Automated Load Balancing Invocation based on Application Characteristics

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Outline

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Motivation

- Modern parallel applications on large systems
  - Difficult to program and extract best performance
  - Performance is limited by most overloaded processor
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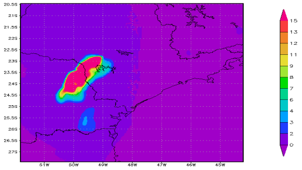
  - Performance is limited by most overloaded processor
  - The chance that one processor is severely overloaded gets higher as no of processors increases
- Load imbalance in parallel applications
  - Leads to drop in system utilization
  - Hampers scalability of the application



Load Balancing Challenges

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- Determining factors
  - Incurred overheads - collection of statistics, execution of strategy to find the new mapping of tasks/work units, moving the tasks
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  - Load balancing strategy selection

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- Adaptive load balancing is needed in a dynamic applications

Meta-Balancer

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- Monitors the application continuously and predicts load behavior
- Identifies when to invoke load balancing for optimal performance based on
  - Predicted load behavior and guiding principles
  - Performance in recent past

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Charm++

- Message-driven parallel programming paradigm based on overdecomposition and migratable objects

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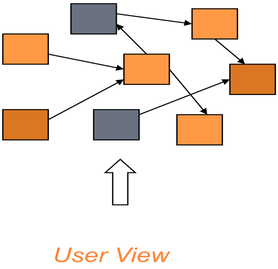

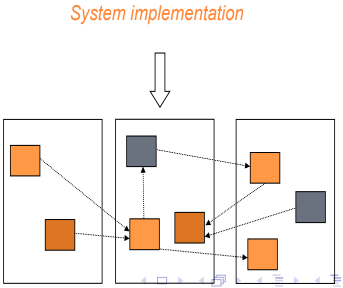

Dynamic Load Balancing Framework in Charm++

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- Based on principle of persistence
- Instruments the application tasks at fine-grained level
- Relies on application user to invoke load balancer and select load balancing strategy
- When the load balancing is invoked
  - Gathers the statistics based on the strategy (centralized or hierarchical)
  - Executes load balancing strategy
  - Migrates objects based on new mapping

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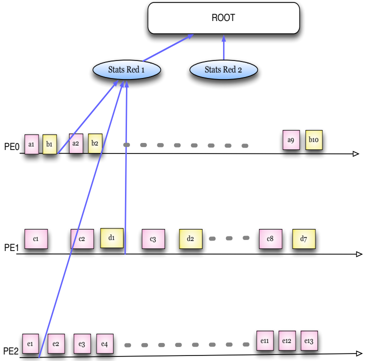
- Implemented on top of Charm++ load balancing framework
- Key responsibilities
  - Monitor the application: collect minimal statistics
  - Identify the iteration to invoke load balancing to optimize performance
  - Form a consensus among participating processors on when to invoke load balancing

Statistics Collection



- Asynchronous collection
  - Overlaps with application execution
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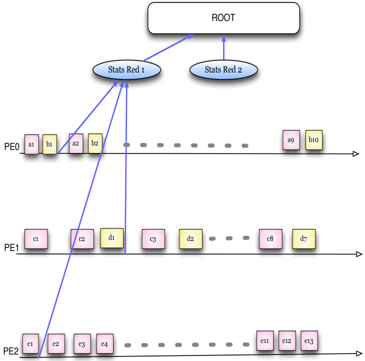

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  - Overlaps with application execution
  - Supported using Charm++'s tree based reduction
  - No barrier for statistics collection
- Minimal statistics
  - Max load
  - Average load
  - Utilization of processors

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- $\zeta > 0$ means load imbalance; leads to performance loss
  - Should load balancing be invoked when $\zeta > 0$?
- Goal - minimize total execution time (application + load balancing overheads)

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$$L_{max} = m * t + l_m$$

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$$\Gamma \quad = \quad \frac{\eta}{\tau} \times \left(\int_0^{\tau} (mt + l_m)dt + \Delta \right) + \int_0^{\eta} (at + l_a)dt$$

