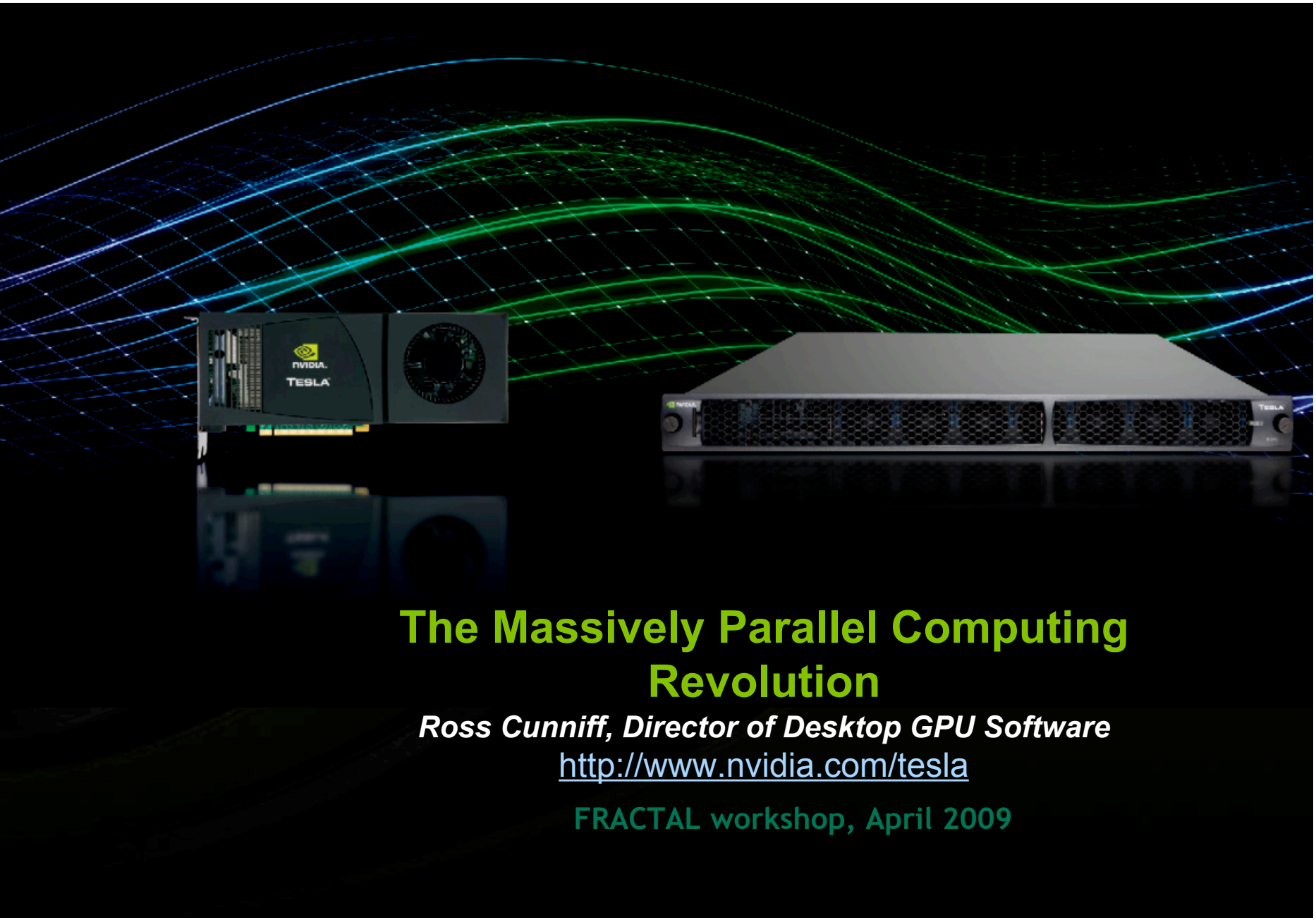


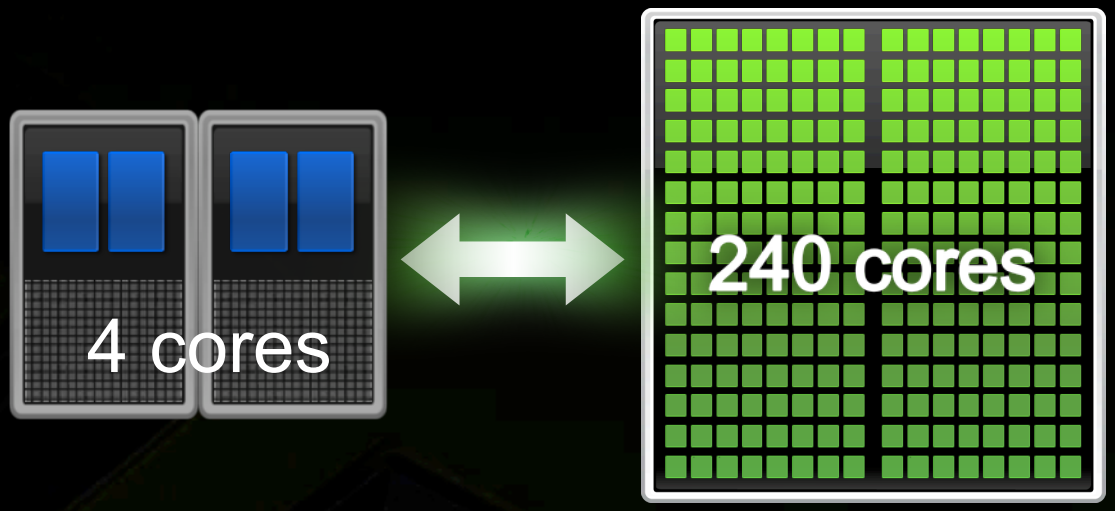
The Massively Parallel Computing Revolution

