Maximizing Speedup through Self-Tuning of Processor Allocation

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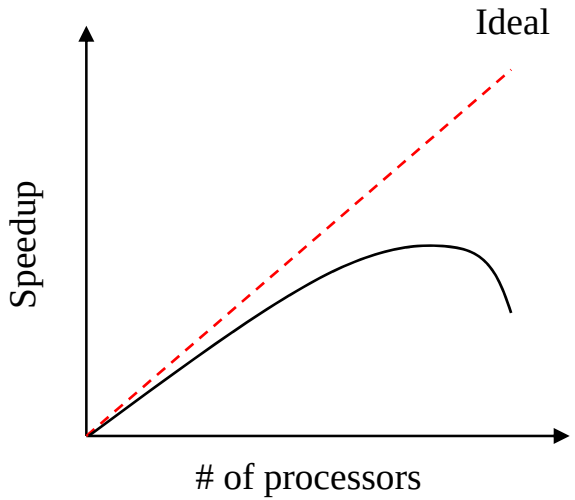
Contents

Introduction

- Does job's speedup increase monotonically with the number of processors?
  - No, many parallel applications achieve maximum speedup at some intermediate allocation.



Introduction

- It may not be possible a priori to determine the best allocation
- No static allocation may be optimal for the entire execution lifetime of a job
- Goal: dynamically determined # of processors
  - To maximize job's speedup
  - Unused processors are released back to the system

Introduction

- How to?
  - Dynamically measures job efficiencies at different allocations
  - Uses these measurements to calculate speedups
  - Automatically adjusts a job's processor allocation to maximize its speedup
    - Method of golden sections (MGS) optimization technique
- This process is called *self-tuning*

Experimental Environment

- Kendall Square Research KSR-2 COMA shared memory multiprocessor
  - OS: OSF/1 (UNIX variant)
- H/W monitoring unit available on each node of the KSR-2 to perform runtime measurements of application efficiency
  - Event monitor
    - Provides cache misses, processor stall time, etc. via read-only registers
- 10 parallel applications
  - Hand-coded applications
  - Complier-parallelized sequential program
  - Only consider iterative parallel applications

Runtime Measurements

- A number of different runtime metrics
  - Execution time
  - Efficiency
    - Directly related to speedup
- Loss of efficiency in shared memory systems due to
  - Parallelization overhead
  - System overhead
  - Idleness
  - Communication
    - Occurs when required data does not reside in local cache
    - Directly related to the processor stall

Runtime Measurements

- Three critical HW counters for measuring system overhead and processor stall time
  - Elapsed wall-clock time
  - Elapsed user-mode execution time
  - Accumulated processor stall time
  - Reading these three register at the beginning and end of each iteration
- Measuring idleness
  - Instrument all PRESTO and CThreads synchronization code to track elapsed idle time using the wall-clock counter
  - Assume all application synchronization takes place through calls to the PRESTO and CThreads libraries rather than through direct manipulation of shared variables

Runtime Measurements

- Efficiency = 1 – (loss of efficiency)
  - Loss of efficiency = system overhead + idleness + processor stall

$$E(p) = 1 - \frac{WT(p) - UT(p)}{WT(p)} - \frac{IT(P)}{WT(p)} - \frac{PST(p)}{WT(p)}$$

- Speedup = # of processors * efficiency

$$S(p) = p \times E(p)$$

Algorithms for Self-tuning

- Method of Golden Sections (MGS)
  - Searches for the maximum of a unimodal function over a finite interval
  - By iteratively using computed function values to narrow the interval in which the maximum may occur

