Core Microarchitecture Performance: Woodcrest Preview

Introduction

The last several months have been quite interesting for me. I spent most of April in Tanzania, installing computers in several rural schools. While I was in Tanzania, I received an invitation from my friend Scott McLaughlin, to attend another Intel reviewer's workshop, this time for Woodcrest based systems, in Hillsboro. Rural internet connectivity in Africa is a little dicey, but I did manage to RSVP.

The last reviewer's workshop in October, 2005 focused around the Bensley platform, which coupled the Dempsey MPU with the Blackford chipset. Based on the results we saw, it appeared that Bensley would put Intel back into the game performance wise, but do little to alleviate power and thermal issues.

However, fate conspired against Dempsey. It turned out there were not sufficient FB-DIMM supplies to launch the platform in March, as was originally planned. As a result, Dempsey's launch was delayed until today (May 23rd), although products have been shipping to partners for two months. Fortunately for Intel, Woodcrest taped out earlier than expected, with fewer bugs, and so the release date for the Woodcrest based variant of Bensley was moved up to June. This means that Dempsey will enjoy a rather short period of time in the limelight, but it seems unlikely that any consumers will mind.

Woodcrest is far more impressive than its predecessor, from both a performance and power efficiency perspective. Dempsey was really intended as a short term product to keep dual socket servers competitive for a quarter or two. Woodcrest is the flagship for Intel's server line, and the lynchpin of their strategy for the next year or so. As a result, everyone at Intel, and all the reviewers were very enthusiastic about the new products, which made the workshop quite a treat.

The reviewer's workshop was May 10th, through the 12th, although I arrived a little early and stayed a day later. The night before the workshop I went to dinner with several friends and acquaintances in the area, which was quite enjoyable. The workshop itself was very similar to the previous one, but much more refined, and the same cast of characters, plus a few more, attended.

This workshop offered an opportunity to bring together an incredible amount of information. Rather than present all of this at once and overloading (or worse, boring) readers, the information will be split into several articles. In this first article, we will focus on describing the Bensley platform with Woodcrest, Intel's estimated performance and our measured performance for Woodcrest systems. Later articles will focus on the actual reviewer's workshop itself, our measured Linux performance and a detailed power analysis for our benchmarks.

A Brief Overview of Bensley

We covered the Bensley platform in great detail in a previous article, which is an excellent refresher. For readers that are less concerned with the intimate details, we will provide a brief recap of the key points. Figure 1 below shows the Bensley system architecture.

