The STREAM Benchmark

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2005-01-27

History

- Scientific computing was largely based on the vector paradigm from the late 1970's through the 1980's
  - E.g., the classic DAXPY loop:

```
REAL*8 X(N),Y(N)
DO I=1,N
  X(I) = X(I) + Q*Y(I)
END DO
```

- If all data comes from memory, this requires 12 Bytes per FLOP (=3*8Bytes/2FLOPS)

History (cont'd)

- Vector machines like the Cray X/MP, Cray Y/MP, Cray C90, CDC Cyber 205, ETA-10, and various Japanese vector systems were built to this target of 12 Bytes/second of peak memory bandwidth per peak FLOP
- Easy to sustain 30%-40% of peak performance for vectorizable code.
  - >90% on LINPACK

History (cont'd)

- 1990: The Attack of the Killer Micros
  - HP PA-RISC (aka "snakes")
  - IBM RS/6000 (aka "RIOS", aka "POWER", aka "POWER1"
- These systems provided performance roughly matching Cray vector machines on many applications, but fell very short on others
- Users were confused….

The Genesis of STREAM

- I was an assistant professor at the University of Delaware in 1990
- My research was on large-scale ocean circulation modelling
  - Vectorizable codes that ran well on vector machines
  - RS/6000-320 gave about 4% of Cray Y/MP performance
- The STREAM benchmark was developed as a proxy for the computational kernels in my ocean models

STREAM Design

- STREAM is designed to measure sustainable memory bandwidth for contiguous, long-vector memory accesses
- Four kernels are tested:
  - COPY: a(i) = b(i)
  - SCALE: a(i) = q*b(i)
  - ADD: a(i) = b(i) + c(i)
  - TRIAD: a(i) = b(i) + q*c(i)
- Arrays should all be much larger than caches

STREAM Design (cont'd)

- The code is set up with dependencies between the kernels to try to prevent excessive optimization
- Recent versions (in FORTRAN and C) have self-contained validation code
- Recent versions (in FORTRAN and C) have OpenMP directives for parallelization
  - Code is NUMA-friendly with "first touch" memory placement
- An MPI version is also available (FORTRAN)

STREAM History

- STREAM was maintained at my FTP site at the University of Delaware from 1991-1996
- STREAM web/ftp sites moved to the University of Virginia in 1996 when I moved to Industry (SGI)
- Current run rules have several publication classes
  - "standard" – no source code changes to kernels
  - "tuned" – modified source code
  - "MPI" – uses MPI source code
  - "32-bit" – uses 32-bit data items and arithmetic

