REDUCING ENERGY CONSUMPTION IN PROGRAMS USING COHESION TECHNIQUE

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Abstract—**The objective of this work is to reduce energy consumption of source programs written in C. The underlying technique employs code transformation which focuses on cohesion. Four classes of transformations will be considered: function, loop optimization, control structure, and operator. Code transformation is evaluated by effectiveness, efficiency, space complexity, number of instructions executed, number of pages, size of memory page allocated, and energy consumption. The results suggest that different cohesion level will affect the energy consumption. Moreover, different types of source code yield different energy consumptions based on cohesion measures.**

Keywords- Cohesion, energy consumption, code transformation.

I. INTRODUCTION

Global warming is the biggest and most serious problem faced by us in this century. Climate change is happening and its effects are real. If we do not attempt to stop global warming, it will be too late to save our planet.

One of the culprits that attributes to the above problem is energy consumed by the use of computerization. The underlying technology rests heavily on hardware and software. The proliferation of software development, especially the high ability of a computer program to assist a user in various forms of communications such as chat, e-mail, WWW, and the Internet, etc. However, these programs still exhibit high power consumption owing to a number of short falls, ranging from poor program design, inefficient algorithms, to bad code. One research area to solve the above problems focuses on source code transformation. The inherent difficulty lies in code comprehension and complexity which render the transformation process hard to reduce energy consumption and maintenance.

The objective of this research aims to reduce energy consumption of computer programs. Our approach exploits program related issues such as memory optimization, instruction scheduling and execution, and code rearrangement, etc. We envision that the impacts of source code transformations [1] on software and energy consumption [2] will be a worthwhile undertaking.

The primary principle of our approach to source code transformation deals with design. Cohesion is a measure of how various program components, namely, input/output, variables and their related structure, are strongly-related and focused on the various responsibilities of a program module. The higher the cohesion level, the tighter the components are knitted. In a highly-cohesive system, code readability and the likelihood of reuse is increased, while complexity is kept manageable. Such advantages benefit easy maintenance, code reuse, and most important of all, less energy consumption by the program. When source code is transformed by resorting to higher cohesion, complexity, number of instructions executed, number of pages allocated, and size of memory pages allocated are lower. In this work, we employ SimpleScalar Simulator and Wattch Simulator to measure program energy consumption.

The rest of the paper is organized as follows. Section 2 briefly describes what cohesion is. Section 3 elucidates on Power Simulator tools. The proposed method is described in Section 4 and the experimental results are in Section 5. Section 6 concludes the paper with some final thoughts.

II. COHESION

Cohesion [3] is a measure of how strongly-related is the functionality expressed by the source code of a software module. Methods of measuring cohesion vary from qualitative measures classifying the source text being analyzed to quantitative measures which examine textual characteristics of the source code to arrive at a numerical cohesion score. Cohesion is an ordinal type of measurement and is usually expressed as "high cohesion" or "low cohesion." Modules with high cohesion tend to be preferable because high cohesion is associated with several desirable traits of software including robustness, reliability, reusability, and understandability whereas low cohesion is associated with undesirable traits such as being difficult to maintain, difficult to test, difficult to reuse, and even difficult to understand.

High cohesion [4, 5] emphasizes on how a single module is responsible to the underlying functionality. As applied to C code, if a module that serves the given function tends to be similar in many aspects, the function is said to have high cohesion. In a highly cohesive programming system, high cohesion also attributes to code readability and the likelihood of reuse, while complexity is kept

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manageable. Nevertheless, some disadvantages of low cohesion persist.

- Increased difficulty in understanding the program modules.
- Increased difficulty in maintaining a system, because logical changes in the domain affect multiple modules, and because changes in one module require changes in related modules.
- Increased difficulty in reusing a module because most applications won't need the random set of operations provided by a module.

The design level cohesion measures [6, 7, 8], in order of the worst to the best type, are as follows:

A. Coincidental cohesion (worst)

Two outputs of a module have neither dependence relationship with each other, nor dependence on a common input.

