Time-energy Measurements of Shared-memory Applications on Modern Multicore Systems

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ABSTRACT

In this article, we present the time-energy data collected and analyzed in our research paper entitled "The Time and Energy Efficiency of Modern Multicore Systems". While the full data set and the source code are available on Github, this data-in-brief article includes some samples, describes the experimental setup and explains how to use the data in conjunction with our time-energy models.

1. INTRODUCTION

Motivated by the increasing number of processor cores (CPU cores) integrated in the same die, we extend Amdahl's [4] and Gustafson's [5] speedup laws to determine both the time and energy efficiency of shared-memory applications on multicore systems. In this paper, we describe our measurements methodology and provide data samples used in our research paper entitled "The Time and Energy Efficiency of Modern Multicore Systems" [2]. The full dataset and the source code of our research models are available on Github [3].

The contributions of this article are:

- the experimental methodology used to acquire time-energy measurements on modern multicore systems. These systems include both high-performance and low-power, homogeneous and heterogeneous, and are representative for server, desktop and mobile domains
- a dataset that includes execution time and energy measurements of up to ten shared-memory applications covering multiple domains on a wide range of modern multicore systems
- the source code implementing the models described in our previous works [1, 2] which serve as a starting point for researchers, developers and system designers

In the next section, we present the format of raw and processed data and include some samples. In Section 3, we describe our methodology.

2. DATA

We provide two data sets for each system and application evaluated in our work, (i) measured, or raw, time-energy values and (ii) model output. Measured time-energy data consists of seven columns, as shown in Table 1 for EP execution on Xeon (see next section for the description of the experimental setup). Each row represents the execution of the given application on the target system using a certain number of cores. The columns represent the number of nodes, number of cores per node, the core clock frequency of the cores, the execution time in seconds (s), the energy in Watts-hour (Wh) and Joules (J), respectively, and the average power consumption in Watts (W). The number of nodes is always one because these experiments are run on single-node shared-memory multicore systems. Our models [1,2] are using the following key columns: Cores, Time and Energy.

For heterogeneous systems, such as XU3 and TX2, we provide four measured data sets per application, as exemplified in Tables 2-5 for EP on XU3. The first two data sets represent the execution with OpenMP static scheduling on big and little cores, respectively. The last two data sets represent the execution on all cores using static and dynamic OpenMP execution, respectively.

Table 1. Raw Time-Energy Measurements (EP on Xeon)

Procs	Cores	Freq	Time[s]	Energy[Wh]	Energy[J]	AvgPower[W]
1	1	2.20GHz	384.14	8.46	30456	79.48
1	2	2.20GHz	195.63	4.60	16560	84.93
1	3	2.20GHz	138.33	3.36	12096	88.32
1	4	2.20GHz	106.39	2.71	9756	92.10
1	5	2.20GHz	89.29	2.31	8316	94.73
1	6	2.20GHz	77.76	2.08	7488	97.18
1	7	2.20GHz	69.07	1.87	6732	99.04
1	8	2.20GHz	62.09	1.73	6228	100.73
1	9	2.20GHz	55.23	1.58	5688	103.89
1	10	2.20GHz	49.65	1.46	5256	107.49
1	11	2.20GHz	49.64	1.46	5256	107.85
1	12	2.20GHz	45.94	1.37	4932	109.42
1	13	2.20GHz	42.85	1.28	4608	110.22
1	14	2.20GHz	40.12	1.20	4320	110.81
1	15	2.20GHz	37.48	1.14	4104	112.08
1	16	2.20GHz	35.42	1.10	3960	112.64
1	17	2.20GHz	34.02	1.06	3816	112.98
1	18	2.20GHz	31.58	0.97	3492	113.88
1	19	2.20GHz	29.93	0.92	3312	114.54
1	20	2.20GHz	28.83	0.89	3204	115.21

Table 2. Raw Time-Energy Measurements on Big Cores with Static Scheduling (EP on XU3)

#Procs	Cores	Freq	Time[s]	Energy[Wh]	Energy[J]	AvgPower[W]
1	1	2.00GHz	710.81	0.02	60.12	9.27
1	2	2.00GHz	363.58	0.01	42.12	12.51
1	3	2.00GHz	250.09	0.01	36.00	15.03
1	4	2.00GHz	197.88	0.01	29.52	15.56

Table 3. Raw Time-Energy Measurements on Little Cores with Static Scheduling (EP on XU3)

