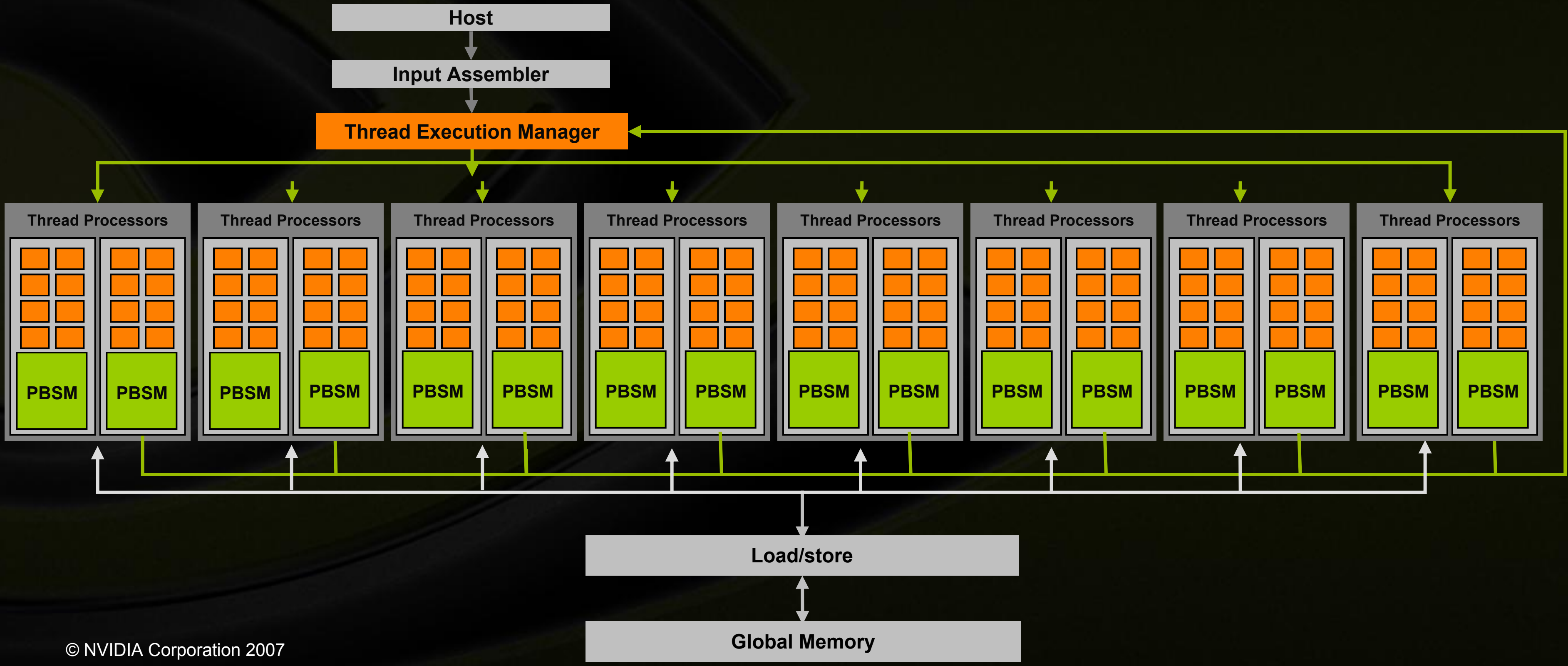
- Theoretical peak performance: 518 GFLOPS
- Sustained µbenchmark performance:
    - Raw math: 472 GFLOPS (8800 Ultra)
    - Raw bandwidth: 80 GB per second (Tesla C870)
- Actual application performance:
    - Molecular dynamics: 290 GFLOPS (VMD ion placement)