Ross Cunniff, Director of Desktop GPU Software

http://www.nvidia.com/tesla

FRACTAL workshop, April 2009

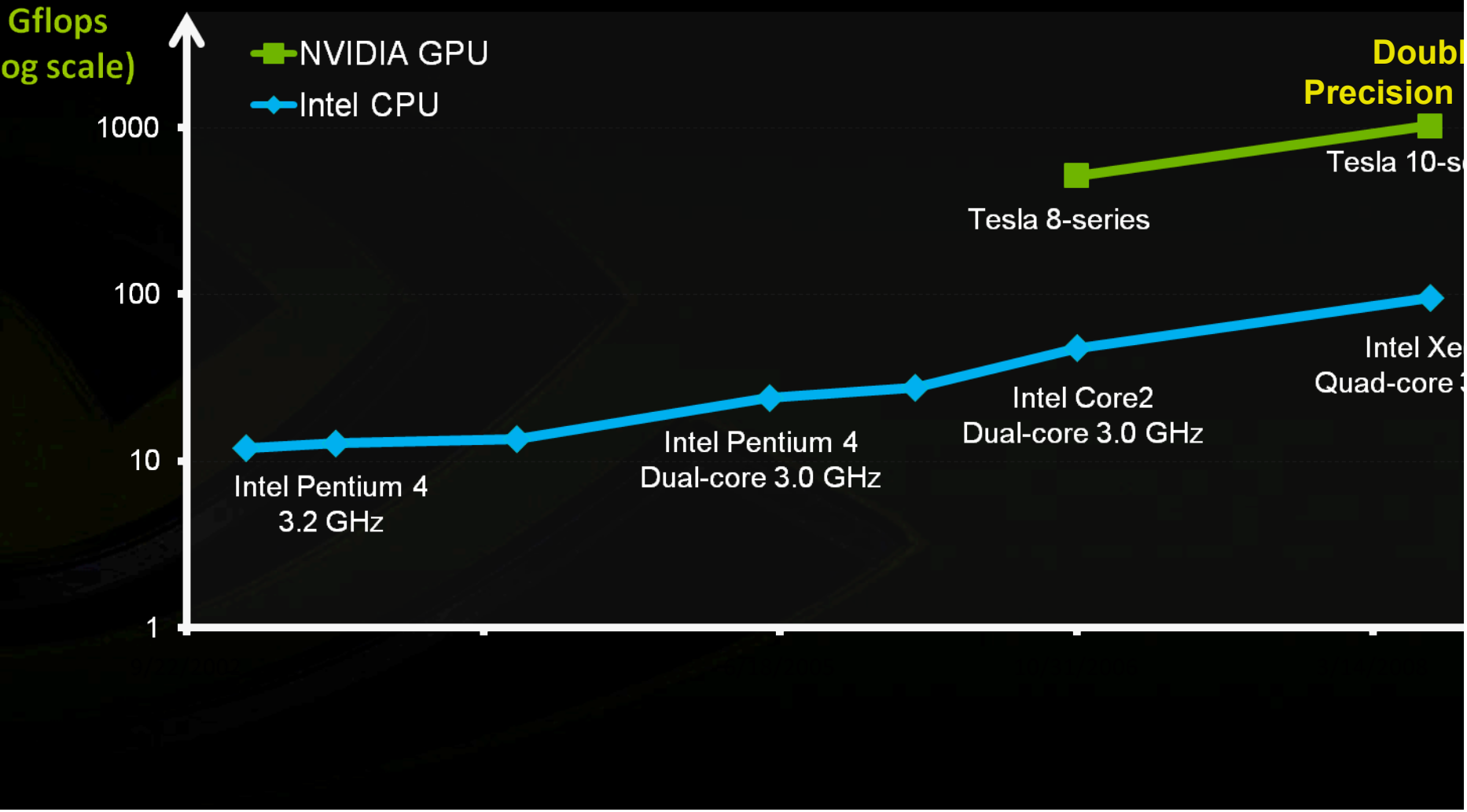
Move to Massive Parallelism



Computing with CPU + GPU

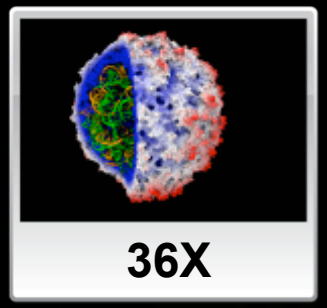
Heterogeneous Computing

Computation Discontinuity



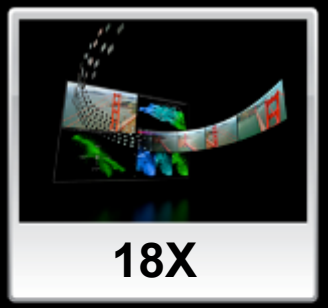
146X

Medical Imaging
U of Utah



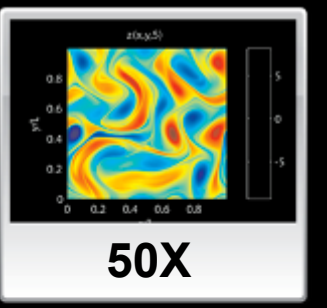
36X

Molecular Dynamics
U of Illinois, Urbana



18X

Video Transcoding
Elemental Tech



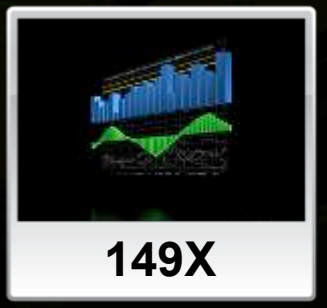
50X

Matlab Computing
AccelerEyes

1(

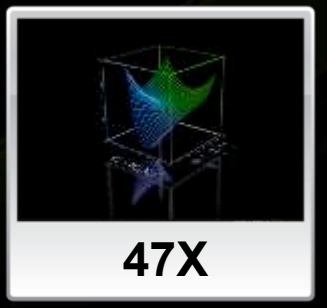
Astro
RI

50x – 150x



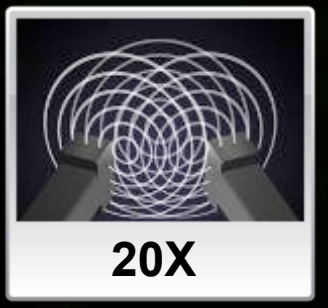
149X

Financial simulation
Oxford



47X

Linear Algebra
Universidad Jaime



20X

3D Ultrasound
Techniscan

130X

Quantum Chemistry
U of Illinois, Urbana

3

Gene S
U of M

Parallel vs Sequential Architecture Evolution

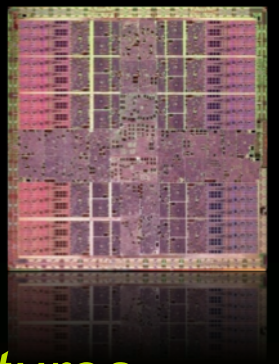
LIAC IV

Cray-1

Maspar

Thinking Machines

Blue Gene



Ma
GP

High Performance Computing Architectures

EC PDP-1

Intel 4004

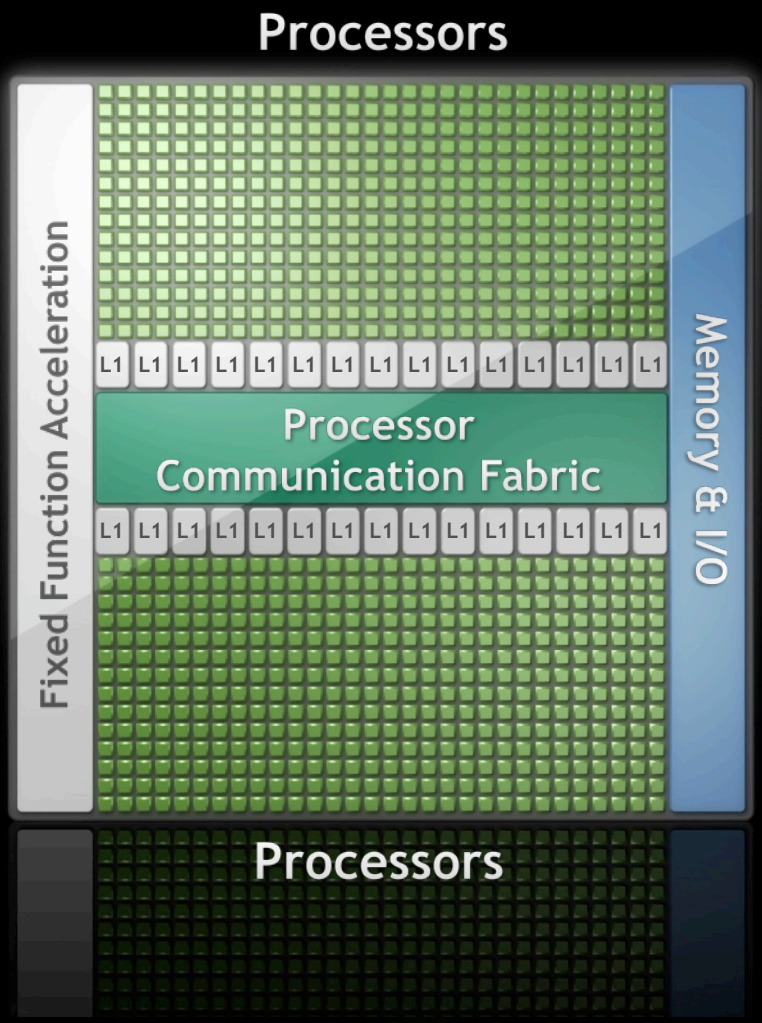
IBM System 360

VAX

IBM POWER4

Mu
x8

Database, Operating System Sequential Architectures



NVIDIA Tesla 10-Series GPU

Massively parallel, many core archite

240 Processor Cores

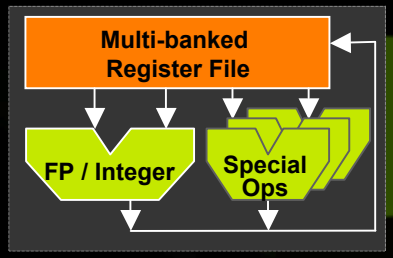
1 Teraflops - 1,000 times Cray X-MP

IEEE Compliant Double Precision Flo

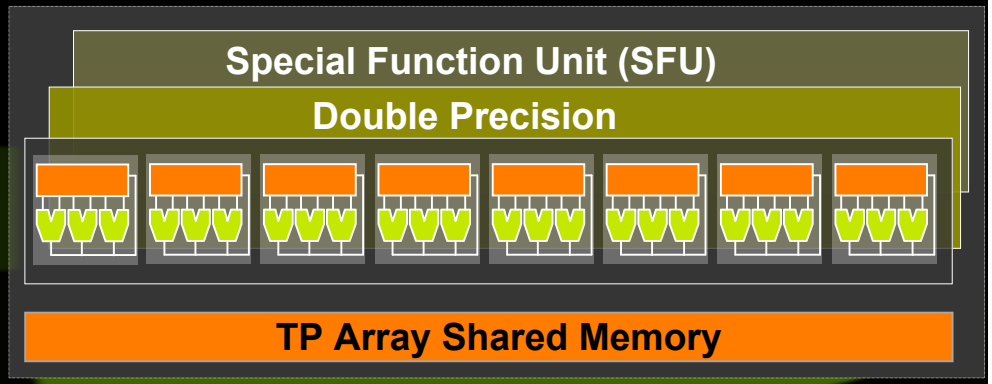
Designed for Scientific Computing

Tesla T10 GPU: 240 Processor Cores

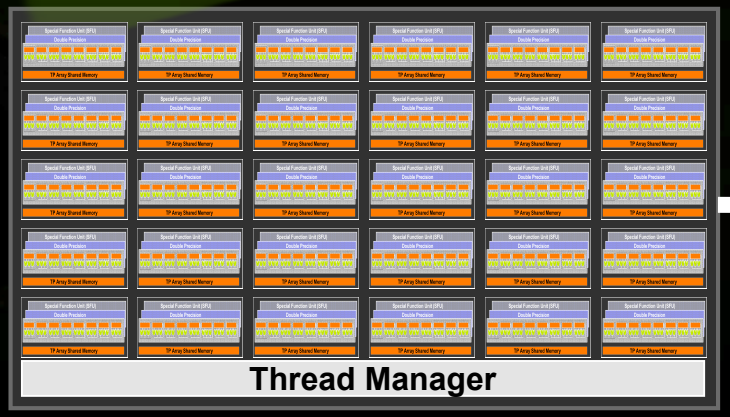
Thread Processor (TP)



Thread Processor Array (TPA)



- Processor core has
  - Floating point / Integer unit
  - Move, compare, logic, branch unit
- IEEE 754 floating point
  - Single and Double
- 102 GB/s high-speed interface to memory

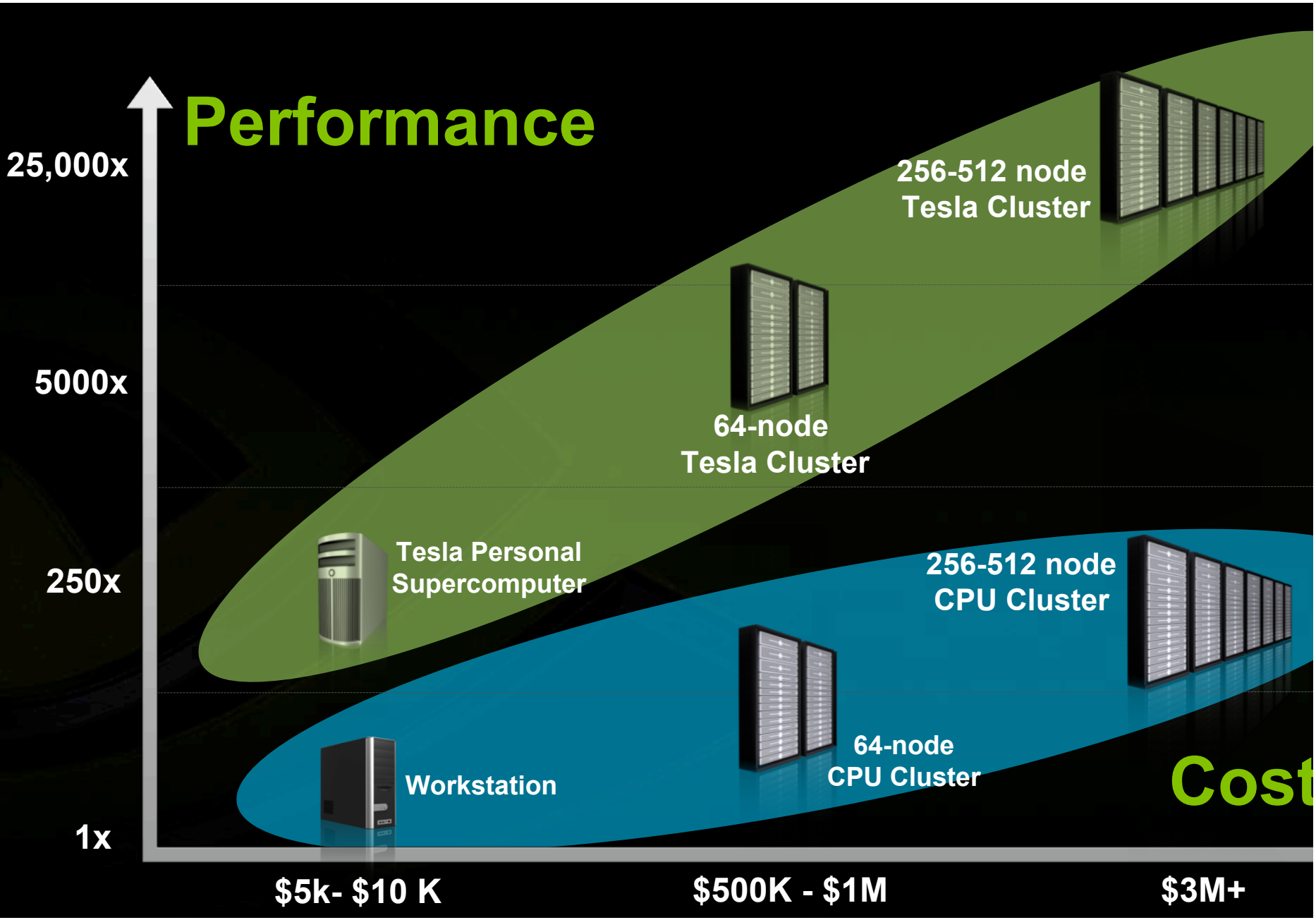


GDDR3

512 bit

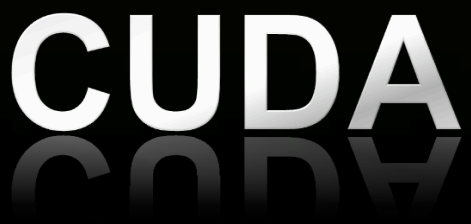
102 GB/

30 TPAs = 240 Processors


Performance
25,000x
5000x
250x
1x
256-512 node
Tesla Cluster
64-node
Tesla Cluster
Tesla Personal
Supercomputer
256-512 node
CPU Cluster
64-node
CPU Cluster
Workstation
Cost
$5k- $10 K
$500K - $1M
$3M+

5000+ Customers / ISVs

Life Sciences & Medical Equipment		Productivity / Misc	Oil and Gas	EDA	Finance	CAE / Mathematica
Max Planck	GE Healthcare	CEA	Hess	Synopsys	Symcor	AccelerEyes
FDA	Siemens	NCSA	TOTAL	Nascentric	Level 3	MathWorks
barts Research	Techniscan	WRF Weather Modeling	CGG/Veritas	Gauda	SciComp	Wolfram
Medtronic	Boston Scientific	OptiTex	Chevron	CST	Hanweck	National Instruments
AGC	Eli Lilly	Tech-X	Headwave	Agilent	Quant Catalyst	Ansys
olved machines	Silicon Informatics	Elemental Technologies	Acceleware		RogueWave	Access Analytic
mith-Waterman	Stockholm Research	Dimensional Imaging	Seismic City		BNP Paribas	Tech-x
NA sequencing	Harvard	Manifold	P-Wave Seismic Imaging			RIKEN
AutoDock	Delaware	Digisens	Mercury Computer			SOFA
NAMD/VMD	Pittsburg	General Mills	ffA			Renault
olding@Home	ETH Zurich	Rapidmind				Boeing
oward Hughes Medical	Institute Atomic Physics	Rhythm & Hues				
RIBI Genomics		xNormal				
		Elcomsoft				
		LINZIK				

