不均一計算環境のための負荷分散法

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1 はじめに

筆者の元々の専門分野は，並列計算機アーキテクチャやマイクロプロセッサ設計である．しかし本学に赴任後はテーマをやや応用側にシフトし，並列処理応用の静的負荷分散方式についても研究を進めてきた．

さて，メディア科学リサーチセンター・情報環境コアでは，情報ネットワークや情報システム環境の研究を行なっている．コアの研究キーワードに“ 分散並列計算 ”が含まれていることから，筆者の専門分野と情報環境コアの関連については自明であろう．以下，本稿では，過去 2 年ほどの研究結果のなかから，情報環境コアの研究活動に関連するテーマを紹介する．

2 Optimizing Process Allocation of Parallel Programs for Heterogeneous Clusters [2]

著者は，並列処理応用の実行時間予測モデルを構築することにより不均一クラスタ上でのプロセス配置を最適化する手法について，数年前から研究を続けてきた．当初の研究 [1] では，HPL (High Performance Linpack) について予測モデルを構築し，最適構成の予測が可能であることを示した．しかし，(1) 検討された応用が HPL だけである，(2) 測定プラットホームが小規模である，(3) 予測誤差が必ずしも小さくない，という問題点が残されていた．

そこで本研究では，測定プラットホームを更新し，4 つの典型的科学技術応用について定量的評価結果を示した．予測モデルを改良した結果，予測誤差も大幅に改善された．クラスタの予測可能性を向上させるための注意点や構築技術についても詳述している．本研究に関する英文論文 [2] のアブストラクトを以下に引用する．

The performance of a conventional parallel application is often degraded by load-imbalance on heterogeneous clusters. Though it is simple to invoke multiple processes on fast PEs to alleviate load-imbalance, the optimal process allocation is not obvious. Kishimoto and Ichikawa presented performance models for HPL (High Performance Linpack), with which the sub-optimal configurations of heterogeneous clusters were actually estimated. Their results on HPL are encouraging, whereas their approach is not yet verified with other applications. This study presents some enhancements of Kishimoto's scheme, which are evaluated with four typical scientific applications: CFD (computational fluid dynamics), FEM (finite element method), HPL (linear algebraic system), and FFT (fast Fourier transform). According to our experiments, our new models (NP-T models) are superior to Kishimoto's models, particularly when non-negative least squares (NNLS) method is used for parameter extraction. The average errors of the derived models were 0.2% for CFD benchmark, 2% for FEM benchmark, 1% for HPL, and 28% for FFT benchmark. This study also emphasizes the importance of predictability in clusters, listing practical examples derived from our work.

3 Constructing Execution-Time Estimation Models from Diverse Processing Elements of Heterogeneous Clusters [3]

2 章に述べた手法では，予測モデルを均一なサブクラスタの実行時間測定結果から構築している．そのため，非常に不均一性の高いヘテロクラスタでは，予測モデルを構築することができない．この欠点を緩和する手法に関して，国際会議論文 [3] のアブストラクトを以下に引用する．

Heterogeneous cluster is a reasonable extension of conventional PC clusters, while it is a difficult target for optimization. Although load imbalance can be alleviated by invoking multiple processes on fast nodes (without modification of source code), the optimal process allocation is not obvious. The preceding studies reported that practical estimation is possible by constructing the execution-time estimation models from homogeneous sub-clusters. In this study, we propose a method to construct the models from diverse processing elements of a heterogeneous cluster, and present some preliminary evaluation results. The derived models were accurate enough to find optimal or sub-optimal allocations, while requiring less nodes for model construction.

