Effect of RAM Amount on the Thermal Behavior of CPU Operating under a Heavy Computational Load

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Abstract

The purpose of this research was to investigate the effects of different RAM amount and fan failure on bulk CPU temperature rises while operating under a heavy computational load. Two sets of experiments, each with varying amounts of RAM were carried out under CPU cooling fan-on and fan-off conditions. A personal computer with an Intel Pentium III CPU was used to conduct the experiments. The computational load was the multiplication of two dimensional matrices (3100 by 3100) containing double precision numbers. To monitor temperature rises, sensitive thermocouples were installed on CPU Heat-sink, the RAM module, and the hard disk.

This paper demonstrates that CPU temperature increases as more RAM becomes available to perform the computation. The authors hypothesize that the increase in CPU temperature is correlated to full CPU utilization to carry out a heavy computational load.

Introduction

Over the past several years, tremendous advances have taken place in the design and performance of personal computers. CPUs having faster processing speed and smaller dimensions are being routinely manufactured for today's PCs. For example, a high end Pentium 4 (P4) CPU for desktop PCs has typical processing capability and speed up to 1,500 MIPS and 2.4 GHz, respectively [1]. Typical P4 CPU dimensions are 35 by 35 mm [1].

In addition to having a fast processor, the performance of a PC is further improved by adding extra memory in the form of RAM. For Pentium processors, RAM comes in Dual Inline Memory Modules (DIMMs) which efficiently provides 64-bit data paths to CPU. This is especially important for the fast execution of applications that use 64-bit data variables.

For applications that need more memory than provided by the original factory installed memory, additional RAM should be installed. It is also possible to use the hard disk as a virtual memory when the application needs more memory than the available physical memory. In such cases, however, the data access speed will be substantially lower than that achieved using RAM. For example, the data access time using virtual memory could be as high as 160,000 times more than that using RAM [2]. In utilizing virtual memory, the CPU needs to page the data to/from a swap file in the hard disk designated for virtual memory. This routine leads to a slowed-down processing of the application. In other words, the CPU utilization for application processing is not one hundred percent.

It is well known that increasing memory improves the processing speed. However, its effect on CPU temperature has not been investigated, particularly under a heavy computational load where a CPU cooling fan failure could occur. This is obviously important, since excessive temperature rises in a CPU of a computer may cause freeze-ups and, in some cases, CPU failures. For this reason, it is important to identify all possible factors that could lead to overheating in CPUs. It should be noted that the maximum allowable current temperature for Pentium CPUs is 85 °C [1, 2]. This paper explores CPU temperature rises in a Pentium III machine with different memory amounts under cooling fan on and off conditions.

Experiment

Set-Up:

The experiments under this research were carried out on a Pentium III PC (Premio) with 128 MB of factory installed RAM and hard disk space of 10 GB. The operating system on this computer was Windows 2000.

Temperature measurements were made using self-adhesive fast response T-type thermocouples with ±1°C accuracy installed on the CPU heat sink, memory module and hard disk (see Figure 1). A fourth thermocouple was used to measure the ambient room temperature. Figure 2 shows the schematic diagram of the experimental set up. As seen in the figure, the thermocouples are connected to an E-Series National Instrument Data Acquisition (DAQ) board through a terminal box (SCB 68). A LabVIEW [3] program was used to monitor and record temperature measurements every minute.

Computational Load:

A program written in Fortran language which performed computationally intensive two-dimensional matrix multiplication calculations of double precision (64-bit) numbers was used as the computational load. The program defined three matrices of double precision data type each with dimensions of 3100 by 3100. This corresponds to 230 MB of memory requirement. In addition to arithmetic operations, the program also contained logical operations in form of IF-THEN clauses. Therefore, this computational load forced the CPU to use its ALU (Arithmetic and Logical Unit) to a high capacity.