GPUs Are Getting Faster, Faster



Manycore GPU – Block Diagram

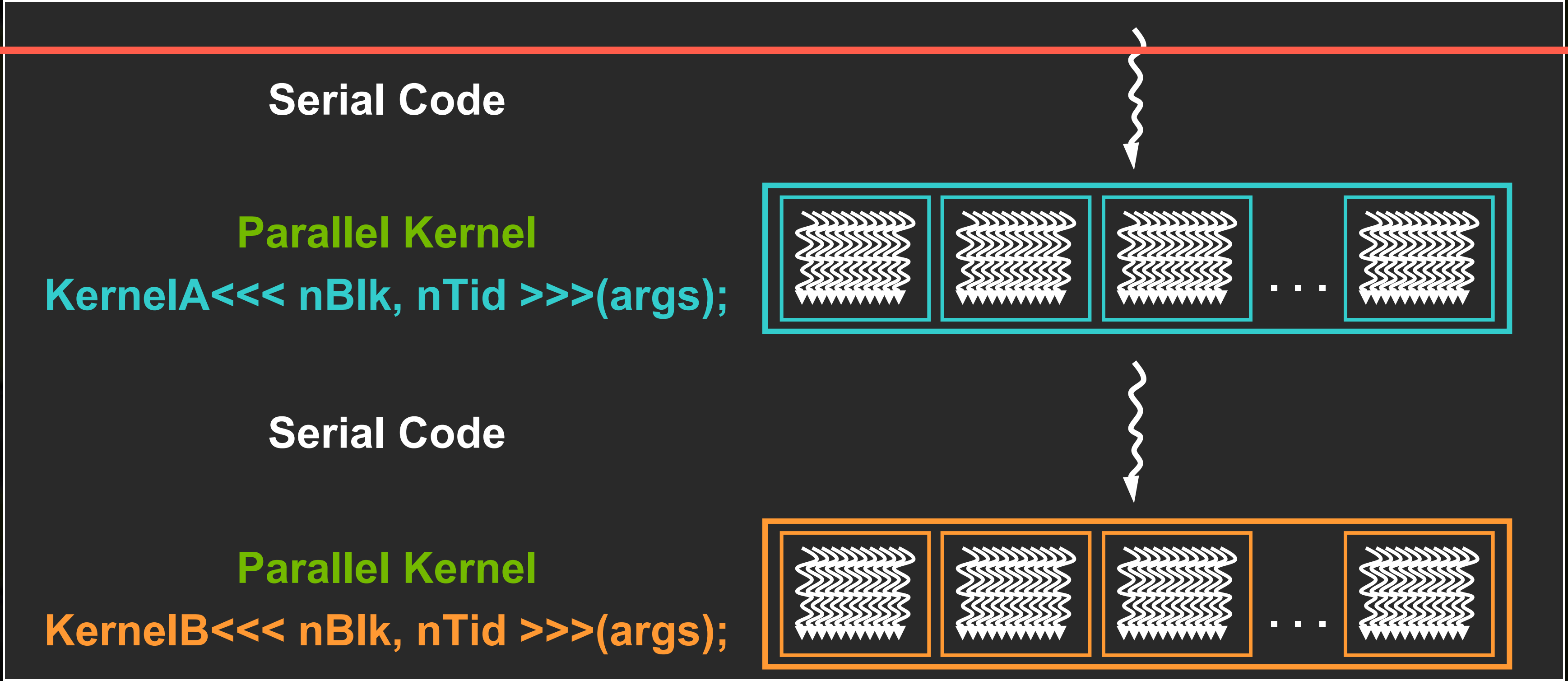
- G80 (launched Nov 2006 – GeForce 8800 GTX)
- 128 Thread Processors execute kernel threads
- Up to 12,288 parallel threads active
- Per-block shared memory (PBSM) accelerates processing



CUDA Programming Model

Heterogeneous Programming

- CUDA = serial program with parallel kernels, all in C
  - Serial C code executes in a CPU thread
  - Parallel kernel C code executes in *thread blocks* across multiple processing elements



Serial Code

Parallel Kernel

KernelA<<< nBlk, nTid >>>(args);

Serial Code

Parallel Kernel

KernelB<<< nBlk, nTid >>>(args);

GPU Computing with CUDA:
A Highly Multithreaded Coprocessor

- The GPU is a highly parallel compute device
  - serves as a coprocessor for the host CPU
  - has its own device memory on the card
  - executes many threads in parallel
- Parallel kernels run a single program in many threads
- GPU threads are extremely lightweight
  - Thread creation and context switching are essentially free
- GPU expects 1000’s of threads for full utilization

CUDA: Programming GPU in C

NVIDIA

- Philosophy: provide minimal set of extensions necessary to expose power

- Declaration specifiers to indicate where things live

```
__global__ void KernelFunc(...);    // kernel function, runs on device
__device__ int  GlobalVar;          // variable in device memory
__shared__ int  SharedVar;          // variable in per-block shared memory
```

- Extend function invocation syntax for parallel kernel launch

```
KernelFunc<<<500, 128>>>(...);      // launch 500 blocks w/ 128 threads each
```

- Special variables for thread identification in kernels

```
dim3 threadIdx;  dim3 blockIdx;  dim3 blockDim;  dim3 gridDim;
```

- Intrinsics that expose specific operations in kernel code

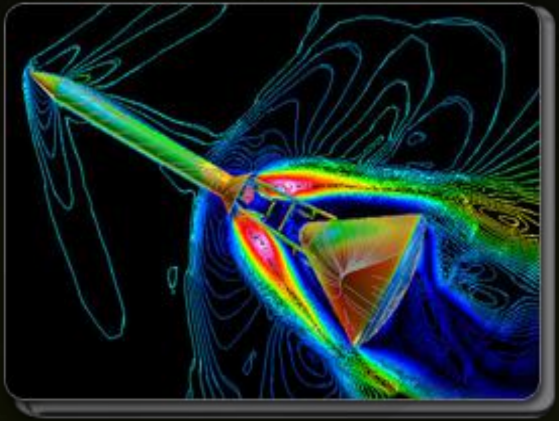
```
__syncthreads();                    // barrier synchronization within kernel
```

Decoder Ring

GeForce®
Entertainment

Quadro®
Design & Creation

Tesla™
High Performance Computing



Architecture: TESLA
Chips: G80, G84, G92, …

A New Platform: Tesla

- HPC-oriented product line
  - C870: board (1 GPU)
  - D870: deskside unit (2 GPUs)
  - S870: 1u server unit (4 GPUs)

Conclusion

- GPUs are massively parallel manycore computers
  - Ubiquitous - most successful parallel processor in history
  - Useful - users achieve huge speedups on real problems
- CUDA is a powerful parallel programming model
  - Heterogeneous - mixed serial-parallel programming
  - Scalable - hierarchical thread execution model
  - Accessible - minimal but expressive changes to C
- They provide tremendous scope for innovative, impactful research