HANDLING LOAD IMBALANCE IN DISTRIBUTED & SHARED MEMORY

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MOTIVATION
INTEGRATED RTS MODEL
APPLICATIONS
INTRODUCTION
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Dynamic variations - Load imbalance

Persistent & Transient imbalance

Vast amounts of on-node parallelism
Can we leverage multi-core shared memory systems to handle transient and persistent load imbalance while maintaining locality with low overhead?
New integrated run-time system that combines distributed programming model with concurrent tasks
INTEGRATED RTS

Infrequent periodic balancing

Fine-grained work-sharing within the node
TRANSIENT & RESIDUAL IMBALANCE
CHARM++ MODEL

Asynchronous Message-Driven Execution

Over-decomposition

Migratability
OVER-DECOMPOSITION

Decompose work & data units to many more pieces than execution units
OVER-DECOMPOSITION

Encapsulation of data and its computation inherently promotes data locality
MIGRATABILITY

Move work units to another execution unit at run time.
CHARM++ SMP MODEL

Takes advantage of multi-core processors

Launches one thread per core
CHARM++ SMP MODEL

Faster intra-node communication

Smaller memory footprint

Enables work-sharing within a node
INTEGRATED RTS

Combines Charm++ over-decomposition distributed memory model with concurrent tasks
PERSISTENT & TRANSIENT LOAD BALANCE

Node-aware load balancers

Fine-grained work-sharing within the node
LOAD BALANCING

Based on principle of persistence
NODE-AWARE LOAD BALANCING

Hierarchical strategy

Coarsening to reduce memory and communication overhead

Different strategies at different levels
HIERARCHICAL LOAD BALANCER
AUTOMATIC LOAD BALANCING

RTS decides when to do load balancing

RTS decides which load balancer to use at each level
FINE-GRAINED WORK-SHARING

User specified tasks that can be executed on any core within a node

Work-stealing queue

With RTS support incurs lesser overhead

CkLoop - Previous work-sharing construct in Charm++
TASK CREATION

Charm++ task API

OpenMP integration
TASK GENERATION & SCHEDULING

Recursive

Broadcast task message

Only when idle

History
RECURSIVE TASKS

Loop iterations split into half forms a task

Work-stealing queue to share work
All the cores within a node receive broadcast message for a task

Atomically increments a variable to obtain the next chunk
ONLY WHEN IDLE

An atomic counter to determine number of idle cores within a node

Selectively creates tasks depending on that counter

Adaptively control number of tasks generated
HISTORICAL DATA

Historical data on fraction of the tasks executed locally

Use this data to determine number of tasks to be created
Issues in the OpenMP interoperation with Charm++

• Resource contention
  – Oversubscription problem by separate Charm++ and OpenMP thread pool

# of hw cores = 4 < # of threads = 10 → oversubscription
OpenMP integration into Charm++

• Use threads on Charm++ Runtime for OpenMP
  – Works on SMP mode of Charm++

• Each OpenMP task become a Charm++ runtime message
  – OpenMP tasks can be migrated among cores within a node
  – Used for transient load balancing within a node

• Modified GNU OpenMP 4.0, forked from GCC 4.9.3
```c
#pragma omp parallel for
for (i = 0; i < n; i++) {
    
}
```
Issues in naïve OpenMP integration

• Overheads of message creation
  – Too many messages are created
  – OpenMP tasks are created even when there is no idle thread on a node

• Applied some optimizations to solve this overheads
Optimizations to solve the overhead of naïve OpenMP integration

- Use an atomic counter
  - keep track of the number of idle threads within a node

- Use a history vector
  - keep record of how many of the OpenMP tasks have been stolen and executed by the other idle threads

- Combine these two heuristics to determine the number of messages to be created
APPLICATIONS
Application Study

- Applications
  - ChaNGa
    - Charm++, Cosmology Simulation
    - Cosmo25 dataset is used
      (Highly clustered 2 billion particles dark simulation)
  - NAMD
    - Charm++, Molecular Dynamics simulation
    - Energy minimization run using collective variable module
      (270,000 atoms and 200,000 bonds)
  - Kripke
    - MPI, Deterministic Particle Transport proxy application
    - Benefit: multiple MPI ranks per node can each parallelize OMP regions across entire node if imbalanced
    - Described in the next talk on AMPI
Application Study

• Machines used for evaluation
  – ANL Vesta, Bluegene Q
    • 2048 nodes, PowerPC A2 1.6Ghz (16 cores, 64 threads)
  – NCSA Blue Waters, Cray XE/XK hybrid
    • 22,640 nodes for Cray XE
    • AMD interlagos 6276 (16 cores, 32 threads)
Projection of ChaNGa with cosmo25 on Blue Waters, Cray XE6 (128K cores)
Projection of ChaNGa with cosmo25 on Blue Waters, Cray XE6 (128K cores)
ChaNGa with cosmo25 on Blue Waters, Cray XE6
NAMD with colvar module on ANL Vesta, Bluegene Q
NAMD with colvar module on Blue Waters, Cray XE6

The graph shows the time per step for both the original implementation and the OpenMP interop version as the number of cores increases. The blue line represents the original time per step, and the red line represents the OpenMP interop time per step. As the number of cores increases from 128 to 2048, the time per step decreases, with the red line consistently below the blue line, indicating a speedup. At 2048 cores, the speedup is approximately 1.76x.
Summary

• We proposed new parallel constructs and OpenMP integration with Charm++

• Solved load imbalance in intra-node level significantly

• In NAMD and ChaNGa, load imbalance in intra-node level is mitigated significantly

• Even MPI application can benefit from this work with AMPI
THANK YOU!