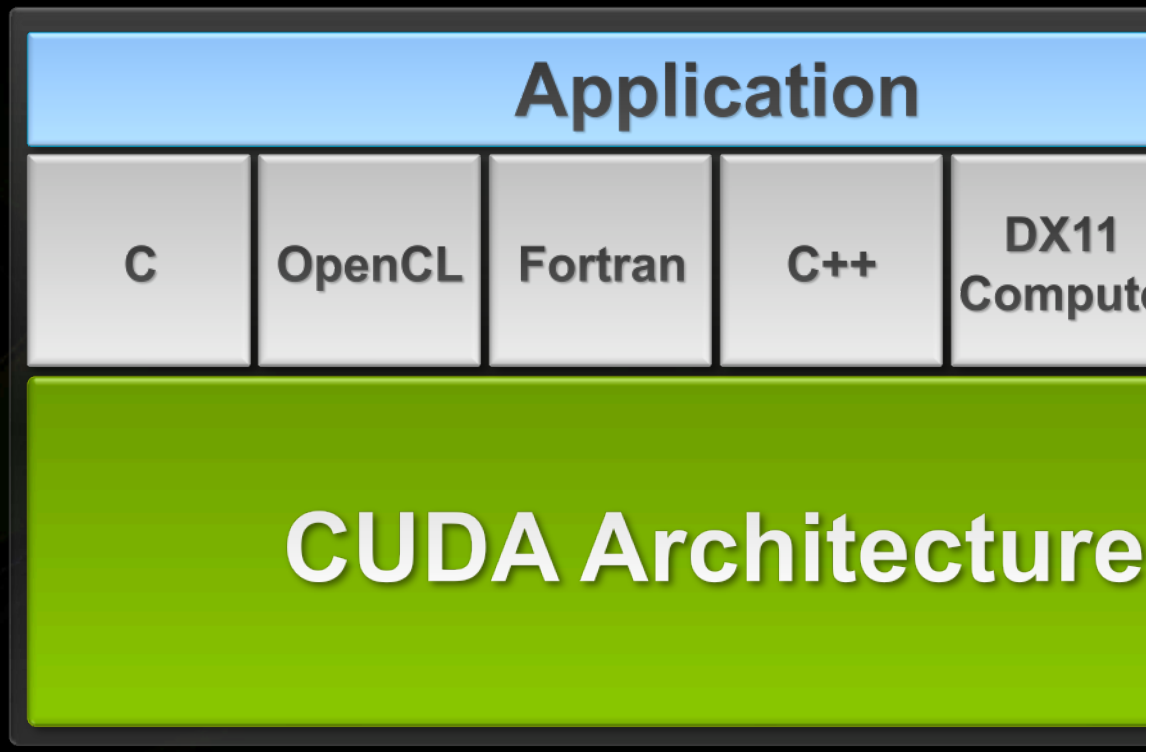


CUDA Parallel Computing Architecture

Parallel computing architecture and programming model

Includes a C compiler plus support for OpenCL and DX11 Compute

Architected to natively support all computational interfaces (standard languages and APIs)



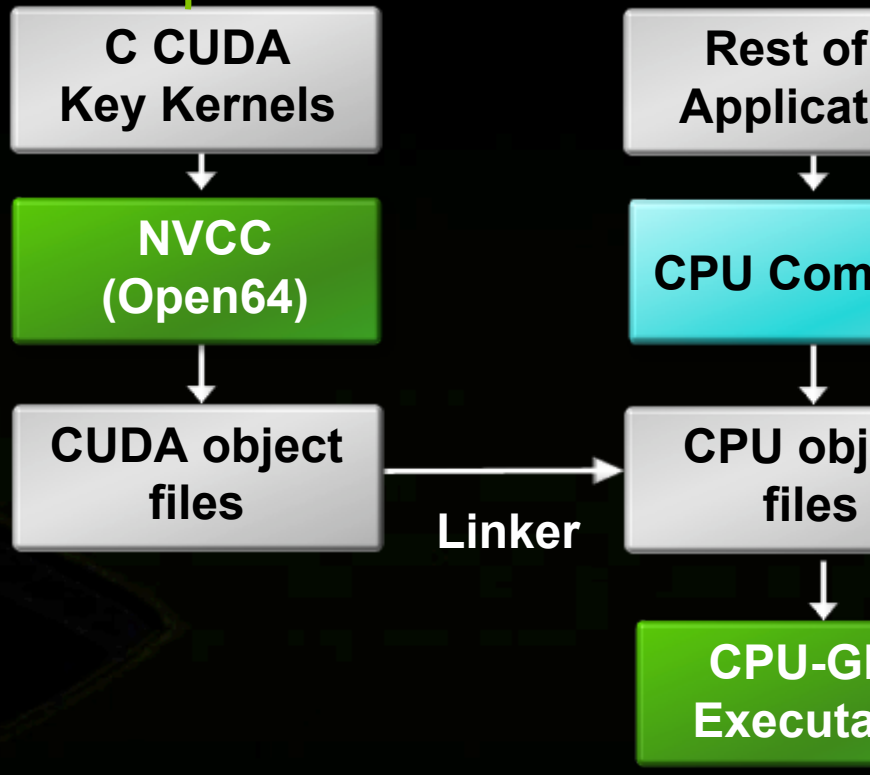
Compiling C for CUDA Applications

```
void serial_function(… ) {
  ...
}
void other_function(int ... ) {
  ...
}
```

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

```
void main( ) {
  float x;
  saxpy_serial(..);
  ...
}
```

Write Parallel CUDA code



C for CUDA : C with few keywords

```
void saxpy_serial(int n, float a, float *x, float *y)
{
    for (int i = 0; i < n; ++i)
        y[i] = a*x[i] + y[i];
}
// Invoke serial SAXPY kernel
saxpy_serial(n, 2.0, x, y);
```

Standard C

```
__global__ void saxpy_parallel(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];
}
// Invoke parallel SAXPY kernel with 256 threads/block
int nblocks = (n + 255) / 256;
saxpy_parallel<<<nblocks, 256>>>(n, 2.0, x, y);
```

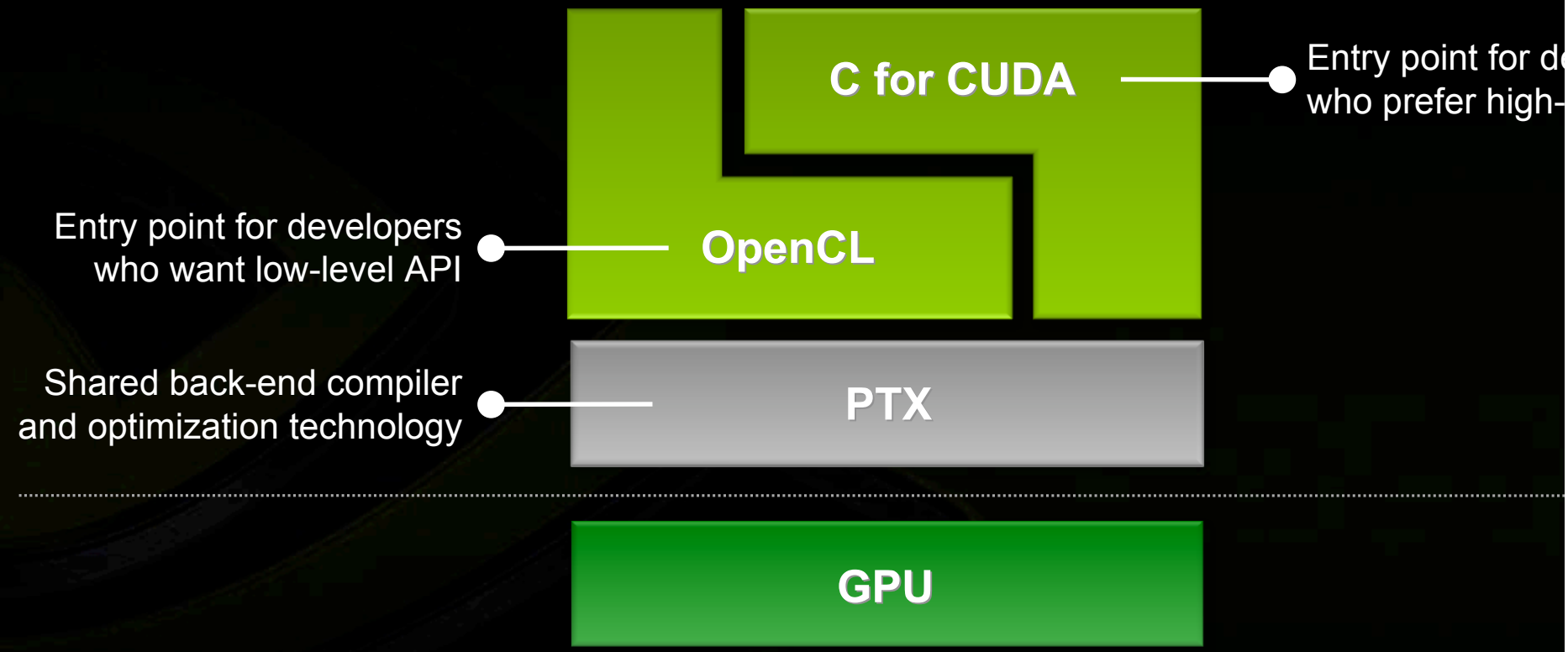
Parallel C

Support for Fortran, Python

- PGI Fortran to CUDA compiler (alpha release)
- Fortran Wrapper for CUDA
  - FLAGON : Library of numerics for Fortran 95
- Full Fortran support in Q4 2009
- Also Available
  - PyCUDA : Python Wrapper for CUDA
  - Java wrappers, .NET integration

Available from www.nvidia.com/tesla

NVIDIA C for CUDA and OpenCL

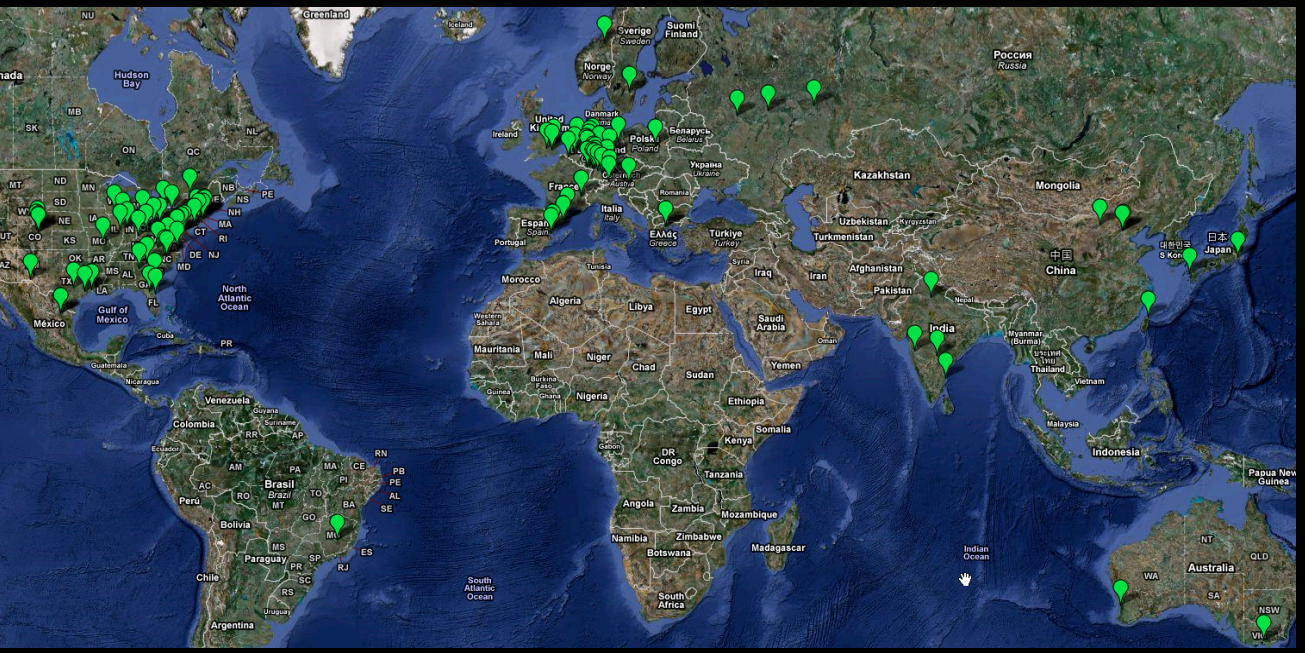


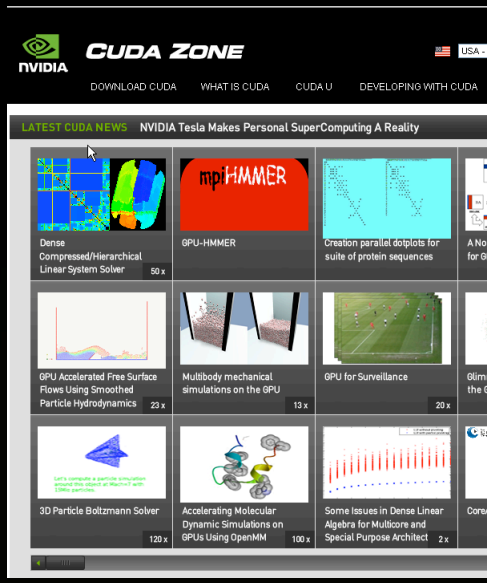
Different Programming Styles

- C for CUDA
  - C with parallel keywords
  - C runtime that abstracts driver API
  - Memory managed by C runtime
  - Generates PTX
- OpenCL
  - Hardware API - similar to OpenGL and CUDA driver API
  - Programmer has complete access to hardware device
  - Memory managed by programmer
  - Generates PTX