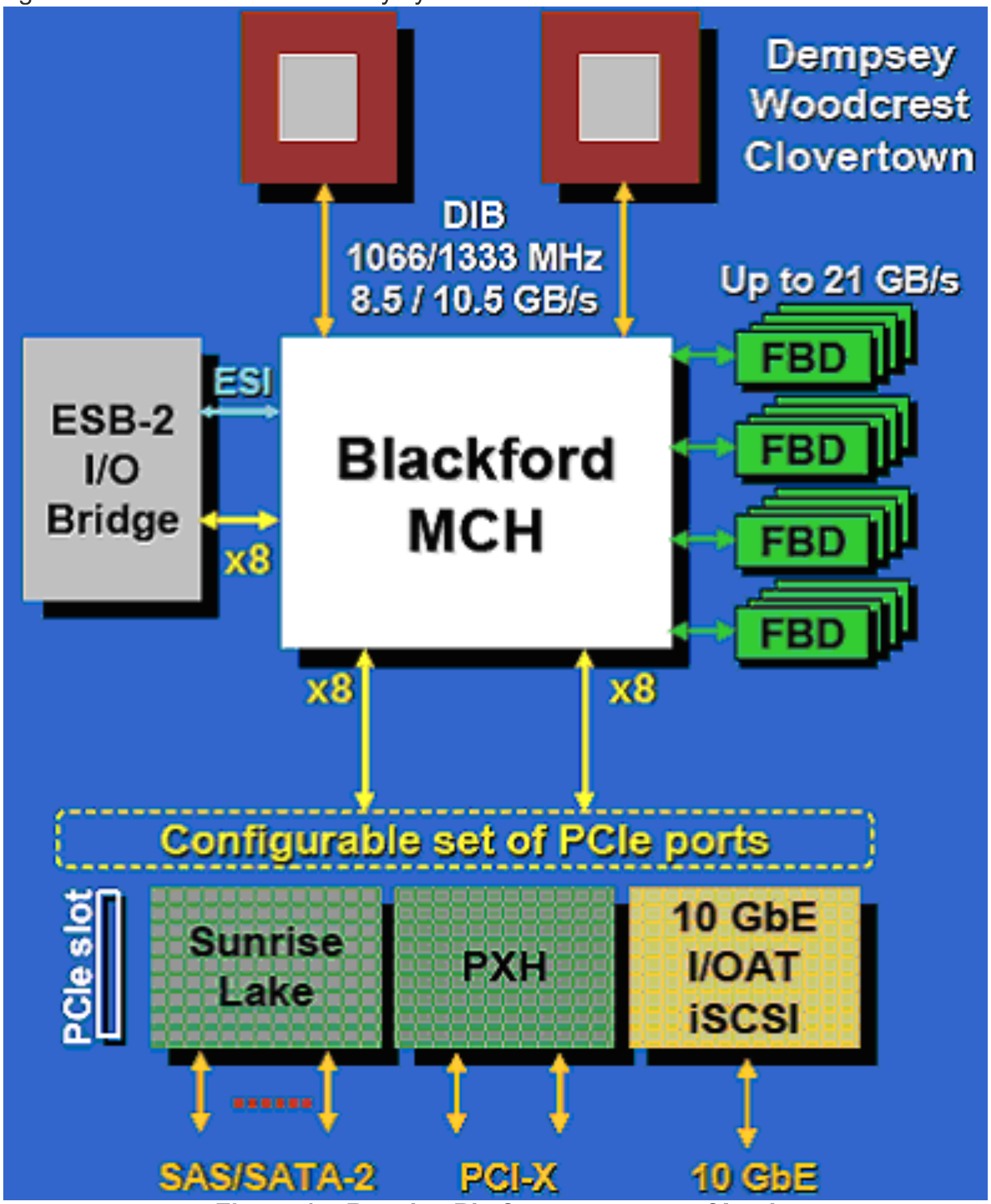

Figure 1 – Bensley Platform, courtesy of Intel

The Blackford chipset will support three generations of MPUs: Dempsey, Woodcrest and in the more distant future, Clovertown. Each MPU will be drop in compatible with the prior generation(s), although a BIOS revision may be necessary. The crucial detail in the diagram is that each front side bus features 8.5 or 10.5GB/s of bandwidth. Collectively, the two are independent segments give the processors 17.1 or 21.1GB/s of bandwidth. Blackford uses four channels of FB-DIMMs, which provides 17.1 or 21.1GB/s of memory bandwidth, balancing the front-side bus capabilities.

The main differences between the different generations of Bensley are the MPUs and the bus speeds. Woodcrest is based on the new Core microarchitecture, which is a dual core, modestly pipelined, out of order, 4-issue MPU implemented in Intel's 65nm high performance process. Woodcrest provides substantially higher IPC and performance than Dempsey, which is based on the older P4 core. For those who wish to review the details of Woodcrest and the Pentium 4, I strongly recommend my coverage from IDF which is exceptionally thorough. It walks through every portion of Woodcrest in comparison to the Pentium 4 and Pentium M cores.

From a system perspective, the big differences come down to cores, caches, busses and power. Each Dempsey has two separate 2MB L2 caches, and two bus interfaces; it is essentially two MPUs on a single package. Woodcrest is a far more elegant and fully integrated solution. The two cores are on the same die and share 4MB of L2 cache and have a unified bus interface. Because there are fewer interfaces (and discontinuities in the bus), the signal is cleaner for Woodcrest and can be clocked up to 1.33GT/s. On top of that, because Woodcrest has a shared L2 cache, there is less coherency traffic. Together these two factors should substantially improve system scalability.

Perhaps most importantly, Woodcrest consumes far less power and dissipates much less heat than Dempsey because the microarchitecture was heavily optimized to reduce power consumption. Woodcrest comes in three varieties, the 40W TDP versions optimized for blades, the mainstream 65W TDP parts, and the 3GHz top bin part which has an 80W TDP. All parts below 3GHz will fall into the 65W or 40W TDP range. In comparison, the top bin Dempsey parts had a 130W TDP, and mid range parts were rated at 95W, and the massive power requirements and thermal issues precluded ever using Dempsey in a blade. On top of this, Woodcrest also has improved sleep states and clock gating which help to lower average power (recall that TDP and average power are quite distinct measures).

