GPU Computing and THE GREEN 500

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Status of High-Performance Computing

We have spent decades focusing on performance, performance, performance (and price/performance).

The Focus on Performance:
The TOP500 List

A ranking of the fastest 500 supercomputers in the world

- Benchmark
  - LINPACK: Solves a (random) dense system of linear equations in double-precision (64 bits) arithmetic.
- Evaluation Metric
  - Performance (i.e., Speed)
    - Floating-Operations Per Second (FLOPS)
- Web Site
  - http://www.top500.org/

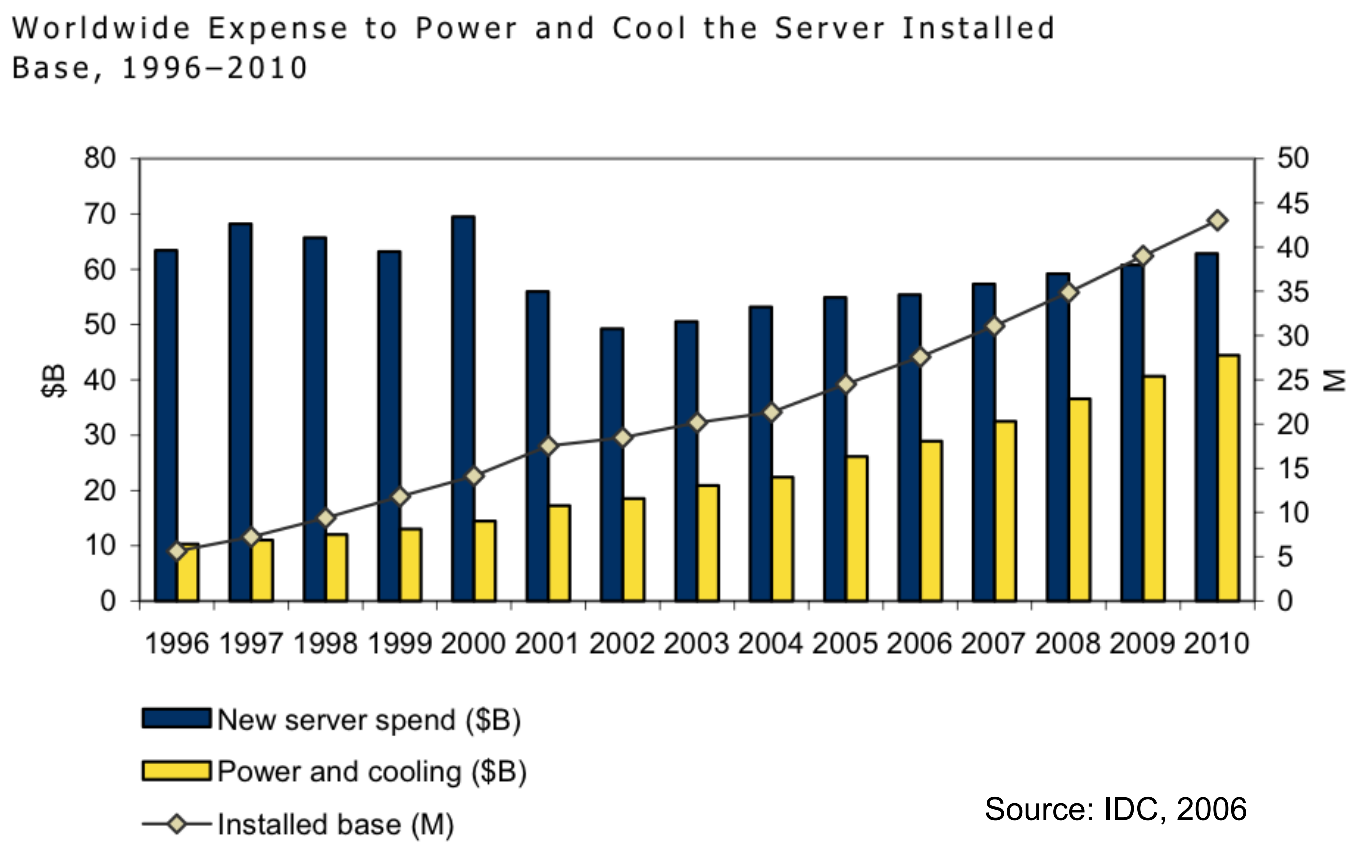
The Focus on Performance:

Gordon Bell Awards at Supercomputing (SC)

- Metrics for Evaluating Supercomputers
  - Performance (i.e., Speed)
    - Metric: Floating-Operations Per Second (FLOPS)
  - Price/Performance → Cost Efficiency
    - Metric: Acquisition Cost / FLOPS
- Performance & price/performance are *important* metrics, but …