CUDA Facts

- 900+ Research Papers
- 115+ universities teaching CUDA





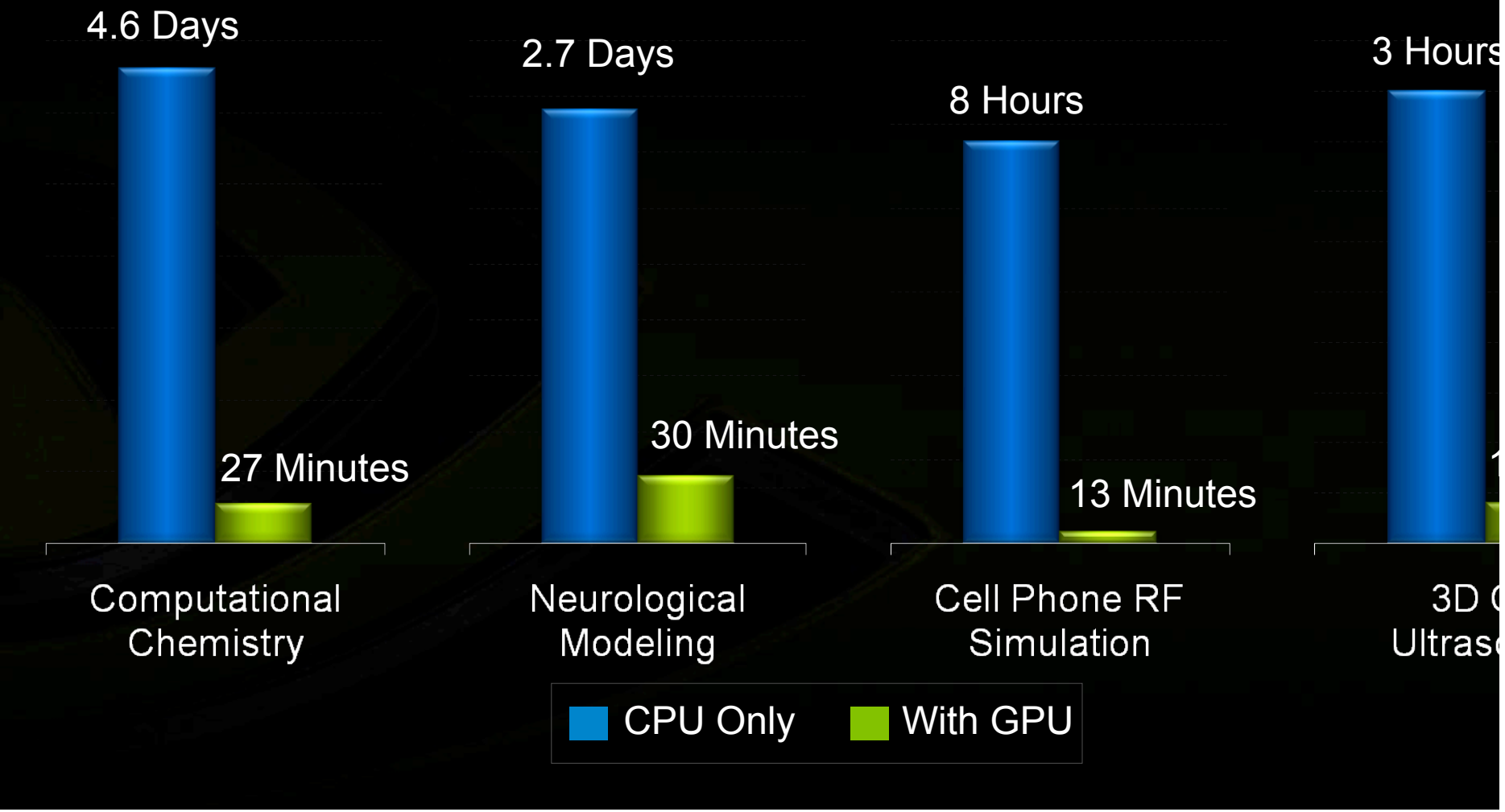
www.NVIDIA.com

- 200+ papers and a
- 110 Million CUDA-E
- 60,000+ Active D

Application Domains

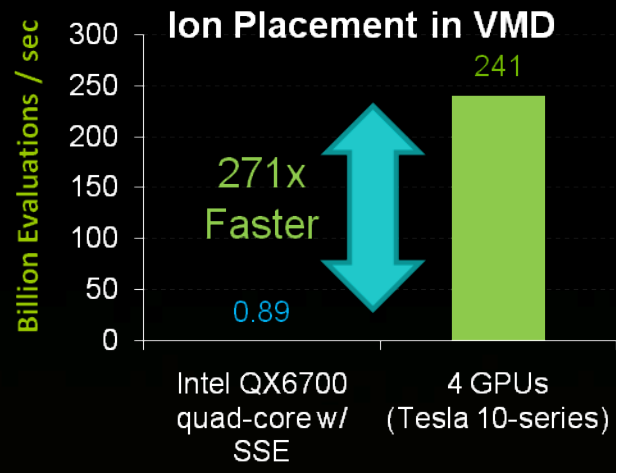
Details at
http://www.nvidia.com/object/vertical_solutions.html

Accelerating Time to Discovery

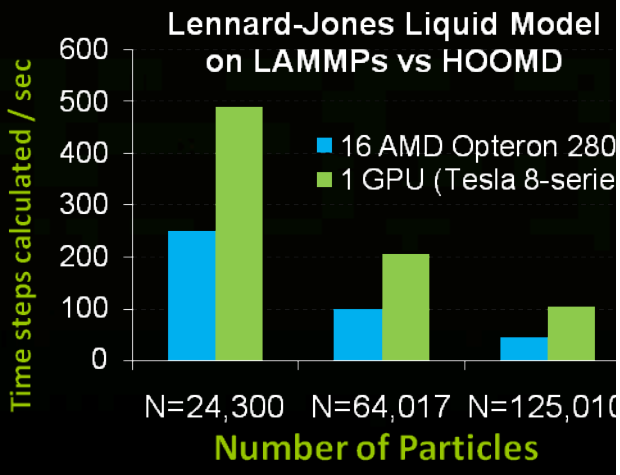


Molecular Dynamics

- Available MD software
  - NAMD / VMD (alpha release)
  - GROMACS (alpha release)
  - HOOMD
- OpenMM : Library for molecular modeling https://simtk.org/home/openmm
  - Jump start work on molecular dynamics



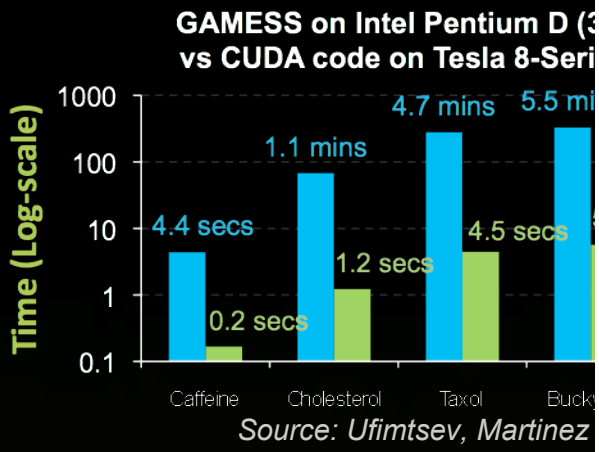
Source: Stone, Phillips, Hardy, Schulten



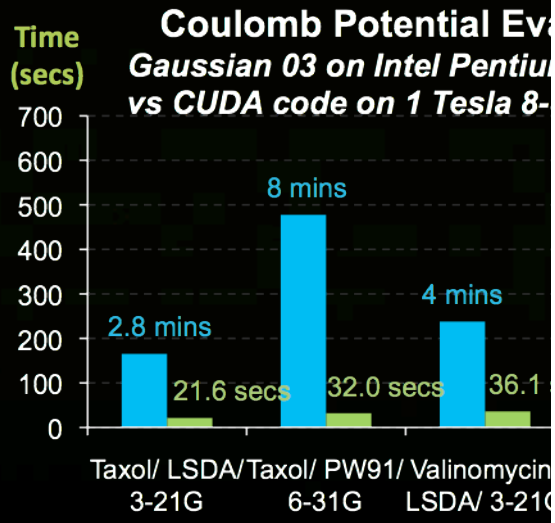
Source: Anderson, Lorenz, Travesset

Quantum Chemistry

- **Available MD software**
  - NAMD / VMD (alpha release)
  - HOOMD
  - ACE-MD
  - MD-GPU
- **Ongoing work**
  - LAMMPS
  - CHARMM
  - Q-Chem
  - Gaussian



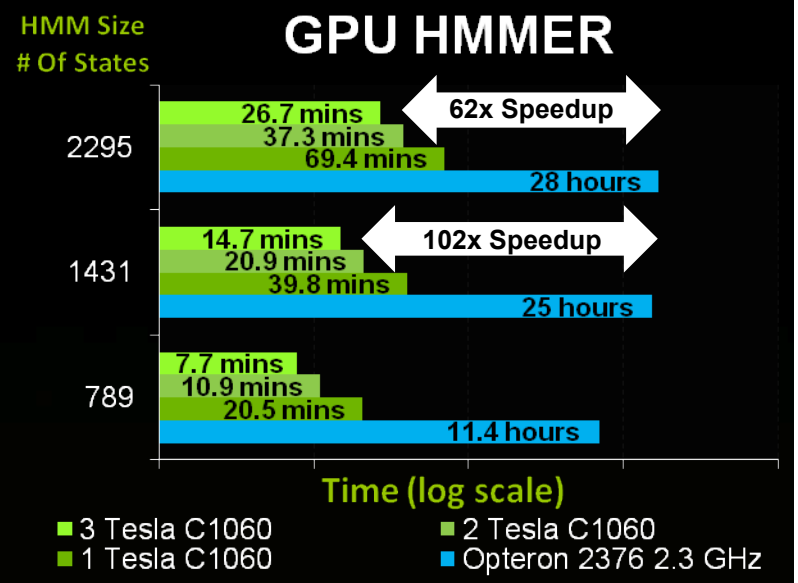
Source: Ufimtsev, Martinez

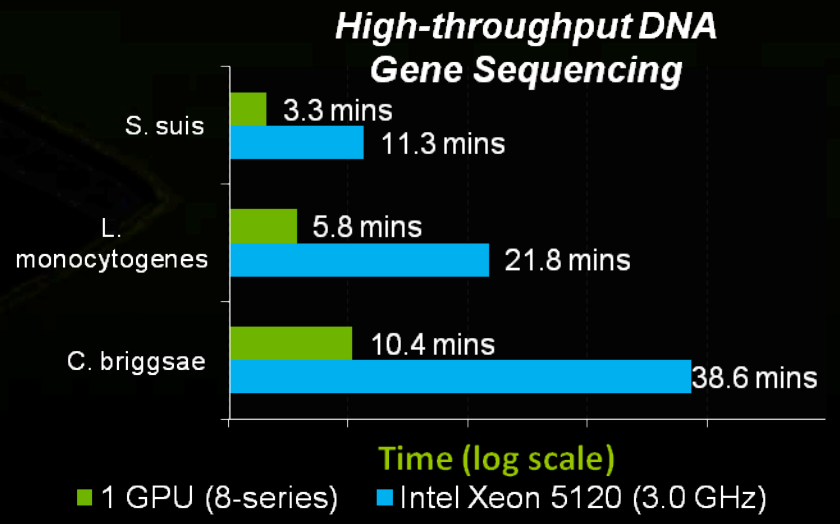


Source: Yasuda

Bio-Informatics

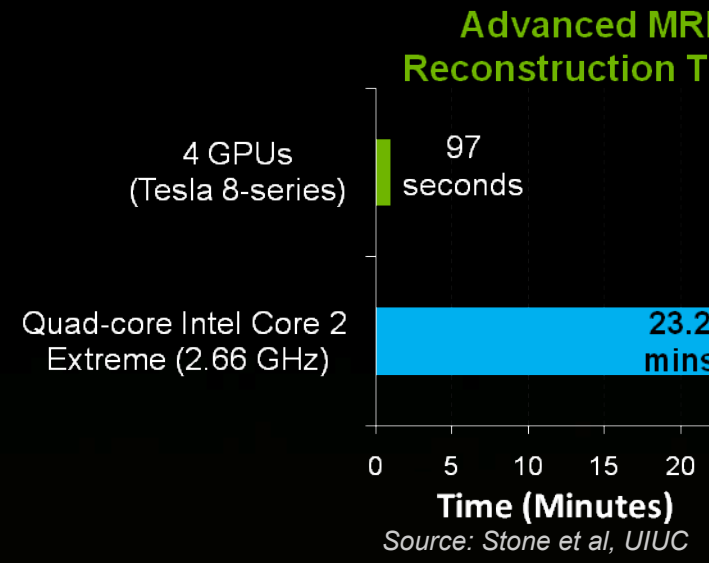
- Available applications
  - GPU HMMER
  - MUMmerGPU sequencing
  - MATLAB acceleration
  - Protein docking