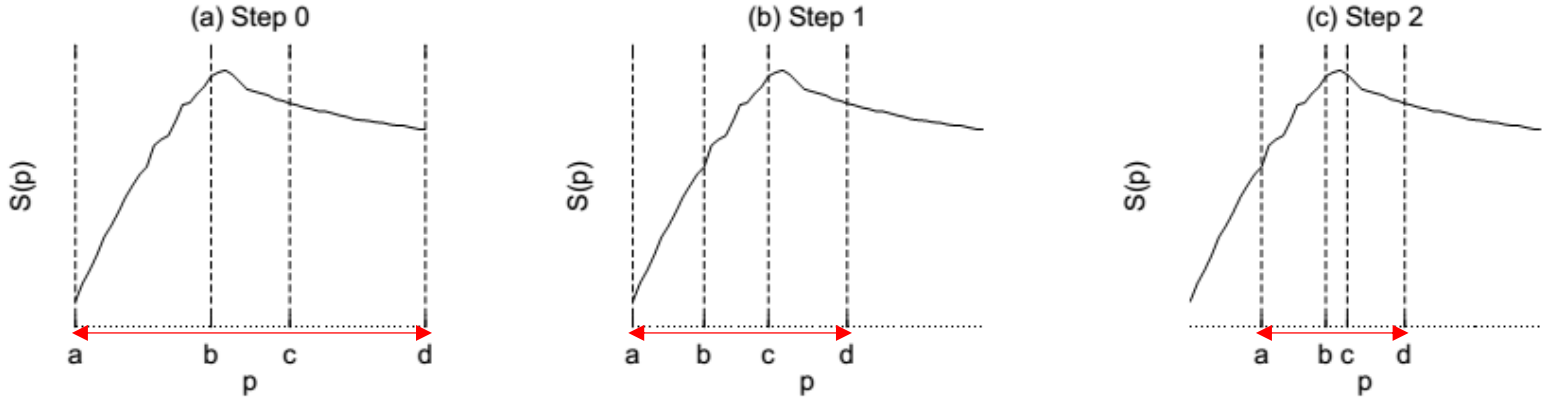
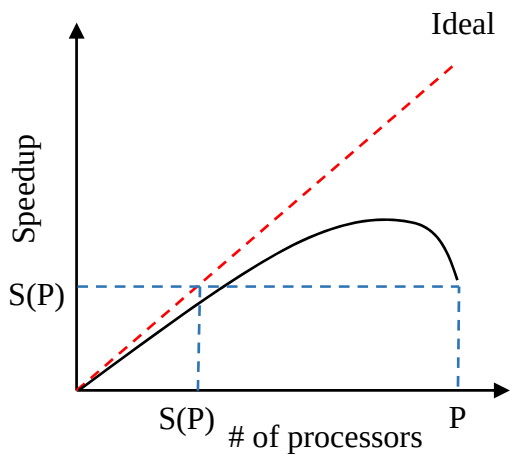


Figure 1: *Two iterations of the method of golden sections: (a) Initial state* a_0, b_0, c_0, d_0*; (b)* $S(b_0) > S(c_0) =>$ $a_1 \leftarrow a_0$, $b_1 \leftarrow d_1 - 0.618(d_1 - a_1)$, $c_1 \leftarrow b_0$, $d_1 \leftarrow c_0$*; (c)* $S(b_1) < S(c_1) => a_2 \leftarrow b_1$, $b_2 \leftarrow c_1$, $c_2 \leftarrow a_2 + 0.618(d_2 - a_2)$, $d_2 \leftarrow d_1$.

Algorithms for Self-tuning

- Assumption
  - Speedup is a single variable function
    - $S(p) : I \rightarrow R$, where the domain is $[1, P]$
  - $S(p)$ can be calculated using equation for any p, $1 \leq p \leq P$, by measuring $E(p)$ for any one iteration
  - Single variable optimization
- Reducing search interval
  - Search domain reduces from $[1, P]$ to $[S(P), P]$
  - Start search in this domain



Algorithms for Self-tuning

- Non-unimodal speedup functions
  - Most speedup functions are unimodal over substantial ranges of processors
  - Simple greedy heuristic to deal with non-unimodal speedup functions
    - Upon encountering non-unimodal case, simply continue the search in the largest subinterval for which the measured speedups are conformal with a unimodal function, and which contains the largest speedup found so far
    - This worked well in practice