The "Cost" of Achieving Performance

- **Electrical *power* costs $$$$.**

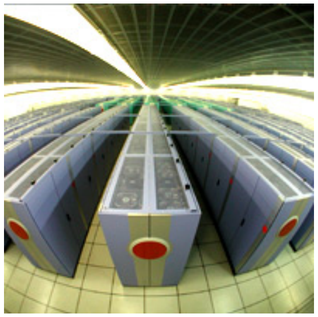


Source: IDC, 2006

The "Cost" of Achieving Performance

Examples: Power, Cooling, and Infrastructure $$$

- Japanese Earth Simulator
  - Power & Cooling: 12 MW → $10M/year



The "Cost" of Achieving Performance

- ***Too much power*** **affects** ***efficiency, reliability, and availability.***
  - Anecdotal Evidence from a "Machine Room" in 2001 - 2002
    - **Winter**: "Machine Room" Temperature of **70-75° F**
      - Failure approximately ***once*** per week.
    - **Summer**: "Machine Room" Temperature of **85-90° F**
      - Failure approximately ***twice*** per week.
  - Arrenhius' Equation (applied to microelectronics)
    - ***For every 10° C (18° F) increase in temperature,***
      … the failure rate of a system doubles.*

* W. Feng, M. Warren, and E. Weigle, "The Bladed Beowulf: A Cost-Effective Alternative to Traditional Beowulfs," *IEEE Cluster*, Sept. 2002.

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"The Green500 List"

- Debuted at SC 2007
- Goal: Raise Awareness in the Energy Efficiency of Supercomputing
  - Drive energy efficiency as a first-order design constraint (on par with performance).

Witnessing Architectural Innovations

- Low-Power Embedded Processors
  - IBM Blue Gene L/P/Q (2004/2007/2010)
- Heterogeneous Multicore on a Chip: Cell
  - LANL Roadrunner (Jun 2008)
- The Next Wave in Heterogeneous Computing: GPU?
  - NUDT Tianhe-1 (Nov 2009)
  - NSCS Dawning Nebulae (Jun 2010)
  - NUDT Tianhe-1A (Nov 2010)

Historical View of GPU Computing

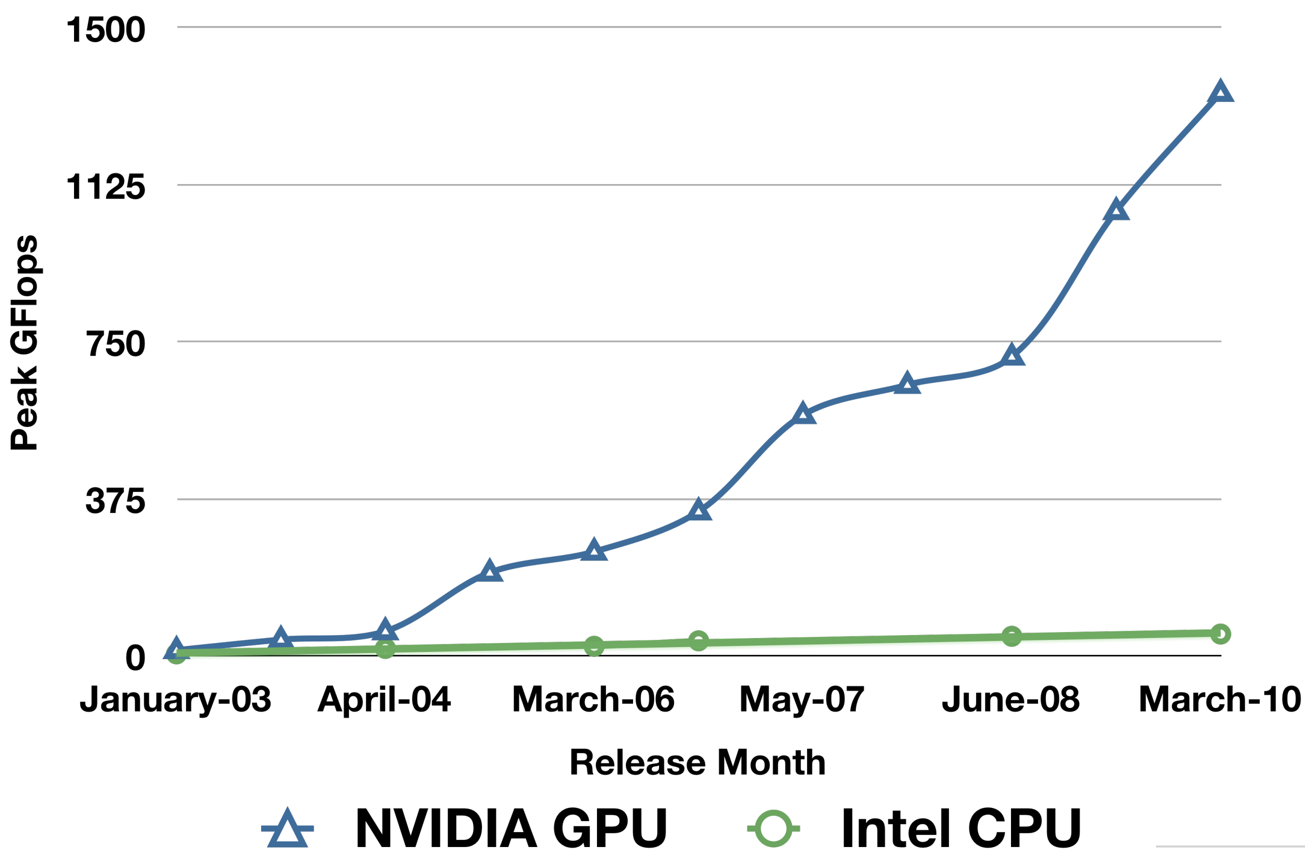
- Using GPUs for Non-Graphical Computing
  - Dates back to 2003
  - DirectX, OpenGL and Cg