B. Conditional cohesion

Two outputs are flag-control dependent on a common input.

C. Iterative cohesion

Two outputs are loop-control dependent on a common input.

D. Communicational cohesion

Two outputs are dependent on a common input. An input is used to compute both outputs, but as neither a condition flag to select one of two outputs nor a loop invariant to compute both outputs.

E. Sequential cohesion

One output is dependent on the other output.

F. functional cohesion (best)

There is only one output in a module.

III. Power simulators

We will explain the two major components of the simulator, namely, SimpleScalar and Wattch below.

A. SimpleScalar

SimpleScalar [9, 10] is a virtual CPU evaluation tool in cycle level on Linux based platform. 'Virtual' means it does not evaluate the actual processor conducts, but emulates a specific processor by C code. SimpleScalar compiles a given piece of C code with emulated CPU and evaluates the performance by analyzing program execute time. The tool set includes a machine definition infrastructure that permits most architectural details to be separated from simulator implementations. All of the simulators distributed with the current release of SimpleScalar can run programs from the above instruction sets. Complex instruction set emulation can be implemented with or without microcode, making the SimpleScalar tools particularly useful for modeling CISC instruction sets.

SimpleScalar is a cycle-accurate architectural level processor simulator. It is distributed free-of-charge to academic non-commercial users, with all source code, making it possible to relatively easily extend the simulator. Ever since SimpleScalar was released, it has become a popular toolset as it included several simulators ranging from a fast functional simulator to a detailed, dynamically scheduled processor model that supported non-blocking caches, speculative execution and state-of-the-art branch prediction. SimpleScalar cannot simulate a whole system, i.e., it can only simulate applications, and does not produce power consumption of the whole system as a result of the simulation.

Some inclusion of SimpleScalar power analysis tools such as Simpower and Wattch are furnished in the form of plugin software. It models physical power comsumption using only numerical expression to measure the gap between actual power consumption and the calculated one. In this research, we use SimpleScalar tool to generate object code.

B. Wattch

Wattch [11, 12] is a simulator that estimates processor power consumption at the architectural level, developed at Princeton University, and is one of the simulators that are based on SimpleScalar. SimpleScalar is used as the cycle level performance simulator that keeps track of which units are accessed per cycle and records the total energy consumed for an application. Wattch uses a modified version of SimpleScalar's sim-outorder, which is extended with an additional number of pipeline stages so that it will be more in line with current microprocessors. Sim-outorder of wattch simulator reports detail on power usage in watts.

IV. Research Methodology

The proposed methodology employs code transformations [13] to reduce the energy consumption at program level. The original C source code is firstly compiled by gcc [14]. The compiled code is then simulated using SimpleScalar and Wattch.

The next step applies code transformation to the same C source code and, following the same previous steps, the simulation results, energy, and power consumption are collected. Finally, the processor energy and the system energy are compared to identify the effectiveness of the transformation under analysis. The flow of this code transformation analysis is illustrated in Figure 1

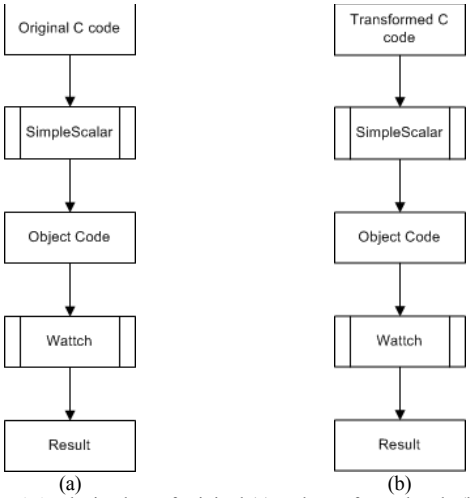

Fig. 1 Analysis Flow of original (a) and transformed code (b).

The simulation is performed using a desktop PC having the following specifications: OS Ubuntu 10.4, CPU Intel Core 2 Duo Processor 2 GHz, 4 GB memory.