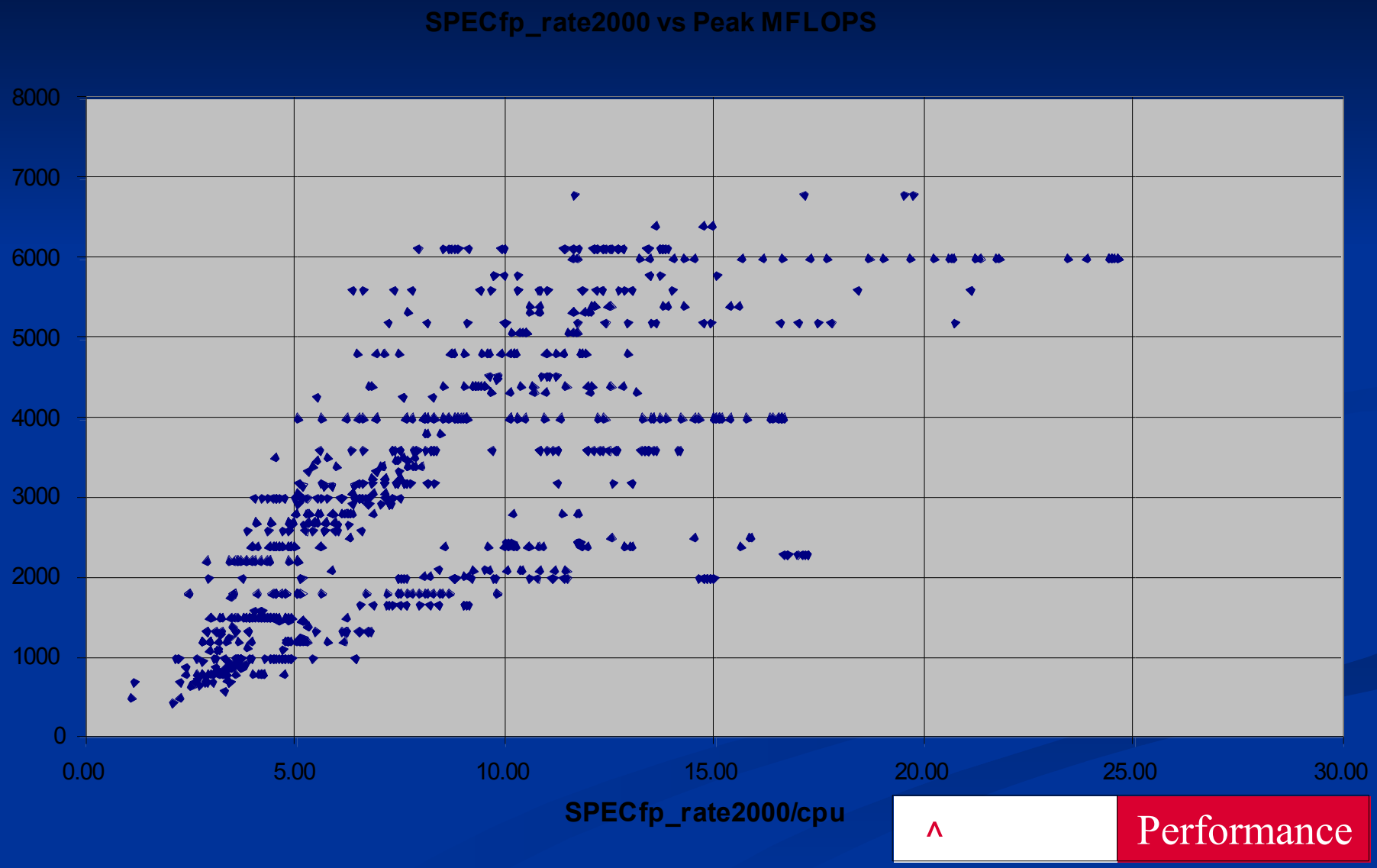
Is STREAM Useful?

- Yes – if its limitations are properly understood
- STREAM is intended as one component of a performance model that includes both processor and memory timings
  - E.g., $T_{total} = T_{cpu} + T_{memory}$
- Such models are intrinsically application dependent
  - Often strongly dependent on cache size