All these improvements make Woodcrest a much more compelling product than Dempsey. While Dempsey brought Intel to performance parity (or near enough) with AMD, power was still a substantial concern. With Woodcrest, Intel will be ahead of AMD in performance for almost all workloads, and will have roughly equivalent or better power and thermal characteristics.

Intel's Performance Claims

In our last visit to Hillsboro, Intel provided quite a few performance estimates comparing Dempsey to previous generation products from Intel, and existing products from AMD. These numbers really served to highlight the benefit of dual core MPUs equipped with a chipset designed from the ground up for dual cores. This time around, we were shown estimates for Woodcrest systems compared to prior products and current AMD offerings. While this information should help to show both the performance improvement from Woodcrest and the competitive landscape, there are several qualifications.

First of all, these estimates are for benchmarks, where performance engineers from each company spend hours tuning and tweaking the performance to get the best score possible. The results may differ when little tuning or optimization is done. Second of all, the hardware used for these results is always top of the line, the most expensive systems out there. Most users will probably not buy the best and opt for something more economical. Lastly, AMD is in the process of releasing the new AM2 socket and MPUs across their entire product line. Socket AM2 will use DDR2 instead of DDR1, increasing the bandwidth. By all accounts, AM2 processors will have anywhere from 1-10% higher performance, although most workloads will only improve by 1-5%. Moreover, AMD may very well bump up their clock speed to 2.8GHz or even 3.0GHz if they are lucky. So with those qualifiers in mind, let’s see what Intel tells us about Woodcrest.