The transformation methods [15, 16] have been partitioned in four classes, each focusing on a specific code aspect:

A. Loop Transformation

B. Data Structure Transformation

C. Subroutine Transformation

D. Control Structure Transformation

A. Loop Transformations

This class includes transformations modifying either the loop body or the control structure of the loop. The proposed transformation produces positive effects in term of reduction of the number of Instruction Cache (I-cache) and Data Cache (D-cache) misses.

The basic idea is to reduce the size of the loop body in order to decrease the number of the I-cache (Instruction cache) misses. In particular, the transformed codes are distributed in disjoint loops to enable the storing of a complete loop in the cache, preventing to access the upper memory levels.

Loop Transformation is effective with I-cache when a loop body is larger than the cache or than a given number of cache blocks and/or the cache is unified.

D-cache could probably occur when the original loop presents expressions with non-interacting arrays so that different arrays can be distributed on disjoined loop bodies.

B. Data Structure Transformation

This type of transformation either modifies the data structure included in the source code or introduces new data structure or modifies the access mode and the access paths. This transformation aims to maximize the use of register to reduce memory and cache accesses.

Array Declaration Sorting is to modify the local array declaration ordering so that the arrays more frequently accessed are placed on top of the stack.

Array Scope Modification converts local arrays into global arrays to store them within data memory rather than on the stack.

C. Subroutine Transformation

This class of transformations includes the set of source code manipulations operating at subroutine level, typically not considered by compilers, analyzing whether or not it is convenient to modify the subroutine interface.

Compilers usually produce object code by queueing the subroutines depending on the source code structure. Subroutine Queueing Reordering sorts the subroutine declarations according to the subroutine call sequence in order to reduce the I-cache misses.

Substitution of a variable passed as an address with a local variable replaces a routine argument passed as an address with a local copy of a variable. This transformation drives the compiler to use registers, minimizing the energy necessary to access such data.

D. Control Structure Transformation

This class gathers source code transformations optimizing either specific operations or control structures.

Conditional Expression Reordering analyzes a complex conditional expression by rearranging the sub-expressions set in order to save energy by exploiting implicit shortcuts operations. The proposed transformation reassembles the sub-expressions by following two sub-conditions being reordered, placing the sub-condition whose probability to be true is higher.

Function Call Preprocessing associates with a specific function a proper set of macros that will substitute a function call with either an equivalent but low energy function call or a specific result. The transformation skips a function call, or reduces its impact, when its actual parameters allow to directly identifying either the returned value or another equivalent function.

V. EXPERIMENTAL RESULTS

Two samples C source code were taken from [4] for the experiment that served as a standard benchmark. The results of the simulation are collections of the following factors: Clock Cycle, No. of Instructions Executed, Avg. Clock Power, Avg. Total Power, I-Cache Miss, and D-Cache Miss.

Clock Cycle refers to the total number of the processor cycle of the current simulation.

No. of Instructions Executed refers to the number of processor instructions being executed.

Avg. Clock Power refers to the average power in milli-watt (mW.) that is consumed by the processor.

Avg. Total Power refers to the average power in milli-watt (mW.) of overall process.

The Instruction Cache Miss (I-Cache Miss) refers to a cache read miss from an instruction cache.

The Data Cache Miss (D-Cache Miss) refers to a cache read miss from a data cache.

Table I shows the original C code (having conditional cohesion) in comparison with the transformed C code (having functional cohesion).

TABLE I. ORIGINAL VS TRANSFORMED CODE LISTING 1

Original C code	Transformed C code

void main()
{
int n1 = 100;
int n2 = 200;
int flag = 1;
int arr1[100];
int arr2[200];
int sum1;
int sum2;
 	
Sum1_or_Sum2(n1, n2, flag, arr1, arr2, &sum1, &sum2);
}
void Sum1_or_Sum2(
int n1, n2;
int flag,
int arr1[], int arr2[],
int *sum1, int *sum2)
{
int i;
 	