τ be the ideal LB period,
η be the total iterations an application executes,
Γ be the total application execution time, and
Δ be the cost associated with load balancing

Model to Predict Ideal LB Period

Equating the differential of total time to zero to minimize it, we obtain

$$\begin{aligned} \frac{d}{d\tau}(\Gamma) &= \eta \times (\frac{m}{2} - \frac{\Delta}{\tau^2}) = 0 \\ \tau &= \sqrt{\frac{2\Delta}{m}} \end{aligned}$$

Model to Predict Ideal LB Period

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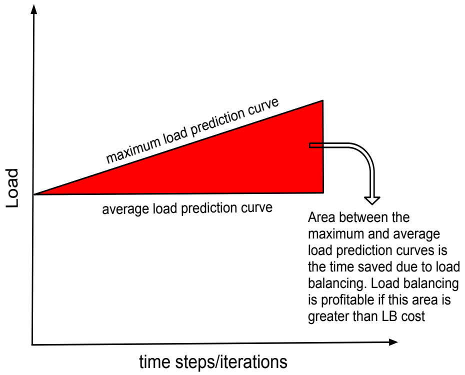
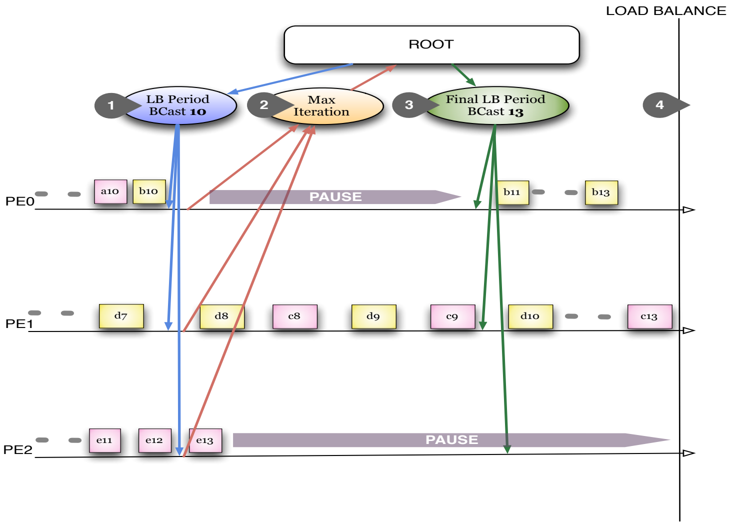


Consensus Mechanism



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- Applications
  - LeanMD: molecular dynamics simulation program
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- Machines used
  - Ranger: SUN constellation cluster at TACC
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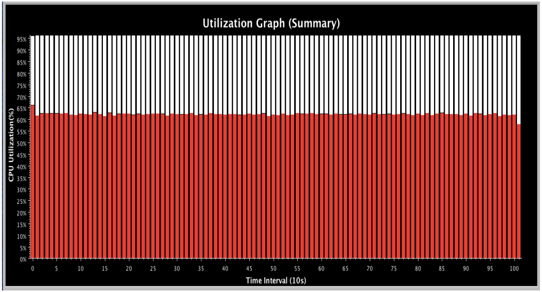
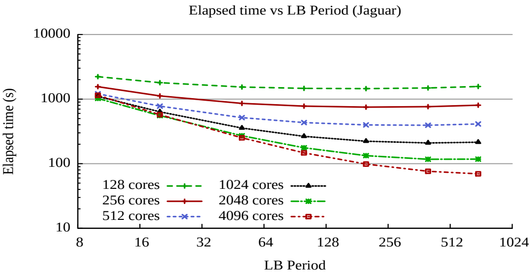
- Three sets of Experiments
  - No Load Balancing
  - Periodic Load Balancing
  - Using Meta-Balancer