Experiment Procedure:

Two sets of experiments corresponding to fan-on and off conditions were conducted. In each set, four runs were carried out. In the first run, the computational load used the original factory installed RAM (128 MB). This RAM was successively increased by factors of 1.5 (192 MB), 2 (256 MB), and 3 (384 MB) for the remaining three runs. Table 1 shows the summary of memory allocations in the computer for each RAM module [4]. Prior to each run, the CPU was allowed to reach steady-state temperature as shown in Table 2.

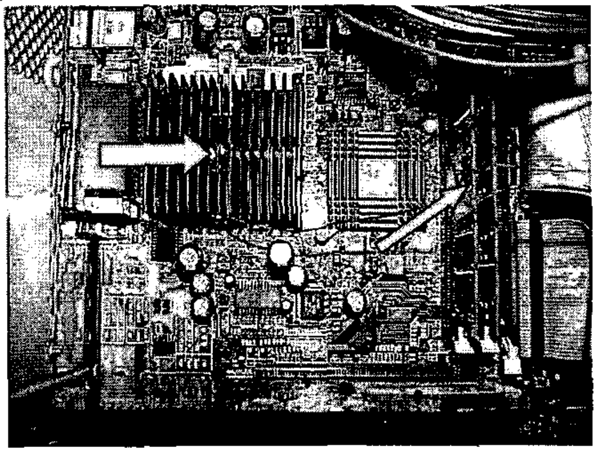

Figure 1: Thermocouples installed on the CPU heat-sink and RAM module

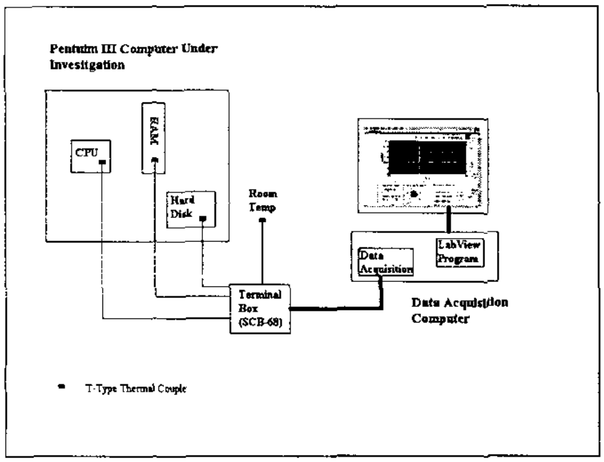

Figure 2: Schematic diagram of the experiment

Table 1: Summary of memory allocation for each RAM amount

	1 Module 128 MB	1.5 Module 192 MB	2 Modules 256 MB	3 Modules 512 MB
Total Physical Memory(KB)	130,544	196,080	261,616	392,688
Available Physical Memory(KB)	59,252	124,680	188,804	301,392
Total Virtual Memory(KB)	441,132	569,684	698,232	943,888
Available Virtual Memory(KB)	309,276	434,884	565,132	794,268
PageFile Space(KB)	310,588	373,604	436,616	551,200

To run the experiments under the fan-off conditions, the power supply to the fan was disconnected, thus simulating the fan failure condition during the execution of a heavy computational load. A program written in LabVIEW recorded four temperature measurements (Ambient Room, CPU, RAM, and Hard Disk temperatures) at one minute time intervals. A spreadsheet program in Microsoft® Excel was used to import the data for graphical and statistical analysis.

Performance graphs [4] of CPU utilization, memory usage, data paging, hard disk data transfer rate were obtained at the beginning and during each run. The main motivation for monitoring the above parameters was to investigate possible correlation between CPU temperature-rises and RAM usage under a heavy computational load.

Results and Analysis

The results of all experimental runs are summarized in Table 2. During the first run (with 128 MB RAM), the CPU temperature rises were not significant. However, it took over 20 hours for the CPU to finish the run. This could be explained as follows: since the RAM amount is considerably smaller than the minimum memory requirements (230 MB) for the execution of the application, the CPU had to use virtual memory to make up for this shortage. Therefore, the CPU had to constantly switch tasks from program execution to data paging to the hard drive. The data paging task is considerably less intensive than program execution. As a result, the CPU utilization during the execution of the application is not 100% as seen in Figure 3. Consequently, the CPU temperature rise was minimal.