- Early Success of Large-Scale GPU Systems
  - Folding@Home: GPU extension available late 2006

- General-Purpose Computing
  - NVIDIA: CUDA
  - AMD: Brook+ → OpenCL
  - Open Standard: OpenCL

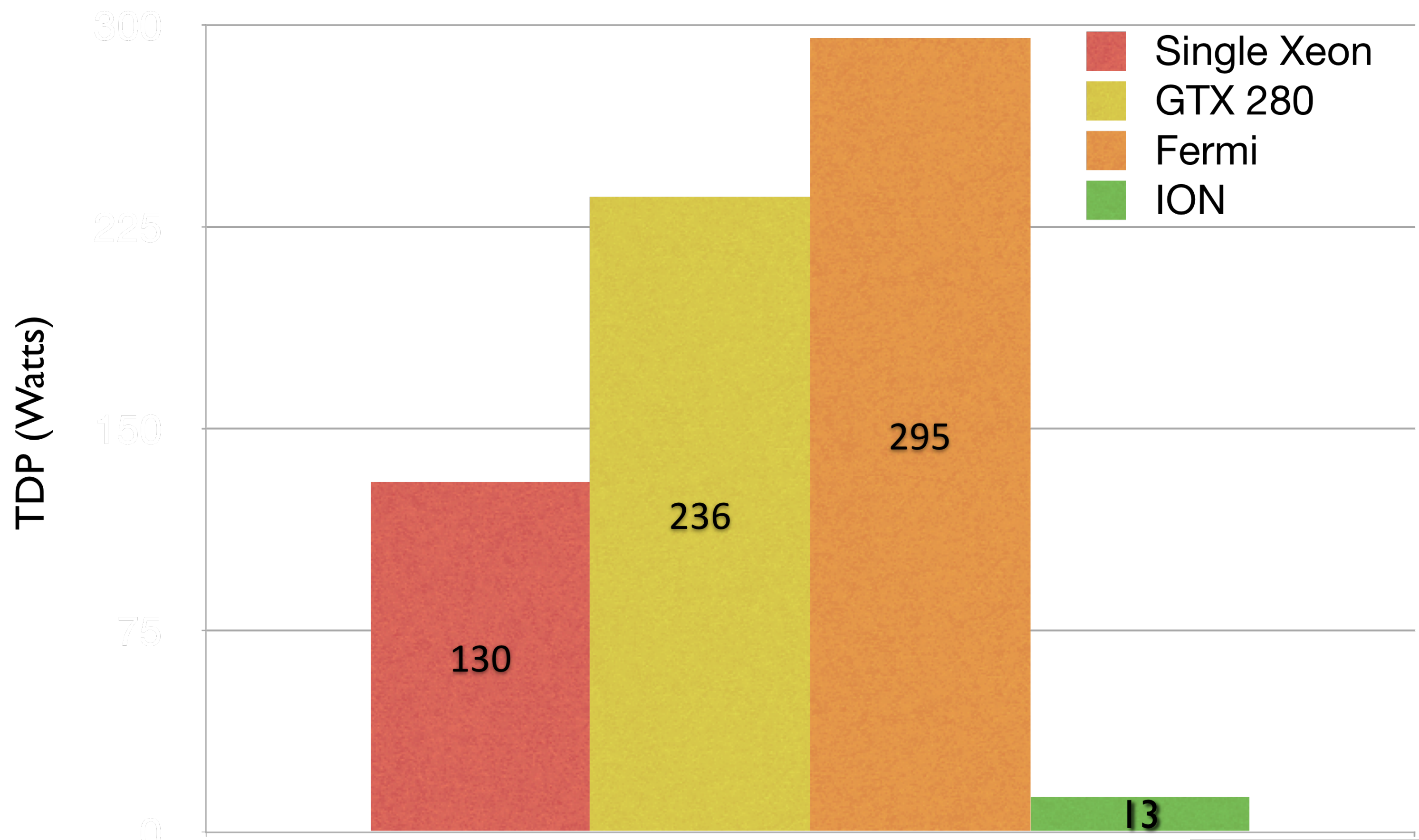
Why GPU?

- Performance



Is the GPU Green?