*sum1 = 0;
*sum2 = 0;
if (flag == 1)
for (i = 0; i < n1; i++)
*sum1 = *sum1 + arr1[i];
else
for (i = 0; i < n2; i++)
*sum2 = *sum2 + arr2[i];
}
	void main()
	{
	int n1 = 100;
	int n2 = 200;
	int flag = 1;
	int arr1[100];
	int arr2[200];
	int sum1;
	int sum2;
	
	if (flag == 1)
	Sum(n1, arr1, &sum1);
	else
	Sum(n2, arr2, &sum2);
	}
	
	void Sum(
	int n,
	int arr[],
	int *sum)
	{
	int i;
	
	*sum = 0;
	for (i = 0; i < n; i++)
	*sum = *sum + arr[i];
	}

Table II summarizes the simulation statistics based on simulation run of code listing 1.

TABLE II. RESULTS OF SIMULATION OF CODE LISTING 1

Parameter	Original	Transformed	%
Clock Cycle	11,034.00	10,878.00	-1.41
No. of Instructions Executed	8368	8354	-0.17
Avg. Clock Power (mW)	28.8	28.4	-1.39
Avg. Total Power (mW)	79.6	78.5	-1.38
I-Cache Miss	335.00	333.00	-0.60
D-Cache Miss	436.00	436.00	-0.00

Table III shows the original C code (having communicational cohesion) in comparison with the transformed C code (having functional cohesion).

Table IV summarizes the simulation statistics based on simulation run of code listing 2.

TABLE III. ORIGINAL VS TRANSFORMED CODE LISTING 2

Original C code	Transformed C code

void main()
{
int n = 100;
int arr[100];
int sum;
int prod;
float avg;
 	
Sum_and_Prod(n, arr, &sum, &prod, &avg);
}
 	
void Sum_and_Prod(
int n,
int arr[],
int *sum,
int *prod,
float *avg)
{
int i;
 	
*sum = 0;
*prod = 1;
for (i = 0; i < n; i++)
{
*sum = *sum + arr[i];
*prod = *prod * arr[i];
}
*avg = *sum / n;
}
	void main()
	{
	int n = 100;
	int arr[100];
	int sum;
	int prod;
	float avg;
	
	sum = Sum(n, arr);
	prod = Prod(n, arr);
	avg = sum / n;
	}
	
	void Sum(int n, int arr[ ])
	{
	int i;
	int sum = 0;
	
	sum = 0;
	for (i = 0; i < n; i++)
	{
	sum = sum + arr[i];
	}
	return sum;
	}
	
	void Prod(int n, int arr[])
	{
	int i;
	int prod;
	
	prod = 1;
	for (i = 0; i < n; i++)
	{
	prod = prod * arr[i];
	}
	return prod;
	}

TABLE IV. RESULTS OF SIMULATION OF CODE LISTING 2

Parameter	Original	Transformed	%
Clock Cycle	11,762.00	11,589.00	-1.47
No. of Instructions Executed	6690	6782	+1.38
Avg. Clock Power (mW)	30.7	30.5	-0.65
Avg. Total Power (mW)	84.9	84.3	-0.71
I-Cache Miss	343.00	339.00	-1.17
D-Cache Miss	426.00	405.00	-4.93

Other results of coincidental, iterative, and sequential cohesion, in comparison with functional cohesion yield similar outcomes.

VI. CONCLUSION

In this paper, we propose a simple technique to reduce energy consumption of a computer program using design cohesion measure. This method is to transform a given piece of C code to increase tighter cohesion level. Both samples source code were simulated on the designated simulation

tool environment. The results show that the original source code consumes more power than the transformed code. This is because we can reduce both I-cache and D-cache misses, clock cycle, and power consumed, with an exception of increase in number of instructions executed in code listing 2. Although we were able to reduce the energy consumption upon improvement with cohesion, the amount of reduced energy was not significantly noticeable. However, the proposed approach exhibited promising opportunities in larger programs. The higher the level of cohesion attained, the more power is conserved by a program. As such, good design level code translates into less energy consumption by subsequent programming applications.

The windfall benefits from the proposed code transformation technique are program readability, better design, lower complexity, and more code reuse.

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