As memory was successively, increased by a factor of 1.5 (192 MB), 2 (256 MB), and 3 (384 MB), the CPU temperature rises with respect to its initial temperature increased as shown in Table 2.

Table 2: Summary of experimental runs

	Fan On				Fan Off			
	128 MB	**192 MB**	**256 MB**	**384 MB**	**128 MB**	**192 MB**	**256 MB**	**384 MB**
CPU Processing Time (min)	1255	110	107	106	stop after 480 min	197	195	193
Avg. Room Temp (°C)	21	21	22	21	21	21	23	22
Initial CPU Temp (°C)	25	26	26	26	32	36	36	36
Max. CPU Temp Rise (°C)	3	7	7	6	10	22	23	23
Avg. CPU Temp Rise (°C)	1.2 ±0.7	5.5 ±1.1	5.6 ±0.6	4.6 ±0.6	7.0 ±1.2	20.0 ±1.0	21.5 ±0.8	21.3 ±0.9
Avg. RAM Temp Rise (°C)	6.1 ±0.7	12.0 ±1.0	8.0 ±0.8	8.5 ±0.8	10.7 ±0.8	15.3 ±1.1	13.7 ±1.1	15.3 ±0.8
Avg. Hard Disk Temp Rise (°C)	7.4 ±0.7	8.0 ±0.6	7.5 ±0.5	6.8 ±0.9	6.3 ±0.7	5.8 ±0.5	5.7 ±0.9	5.7 ±0.8

The maximum CPU temperature rise with respect to the initial temperature was approximately 3.0°C with 128 MB RAM (fan-on). Increasing the RAM to 384 MB resulted in a maximum temperature rise of approximately 6°C. With the

CPU fan-off, the maximum temperature rise was about 10°C using 128 MB in the RAM. This temperature rise jumped to nearly 23°C when the RAM was increased to 384 MB.

As seen in Table 2, the temperature rises in the CPU are normally low under fan-on condition; however, these could be significantly high when the fan is off and the CPU has to work intensively. Further, local temperature-rises within the CPU could be even higher than the bulk temperature measured by a single sensor such as the one used in our experiment.

Furthermore, as expected, the speed of program execution increased with RAM amount as seen in Table 2. The least processing speed (106 minutes) was achieved with RAM amount of 384 MB. According to Figures 3-6 and Table 2, it is possible to identify a RAM amount that provides optimal values for both CPU temperature rise and speed of calculation. For example, in our case, the RAM amount of 192 MB provides the optimal solution for both fan-on and fan-off cases (see Table 2 and Figure 4).

In addition, it is clear from Table 2 that temperature rises in hard disk are not significant for both scenarios. However, it should be pointed out that for RAM amount of 128 MB, the hard disk was being constantly used as virtual memory which is an I/O intensive task. This in turn could lead to high temperature and failure in hard disk for very prolonged operations. It is also evident from Table 2 that RAM temperature rises could be appreciable especially in the case of fan-off.

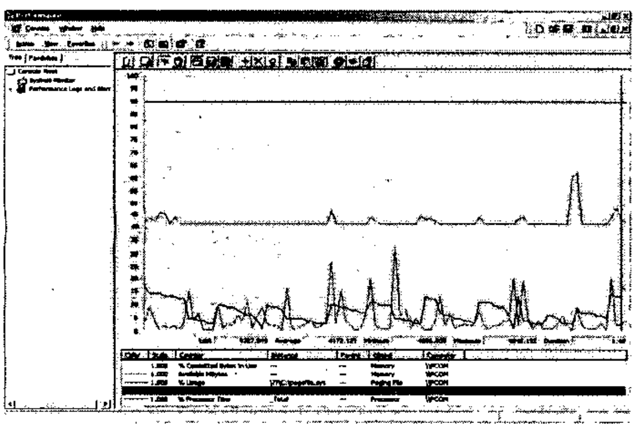

Figure 3: Performance graph of the CPU with 128 MB of RAM

Conclusions

Our experimental results and analysis indicate that when sufficient memory is available to a computationally intensive load, the CPU utilization to the load is near one hundred percent. This in turn could result in significant CPU temperature-rises in case of a poor CPU cooling system