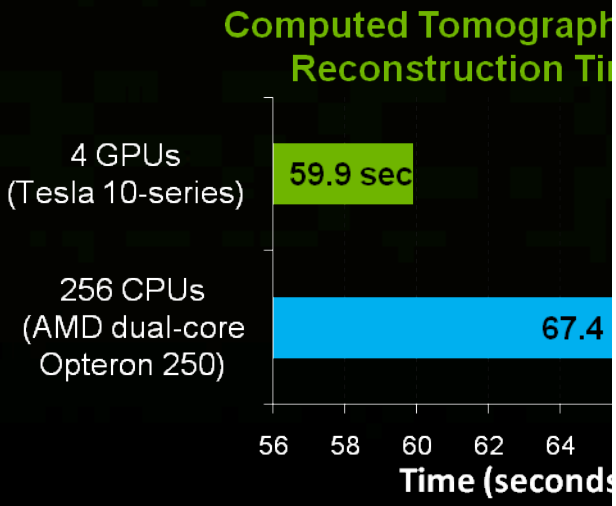


Medical Equipment

- GE Healthcare : CT
  - 40% increase in CT resolution
  - 2x increase in frame rate
- Techniscan: Ultra-sound
  - High resolution ultra-sound
  - 2x increase in acquisition
- Digisens : Tomography
  - Tomography reconstruction
- Several others on
  - X-Ray, Flow Cytometry, MRI, etc



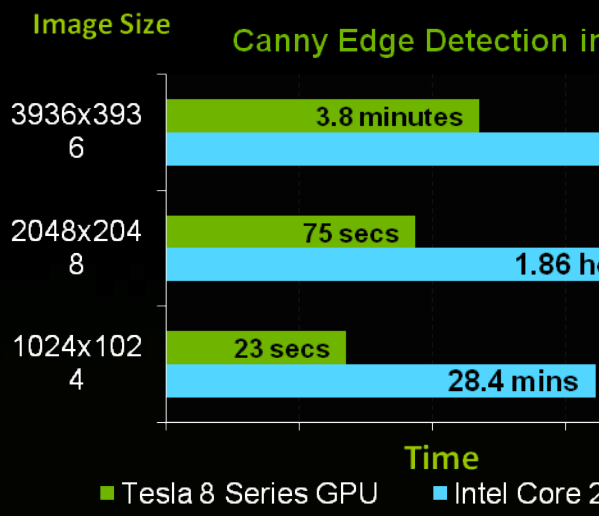
Source: Stone et al, UIUC

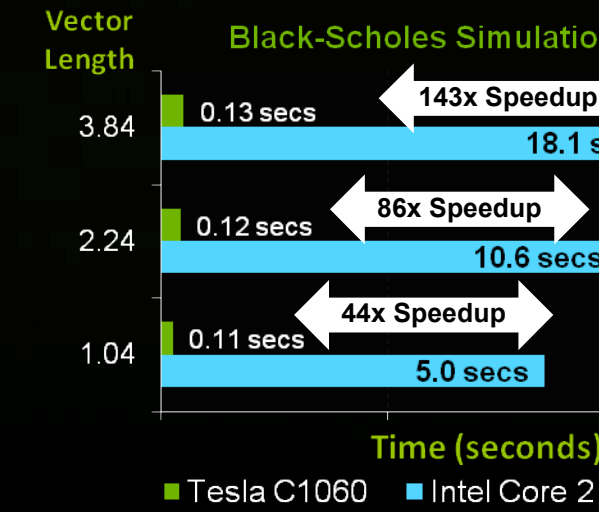


Source: Batenburg, Sijbers, e

MATLAB: Acceleration with GPUs

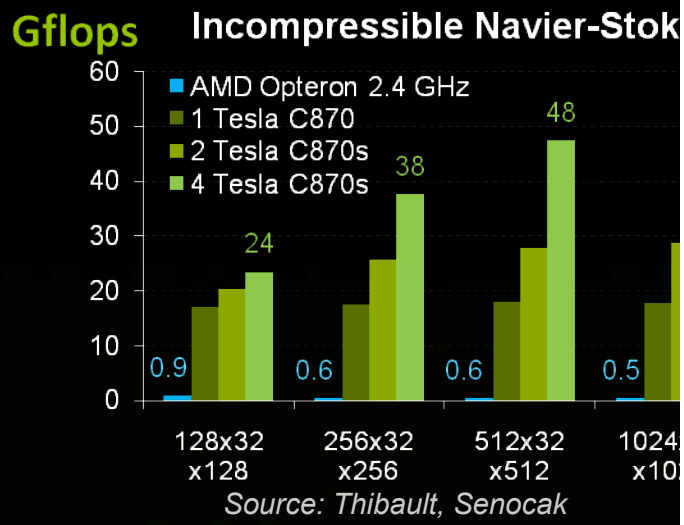
- Jacket CUDA plugin from Accelereyes
  - http://www.accelereyes.com
  - 15-day trail version avaiable
- Tesla GPU in a workstation
  - For MATLAB and research



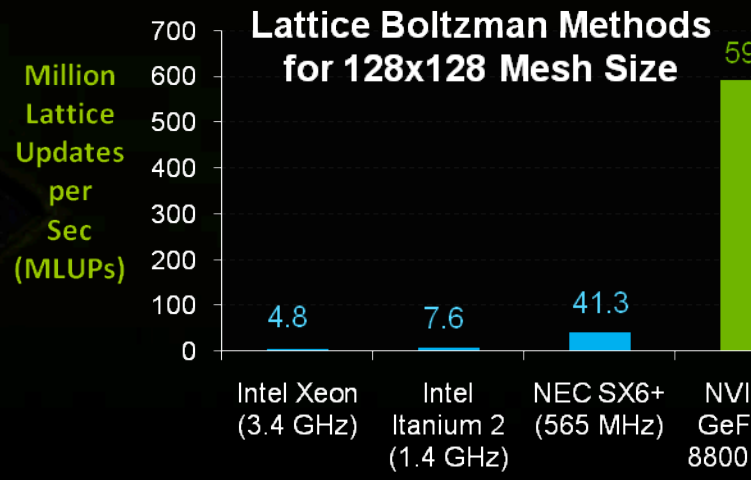


Computational Fluid Dynamics (CFD)

- **Ongoing work**
  - Navier-Stokes
  - Lattice Boltzman
  - 3D Euler Solver
  - Weather and ocean modeling



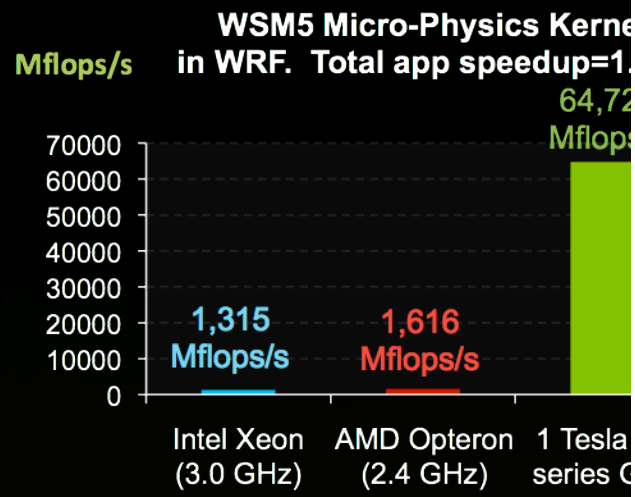
Source: Thibault, Senocak



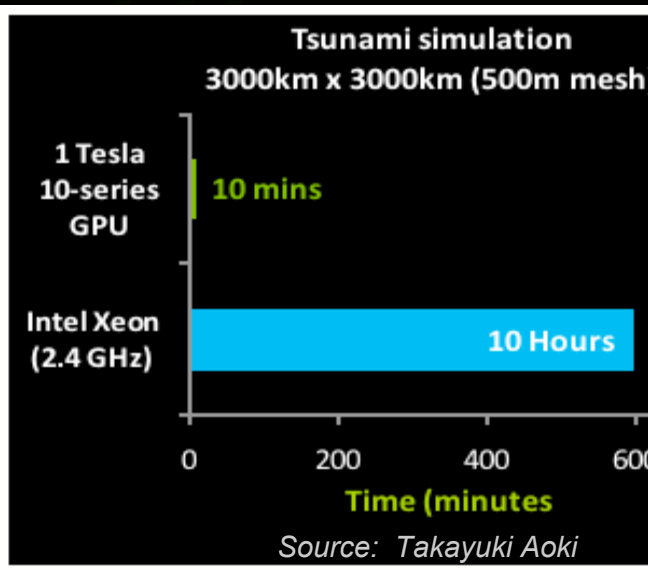
Source: Tolke, Krafczyk

Weather, Atmospheric, & Ocean Modeling

- **CUDA-accelerated WRF available**
  - 25-30% speedup in WRF so far
  - Other kernels in WRF being ported
- **Ongoing work**
  - Tsunami modeling
  - Ocean modeling
  - Several CFD codes



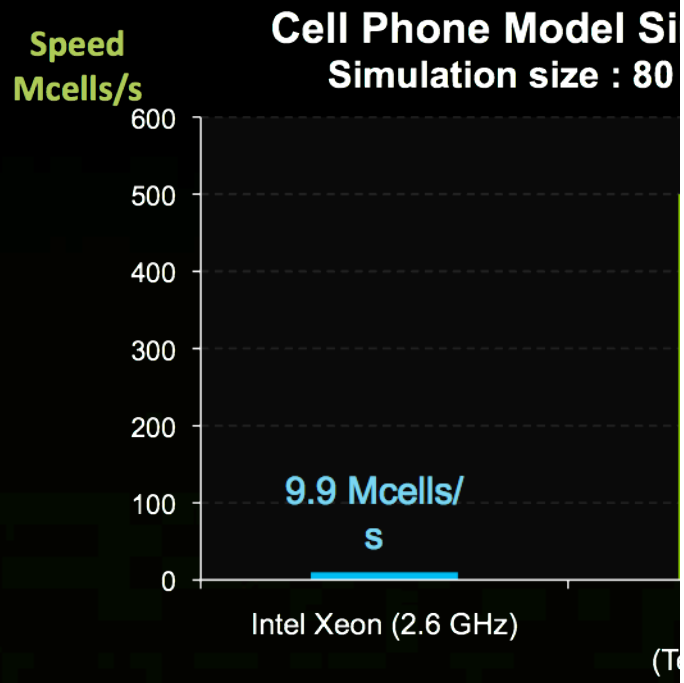
Source: Michalakes, Vachharajani



Source: Takayuki Aoki

Electromagnetics / Electrodynamics

- **FDTD Solvers**
  - Acceleware
  - EM Photonics
  - CUDA Tutorial
- **Ongoing work**
  - Maxwell equation solver
  - Ring Oscillator (FDTD)
  - Particle beam dynamics simulator