#Procs	Cores	Freq	Time[s]	Energy[Wh]	Energy[J]	AvgPower[W]
1	1	2.00GHz	1607.79	0.03	99.00	6.65
1	2	2.00GHz	820.67	0.01	53.28	7.10
1	3	2.00GHz	548.60	0.01	37.80	7.51
1	4	2.00GHz	413.19	0.01	29.88	7.89

Table 4. Raw Time-Energy Measurements on All Cores with Static Scheduling (EP on XU3)

#Procs	Cores	Freq	Time[s]	Energy[Wh]	Energy[J]	AvgPower[W]
1	1	2.00GHz	714.61	0.017	61.2	9.24
1	2	2.00GHz	363.75	0.012	43.2	12.45
1	3	2.00GHz	250.87	0.01	36	14.69
1	4	2.00GHz	198.74	0.008	28.8	15.32
1	5	2.00GHz	321.7	0.01	36	10.94
1	6	2.00GHz	273.5	0.008	28.8	11.10
1	7	2.00GHz	235.14	0.007	25.2	11.35
1	8	2.00GHz	206.75	0.007	25.2	11.67

Table 5. Raw Time-Energy Measurements on All Cores with Dynamic Scheduling (EP on XU3)

#Procs	Cores	Freq	Time[s]	Energy[Wh]	Energy[J]	AvgPower[W]
1	1	2.00GHz	709.82	0.017	61.2	9.25
1	2	2.00GHz	364.94	0.012	43.2	12.47
1	3	2.00GHz	248.67	0.01	36	15.11
1	4	2.00GHz	198.96	0.008	28.8	15.31
1	5	2.00GHz	179.27	0.007	25.2	15.32
1	6	2.00GHz	162.8	0.007	25.2	15.41
1	7	2.00GHz	149.53	0.006	21.6	15.54
1	8	2.00GHz	137.73	0.006	21.6	15.67

Model output data consists of nine columns, as shown in Table 6 for EP running on Xeon when Amdahl's law [4] for speedup is used. The first column represents the number of cores used for execution, while the other eight columns represent measured and predicted speedup, energy savings, execution time and energy, respectively. In addition, the source code implementing the model reports the sequential fraction and the RMSD between measured and predicted values across all core counts.

The speedup values for EP running on Xeon are plotted in Figure 1 and summarized in Table 6. The predicted values are computed using Amdahl's law [4]. On the other hand, Figure 2 plots the same measurements, while the predicted speedup is determined using Gustafson's law [5]. The results for other systems are presented in our research papers [1,2].

Table 6. Model Output Data (EP on Xeon, Amdahl's Law)

Cores	Measured Speedup	Predicted Speedup	Measured Energy Savings	Predicted Energy Savings	Measured Time	Predicted Time	Measured Energy	Predicted Energy
1	1	1	0	0	384.1	384.1	30530	24233.8
2	1.96	1.94	0.456	0.464	195.6	198	16615.1	13024.5
3	2.78	2.82	0.6	0.619	138.3	136	12217.2	9288
4	3.61	3.66	0.679	0.696	106.4	105	9798.4	7419.8
5	4.3	4.45	0.723	0.743	89.3	86.4	8458.3	6298.9
6	4.94	5.19	0.752	0.773	77.8	73.9	7556.8	5551.6
7	5.56	5.9	0.776	0.796	69.1	65.1	6841	5017.8
8	6.19	6.57	0.795	0.812	62.1	58.4	6254.2	4617.5
9	6.96	7.21	0.812	0.825	55.2	53.3	5737.6	4306.1
10	7.74	7.82	0.825	0.835	49.6	49.1	5336.9	4057
11	7.74	8.4	0.825	0.844	49.6	45.7	5353.9	3853.2
12	8.36	8.95	0.835	0.851	45.9	42.9	5026.8	3683.4
13	8.96	9.47	0.845	0.857	42.9	40.5	4723	3539.7
14	9.57	9.98	0.854	0.862	40.1	38.5	4445.6	3416.5
15	10.25	10.46	0.862	0.866	37.5	36.7	4200.6	3309.7
16	10.85	10.92	0.869	0.87	35.4	35.2	3989.6	3216.3
17	11.29	11.36	0.874	0.874	34	33.8	3843.4	3133.9
18	12.16	11.79	0.882	0.877	31.6	32.6	3596.3	3060.6
19	12.83	12.19	0.888	0.879	29.9	31.5	3428.1	2995.1
20	13.32	12.59	0.891	0.882	28.8	30.5	3321.6	2936.1