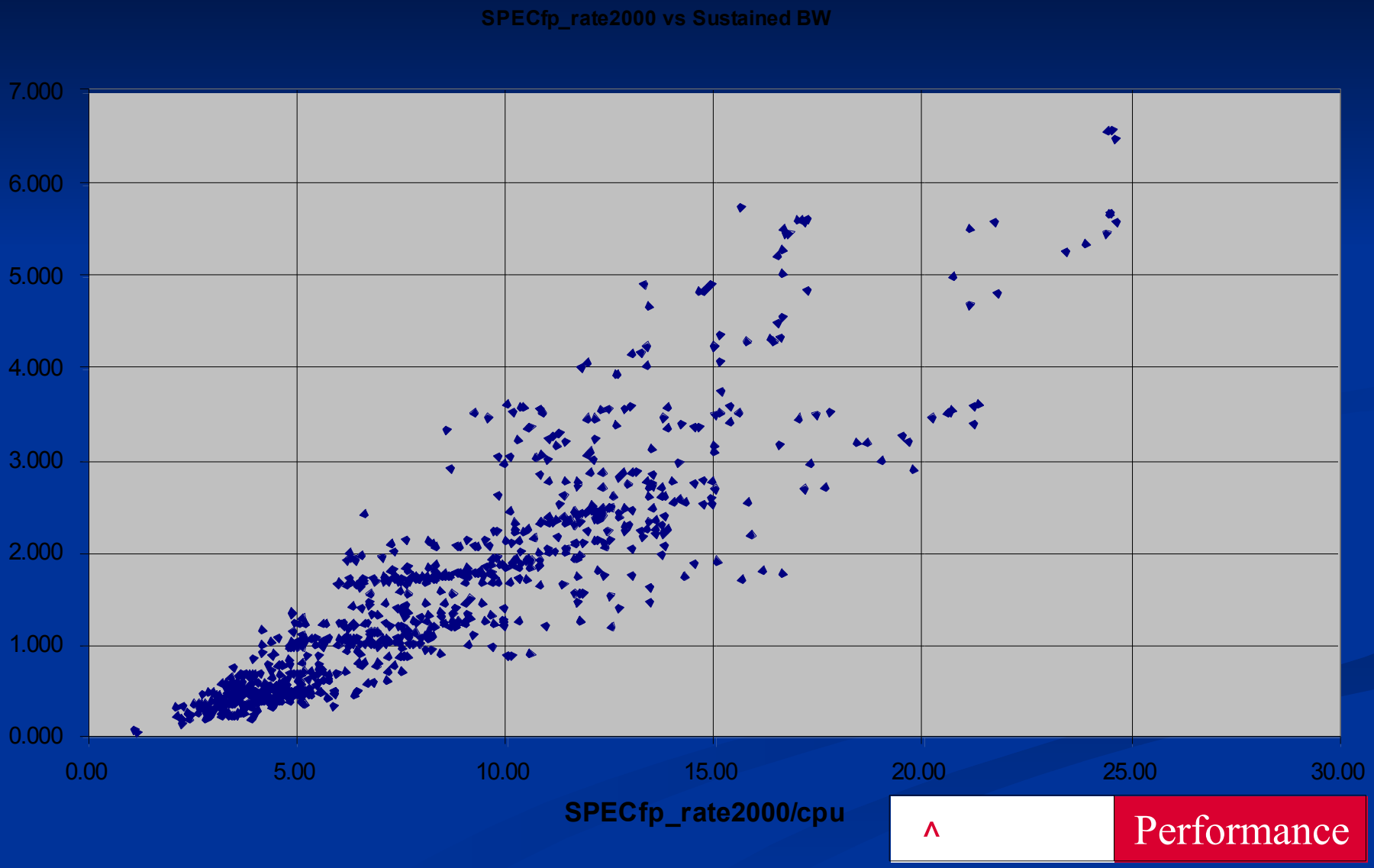
The Big Question

- Q: How should one think about composite figures of merit based on such a collection of low-level measurements?
- A: Composite Figures of Merit must be based on "time" rather than "rate"
  - i.e., weighted harmonic means of rates
- Why?
  - Combining "rates" in any other way fails to have a "Law of Diminishing Returns"

Does Peak GFLOPS predict SPECfp_rate2000?



Does Sustained Memory Bandwidth predict SPECfp_rate2000?

