Preliminary Evaluation of Dynamic Load Balancing Using Loop Re-partitioning on Omni/SCASH

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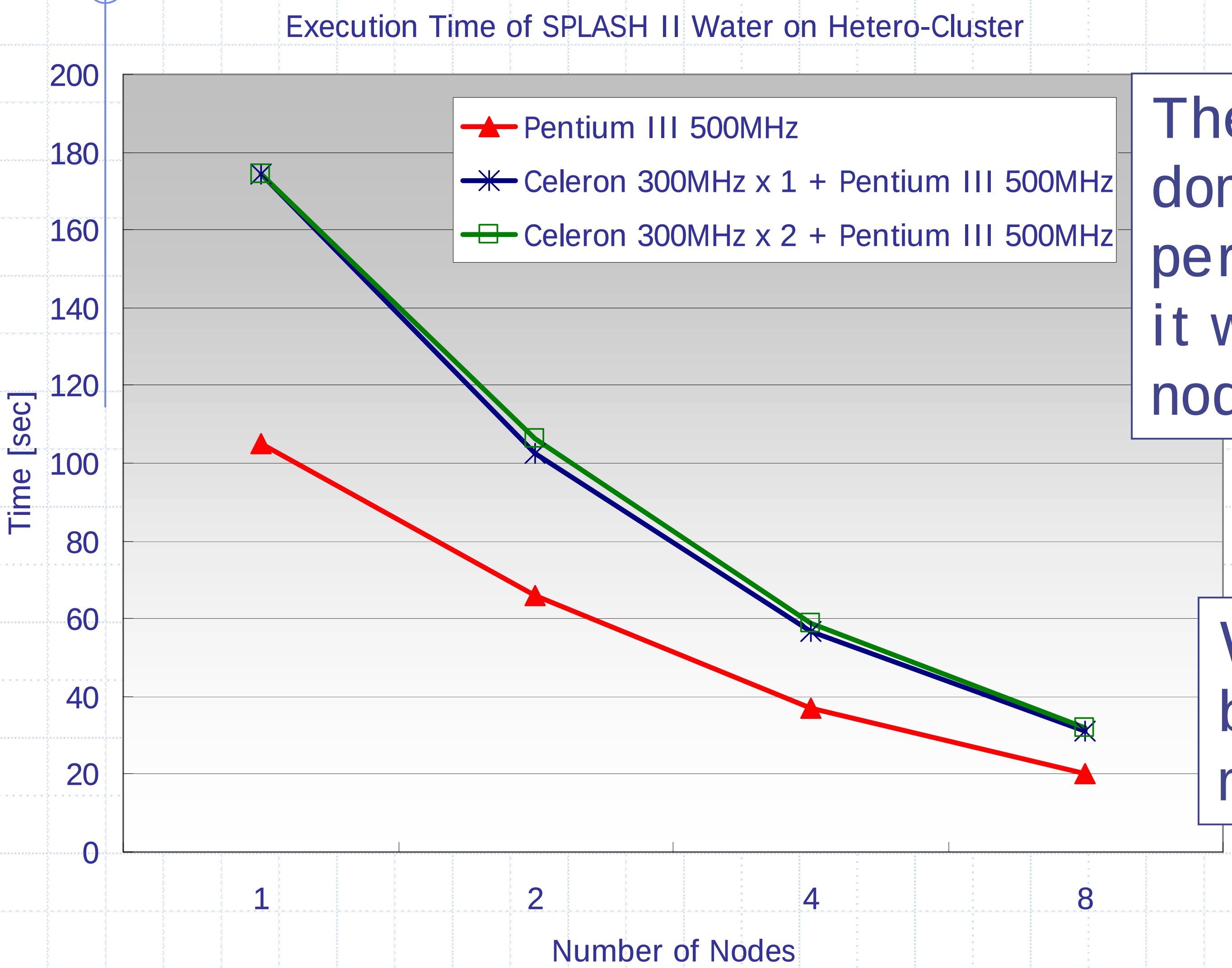
Background

- Commodity cluster tends to be heterogeneous in performance
  - Incremental extension of nodes
  - Incremental upgrade of nodes
  - Cluster of clusters
- When a program is executed on hetero-cluster, its total performance is often dominated by the slowest host.