LeanMD with No Load Balancing



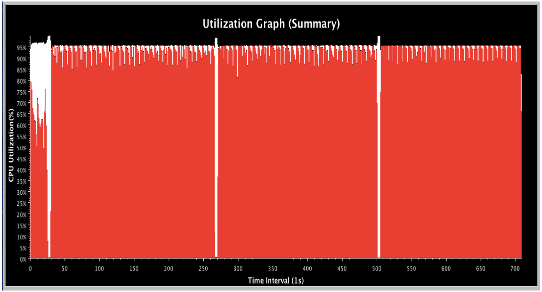
- Overall processor utilization is 65%
- No significant variation in processor loads during the run

LeanMD with Periodic Load Balancing



- Frequent load balancing increases execution time
- Periodic load balancing may not give performance benefit

LeanMD with Meta-Balancer



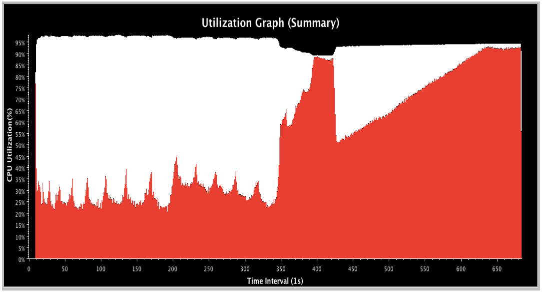
- Invoked load balancer at the beginning
- Thereafter frequency of load balancing is low
- Improved performance by 31% and the overall utilization to 95%

LeanMD - Comparison of Execution Time

Core	No LB (s)	Periodic LB (Period) (s)	Meta-Balancer (s)
128	1945.16	1451.30 (200)	1388.29
256	1005.22	750.11 (200)	695.55
512	516.47	393.30 (400)	355.85
1024	264.15	209.64 (400)	190.52
2048	135.92	116.69 (400)	94.33
4096	70.68	69.6 (700)	57.83

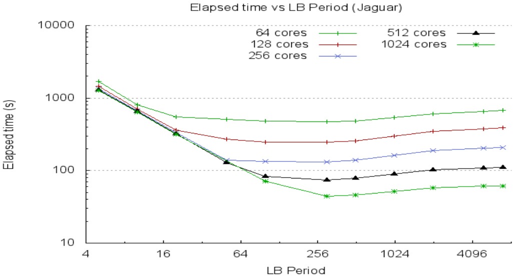
Meta-Balancer outperforms periodic load balancing

Fractography with No Load Balancing



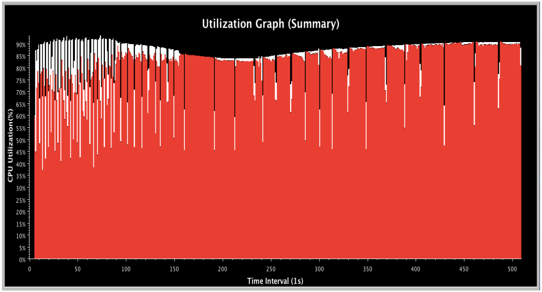
- Large variation in processor utilization
- Low utilization leading to resource wastage

Fractography with Periodic Load Balancing



- Frequent load balancing leads to high overhead and no benefit
- Infrequent load balancing leads to load imbalance and results in no gains

Fractography with Meta-Balancer



- Identifies the need for frequent load balancing in the beginning
- Frequency of load balancing decreases as load becomes balanced
- Increases overall processor utilization and gives gain of 31%

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  - Depends on the application characteristics
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- Meta-Balancer adaptively identifies load balancing period

Conclusion

- Difficult to find the optimum load balancing period
  - Depends on the application characteristics
  - Depends on the machine the application is run on
- Meta-Balancer automates the decision of when to invoke load balancing based on application characteristics
- Meta-Balancer adaptively identifies load balancing period
- Meta-Balancer obtains substantial gains and avoids repetitive experimentation

Future Work

- Extend Meta-Balancer to select load balancing strategy
  - Computation vs Communication strategy
  - Refinement vs Comprehensive strategy
  - Centralized vs Distributed strategy

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  - Computation vs Communication strategy
  - Refinement vs Comprehensive strategy
  - Centralized vs Distributed strategy
- Better models for predicting load

Thank you!