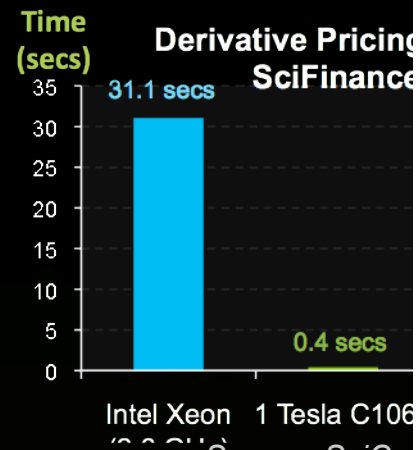


FDTD Acceleration usi

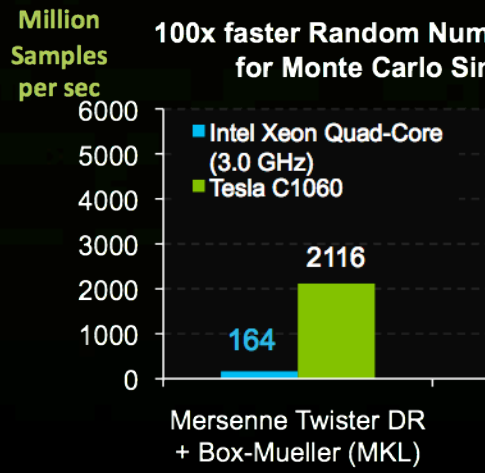
Source: Accelewa

Computational Finance

- **Financial Computing Software vendors**
  - SciComp : Derivatives pricing modeling
  - Hanweck: Options pricing & risk analysis
  - Aqumin: 3D visualization of market data
  - Exegy: High-volume Tickers & Risk Analysis
  - QuantCatalyst: Pricing & Hedging Engine
  - Oneye: Algorithmic Trading
  - Arbitragis Trading: Trinomial Options Pricing
- **Ongoing work**
  - LIBOR Monte Carlo market model
  - Callable Swaps and Continuous Time Finance

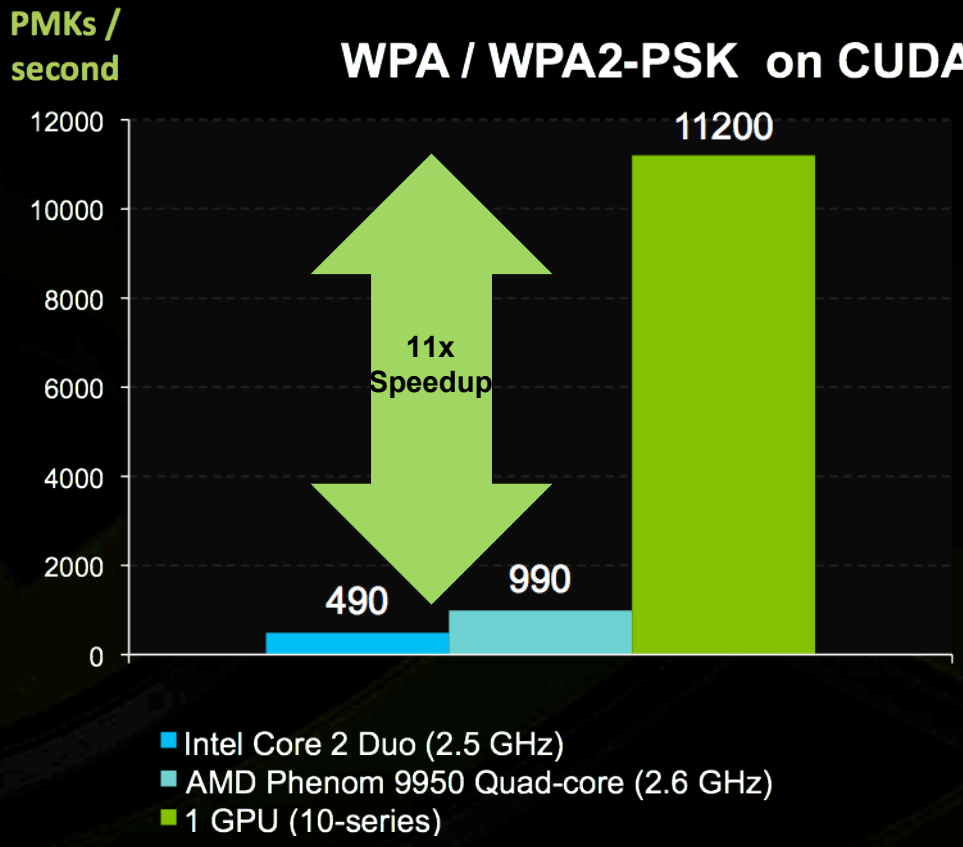


Source: SciCo

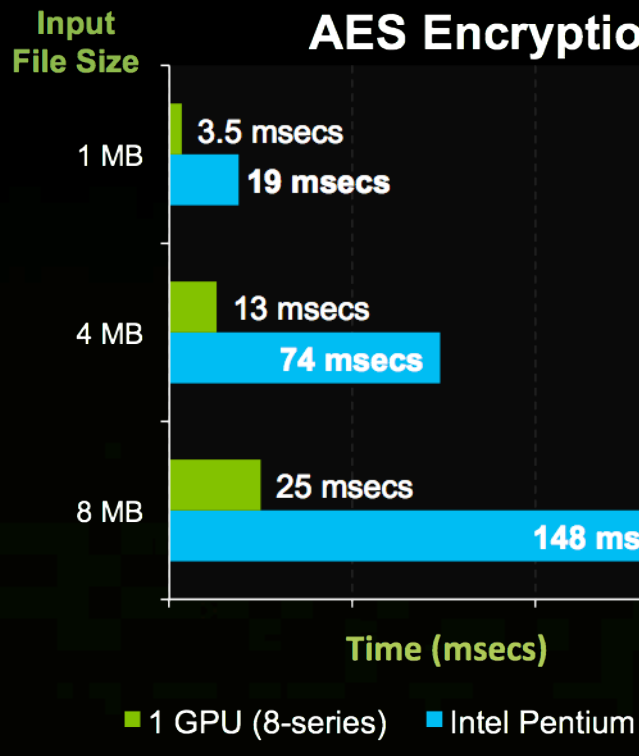


Source: CUDA

Encryption

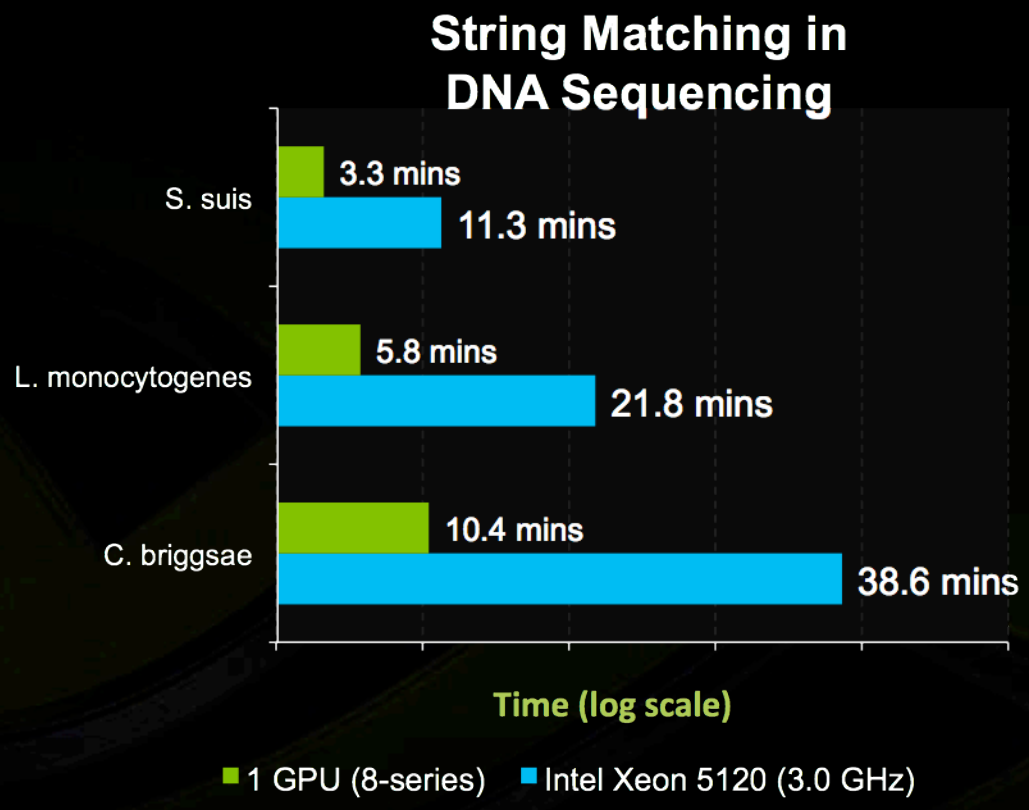


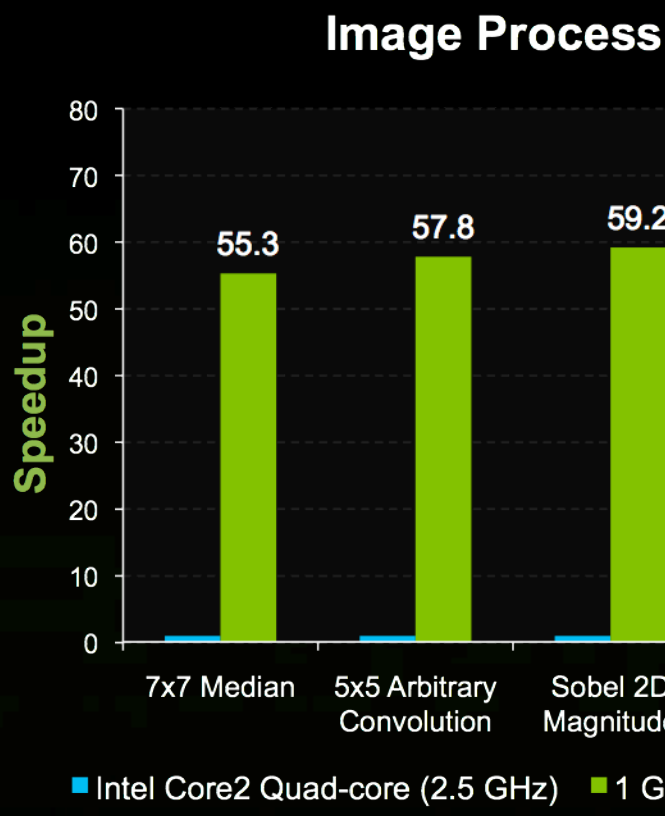
Source: http://code.google.com/p/pyrit/



Source: S. Manavski

Pattern Matching



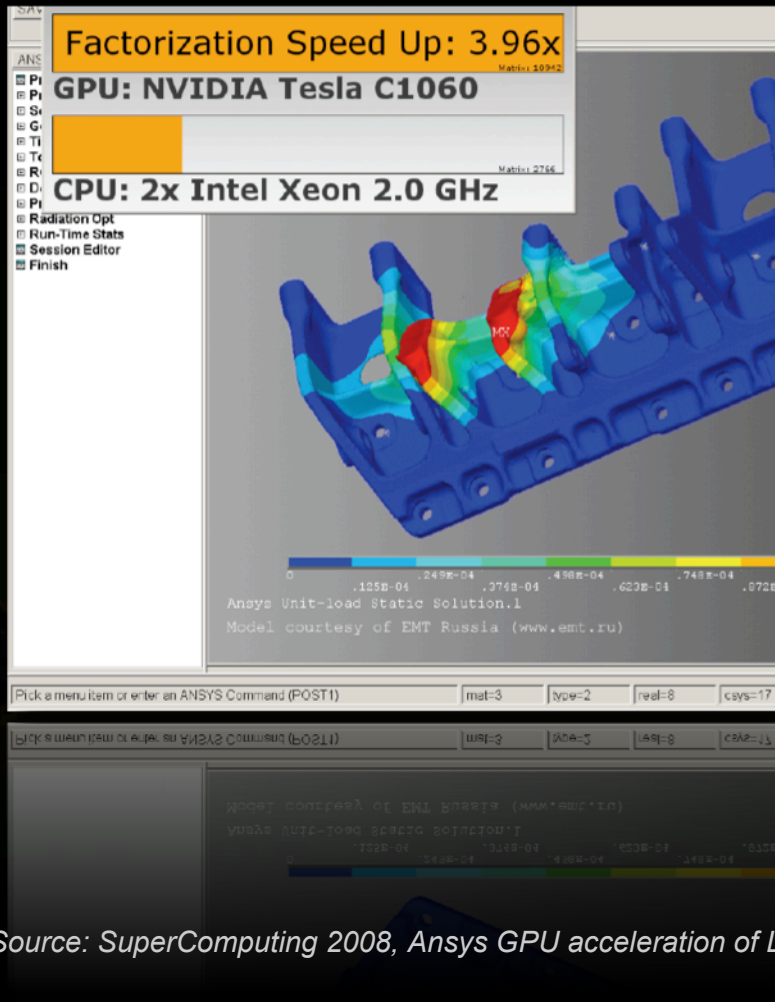


ANSYS Mechanical (Beta)

"CUDA allows us to leapfrog in a very compute intensive part of ANSYS."