*We'll abbreviate performance heterogeneous cluster as hetero-cluster

An Example of Performance Degradation on Hetero-Cluster



The slower nodes dominate the entire performance as if it were all 300MHz nodes

We need a load balancing mechanism

In This Work

- We extended Omni/SCASH to support hetero-clusters
  - Loop re-partitioning mechanism to achieve dynamic load balancing based on runtime performance
  - Page migration mechanism based on page reference counting (not yet implemented completely)
- We report the effect of loop re-partitioning on hetero-cluster

Omni/SCASH [Sato et al. '00] (http://www.pccluster.org/)

- One of the OpenMP implementation on Software DSM, SCASH [Harada et al. '98]
- Translates C or F77 + OpenMP programs into C with runtime library calls
  - Intermediate code (Xobject) is a kind of AST
    - Omni provides Java class libraries to process the AST easily
    - Each node of the AST is a Java object
  - Omni encapsulates each parallel region into a separate function which is invoked from master thread
  - A Global variable is allocated by the SCASH function and transposed to the pointer to that

Target Problems

- Load imbalance caused by runtime settings
  - Esp. when an application is executed on hetero-cluster

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- Static techniques are inadequate, because the performance ratio varies on each cluster setting

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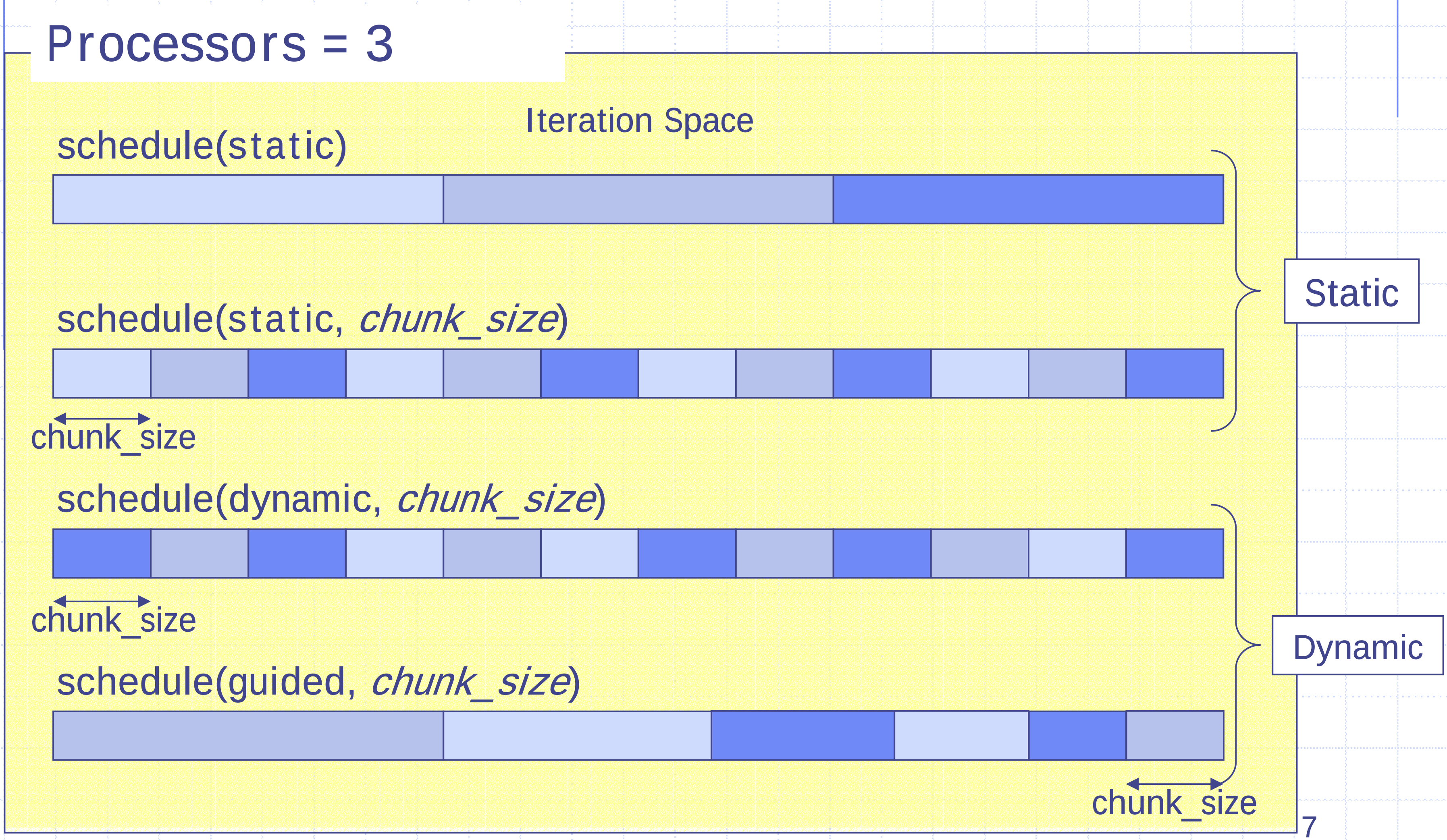
- Dynamic scheduling based on runtime performance + page migration

OpenMP Schedulings



Our Proposal: Profiled Scheduling

- Load balancing based on runtime self-profiling
- Target: parallel loops specified with the “#pragma omp for” directive
- Measures the execution time of the target loop on each thread
- Adjusts chunk size of the parallel loop dynamically based on measured performance
- Assumptions:
  - The application has no load imbalance inherently
  - The target loop has no changes of a work load among the iterations