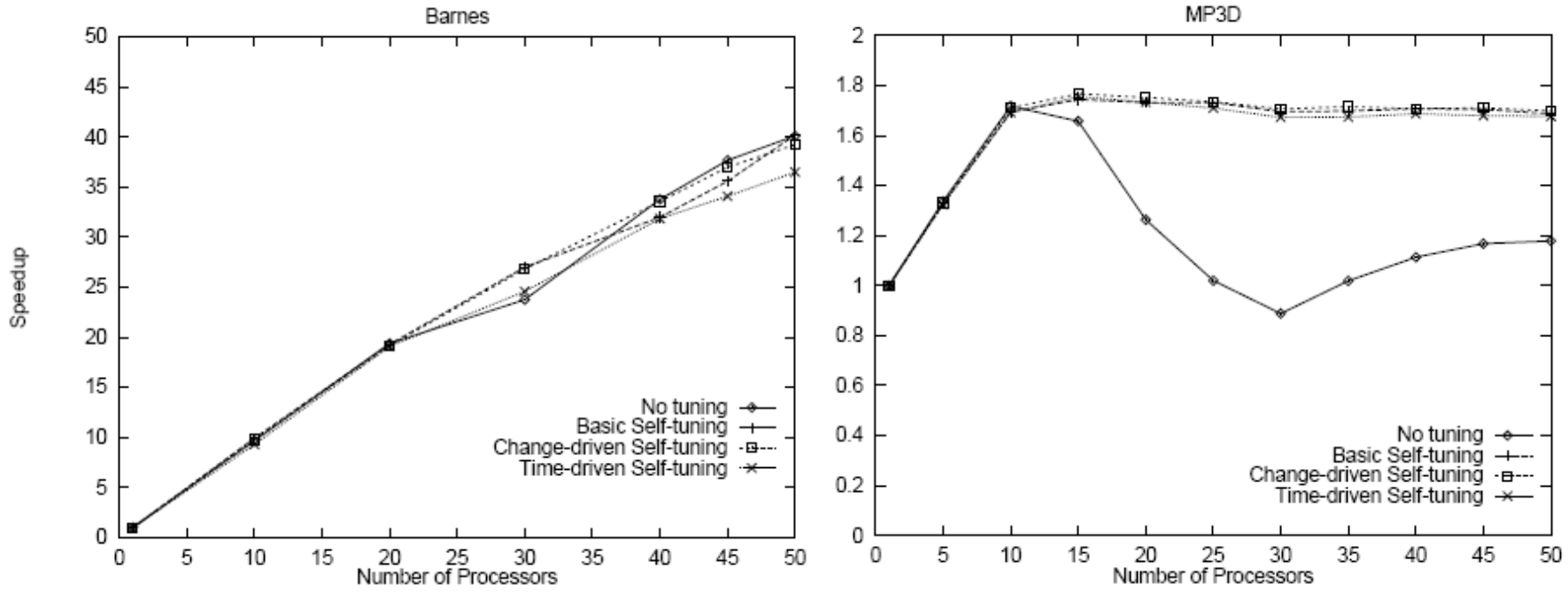
Algorithms for Self-tuning

- Validity check for three assumptions
  - For non-unimodal speedup functions, heuristic-based extended MGS search procedure will correctly locate the global maximum
  - Speedup values seen at the beginning of execution are good representations of the job’s behavior in the indefinite future
  - The speedup values of successive iterations are directly comparable