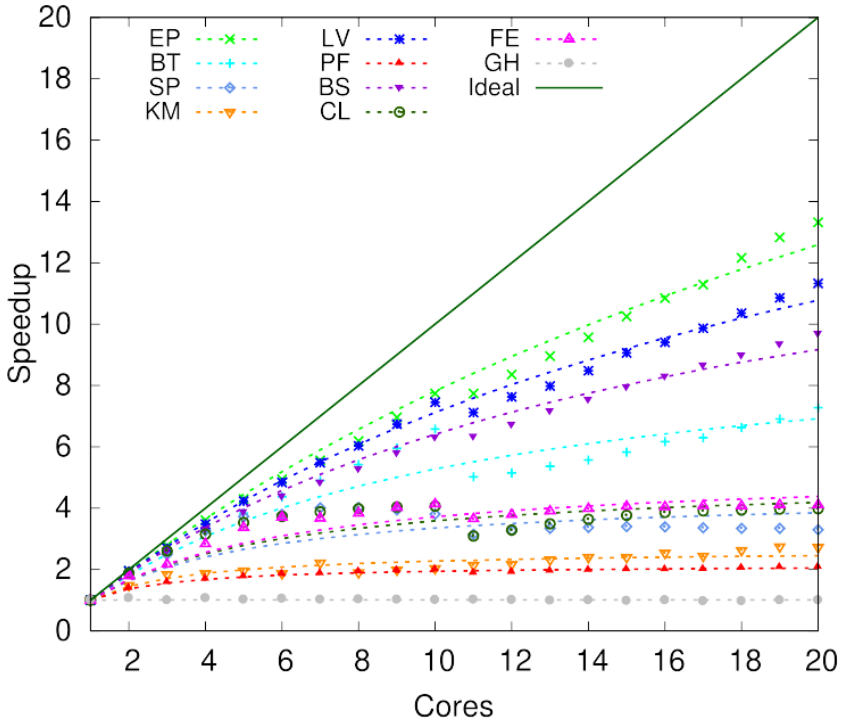

Figure 1. Amdahl Speedup on Xeon

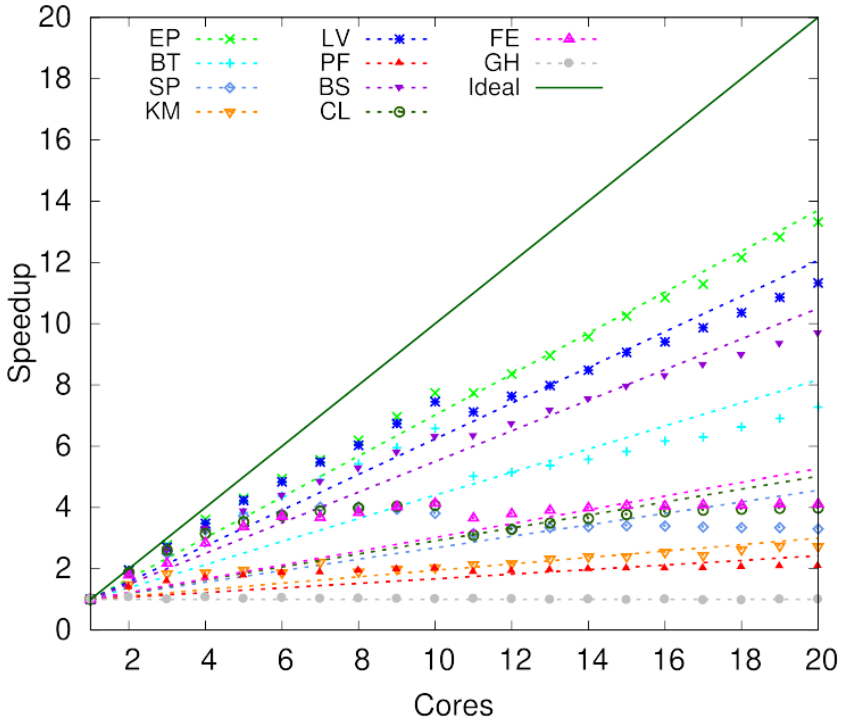

Figure 2. Gustafson Speedup on Xeon

Table 7. Systems

System	CPU	Cores	Frequency [GHz]	Memory [GB]
AMD	AMD Opteron K10	48	2.10	64 (NUMA)
ARM	Cavium ThunderX (64-bit ARM)	48	2.00	128 (UMA)
Xeon	Intel Xeon E5-2630 v4	10 (20 HT)	2.20	64 (UMA)
i7	Intel Core i7-6700	4 (8 HT)	3.40	16
Pi3	ARM Cortex-A53	4	1.20	1
XU3	ARM big.LITTLE HMP (ARM Cortex-A15 + ARM Cortex-A7)	8 (4+4)	2.00	2
TX2	HMP (Denver + ARM Cortex-A57)	6 (2+4)	2.04	8

Table 8. Applications

Application	Benchmark Suite	Input Size	OpenMP Scheduling
EP (Embarrassingly Parallel)	NPB [6]	Class C (Random-number pairs: 2^{32})	default
BT (Block Tri-diagonal Solver)	NPB [6]	Class C (Grid size: 162 x 162 x 162, Iterations: 200)	static
SP (Scalar Penta-Diagonal solver)	NPB [6]	Class C (Grid size: 162 x 162 x 162, Iterations: 400)	static
LV (LavaMD)	Rodinia [7]	Boxes1d: 24	default
KM (Kmeans)	Rodinia [7]	n=1,000,000 m=34 k=5	static
PF (Pathfinder)	Rodinia [7]	Width (rows): 900000, number of steps (columns): 500	default
BS (BlackScholes)	Parsec [8]	4,000,000 options	default
CL (CloverLeaf)	Mantevo [9]	Grid size 1000, end_time=30.0	default
FE (miniFE)	Mantevo [9]	nx=150	default
GH (miniGhost)	Mantevo [9]	nx=100, num_tsteps=1,000	default

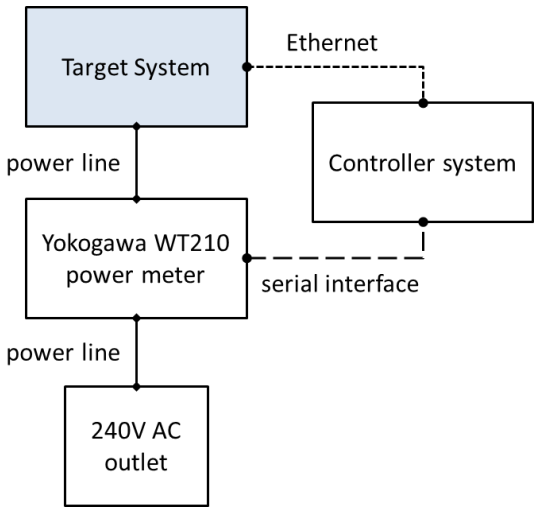

Figure 3. Experimental Setup

3. EXPERIMENTAL DESIGN, MATERIALS AND METHODS