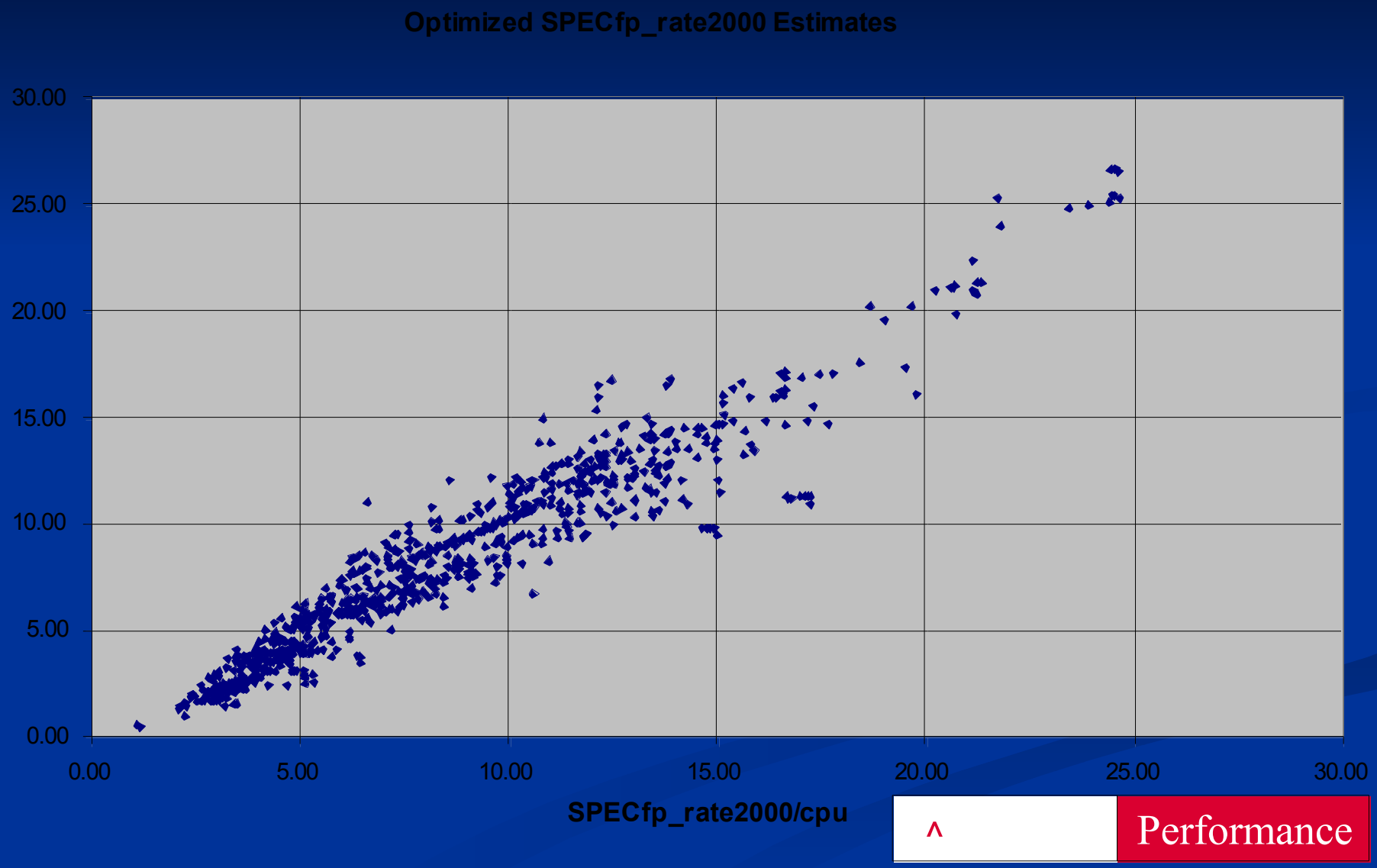


A Simple Composite Model

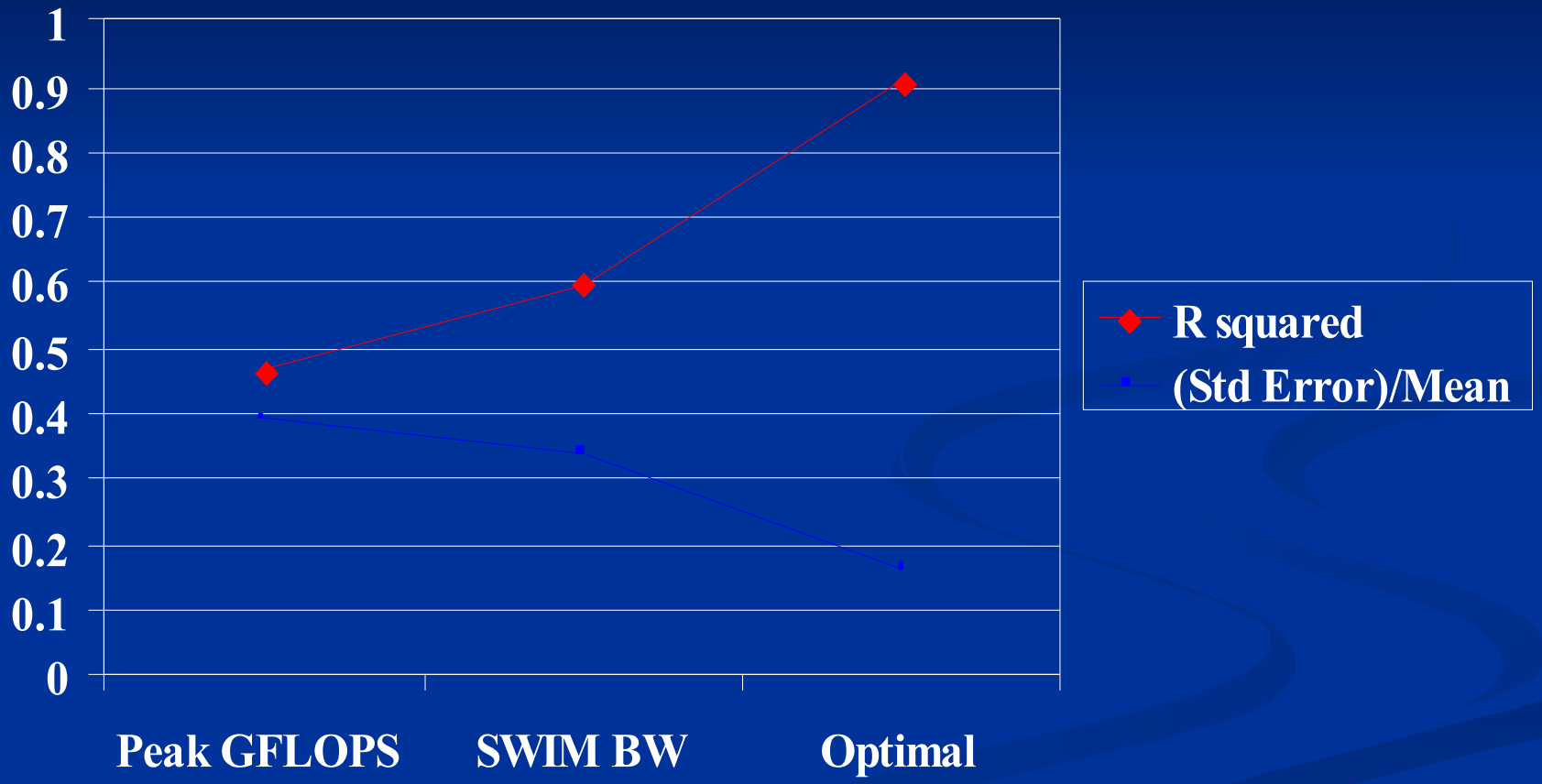
- Assume the time to solution is composed of a compute time proportional to peak GFLOPS plus a memory transfer time proportional to sustained memory bandwidth
- Assume “x Bytes/FLOP” to get:

$$\text{"Balanced GFLOPS"} \equiv \frac{1\ \text{"Effective FP op"}}{\left(\frac{1\ \text{FP op}}{\text{Peak GFLOPS}}\right)+\left(\frac{x\ \text{Bytes}}{\text{Sustained GB/s}}\right)}$$

Does this Revised Metric predict SPECfp_rate2000?