The Syntax of Profiled Scheduling

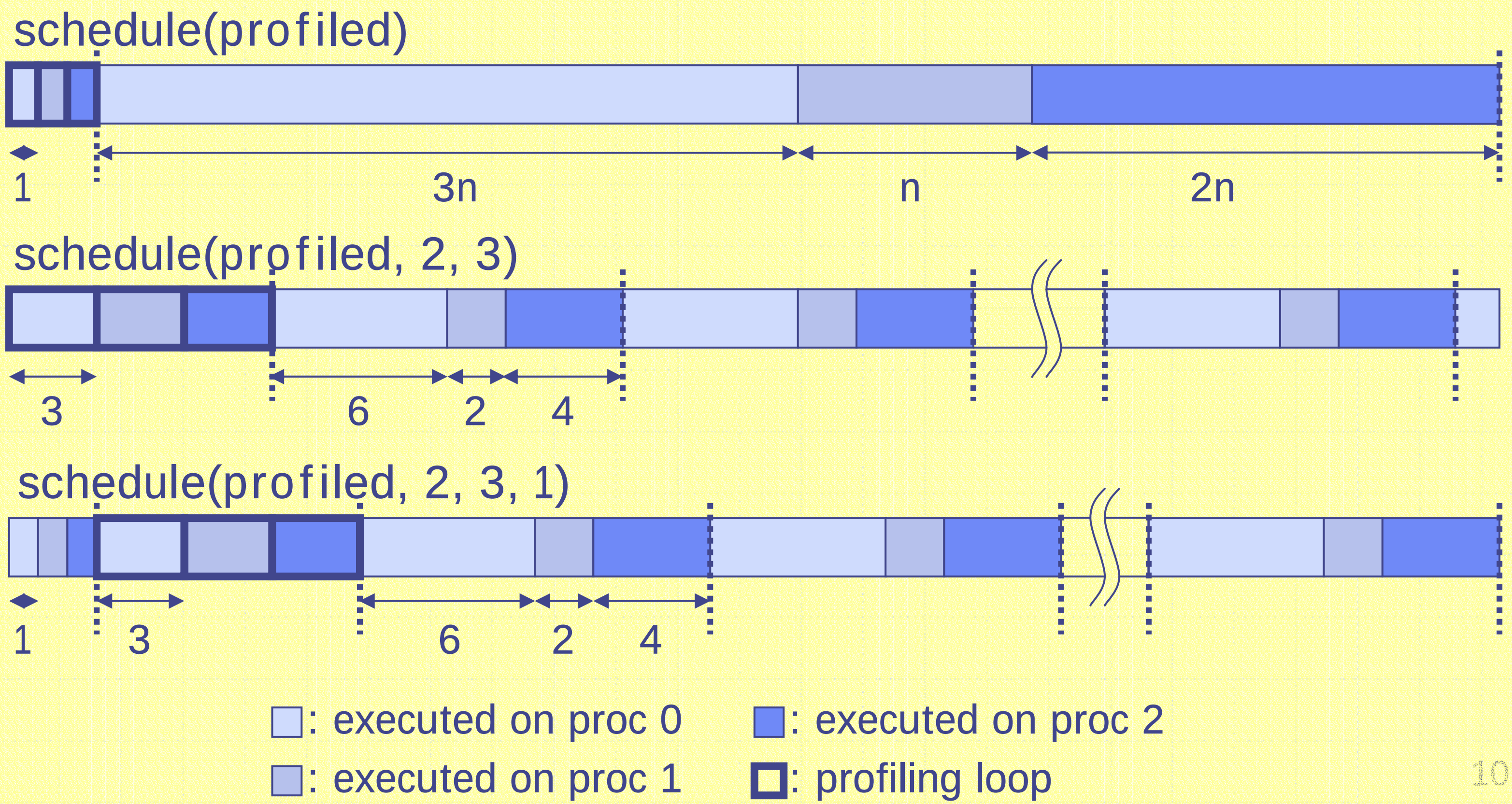
```
#pragma omp [parallel] for
        schedule(profiled[, chunk_size[, eval_size[, eval_skip]]])
```

- eval_skip specifies the initial iteration size which is executed normally
  - When eval_skip is omitted or 0, start profiling from the head of iters
- eval_size specifies the size of profiling iterations
  - When eval_size is omitted, evaluation loop size: 1
- chunk_size specifies the size of chunk
  - When the chunk_size is omitted or 0, divide remaining iters in a block manner based on performance ratio
  - When the chunk_size = n (n > 1), divide remaining iters cyclically based on performance ratio

Examples of Profiled

```
#pragma omp [parallel] for
        schedule(profiled[, chunk_size[, eval_size[, eval_skip]]])
```