Algorithms for Self-tuning

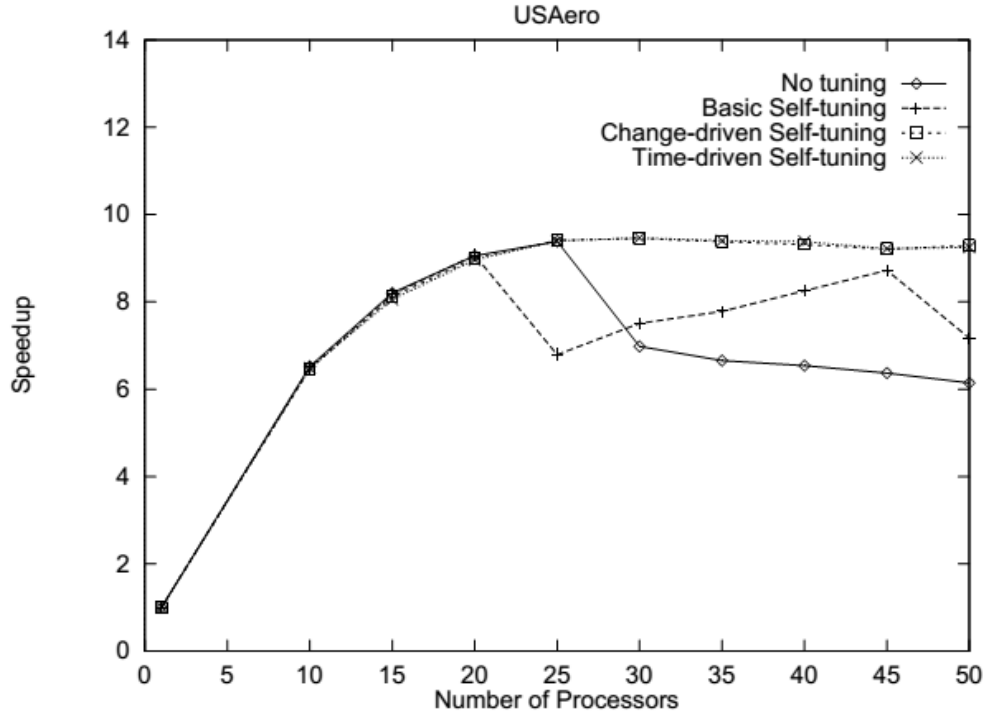
- Change-driven self-tuning algorithm
  - Continuously monitors job efficiency and re-initiates the search procedure whenever it notices a significant change in efficiency
- Time-driven self-tuning algorithm
  - Includes change-driven self-tuning
  - Will also rerun the search procedure periodically regardless of change in job efficiency
  - Considering the possibility that job efficiency changes in the middle of a change-driven self-tuning search

Performance



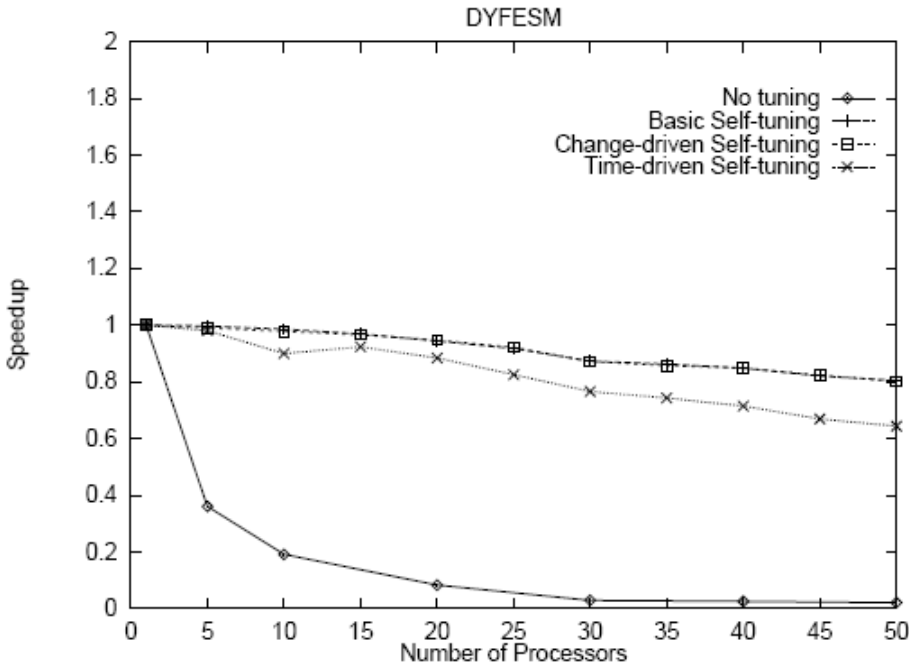
- Self-tuning imposes very little overhead
- Basic self-tuning can significantly improve performance over no-tuning

