The Green Index (TGI):
A Metric for Evaluating Energy Efficiency in HPC Systems

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Metrics for Energy Efficiency

- **Energy-Delay Product (EDP)**
  - Used primarily in circuit design
  - Variants can be used to emphasize more on energy or performance

- **FLOPS/Watt**
  - Used in high-performance computing
  - Metric for ranking in Green500 list

Issue with Traditional Metrics?

• “In fact, in many cases it has become clear to the panel that the non-computational aspects of the energy problem, especially the energy in data transport, will dwarf the traditional computational component in future.” – DARPA-IPTO Exascale Computing Study.

Source: William J. Dally, GPU Computing to Exascale and Beyond, Keynote Talk at SC 2010
Issue with Workload?

• LINPACK
  – Focus on CPU
    … but what about the other subsystems?

EE HPC WG – TOP500 – Green Grid – Green500 Goals
• Identify workloads for exercising other sub-systems; e.g., memory, storage, I/O
• Refine methodology for measuring the power of supercomputers
• Identify appropriate metrics for energy efficiency
Our Approach: New Workload and Metric

• Use multiple benchmarks
  – Stress different components

• Arrive at a system-wide energy efficiency metric
  – Represent all components of the system
Challenges

• Different benchmarks use different metrics
  – HPL uses FLOPS
  – STREAM uses mega bytes per second (MBPS)

• How to combine these metrics? Should they be combined?
  – Which metric should be used?
  – How to arrive at a single number?
The Green Index (TGI)

- Methodology to represent system-wide energy efficiency
  - Use multiple benchmarks
- Single number
  - Combine metrics from each of the benchmark
- Energy efficiency relative to a reference system
  - Similar to SPEC rating

\[
\text{SPEC rating} = \frac{\text{Performance of Reference System}}{\text{Performance of System Under Test}}
\]
Algorithm To Calculate TGI

• Calculate performance-to-power ratio* for each benchmark

\[ \text{EE}_i = \frac{\text{Performance}_i}{\text{Power Consumed}_i} \]

• Obtain the relative energy efficiency (REE) w.r.t. the reference machine. REE is dimensionless.

\[ \text{REE}_i = \frac{\text{EE}_i}{\text{EE}_{\text{Ref}_i}} \]

*i represents the set of all benchmarks and Ref represents the reference machine

* Note: We use performance-to-power ratio as the metric of choice. However, any other efficiency metric can be used with TGI.
Algorithm To Calculate TGI

• For each benchmark, assign a weighting factor \( W_i \)

• Sum across the product of REEs and \( W_i \) to arrive at TGI for the system

\[
TGI = \sum W_i \times \text{REE}_i
\]
Assigning Weights ($W_i$)

- Arithmetic Mean
  - Assign equal weights to all the benchmarks

- Geometric Mean

- Weighted Arithmetic Mean (WAM)
  - Time ($W_{ti}$)
  - Energy ($W_{ei}$)
  - Power ($W_{pi}$)
Assigning Weights ($W_i$)

- Time as weight
  \[ W_{t_i} = \frac{t_i}{\sum_i t_i} \]

- Energy as weight
  \[ W_{e_i} = \frac{e_i}{\sum_i e_i} \]

- Power as weight
  \[ W_{p_i} = \frac{p_i}{\sum_i p_i} \]

TGI = \[ \frac{1}{\sum_i t_i \cdot E E_{Ref_i}} \cdot \sum_{i=0}^{n} \frac{t_i \cdot M_i}{t_i \cdot p_i} \]

TGI = \[ \frac{1}{\sum_i e_i \cdot E E_{Ref_i}} \cdot \sum_{i=0}^{n} \frac{e_i \cdot M_i \cdot t_i}{t_i \cdot e_i} \]

TGI = \[ \frac{1}{\sum_i p_i \cdot E E_{Ref_i}} \cdot \sum_{i=0}^{n} \frac{p_i \cdot M_i}{t_i \cdot p_i} \]
Systems Used

• Reference System (System G)
  – Two (2) Intel Xeon 5462 quad-core processors at 2.8 GHz
    • 128 nodes → 1,024 cores
  – 8GB memory
  – QDR InfiniBand

• System Under Test (Fire)
  – Two (2) AMD Opteron 6134 (Magny Cours) oct-core processors at 2.3 GHz
    • 8 nodes → 128 cores
  – 32 GB of memory
  – QDR InfiniBand
Benchmarks Used in TGI

• High-Performance LINPACK (HPL)
  – Stresses the CPU component of the system
  – Output metric: Floating-point operations per second (FLOPS)

• STREAM Benchmark
  – Stresses the memory sub-system
  – Output metric: Megabytes per second (MPBPS)

• IOZone
  – Stresses the I/O sub-system
  – Output metric: Megabytes per second (MPBPS)
Energy Efficiency of Benchmarks (Fire Cluster)

**Energy Efficiency of IOzone**

![Graph showing energy efficiency of IOzone over the number of processes.]

**Energy Efficiency of Stream**

![Graph showing energy efficiency of Stream over the number of processes.]

**Energy Efficiency of HPL**

![Graph showing energy efficiency of HPL over the number of processes.]

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The Green Index (Scalability)

![Graph showing the relationship between number of processes and arithmetic mean. The Green Index decreases as the number of processes increases.]
The Green Index (Weighting Factors)

**Weighted Arithmetic Mean**

- **Weights Using Time**

![Graph 1](image1.png)

**Weighted Arithmetic Mean**

- **Weights Using Power**
- **Weights Using Energy**

![Graph 2](image2.png)
Future Work

- Benchmark more systems
- Methodology for heterogeneous systems
- Rigorous study for weight factor assignment
- Adapt TGI based on application
  - Assign weights based on component utilization by application?
  - Analyze whether the system is energy efficient for a particular application

- System-wide → Center-wide
  - Include cooling infrastructure ...
Summary

- The Green Index (TGI)
  - A methodology to provide insights into system-wide energy efficiency
  - Comparison with traditional metrics (performance-to-power ratio)
  - Preliminary analysis

For more information,