Maximizing Speedup through Self-Tuning of Processor Allocation

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Introduction

- Many parallel applications achieve maximum speedup at some intermediate allocation
  - Job’s speedup does not increase monotonically with # of processors
- Goal: **dynamically** determine # of processors
  - Unused processors are released back to the system
- **Why dynamic?**
  - 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
- **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
Introduction

How to?
- Relies on appropriate HW support to measure efficiencies
  - Method of golden sections (MGS) optimization technique
    - MGS finds 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
  - Iterative parallel applications
    - Majority of the execution is driven by a sequential loop
    - Measurements taken for a particular iteration are good predictors of near future behavior
- This process is called self-tuning
Experimental environment

- Kendall Square Research KSR-2 COMA shared memory multiprocessor
  - KSR KAP preprocessor
  - KSR PRESTO runtime system
- HW monitoring unit available on each node of the KSR-2 to perform runtime measurements of application efficiency
  - Event monitor
    - Via read-only registers
- 10 parallel applications
  - Hand-coded applications
  - Compiler-parallelized applications
A number of different metrics

- Execution time
- **Efficiency**
  - Directly related to speedup

Loss of efficiency in shared memory systems due to...

- Parallelization overhead
  - Typically small
- System overhead
- Idleness
- Communication
  - Occurs when required data does not reside in local cache
  - Directly related to the *processor stall*
Runtime measurements

- Per-node event monitors on the KSR-2 maintain three critical HW counters:
  - Elapsed wall-clock time
  - Elapsed user-mode execution time
  - Accumulated processor stall time

- Measuring system overhead and processor stall time:
  - 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

- Efficiency = 1 - loss of efficiency
  = 1 - system overhead - idleness - processor stall

- Speedup = # of processors * efficiency
Algorithms for Self-tuning

- Assumes no knowledge of application structure other than the fact that the application is iterative
- 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
- Algorithm begins by executing one iteration using all $P$ available processors
  - Search domain reduces to $[S(P), P]$
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

- Validity check for three assumptions
  - For non-unimodal speedup functions, heuristic-based extended MGS search procedure will correctly locate the global maximum
    - Never violated in experiments
  - Speedup is not a function of time
    - False
  - The speedup values of successive iterations are directly comparable
    - False
Algorithms for Self-tuning

- Change-driven self-tuning
  - Continuously monitors job efficiency and re-initiates the search procedure whenever it notices a significant change in efficiency

- Time-driven self-tuning
  - 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.
- 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 \((p_1, p_2, \ldots, p_N)\) 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 its own allocation and not on the allocations for any other phases
    - Allocation in phase \( n \) dictates a problem partitioning
    - Partitioning affects the amount of communication required in phase \( n+1 \)

- **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
  - Peak speedups are data or time dependent
- 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
    - Dynamic