The experimental setup used in our work is depicted in Figure 3. To collect power and energy, we use a Yokogawa WT201 power meter connected to the 240V AC power line. A controller system is used to start the experiments and collect execution and power data. The power and energy samples are collected once per second.

Table 7 summarizes the characteristics of the target systems used in our work. This table should serve as a reference for users that apply our models [1,2], or any other time-energy models for shared-memory multicore systems. The systems are selected to represent both homogeneous and heterogeneous systems, both brawny and wimpy nodes, as well as server, desktop and mobile domains. Hence, AMD and Xeon represent homogeneous brawny servers, while ARM is an emerging homogeneous wimpy server. i7 represents homogeneous brawny desktops and Pi3 represents homogeneous wimpy mobile devices. Both systems have low core counts, which is typical for desktop and mobile domains. Lastly, XU3 and TX2 represent heterogeneous systems, both being wimpy mobile nodes. To the best of our knowledge, there is no heterogeneous multicore server system available in the market.

Table 8 summarizes the shared-memory applications used in our work. These applications are selected from well-known benchmarking suites, such as NPB [6], Rodinia [7], Parsec [8] and Mantevo [9]. These applications cover a wide range of sequential fractions, from less than 1% to more than 99%. In addition to the first seven applications presented in our previous work [1,2], we provide data for CloverLeaf (CL), miniFE (FE) and miniGhost (GH) benchmarks from Mantevo suite [9], running on Xeon, i7 and Pi3.

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