White Paper

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PERFORMANCE ANALYSIS OF INTEL® PENTIUM® M AND PENTIUM 4 PROCESSORS

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The increased demand for portable computers with longer battery life, coupled with the growing power budget required for desktop processors, have made it impractical to use desktop processors in mobile platforms. The Intel Pentium M is the first Intel processor designed specifically for mobile platforms. Since its introduction in 2003, it has largely displaced the Mobile Pentium 4 and Pentium 4 processors in portable computers.

The Pentium M architecture balances performance and power consumption. Its architecture allows the Pentium M to operate at lower frequencies, but often outperform its higher-frequency predecessor, the Mobile Pentium 4. In some instances, the Pentium M also performs competitively with the higher-frequency Pentium 4 processors favored in desktop systems.

The Pentium M processor marked a significant shift in the Intel mobile platform architecture. Before the Pentium M, Intel mobile processors were architecturally the same as desktop processors, but were run at lower frequencies to reduce power consumption and meet thermal requirements. For this reason, the performance of these mobile platforms has traditionally been lower than platforms based on higher-frequency desktop processors. With the Pentium M, fundamental architectural changes enable competitive performance at lower frequencies, power consumption, and thermal levels.

This white paper compares the architecture and performance of the Pentium M to higher-frequency Pentium 4 processors. This study highlights the fact that, when evaluating mobile platform performance, factors other than processor frequency are becoming more important.

Processor Architecture

Table 1 compares the processor architecture of the Pentium M and Pentium 4. In order to achieve competitive performance with the thermal constraints of a mobile platform, the Pentium M is equipped with several power-aware performance features: micro-ops fusion, advanced branch prediction, and a dedicated stack manager.

A micro-op is the most basic operation of the microprocessor. Under micro-ops fusion, the processor micro-operations are kept united through most of the out-of-order core of the processor. This effectively reduces the number of micro-ops, which helps to cut down on the energy required to complete the instruction sequence, thereby minimizing power consumption.

Feature	Pentium M	Pentium 4
Transistor process	77 million 90 nanometer (nm)	125 million 90 nm
Die size	84 millimeters (mm)	112 mm
L1 and L2 cache sizes	64 Kilobytes (KB) L1 2 megabytes (MB) L2	16 KB L1 1 MB L2
Bus	533 MHz	800 MHz
Pipeline stages	Less than 31*	31
Features	• Micro-ops fusion • Dedicated stack manager	-
Branch Prediction	Indirect branch predictor and loop detector	Branch predictor
Streaming SIMD Extensions (SSE) support	SSE/SSE2	SSE/SSE2/SSE3
Support for Hyper-Threading Technology (HT)	No	Yes

Source: Intel Corporation

*The shorter pipeline of the Pentium M helps reduce the pipeline-flush recovery time in unpredictable code, which in turn helps improve the overall system performance. In contrast, the longer pipeline of the Pentium 4 allows higher clock speeds, but this comes at the expense of a lower number of instructions per cycle (IPC) and much higher power consumption.

Table 1. Processor Architecture Comparison

The dedicated stack engine further reduces the number of micro-ops in flight by providing its own dedicated "adders"[1] to perform all stack updates. This approach frees up the integer execution units to work on other instructions in the pipeline. The result is fewer micro-ops per task, which reduces the power consumption per task.

An improved branch prediction algorithm significantly reduces overall power consumption. With fewer mispredicted branches, the number of wasted operations executed is reduced. Two additional predictors—the Indirect Branch Predictor and Loop Detector—also help to improve the prediction rate by tracking special program flows. Even the processor bus of the Pentium M helps to lower power consumption through circuit methods.

Performance Analysis

The benchmarks used by Dell Performance labs to compare the performance of the processors are broken up into four categories: office productivity, gaming, CPU, and workstation. The system configurations used in these benchmarks are shown in Table 2. The configurations were designed to isolate processor performance as much as possible by using identical hard drives and graphics cards.