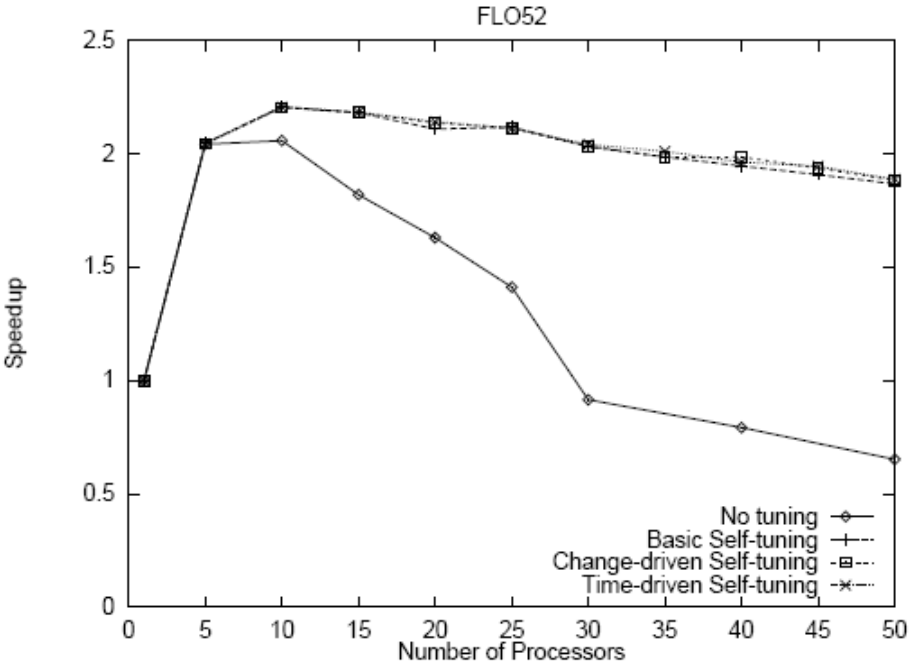
Performance



- Change-driven self-tuning can significantly improve performance over basic self-tuning

Performance





- Time-driven self-tuning is not useful for the applications studied here
- The performance benefit of self-tuning can be limited by the cost of probes