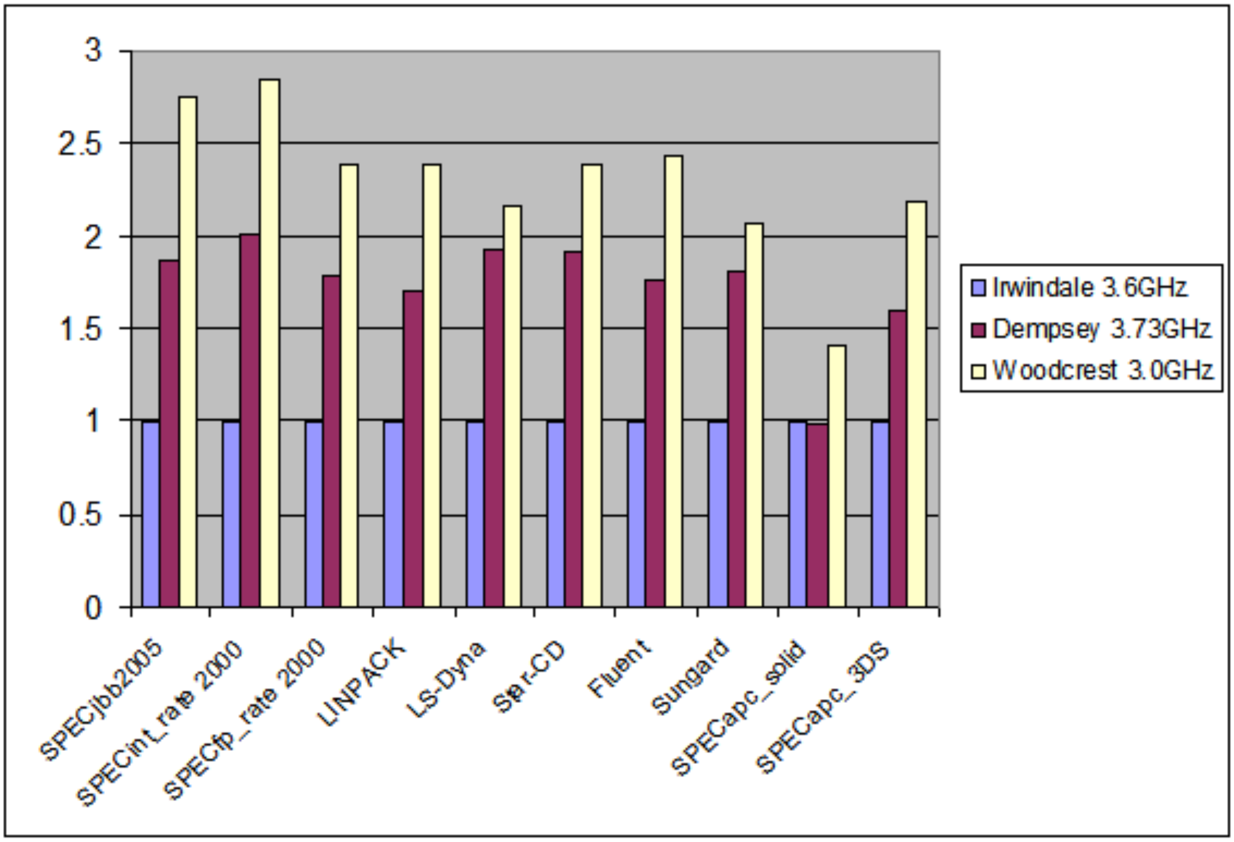

Figure 2 – Relative Intel System Performance

Figure 2 above compares the performance for Intel systems over three generations, *according to Intel*. Irwindale is a 90nm, single core, 3.8GHz MPU, with 2MB of L2 cache and an older chipset. Dempsey is basically a pair of Irwindales shrunk to 65nm in a single package, using the newer Blackford chipset. Woodcrest uses a slightly faster version of the Blackford chipset, with a much better MPU, also at 65nm.

The scaling for Dempsey is reasonable, an across the board 50-90% improvement for going to two cores. However, Woodcrest is simply amazing, it is twice as fast as the 90nm Irwindale on almost every benchmark, and on SPECjbb2005 (which is the best indicator of server performance in the sample), it is 2.75x faster. While Woodcrest is really head and shoulders above Irwindale, it is also a very noticeable improvement over Dempsey. For the workloads shown above, it is 10-50% faster, in the same process technology.

The one exception to these improvements is SPECapc using Solid Works. Based on the results above, it appears that this particular benchmark is most likely single threaded, or written in such a way that it does not benefit from more than a certain number of threads or processors. Solid Works does speed up by about 40% with Woodcrest, but that appears to be consistent with single threaded gains. Moreover, if there was any benefit from having more processors, surely Dempsey would see improvements, yet it does not. While there is a strong graphical component to SPECapc, 3DS Max scales moderately well with the newer processors, so clearly additional CPU power can be useful for the SPECapc benchmark. Why the Solid Works engine is not able to use the additional CPUs is unclear, but it certainly is a special case worth mentioning.