	Pentium M System	Pentium 4 System
CPU	2.13-GHz Pentium M 533 FSB	3.8-GHz Pentium 4 800 FSB
Hard drive	Seagate 120-GB 7200 RPM	Seagate 120-GB 7200 RPM
Operating system	Microsoft® Windows® XP, Service Pack 2	Microsoft Windows XP, service pack 2
Video card-gaming	ATI X800XT 256 MB	ATI X800XT 256 MB
Video card-workstation	Nvidia FX 3400 256 MB	Nvidia FX 3400 256 MB
Memory	1 GB (2 x 512-MB DDR2 533 MHz)	1 GB (2 x 512-KB DDR2 533 MHz)

Table 2. Performance Benchmark System Configurations

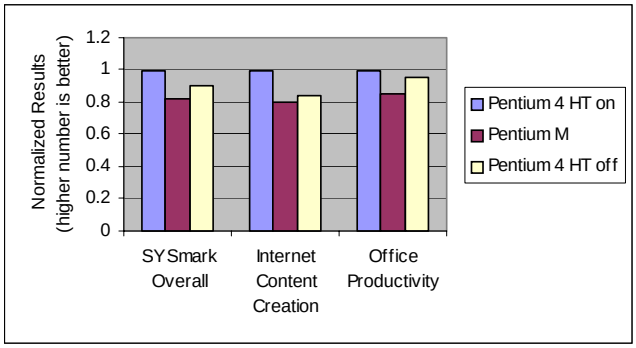

Figure 1. Sysmark 2004 Relative Results

Office Productivity Benchmarks

The benchmarks analyzed were SYSmark 2004, Business Winstone 2004, Multimedia Content Creation Winstone 2004 and PCMark 2004. These results are summarized in Figures 1 and 2.[2]

SYSmark is a multithreaded application, so it scales well with physical or logical (via Hyper-Threading Technology) processors. This gives the Pentium 4, which supports Hyper-Threading Technology, an advantage over Pentium M, which does not. Between the subtests, the Pentium 4 shows the biggest lead on Internet Content Creation, largely due to its faster clock speed and a more-efficient floating point unit. The gains on the office productivity portion of the test can be linked to the faster frontside bus speed of the Pentium 4. With Hyper-Threading Technology disabled on the Pentium 4, the gap between the two processors shrinks. The Pentium 4 also receives a higher PC Mark CPU score due to its support for Hyper-Threading Technology. However, on Business Winstone 2004, the larger cache of the Pentium M proves to be a major benefit and helps it to move past the Pentium 4.

1. Adders are functional units in the microprocessor that perform arithmetic addition operations.
2. Actual performance will vary based on configuration, usage, and manufacturing variability.

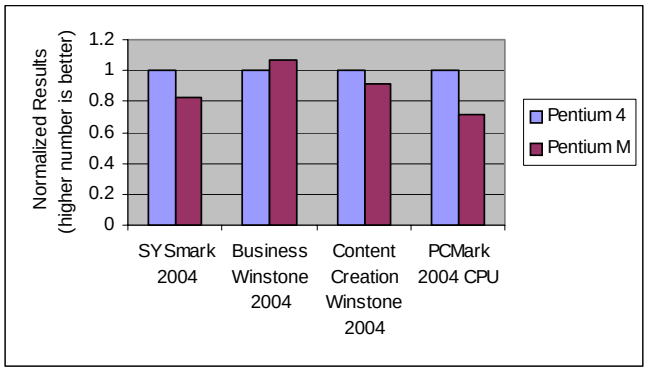

Figure 2: Office Productivity Benchmark Relative Results

Gaming Benchmarks

All gaming benchmarks were run at a medium resolution of 1024x768 using identical desktop high-end graphics cards to isolate CPU performance. The use of a high-end desktop graphics card on a mobile system is not feasible outside the lab, given the limited thermal headroom available on mobile platforms. Similarly, the use of a high-end desktop Pentium 4 at full performance (that is, maximum frequency) is also not feasible on a mobile platform.

The gaming benchmark results are summarized in Figure 3. The Pentium M exhibits very good gaming performance compared to the Pentium 4, because of the larger cache and shorter pipeline of the Pentium M. (See comparison of Pentium M and Pentium 4 in Table 1.)[2]

In UT2004 and FarCry, the Pentium M wins on all the subtests. This is also the case in Doom3. In the multi-threaded 3Dmark05, however, the Pentium 4 holds a huge lead over the Pentium M on the CPU subtest. The Pentium 4 support for Hyper-Threading Technology gives it a performance boost. This gap shrinks with Hyper-Threading Technology disabled. With the exception of the Aquamark and 3DMark05 CPU test, the other gaming benchmarks are not designed to take advantage of Hyper-Threading Technology and show very little performance gain with the feature enabled.