Statistical Metrics

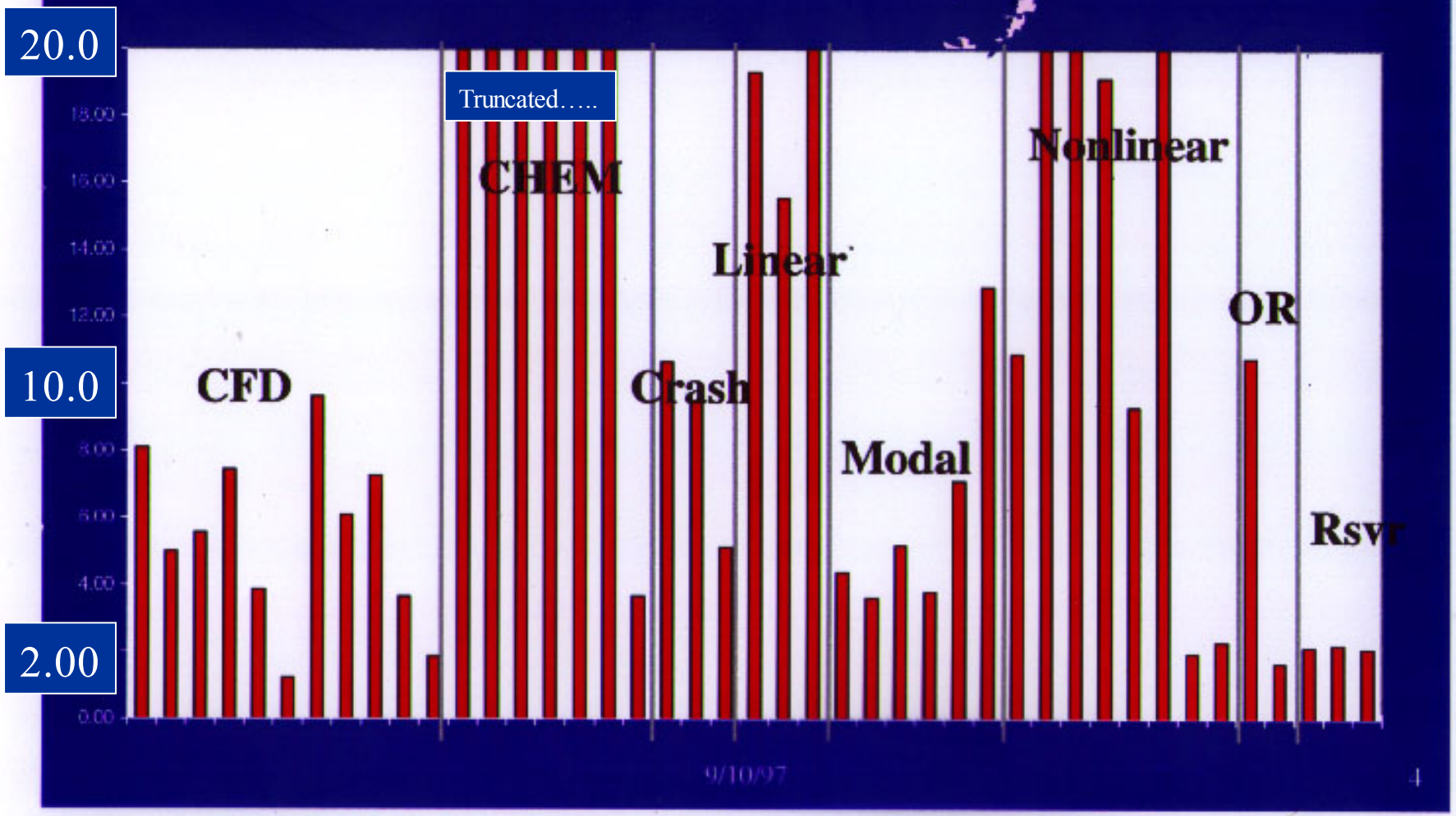


^ Performance

What about other applications?

- Effectiveness of caches varies by application area
- Requirements for interconnect performance vary by application area
  - Some apps are short-message dominated
  - Some apps are long-message dominated
- Composite models can be tuned to specific application areas – if app properties known