Example: Num Proc = 3, Performance Ratio = 3:1:2



Code Translation when Profiled Scheduling is Specified

```
#pragma parallel omp for schedule(profiled, 10)
    for (i = 0; i < n; i++) {
        LOOP_BODY;
    }
```

User code

Translated at the level of the intermediate representation of Omni

```
static void __ompc_func(void **__ompc_args) {
  int i, lb, ub, step;
  long long start = 0, stop = 0;
  lb = 0, ub = N, step = 1;
  _ompc_profiled_sched_init(lb, ub, step, 10);
  while (_ompc_profiled_sched_next(&lb, &ub, start, stop)) {
    _ompc_profiled_get_time(&start);
    for (i = lb, i < ub; i += step) {
        LOOP_BODY;
    }
    _ompc_profiled_get_time(&stop);
  }
}
```

Translated code

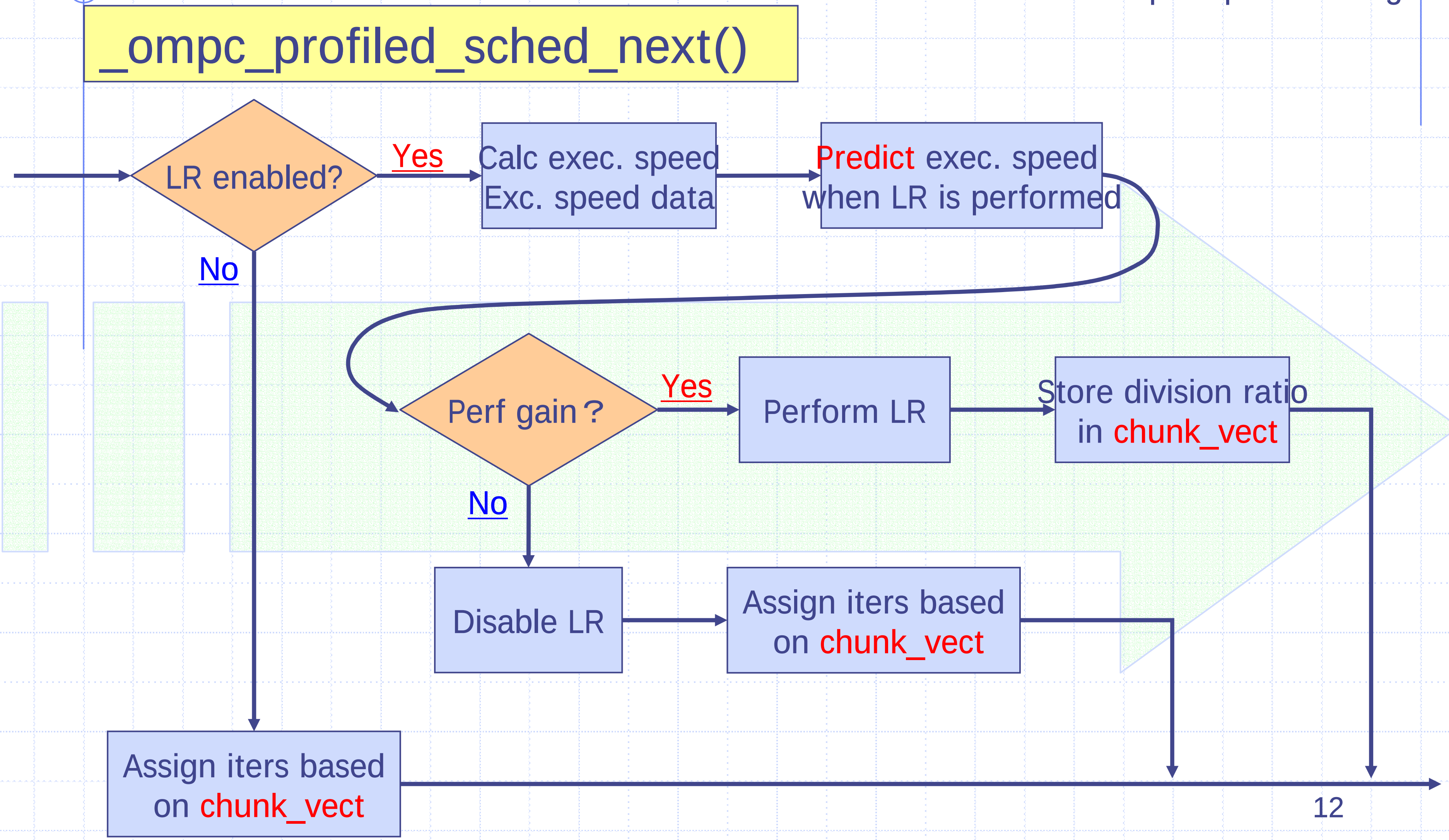
Runtime performance measurement

Dynamic load balancing based on performance prediction (loop re-partitioning)