Gene Poole
Principle SW Developer, ANSYS

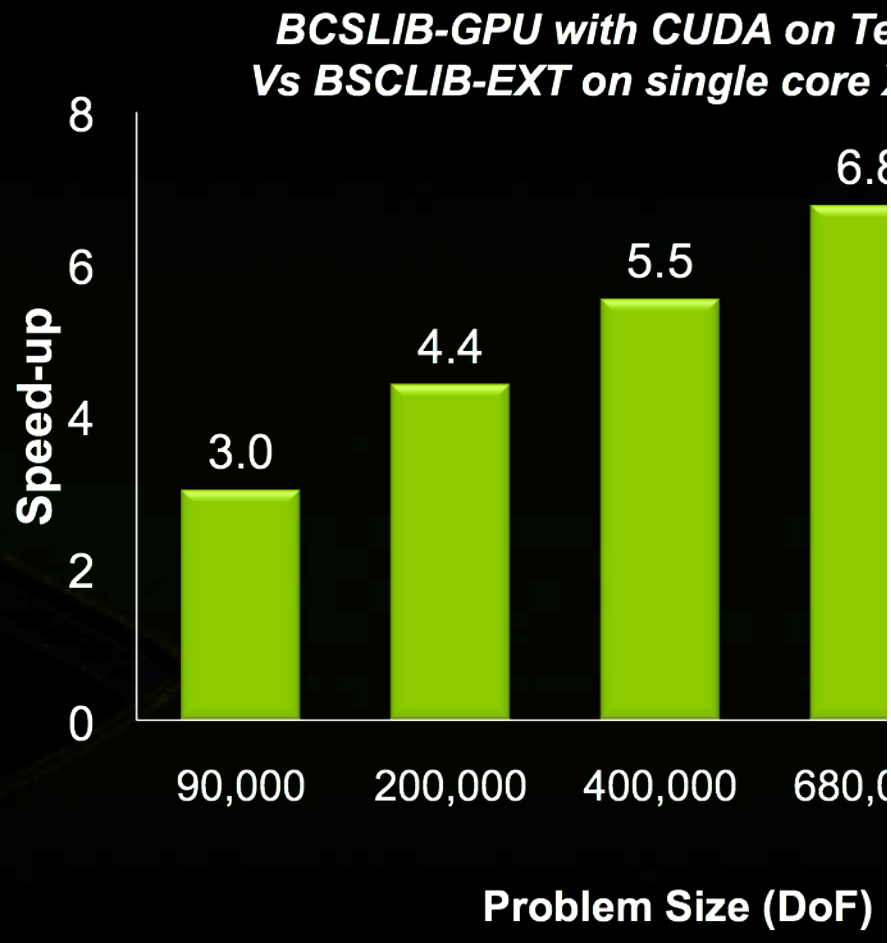
Hear Gene at http://www.youtube.com/nvidiatesla



Source: SuperComputing 2008, Ansys GPU acceleration of L

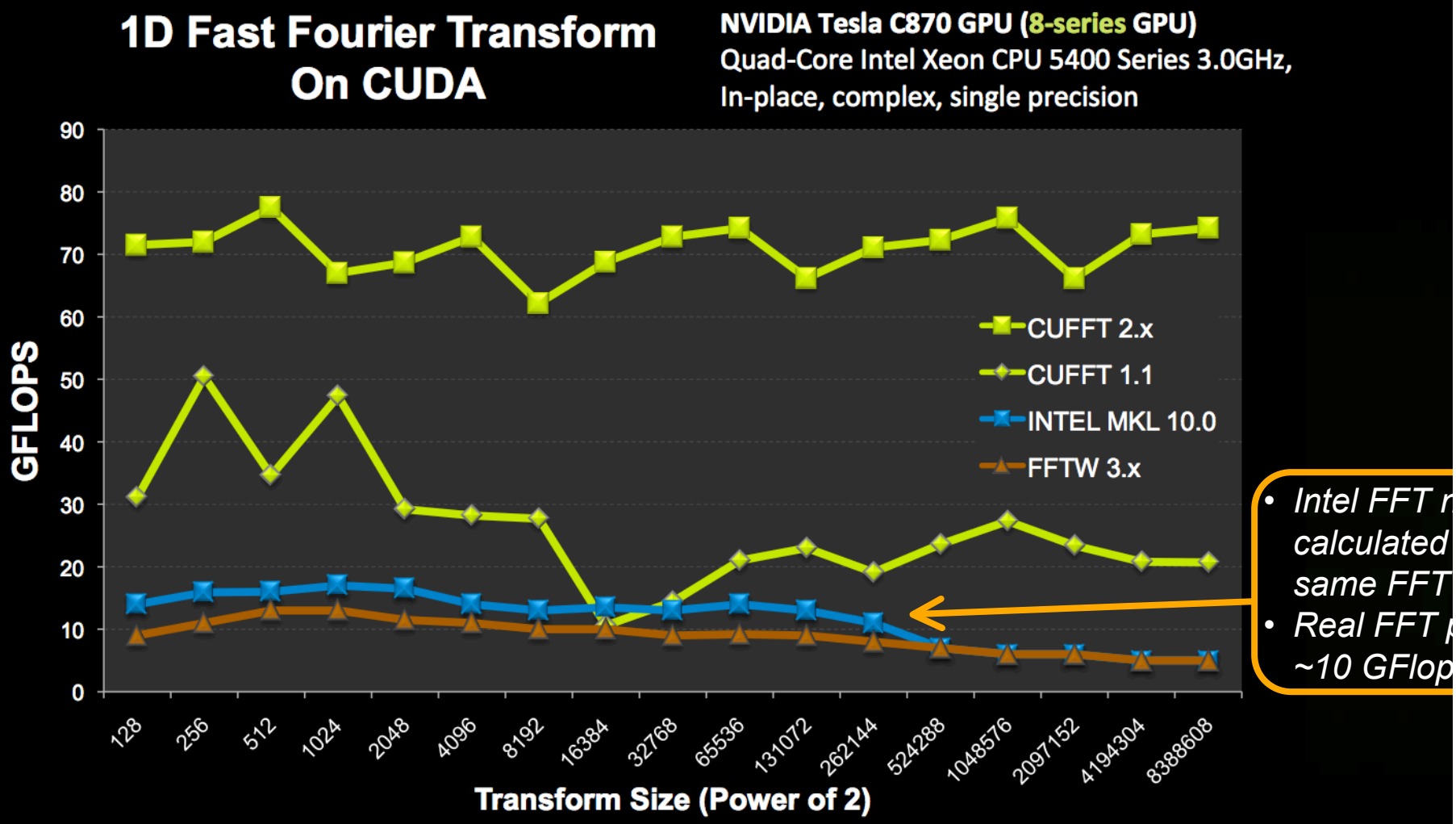
BCSLib-GPU : Sparse-Matrix Solver

- Used several solvers from Ansys, MSC
- Statics, Lanczos iterations, and Dynamics analyses
  - Not just LDL^T factorization
- Beta now, Release April 09



Libraries

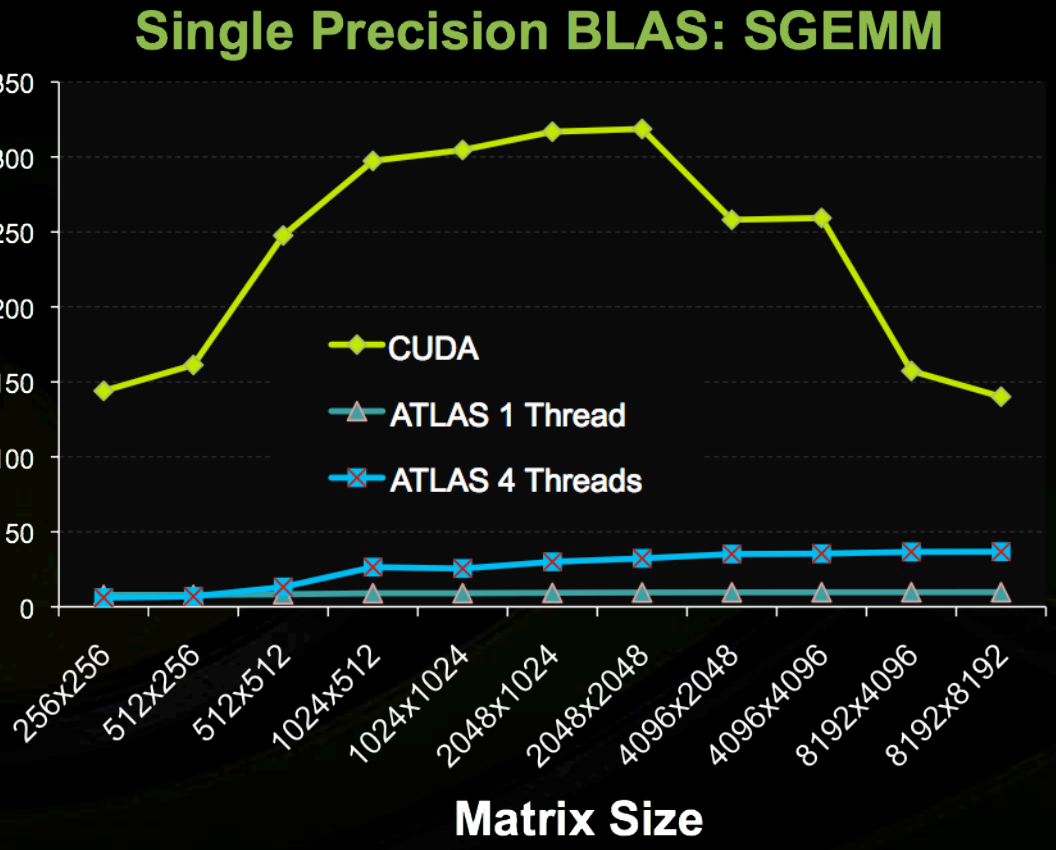
FFT Performance: CPU vs GPU (8-Series)

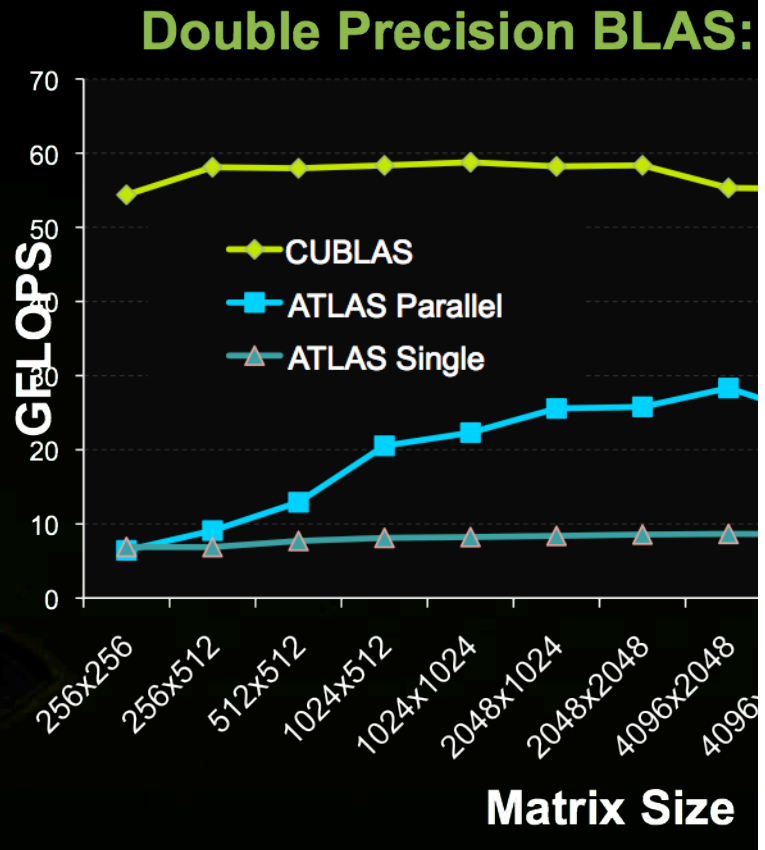


- *Intel FFT r*
  calculated
  same FFT
- *Real FFT p*
  ~10 GFlop

Source for Intel data : http://www.intel.com/cd/software/products/asmo-na/eng/266852.htm