- Thermal Design Power

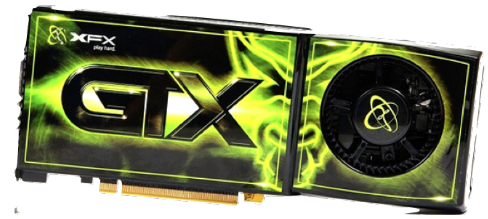


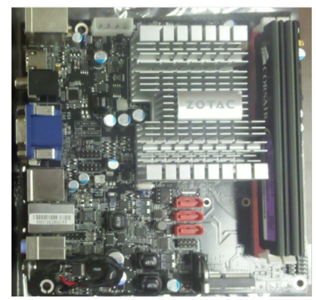
Evaluating the Greenness of GPUs

- Power and Energy Efficiency of "Computational Dwarfs"

- Platforms
  - Xeon E5405: Multicore CPU
  - GTX 280: Discrete GPU
  - ION: Integrated CPU+GPU

GTX 280





ION

- Dwarf → Application
  - N-body → GEM: Electrostatic Surface Potential for Molecular Modeling
  - Structured Grid → SRAD: Image Smoothing
  - Dynamic Programming → Needleman-Wunsch: Sequence Alignment
  - Dense Linear Algebra → K-means: Clustering

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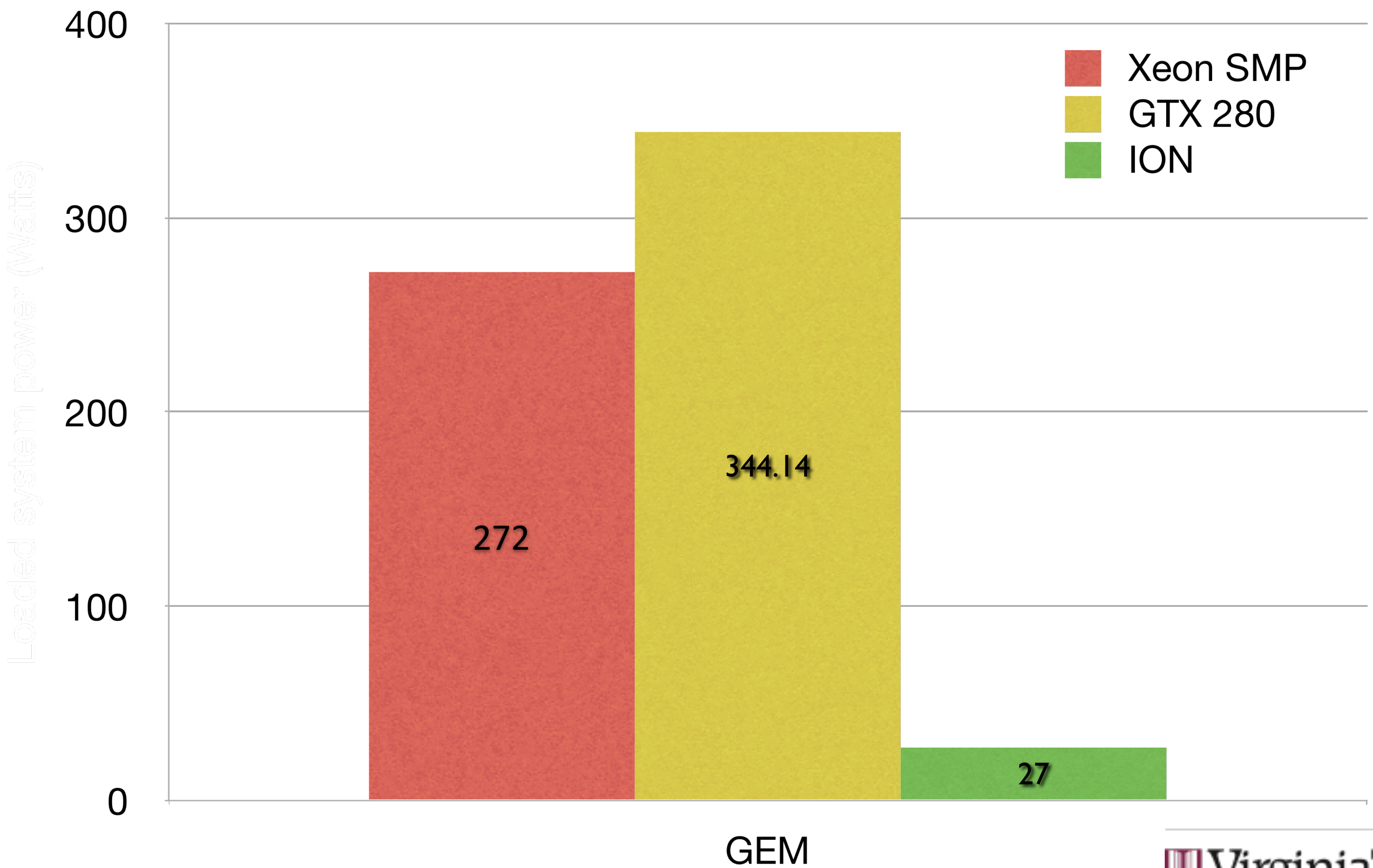
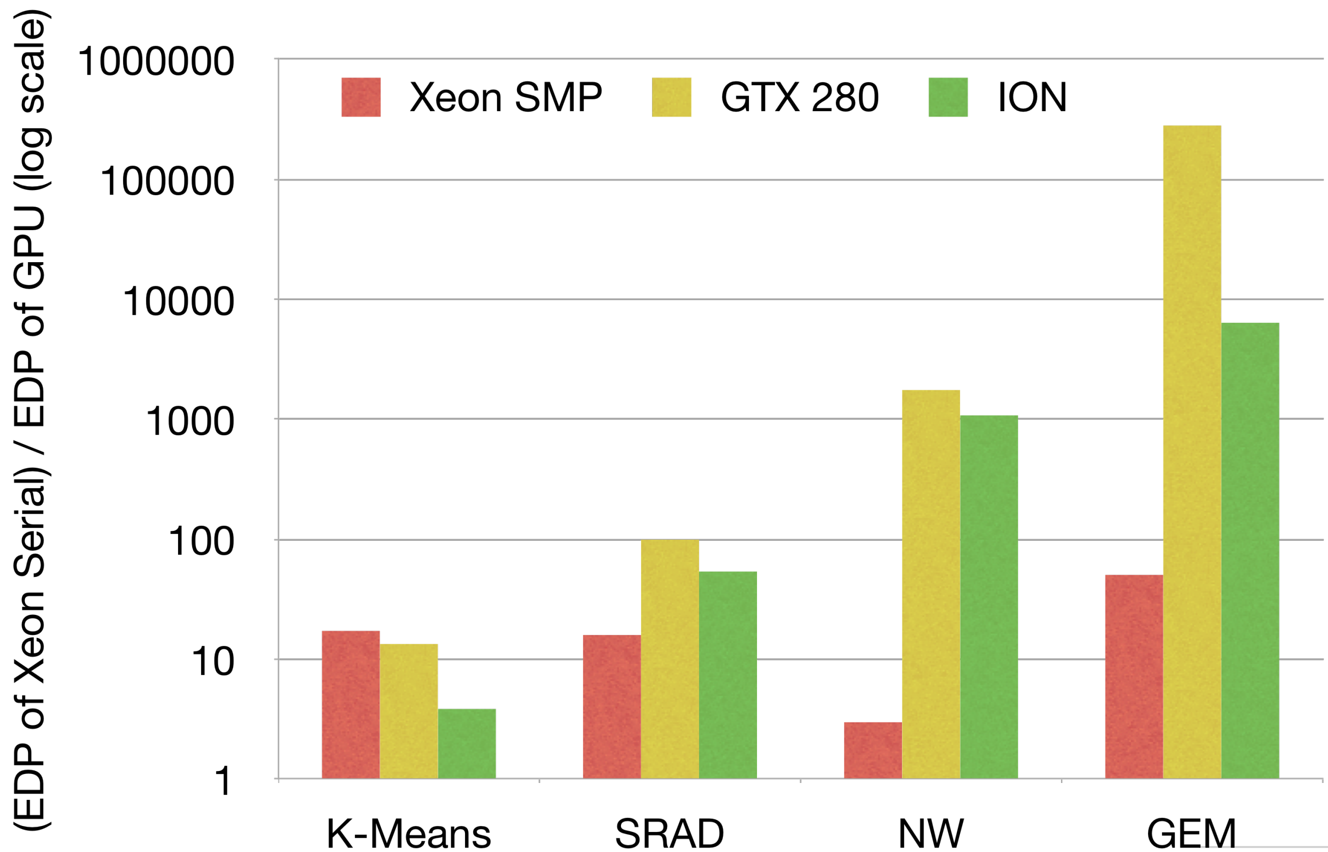
System Power