- __o... the
- _om... mea... performance
- _ompc_profiled_sched_next() calculates the next chunk of iteration based on measured performance

Overview of Loop Re-partitioning Algorithm

LR: loop re-partitioning



Dynamic/Guided v.s. Profiled

- Dynamic/Guided scheduling
  - Needs atomic access to the index managed centrally at every sub-loop index calculation
  - Involves communication on the distributed memory environment
- Profiled scheduling
  - Doesn't need the index managed centrally
  - Each thread has chunk size for all threads in chunk_vector
  - Communication occurs only after evaluation loop
    - When the target loop has no changes of a work load among the iterations, loop re-partitioning may complete on its first attempt

Dynamic Page Migration Idea (1/2)

- Counts the number of page faults at the SDSM level (c.f. precise page reference counting with hardware support [Nikolopoulos et al. '00])
- Migrates the page to the node with the most number of remote references to the given page
  - Because we can't count local accesses directly, unnecessary page migration may occur

Dynamic Page Migration Idea (2/2)

- Keeps migration records to avoid the page ping-pong, and restore locality within several repetition
- Performs page migration only during the target parallel loops
  - Excludes unnecessary page reference data
  - Enables timely page migration based on appropriate page reference data
- We plan
  - Speculative page migration based on feedback from loop re-partitioning
  - Re-enable loop re-partitioning after page migration

Coordinate Profiled Scheduling with Page Migration

- Profiled scheduling and page migration affect each other
  - Loop re-partitioning will cause poor data locality
  - Page migration will affect performance prediction
- Exploits both profiled scheduling and page migration gradually
  - Both will reach the stable state in early stage of iterations
  - Needs some heuristics to balance both