At the highest resolution tested (1600x1200), benchmarks are more graphics-intensive. At this resolution, performance is limited primarily by the graphics card. For this reason, there is little performance difference between the two processors, as shown in Figure 4.

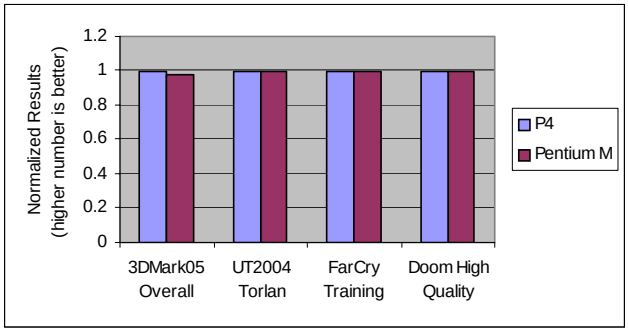

Figure 4: Gaming Benchmark Relative Results at 1600x1200 Resolution

Overall, the frontside bus speed appears to be the limiting factor for the Pentium M and an increase in bus speed could potentially widen the gap in favor of the Pentium M.

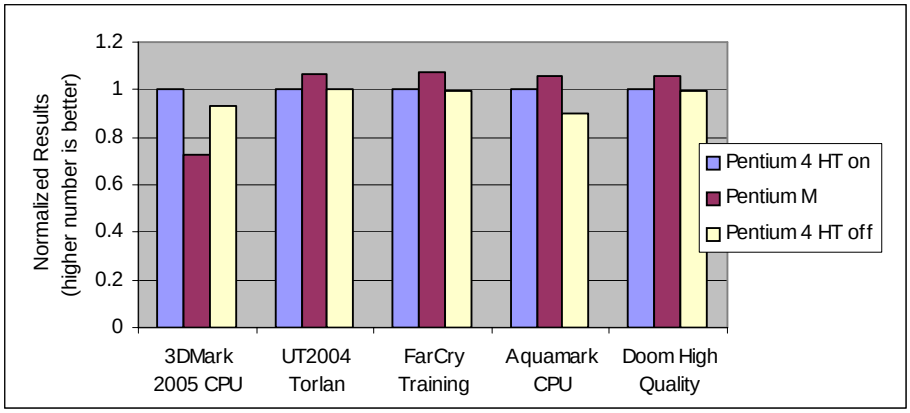

Figure 3: Gaming Benchmark Relative Results

CPU Benchmarks

SPEC CPU2000 was the main benchmark used to compare performance between the two processors. The larger cache and higher instructions per clock rating of the Pentium M, coupled with its shorter pipeline, give it a slight advantage on the integer portion of this benchmark. The Pentium 4 processor performed better on floating-point benchmarks because of its more efficient floating-point unit and SSE performance, and higher clock speed. The SPECfp suite depends heavily on system bus bandwidth. As a result, the Pentium 4 has an inherent advantage because of its higher bus speed in a desktop configuration. The results are summarized in Figure 5.[2]

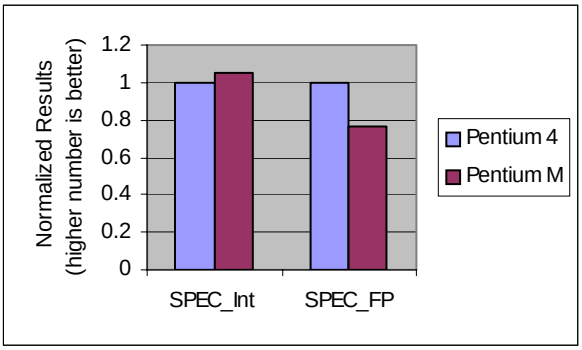

Figure 5: CPU Benchmark Relative Results

Workstation Benchmarks

The Pentium 4 processor had the performance lead on most of the benchmarks. 3D workstation applications are heavily dependent on bus latency and bandwidth. The lower bus speed of the Pentium M is a major reason for its lower performance. Even so, the Pentium M is reasonably competitive in these benchmarks because of its larger cache. The results are summarized in Figure 6.[2]

Battery Life and Weight

The performance-improving features built into the architecture of the Pentium M—micro-ops fusion, advanced branch prediction, and dedicated stack manager—also reduce overall power consumption. Shorter pipelines that do more work per clock require fewer transistors, and transistors that clock slower require less power. As a result, a mobile platform based on the Pentium M can be extremely power efficient.