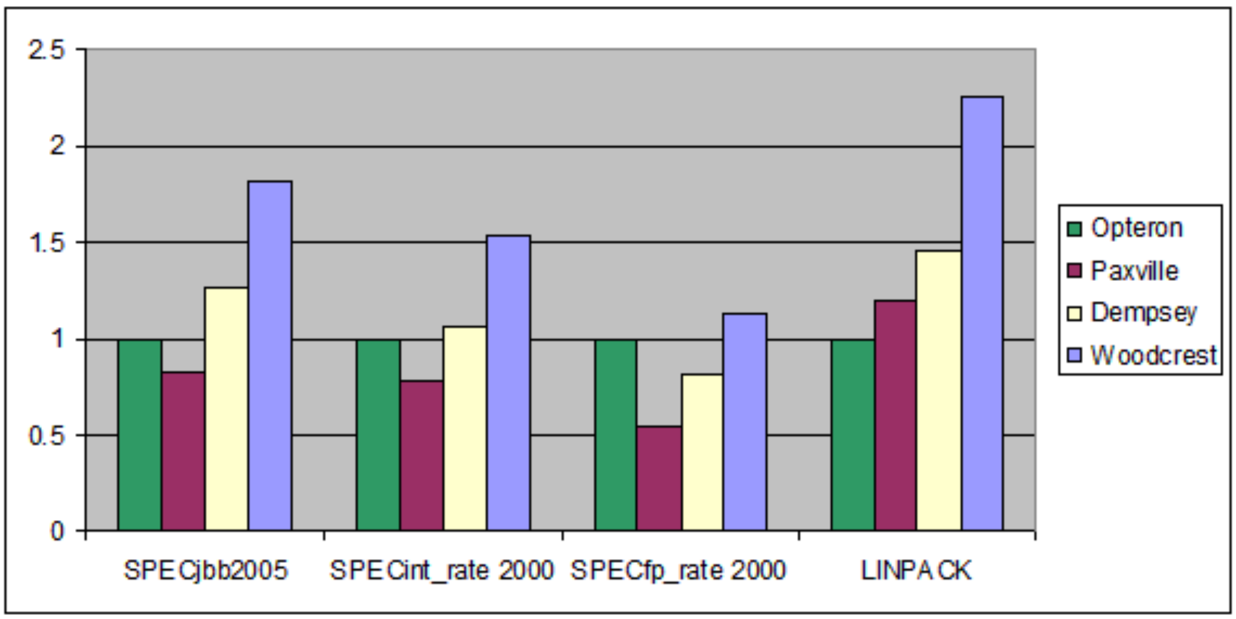

Figure 3 – Intel Competitive Estimates

Intel also provided a direct comparison between Paxville, Dempsey, Woodcrest and the best published Opteron systems in several benchmarks. Considering the source, all these numbers should be taken with a grain of salt. Now the really interesting question is will our real world benchmarks show the same numbers as Intel's projections…

System Line-up and Methodology

For this preview, we used two PDKs: a newer Woodcrest system and a Dempsey system from our prior review. PDKs are pre-production systems for key partners to validate hardware, software, drivers, operating systems, compilers, etc. The system we received and tested is fairly modest, and should provide good insights into realistic performance. This system will be released in June, so the results are an underestimate of actual performance; a month of tuning will improve the situation somewhat.

The point of this preview is to examine how the Woodcrest and Blackford platform will improve over the existing Dempsey and Blackford platform. We do not have newer socket AM2 Opterons for comparison, although some estimates can be made. The two systems we used for testing are summarized below:

	Dempsey	Woodcrest
CPU	2x 3.46GHz Dempsey 4MB L2 cache	2x 3.0GHz Woodcrest 4MB L2 cache
FSB	2x 1066MT/s, 17.1GB/s	2x 1333MT/s, 21.1GB/s
Chipset	Intel Blackford	Intel Blackford
Memory	8x 512MB FBD-533	4x 1GB FBD-533
Timings	Default	Default
Hard Drive	2x WD Raptor 74GB 10K RPM	2x WD Raptor 74GB 10K RPM
OS	Windows Server 2003 EE (64b)	Windows Server 2003 EE (64b)
JVM	BEA JRockit 5.0 R26 (32b)	BEA JRockit 5.0 R26 (32b)

Since we are doing a server comparison, Hyper-Threading was enabled for the Dempsey system. The snoop filter for Blackford was disabled in the BIOS.

Our methodology for testing was rather simple. Each system had it a pair of hard drives, and we installed Microsoft Windows Server 2003 EE (64 bit) on one drive, the other drive was used for applications and data. Then we installed all the relevant software, in particular the JVM and .Net Runtime 2.0 (64 bit). Most benchmarks were run 4 times; the first time is to warm up the caches, and then 3 times which were measured. All tests were run in 64 bit mode, except for the Java benchmarks, which used 32 bit JVMs due to inter-operability concerns. Certain benchmarks such as SPECjbb2005 and XML Test 1.1 do not require warm up runs. Our results are the averages of the three valid runs, and after each benchmark, the system is shut down. Since few benchmarks are perfectly repeatable (i.e. results differ for each run), the standard deviation for the three runs are also reported. Factors that can cause variation include the operating system's scheduling decisions, multi-threading, inter-processor communication, I/O etc. In general, the standard deviations were all very small, and even the smallest measured differences were statistically significant.

Cinebench 9.5 (64 bit)

Cinebench is one of the more popular software rendering tests. It is free, and runs on multiple platforms: Windows 32b, 64b and OS X. We will be using the CPU test, which renders a scene using a ray-tracing engine. The ray-tracer operates in both a single threaded mode and an SMP aware mode, but lacks fine grained control over threading and process count. The Dempsey system runs using 8 threads, and Woodcrest uses 4 threads. The benchmark is designed to run out of memory, so there should be no waiting for disk I/O.