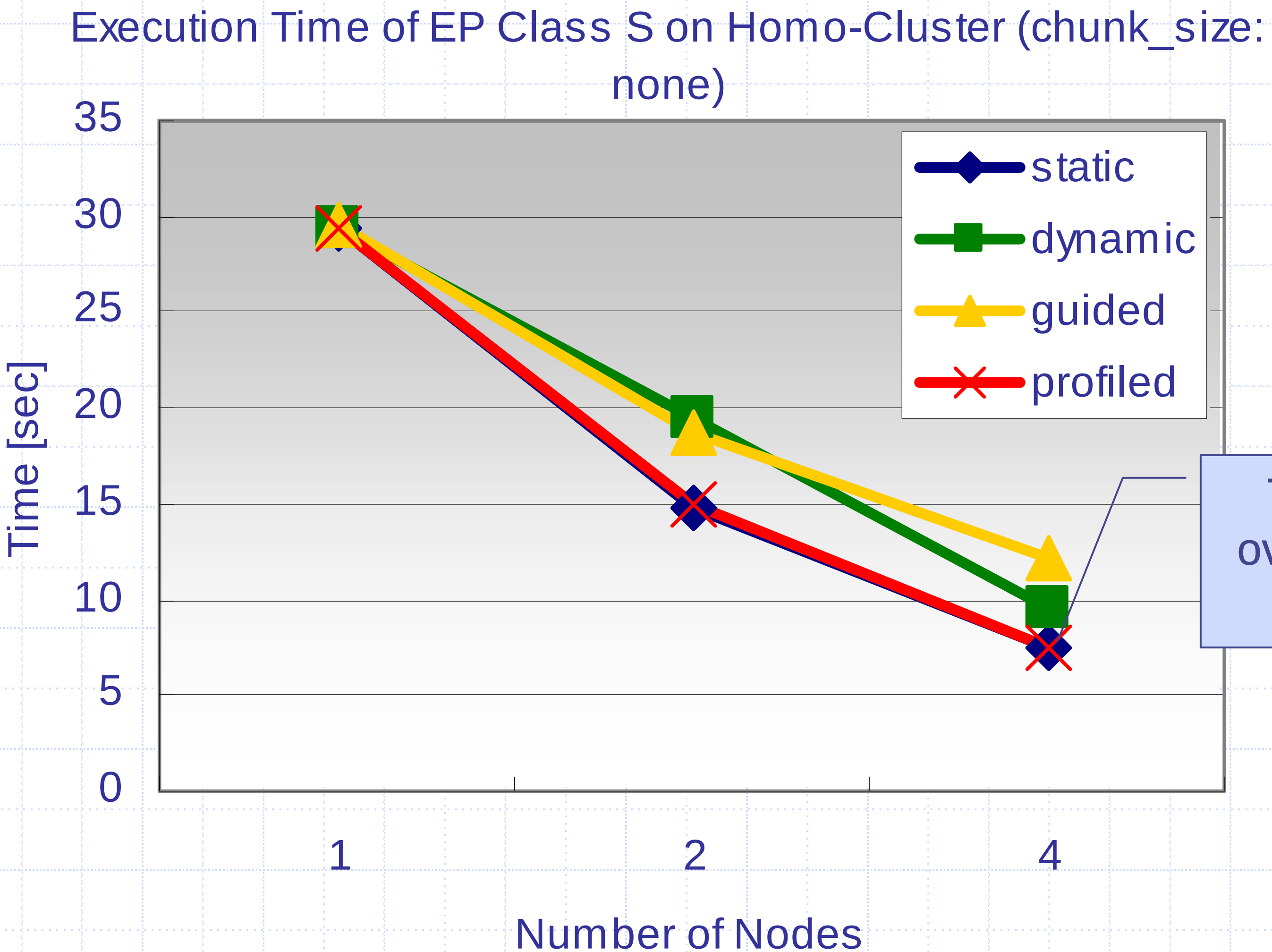
Preliminary Evaluation

- Evaluation points
  - Overhead of profiled scheduling itself on performance homogeneous settings
  - Comparison against static, dynamic and guided scheduling on performance heterogeneous environment
- Benchmark programs
  - NPB2.3 EP (C + OpenMP version made by RWCP)
    - Due to few communications, we can evaluate pure efficiency of profiled scheduling
  - NPB2.3 CG (C + OpenMP version made by RWCP)
    - Data locality has large impact on performance, because there are many accesses to shared arrays
    - We can anticipate that there may be performance drops without some page migration mechanism

Evaluation Environment

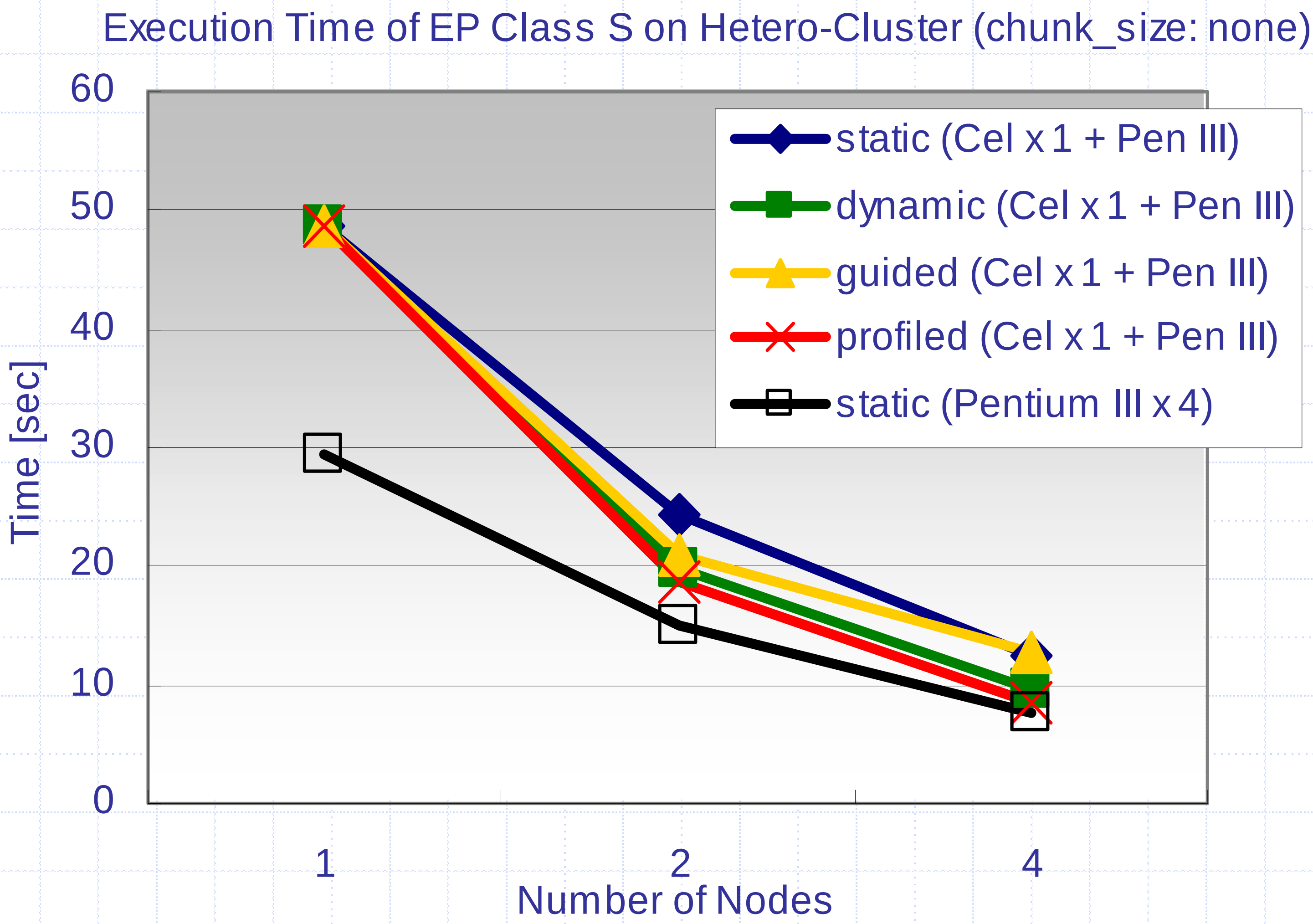
- Performance heterogeneous cluster
  - Pentium III 500MHz node x 6
  - Celeron 300MHz node x 1
  - Other settings are the same
    - Intel 440BX Chipset
    - 512MB Memory
    - Myrinet M2M-PCI32C
- RedHat 7.2 (linux-2.4.18)
- SCore-5.0.1
- gcc-2.96 -O