- Loaded Power for GEM Application (in Watts)



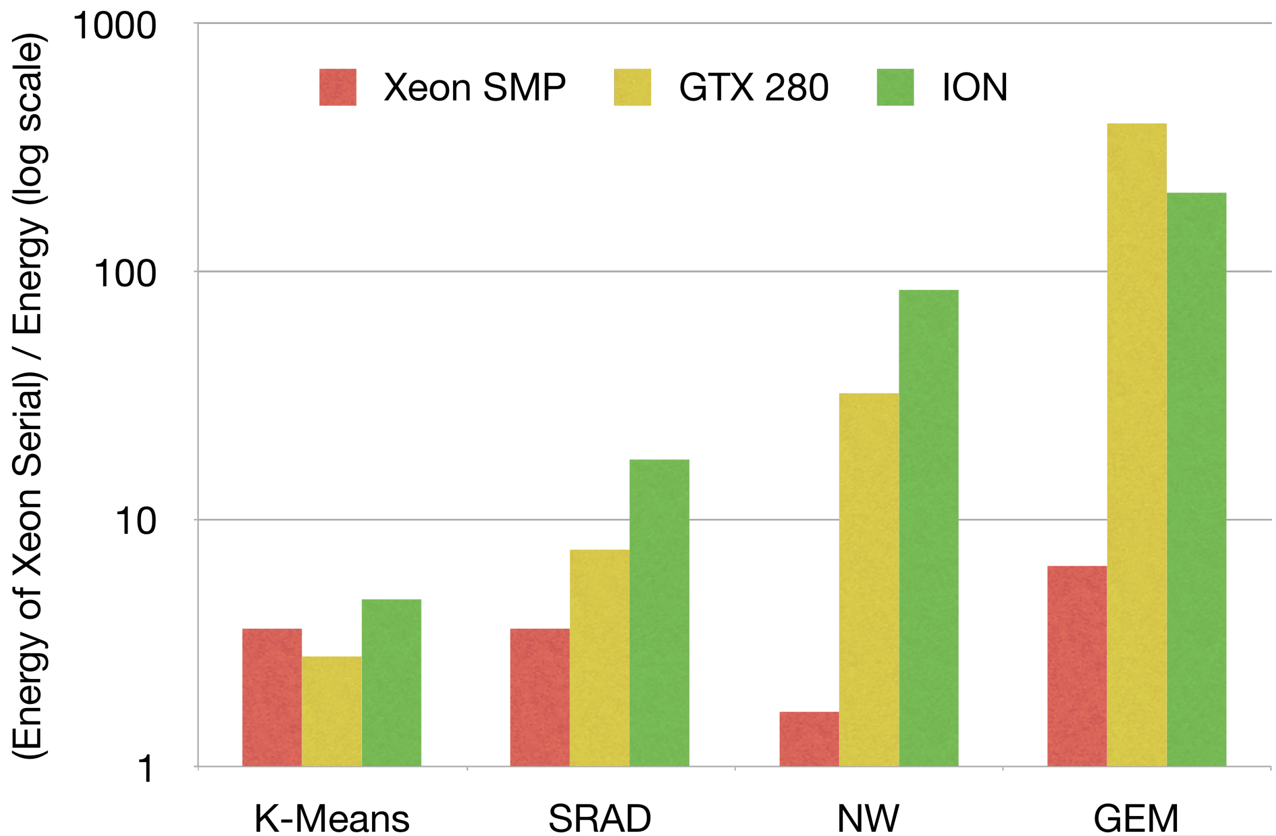
Energy Efficiency (EDP)

- EDP "Speedup" over the Serial Version
  - Higher is better



Overall Energy Consumption

- Energy Consumption "Speedup" over the Serial Version
  - Higher is better



GPU Systems on the Green500

- First Debuted on the November 2009 List (at SC|09)
- Tianhe-1: Predecessor to Tianhe-1A
  - 2,560 dual-GPU ATI Radeon HD 4870 X2
  - Performance: 0.5 petaflops
  - Energy Efficiency: 379 Mflops/W
- The Proliferation of GPU Supercomputing on

November 2009

- 8 of top 10 slots are accelerator-based but only *one* is GPU-based.

Green500 Rank	MFLOPS/W	Site*	Computer*	Total Power (kW)
1	722.98	Forschungszentrum Juelich (FZJ)	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	59.49
1	722.98	Universitaet Regensburg	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	59.49
1	722.98	Universitaet Wuppertal	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	59.49
4	458.33	DOE/NNSA/LANL	BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Infiniband	276
4	458.33	IBM Poughkeepsie Benchmarking Center	BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Infiniband	138
6	444.25	DOE/NNSA/LANL	BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband	2345.5
7	428.91	National Astronomical Observatory of Japan	GRAPE-DR accelerator Cluster, Infiniband	51.2
8	379.24	National SuperComputer Center in Tianjin/NUDT	NUDT TH-1 Cluster, Xeon E5540/E5450, ATI Radeon HD 4870 2, Infiniband	1484.8
9	378.77	King Abdullah University of Science and Technology	Blue Gene/P Solution	504
9	378.77	EDF R&D	Blue Gene/P Solution	252

THE GREEN 500 June 2010

- 8 of top 10 slots are accelerator-based but only *one* is GPU-based.

Green500 Rank	MFLOPS/W	Site*	Computer*	Total Power (kW)
1	773.38	Forschungszentrum Juelich (FZJ)	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	57.54
1	773.38	Universitaet Regensburg	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	57.54
1	773.38	Universitaet Wuppertal	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	57.54
4	492.64	National Supercomputing Centre in Shenzhen (NSCS)	Dawning Nebulae, TC3600 blade CB60-G2 cluster, Intel Xeon 5650/ nVidia C2050, Infiniband	2580
5	458.33	DOE/NNSA/LANL	BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Infiniband	276
5	458.33	IBM Poughkeepsie Benchmarking Center	BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Infiniband	138
7	444.25	DOE/NNSA/LANL	BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband	2345.5
8	431.88	Institute of Process Engineering, Chinese Academy of Sciences	Mole-8.5 Cluster Xeon L5520 2.26 Ghz, nVidia Tesla, Infiniband	480
9	418.47	Mississippi State University	iDataPlex, Xeon X56xx 6C 2.8 GHz, Infiniband	72
10	397.56	Banking (M)	iDataPlex, Xeon X56xx 6C 2.66 GHz, Infiniband	72