While the documentation indicates an 80-90% speed up for the second CPU, and around 10-20% for multithreading on a Pentium 4 Xeon, we have found in the past that the benchmark does not scale quite as well from two to four processors.

The benchmark is normalized to the performance of a 1GHz Pentium 4 system, which has a score of 100. So the single threaded Woodcrest is approximately 5x faster than a 1GHz Pentium, while the Woodcrest is roughly 16x faster in SMP operation.

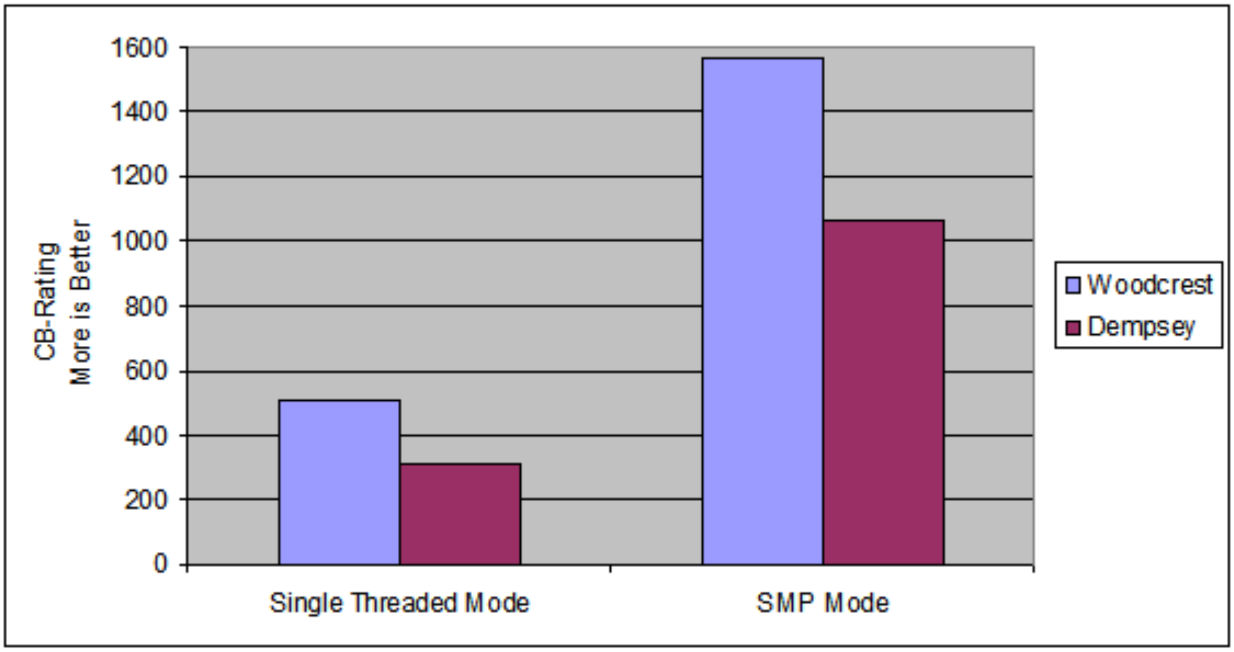

Figure 4 – Cinebench CPU Performance

Unsurprisingly, Woodcrest leads Dempsey in single threaded performance, by about 60%; the 128b wide SSE units and 128b loads and stores are probably responsible for most of this lead. However, Woodcrest does not scale up quite as well as Dempsey. Woodcrest improves by a factor of 3.07x up to 4 threads, while Dempsey improves by 3.41x as it goes to 8 threads. Woodcrest still leads by a substantial margin (40%) under SMP mode, but this is somewhat puzzling.

This discrepancy is most likely due to Dempsey's multithreading capabilities and Woodcrest's bandwidth demands. Perfect scaling for Woodcrest would be a four fold improvement, while Dempsey could theoretically quadruple performance (due to having 4 cores), plus another 10-20% for multithreading. So perfect scaling for Dempsey could be any where from 4.4x to as high as 4.8x. The other issue is that in theory, Woodcrest has 2x the SSE throughput that Dempsey does. This is partially why it does so much better in single threaded mode. However, more throughput is just wasted unless data is being delivered to the core. Therefore, Woodcrest requires substantially more memory bandwidth than Dempsey does, and perhaps that is holding back multiprocessor scaling.