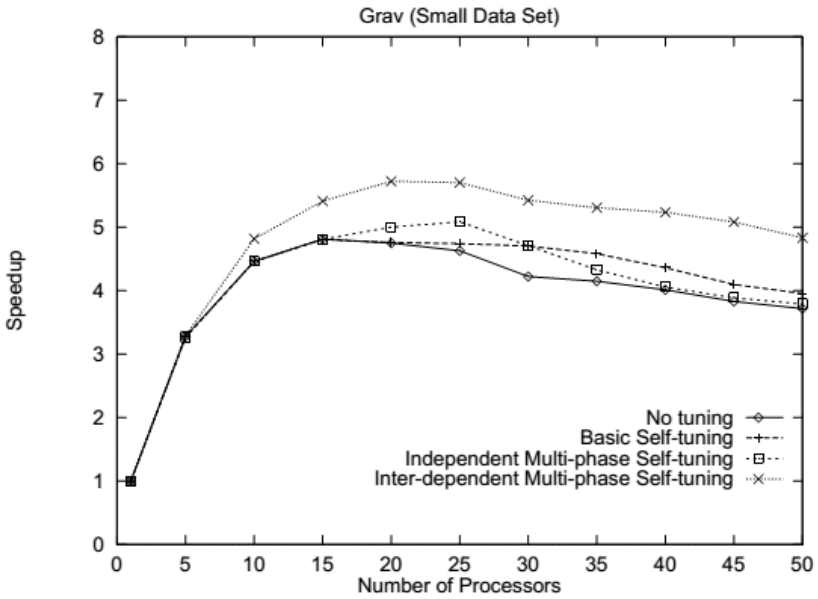
Multi-phase Self-tuning

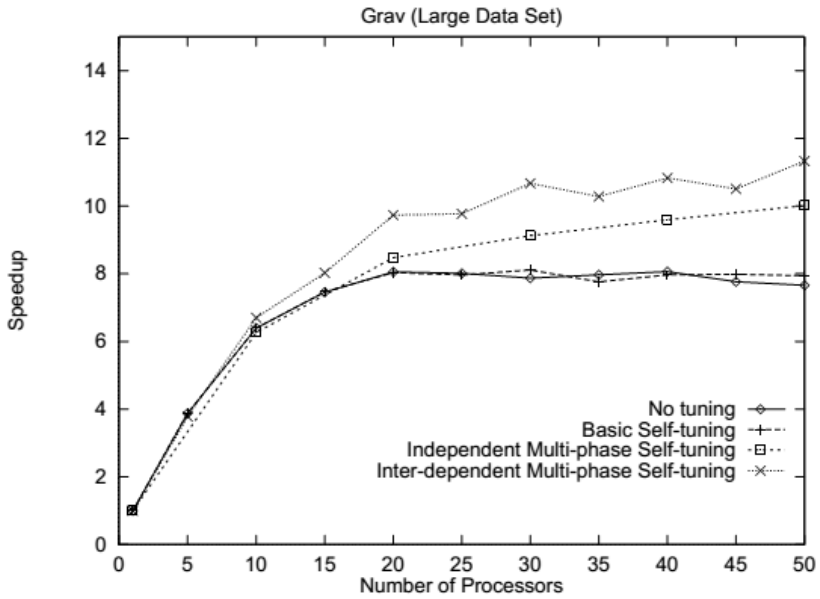
- The iterations of some applications are composed of multiple parallel phases
  - Phases: specific piece of code
    - A parallel loop in a compiler-parallelized program
    - A subroutine in a hand-coded parallel program
- Assume that on each entry to and exit from a phase, the runtime system is provided with the unique ID of the phase
  - Find a processor allocation vector (p1, p2, ..., pN) that maximizes performance when there are N phases in an iteration

Multi-phase Self-tuning

- Independent multi-phase self-tuning (IMPST)
  - Merely apply self-tuning to each phase independently
  - Simple
  - Problem : performance of each phase depends only on it own allocation and not on the allocations for any other phases
- Inter-dependent multi-phase self-tuning (DMPST)
  - Simulated annealing and a heuristic-based approach
  - Randomized search technique
    - Choosing an initial candidate allocation vector
    - Selecting a new candidate vector (apply random multiplier)
    - Evaluating and accepting new candidate vectors until steady state
    - Terminating the search

Multi-phase Self-tuning





- Multi-phase techniques are able to achieve performance not realizable by any fixed allocation
- Inter-dependent self-tuning yields better performance than independent self-tuning

Conclusion

- Maximizing application speedup through runtime, self-selection of an appropriate number of processors on which to run
  - Based on ability to measure program inefficiencies
- Simple search procedures can automatically select appropriate numbers of processors
  - Relieves the user of the burden of determining the precise number of processors to use for each input data set
  - Potential to outperform any static allocation