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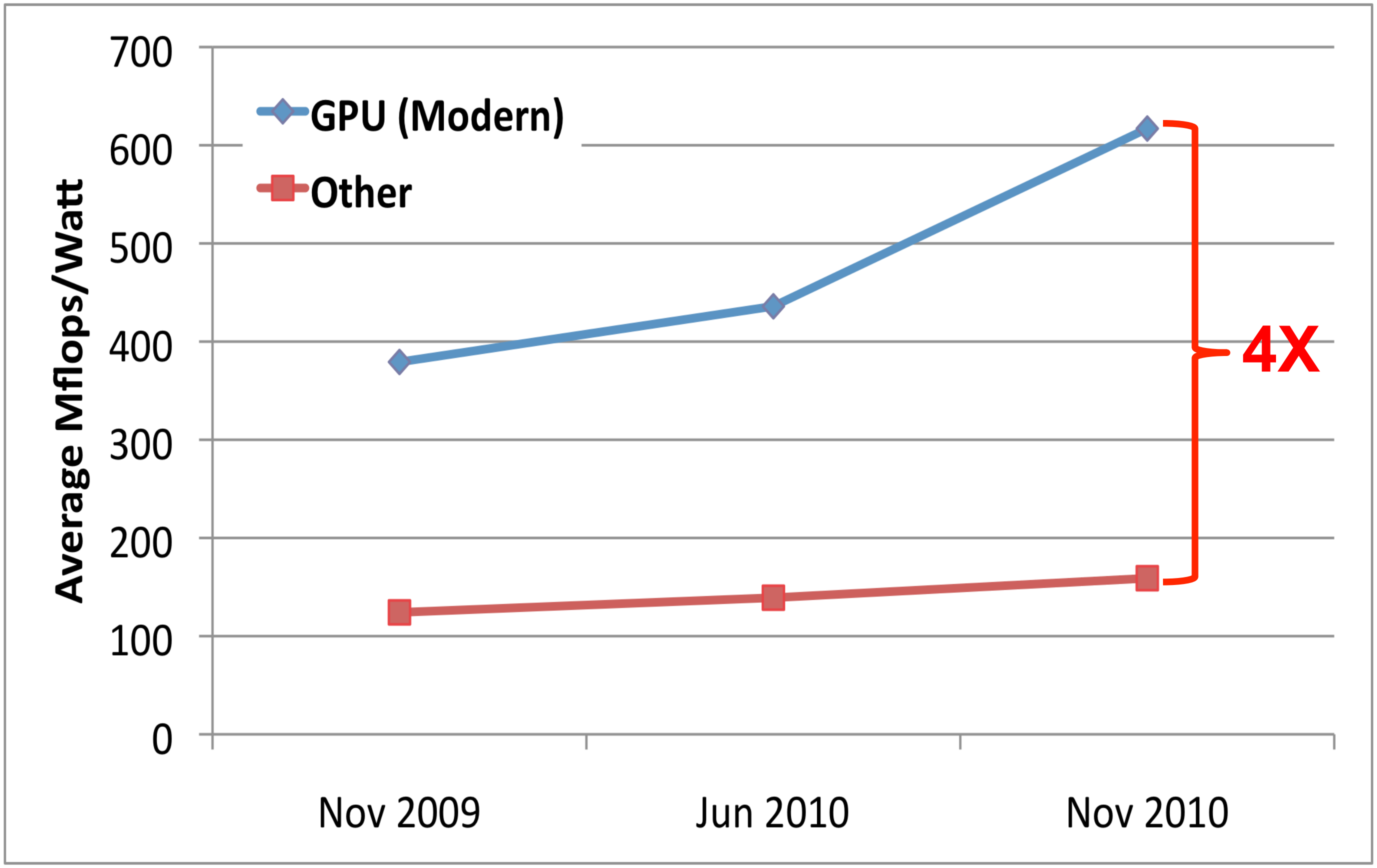
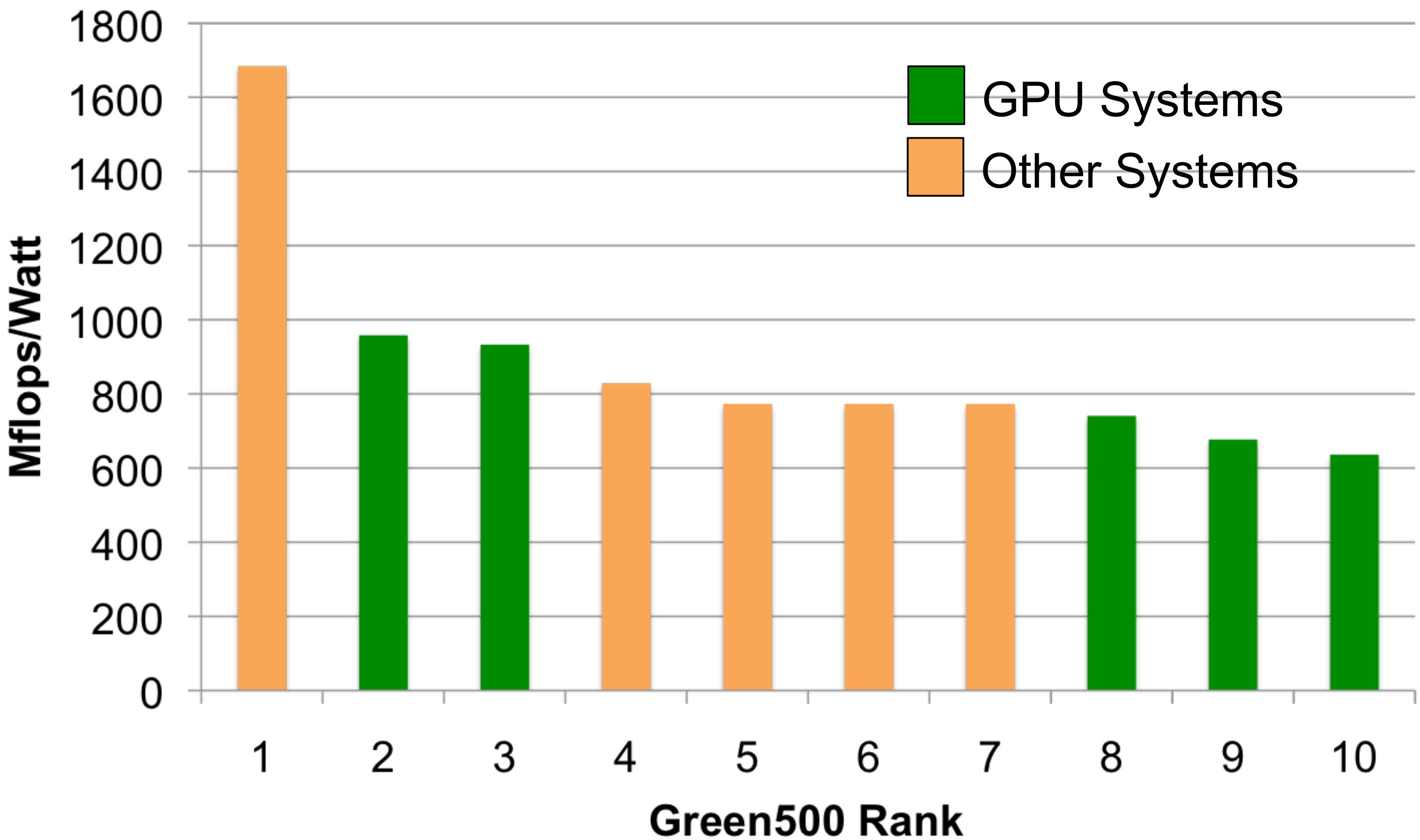
- 8 of top 10 slots are accelerator-based with 5 being GPU-based.