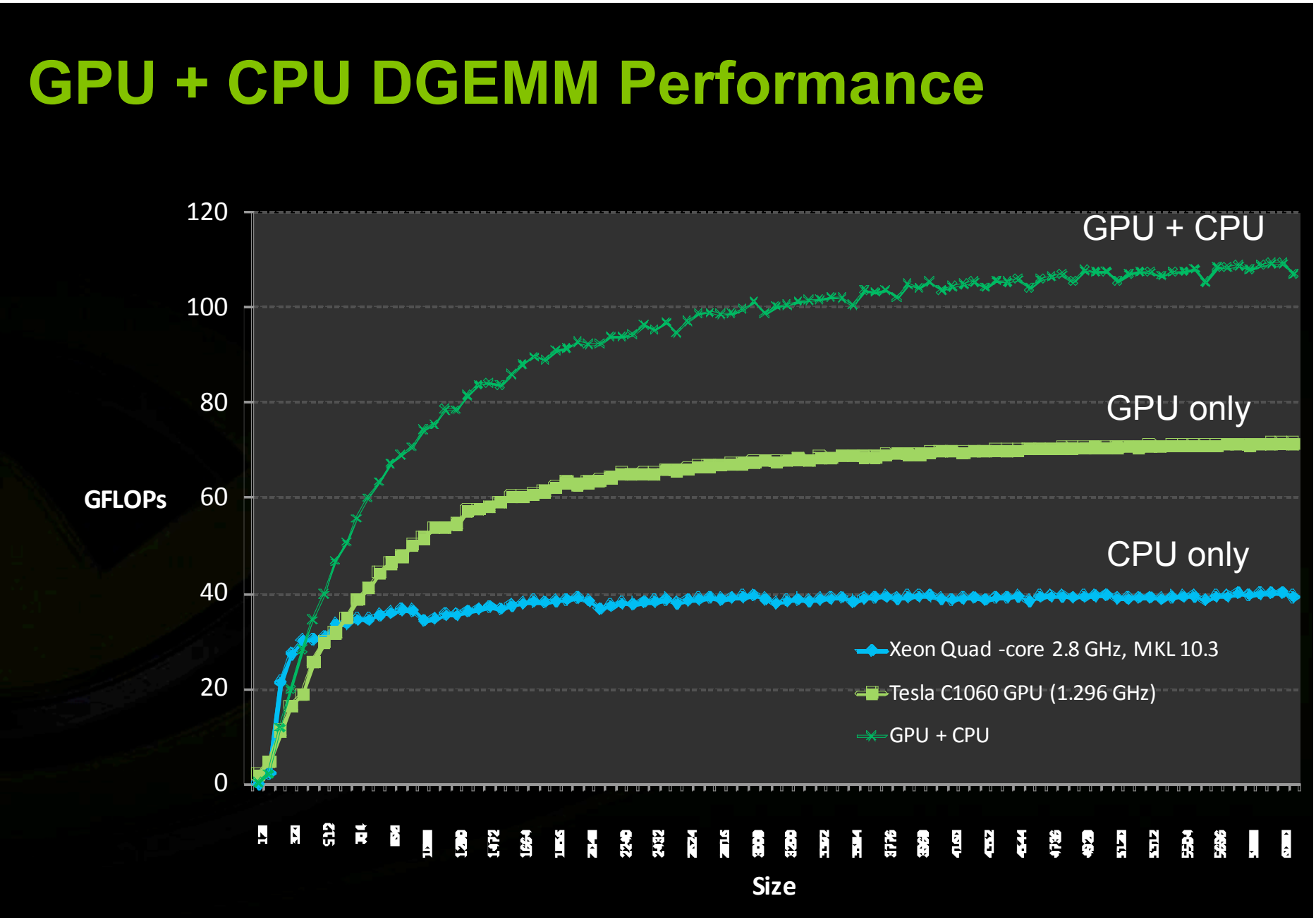
BLAS: CPU vs GPU (10-series)



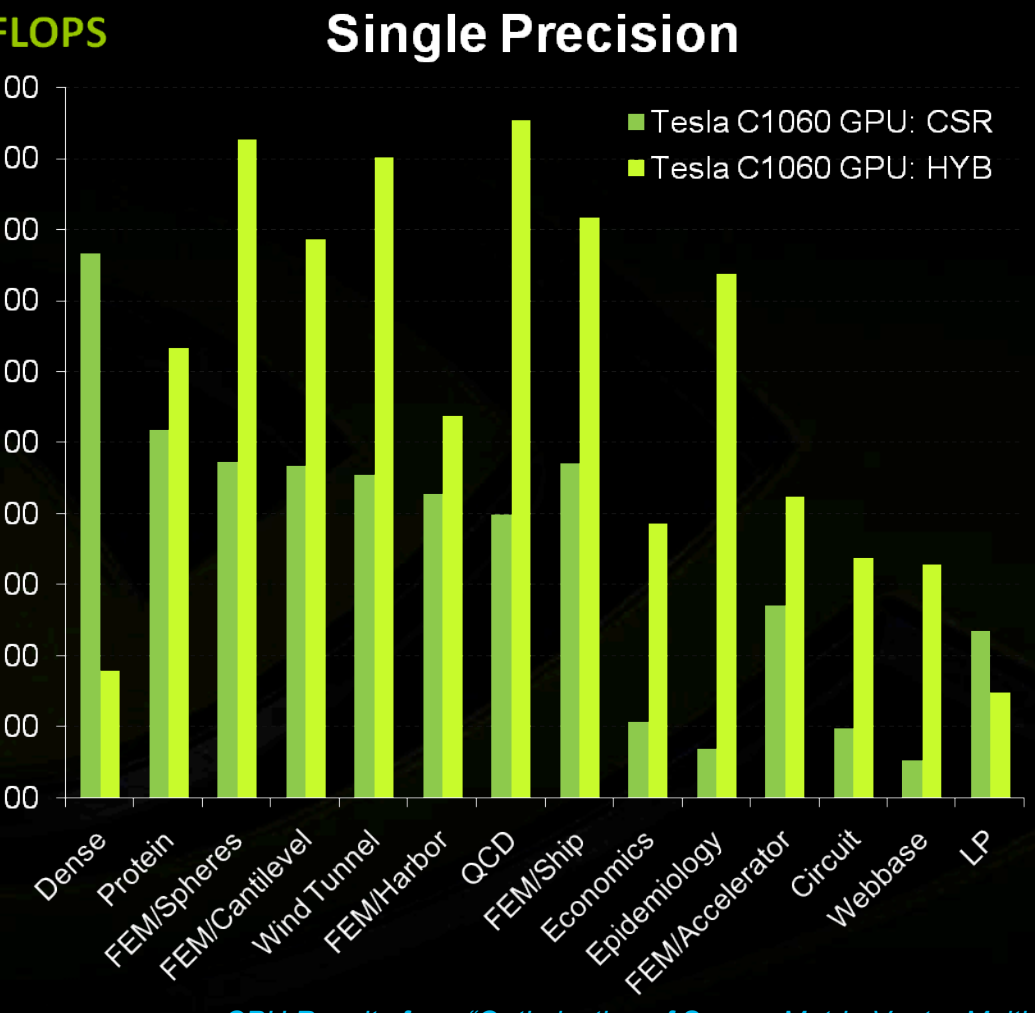


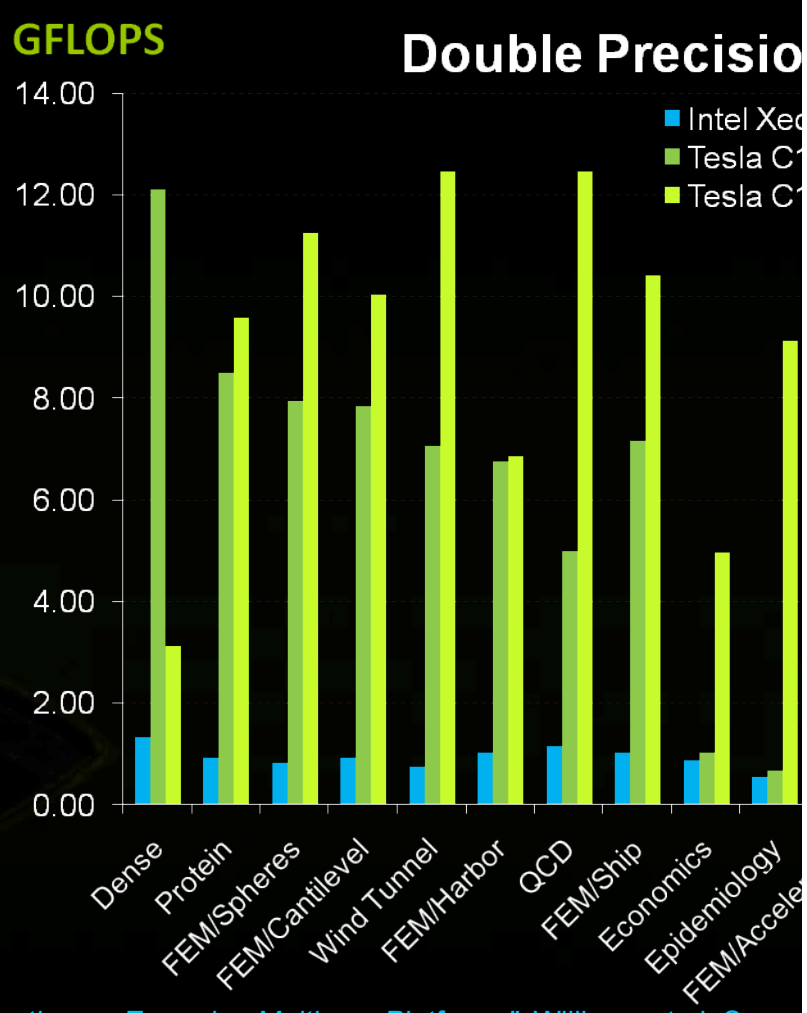
CUBLAS: CUDA 2.0, Tesla C1060 (**10-series** GPU)
ATLAS 3.81 on Dual 2.8GHz Opteron Dual-Core

GPU + CPU DGEMM Performance



Results: Sparse Matrix-Vector Multiplication (SpMV) on CUDA





CPU Results from "Optimization of Sparse Matrix-Vector Multiplication on Emerging Multicore Platforms", Williams et al, Super

More Information

- Tesla main page
  - http://www.nvidia.com/tesla
  - Product Information
  - Software tools & libraries
- Vertical Solutions
  - http://www.nvidia.com/object/vertical_solutions.html
- CUDA Zone
  - http://www.nvidia.com
  - Applications, Papers,
  - Learn CUDA: self-pace tutorials
- Hear from Developers
  - http://www.youtube.com/nv

NVIDIA: Leadership in GPU computing

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30+ CUDA GPU clusters

115+ Universities Tea
900+ research p

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Erlangen
ETH Zurich
Georgia Tech
Grove City College
Harvard
IISc Bangalore
IIIT Hyderabad
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ITESM
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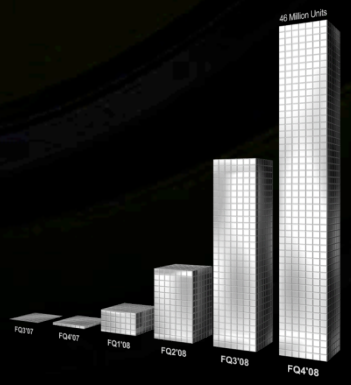
Kent State
Kyoto
Lund
Maryland
McGill
MIT
North Carolina

110 M CUDA enabled GPUs
60,000+ active developers



150K CUDA compiler downloads