The authors suggest that in order to avoid excessive temperature-rises due to execution of a heavy computational load, one might consider carefully devised software-interrupts to provide the CPU with some respite from computation. However, this should be performed in a manner that does not lead to excessively prolonged CPU processing times. For example, in our research we noticed that the processing time increased rather substantially when the CPU was operating at elevated temperatures (note the CPU processing times for fan-on and fan-off conditions in Table 2). Therefore, the software-interrupts that normally are considered to increase the computational time, might in fact improve the overall CPU processing times since CPU would operate at lower temperatures.

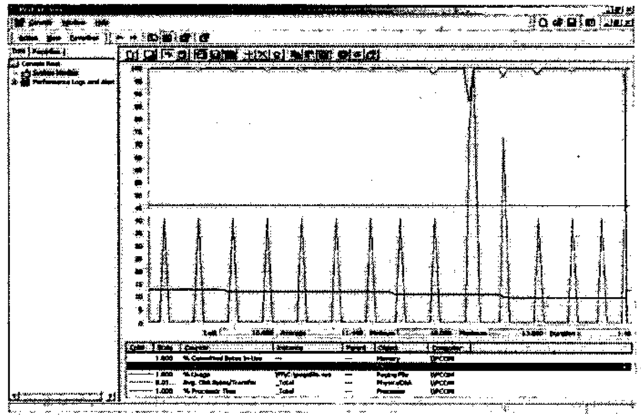

Figure 4: Performance graph of the CPU with 192 MB of RAM

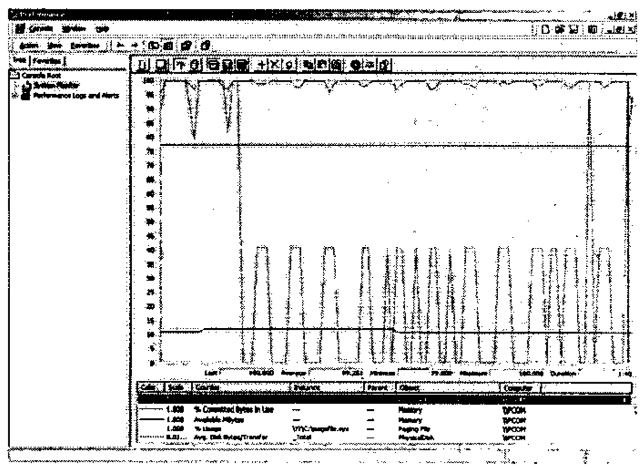

Figure 5: Performance graph of the CPU with 256 MB of RAM

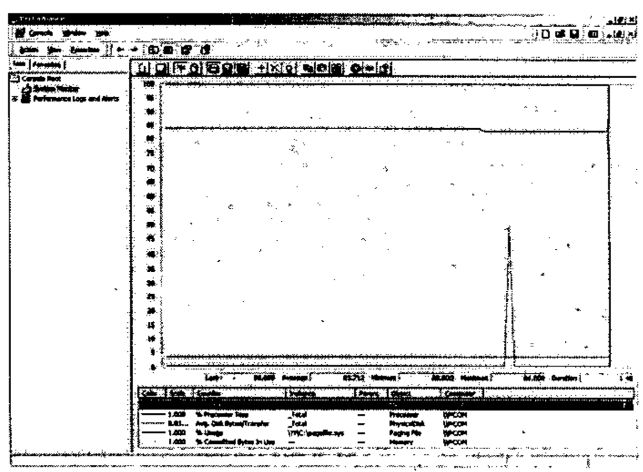

Figure 6: Performance graph of the CPU with 384 MB of RAM

These results should be particularly helpful to individuals and organizations that heavily use PCs in computation, database processing, multimedia, and networking.

Acknowledgments

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