EP Class S Performance (Homogeneous Settings)

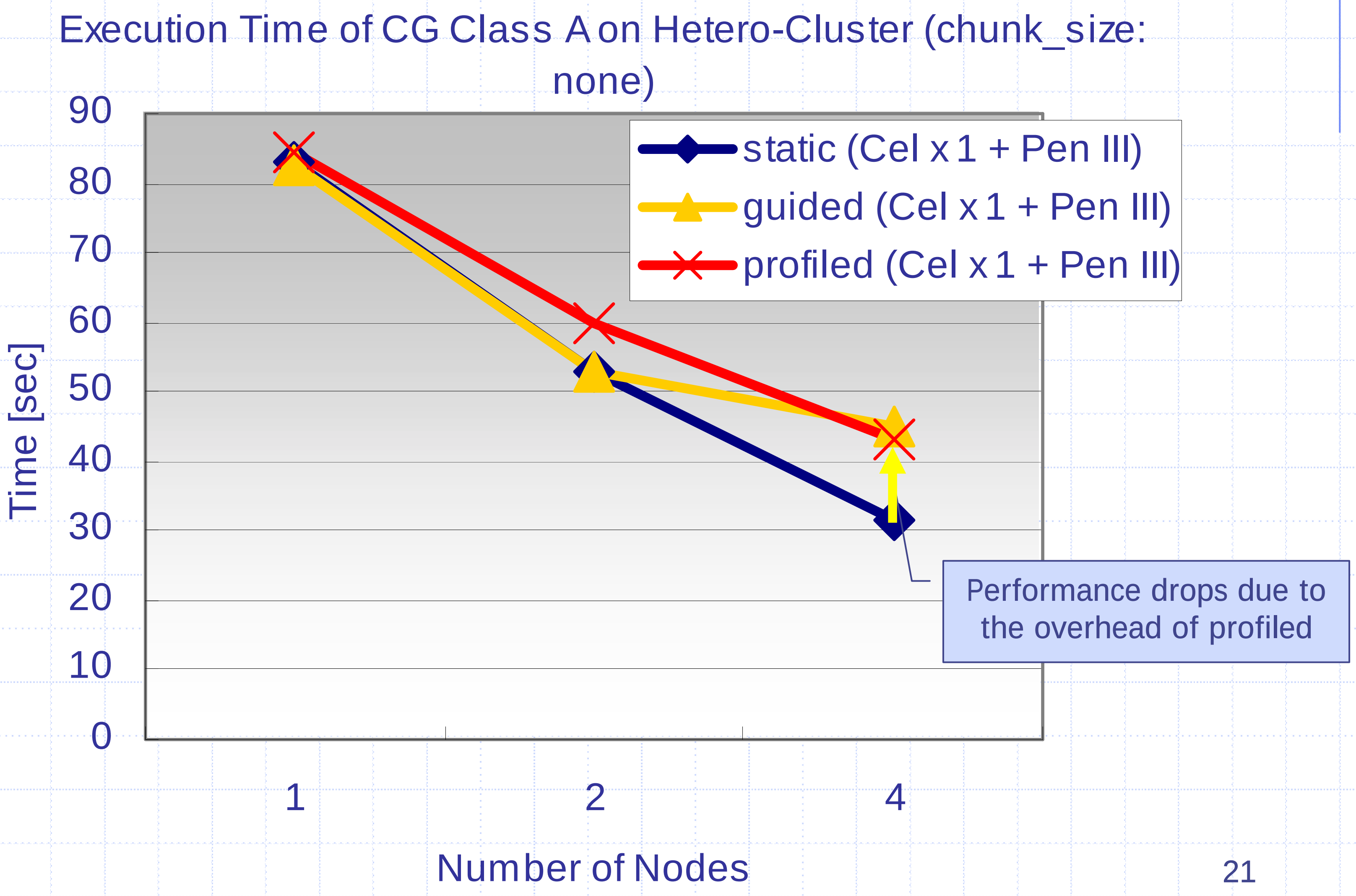


There is no overhead with profiled

EP Class S Performance



CG Class A Performance



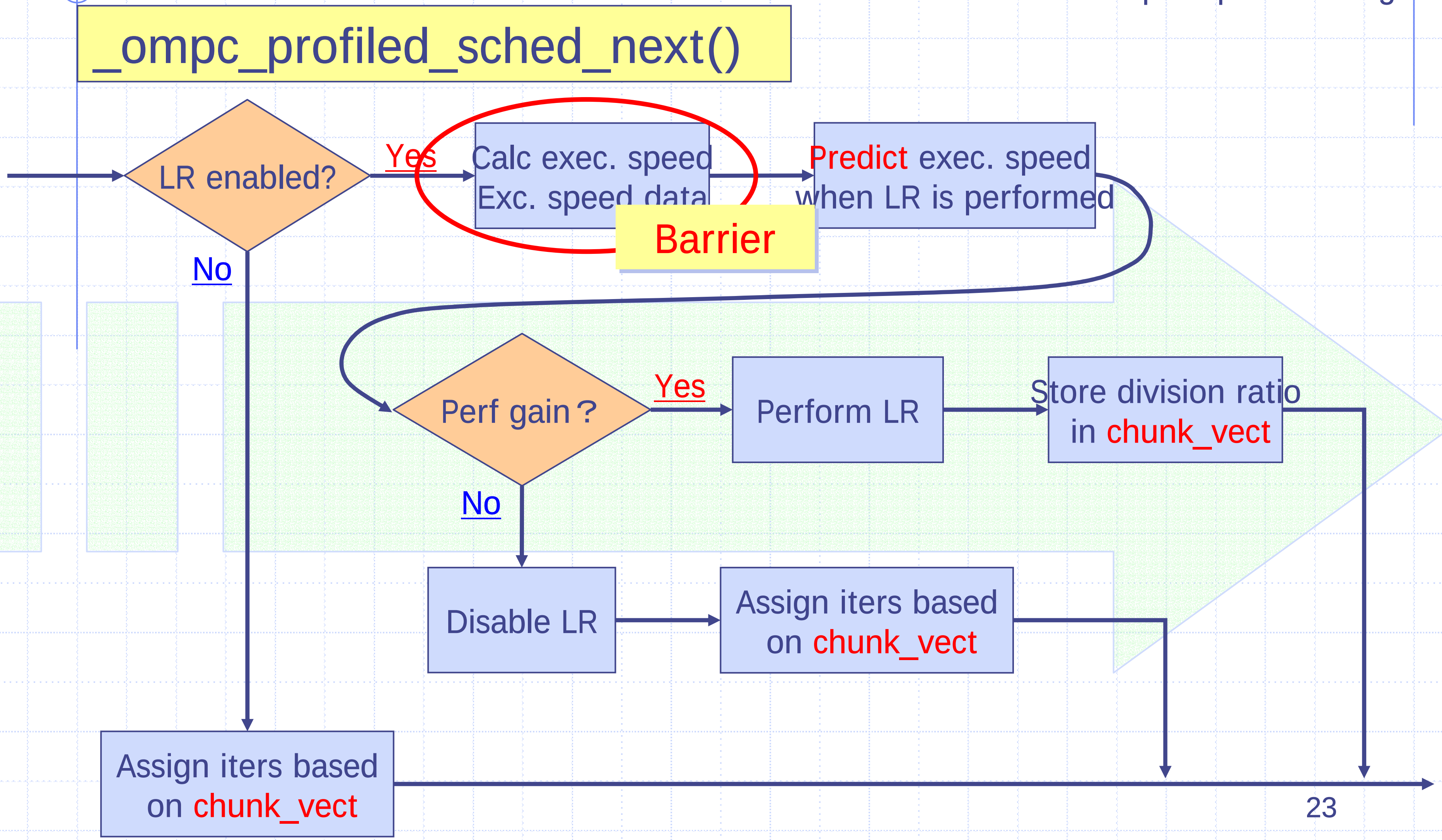
Breakdown of CG Class A

	Static	Profiled
L2 miss ratio	29.6%	31.1%
Page Fault at SCASH Level	16456	27201
Barrier	5088	8006

- More page faults with profiled, because the data access range may change on each iteration
- More barriers with profiled, because it will repeat unnecessary profiling loops (see next figure)

Overview of Loop Re-partitioning Algorithm (again)

LR: loop re-partitioning



Conclusion

- We extended Omni/SCASH to support profiled scheduling for dynamic load balancing
- We made sure that profiled scheduling is more effective than static/dynamic/guided one on hetero-cluster with EP which are not influenced by data placement
- Profiled scheduling reveals its overhead due to changes in data access ranges
- We showed the plan of page migration extension to SCASH

Future Work

- Complete the implementation of page migration
- Integrate loop re-partitioning with page migration
- Evaluate this system with more applications