BW Reduction due to 4 MB Cache



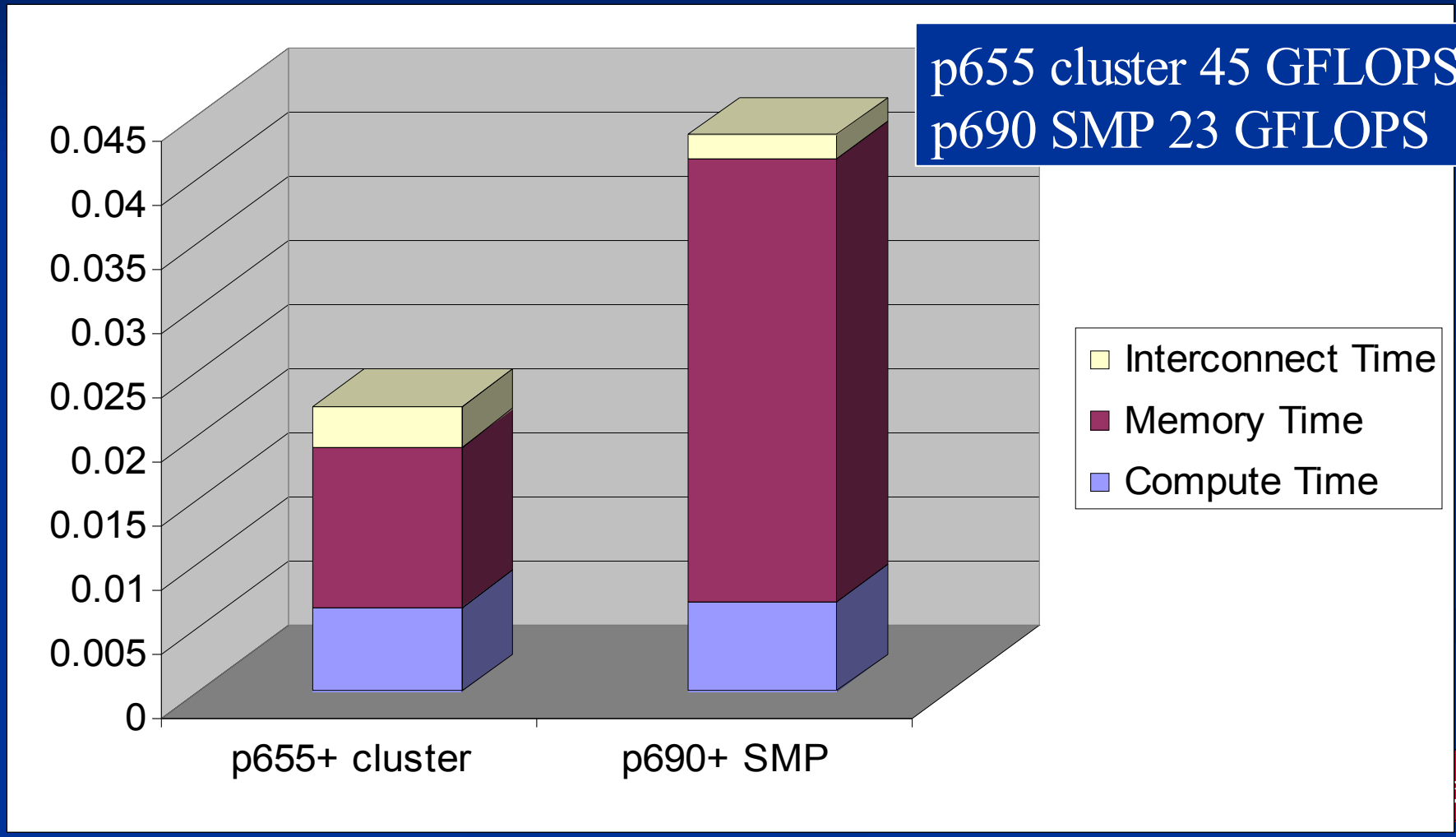
An Example Model tuned for CFD

- Analyze applications and pick reasonable values:

$$\text{"Balanced GFLOPS"} \equiv \frac{1\ \text{"Effective FP op"}}{\left(\frac{1\ \text{FP op}}{\text{LINPACK GFLOPS}}\right)+\left(\frac{2\ \text{Bytes}}{\text{STREAM GB/s}}\right)+\left(\frac{0.1\ \text{Bytes}}{\text{Network GB/s}}\right)}$$

- Two cases tested:
  - Assume long messages (network BW tracks PTRANS)
  - Assume short messages (network BW tracks GUPS)
- The relative time contributions will quickly identify applications that are poorly balanced for the target workload