In contrast, the longer pipelines and higher clock speeds of the Pentium 4 result in much higher power consumption and lower battery life. For this reason, portable computers based on the Pentium 4 processor must use higher-capacity batteries to achieve similar battery life, but this increases the weight of the system. Systems based on the Pentium M can be lighter because lower-capacity battery packs can be used without compromising battery life or performance. Also, due to lower power dissipation from the Pentium M, the thermal solutions required to keep the processor cool are lighter, which further reduces system weight.

Mobilemark 2002 was used to compare battery life between the Inspiron™ 5160 (Mobile Pentium 4 with HT) and the Inspiron 8600 (Pentium M). These systems have different chip sets, processors, display panels, and batteries. However, to get a feel for the battery life difference, we matched up other system components such as the graphics card, hard drive, and memory to keep the comparison as similar as possible. The results are summarized in Table 3. These results show that the

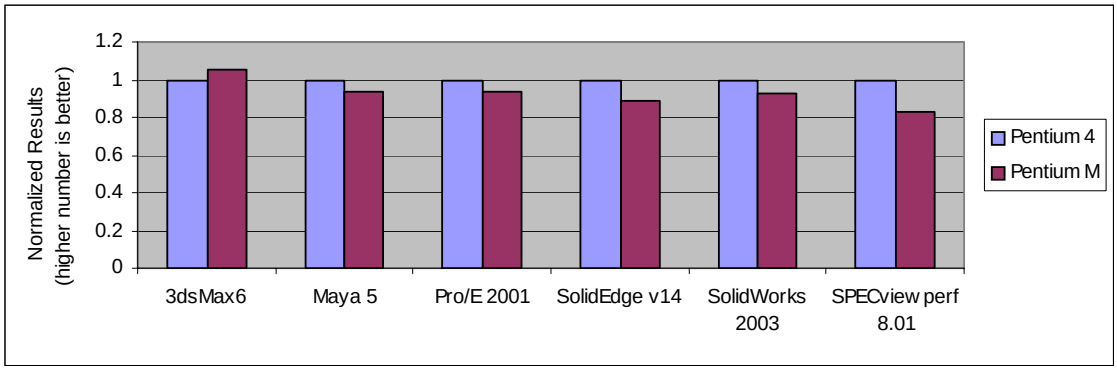

Figure 6: Workstation Benchmark Relative Results

	Inspiron 5160	Inspiron 8600
CPU	3.2-GHz Mobile Pentium 4, Hyper-Threading enabled	1.7-GHz Pentium M
Video Card	nVidia GeForce FX Go5200 32 MB	nVidia GeForce FX Go5200 32 MB
Memory	1 x 256 MB DDR 333-MHz	1 x 256 MB DDR 333-MHz
Panel	SXGA+	WUXGA
Battery	96 watt hours	72 watt hours
Maximum battery life[3]	197 minutes	266 minutes
Average system power	29.24 watts	16.22 watts
Base weight	8.3 lbs	6.6 lbs

Table 3. Battery Life System Setup

Inspiron 8600 has better battery life and is lighter than the Inspiron 5160.[3]

Conclusion

This study shows that the Pentium M is competitive on almost all benchmarks. From a purely performance standpoint, its best showing is on the gaming benchmarks where it outperformed the Pentium 4 on several tests. In mobile platforms, where battery life and thermal issues take precedence, the Pentium M provides comparable performance with longer battery life and lower weight. It also frees up power and thermal capacity, thus permitting the use of higher-performance components such as higher-end video cards. (See sidebar.) On most of the system-level and workstation benchmarks, the Pentium M is not far behind the desktop Pentium 4. With the increased use and popularity of portable computers, battery life and weight have become important deciding factors for most consumers. It is here that the Pentium M shines with its impressive battery life numbers and lower weight.

Each computer system has a fixed power and thermal limit or "budget." This budget is affected by the system's size and weight. System designers make various trade-offs to meet the power and thermal budget. The lower power requirements of the Pentium M processor frees up power and thermal capacity that can be used to provide features such as higher-end graphics or memory solutions that need the extra power, or a second hard drive for a RAID solution.

References

- http://www.intel.com/technology/itj/2003/volume07issue02/art03_pentiumm/p01_abstract.htm.

Steven Sexton, Systems Engineer with Dell System Performance Analysis, was an additional contributor to this white paper.

3. Actual battery life will vary based on configuration, usage, and manufacturing variability.