4 Estimating the Optimal Configuration of a Heterogeneous Cluster: the Case of NAS Parallel Benchmarks [4]

2 章に述べた研究では，合計 4 つの科学技術応用を用いて最適構成予測の有効性を示した．しかし，更

に多くの応用プログラムにおいても，最適構成予測手法の有効性を示す必要がある．そこで本研究では，NPB (NAS Parallel Benchmarks) の 4 つのプログラムについて，我々の手法を評価した．以下に国際会議論文 [4] のアブストラクトを引用する．

Invoking multiple processes on fast processing elements is a simple way of alleviating load-imbalance in heterogeneous clusters, while the optimal process allocation is not obvious. It is also important to select the optimal subset of PEs, though it is difficult to deter-mine. Ichikawa et al. presented a scheme to estimate the optimal configuration of a heterogeneous cluster, based on the execution-time estimation models of four parallel applications (CFD, FEM, HPL, and FFT). This study examines their scheme with four new appli-cations, which were taken from NAS parallel bench-marks. For CG and LU, the estimation errors are less than 30% in most cases, while the errors remain larger than 100% in some cases of MG and FT. More im-provements are desired for communication-oriented applications such as MG and FT.

5 Estimating the Optimal Configuration of a Multi-Core Cluster: A Preliminary Study [5]

昨今のプロセッサではマルチコア構成が急速に普及しており，科学技術計算においてもマルチコア PC クラスタが主流となりつつある．そこで我々の最適構成予測手法をマルチコアクラスタに適用し，マルチコアクラスタの最適構成が可能か，検討・評価した．

この技術は未完成であり現在も研究中であるが，第一報を国際会議で発表しポジティブな評価を得た．この国際会議論文 [5] のアブストラクトを以下に引用する．

While multi-core processors became crucial elements of high-performance computing, the clusters of multi-core processors are still difficult target for optimization, since the communication time differs significantly in intra-node communication and inter-node communication. It is thus very important to select the optimal configuration of multi-core clusters; i.e., to find the optimal number of processes and to find the optimal allocation of processes to nodes. This study first elucidates the multi-core specific issues by examining the effect of process allocation in a multi-core cluster, using divergent and convergent allocations of four benchmark programs. Then, the estimation of optimal configuration is attempted for divergent and convergent allocations, using execution-time estimation models for single-core clusters. Though the estimation errors were less than 20% in most cases, further improvement is expected by incorporating the enhancements for multi-core systems into estimation models.

6 おわりに

不均一クラスタのための負荷分散法に関しては，本稿で述べたとおり継続的に研究を進めてきた．今後も，さらに改良を加えて，実用的予測システムを構築してゆきたい．具体的には，予測精度の向上と，不均一ネットワークのモデル化，既存モデルとの融合などのテーマが考えられる．

発表論文

[1] Yoshinori Kishimoto, Shuichi Ichikawa: “Optimizing the Configuration of a Heterogeneous Cluster with Multiprocessing and Execution-Time Estimation,” Parallel Computing, Vol. 31, No. 7, pp. 691–710 (2005).

[2] Shuichi Ichikawa, Sho Takahashi, Yuu Kawai: ”Optimizing Process Allocation of Parallel Programs for Heterogeneous Clusters,” Concurrency and Computation: Practice and Experience, Vol. 21, No, 4, pp. 475–507 (2009).

[3] Shuichi Ichikawa, Yuu Kawai: ”Constructing Execution-Time Estimation Models from Diverse Processing Elements of Heterogeneous Clusters,” Proceedings of IEEE TENCON 2008, pp. 1–6 (2008). (CDROM)

[4] Shuichi Ichikawa, Masayoshi Asakura, Yusuke Sakumoto: ”Estimating the Optimal Configuration of a Heterogeneous Cluster: the Case of NAS Parallel Benchmarks,” Proceedings of 8th International Conference on Applications and Principles of Information Science (APIS 2009), pp.241–244 (2009).

[5] Shuichi Ichikawa, Shoichiro Takagi: ”Estimating the Optimal Configuration of a Multi-Core Cluster: A Preliminary Study,” Proceedings of the International Conference on Complex, Intelligent and Software Intensive Systems (CISIS 2009), pp. 1245–1251 (2009).