Green500 Rank	MFLOPS/W	Site*	Computer*	Total Power (kW)
1	1684.2	IBM Thomas J. Watson Research Center	NNSA/SC Blue Gene/Q Prototype	38.8
2	958.35	GSIC Center, Tokyo Institute of Technology	HP ProLiant SL390s G7 Xeon 6C X5670, Nvidia GPU, Linux/Windows	1243.8
3	933.06	NCSA	Hybrid Cluster Core i3 2.93Ghz Dual Core, NVIDIA C2050, Infiniband	36
4	828.67	RIKEN Advanced Institute for Computational Science	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect	57.96
5	773.38	Forschungszentrum Juelich (FZJ)	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	57.54
5	773.38	Universitaet Regensburg	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	57.54
5	773.38	Universitaet Wuppertal	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D-Torus	57.54
8	740.78	Universitaet Frankfurt	Supermicro Cluster, QC Opteron 2.1 GHz, ATI Radeon GPU, Infiniband	385
9	677.12	Georgia Institute of Technology	HP ProLiant SL390s G7 Xeon 6C X5660 2.8Ghz, nVidia Fermi, Infiniband QDR	94.4
10	636.36	National Institute for Environmental Studies	GOSAT Research Computation Facility	117.15

Energy Efficiency of Modern GPU-Based Supercomputers on the Green500



10 Greenest Supercomputers on the Green500



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Acknowledgements

CCF-0848670

Behind the Scenes …

- Thomas Scogland
- Balaji Subramaniam
- Heshan Lin
- Mark Gardner

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SyNeRGy Laboratory

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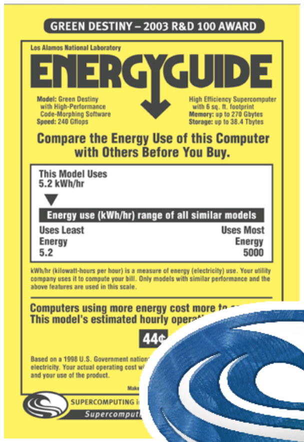

SUPERCOMPUTING in SMALL SPACES

http://sss.cs.vt.edu/

CHREC NSF Center for High-Performance Reconfigurable Computing

http://www.chrec.org/

mpiBLAST

http://www.mpiblast.org/

THE GREEN 500™

http://www.green500.org/