Comparing p655 cluster vs p690 SMP Assumes long messages



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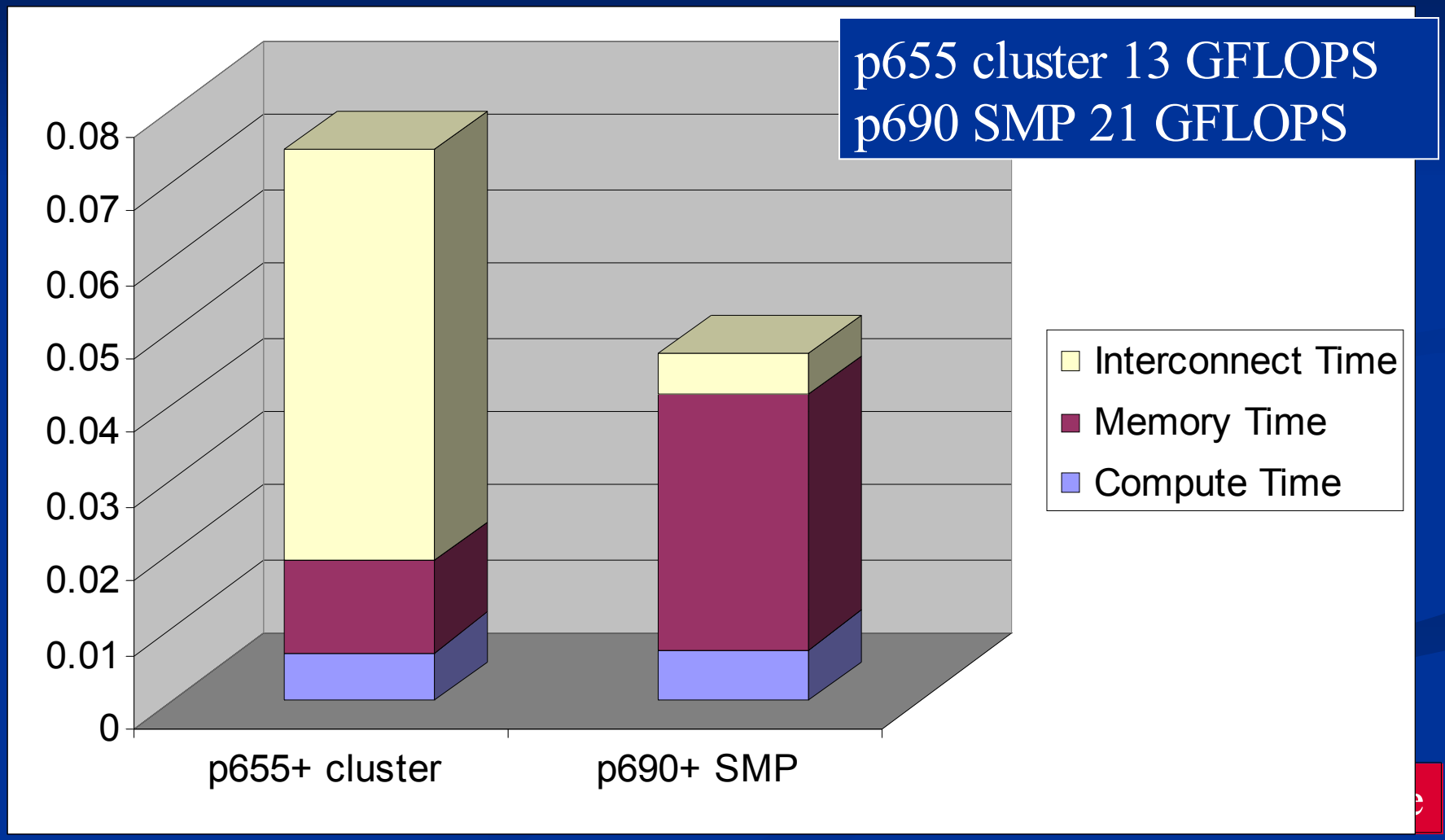

Summary

- The composite methodology is
  - Simple to understand
  - Based on the components of the HPC Challenge Benchmark
  - Based on a mathematically correct model of performance
- Much work remains on documenting the work requirements of various application areas in relation to the component microbenchmarks