The standard deviations for the single threaded runs were 4.63 and 5.31 for Woodcrest and Dempsey. The multithreaded runs had slightly higher standard deviations, 7.78 and 8.75 respectively.

POV-Ray 3.7 Beta 12a

Our second rendering test comes courtesy of POV-Ray. The 3.7 build of POV-Ray is still in beta, after nearly a year and a half, and the latest build is 12a. Performance for POV-Ray is a throughput measure; pixels/sec for the standard benchmarking image.

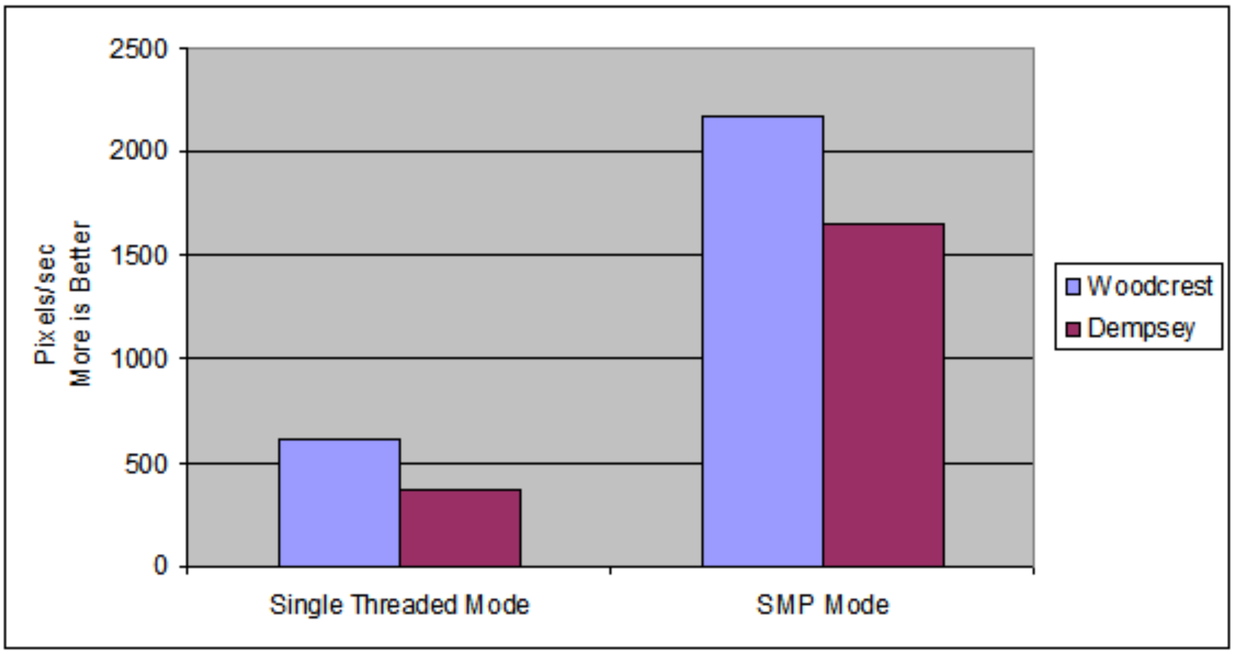

Figure 5 – POV-Ray CPU Performance

Predictably the results for POV-Ray are quite similar to those for Cinebench. Woodcrest starts off about 2x faster than Dempsey with no threading, but in SMP mode, the lead narrows to around 30%. Both systems show exceptional scaling, a factor of 3.55x for Woodcrest and a factor of 4.54x for Dempsey. This is hard proof that multithreading plays a role in Dempsey's scaling, although only fine grained thread control in the benchmark would allow us to quantify what portion of the scaling is due to multiple processors and what portion is due to multiple threads.

The standard deviation for single threaded execution with Woodcrest was 5.3 pixels/sec, while Dempsey was 7.4 pixels/sec. The multithreaded deviations were worse at 13.3 and 8.8 pixels/sec, but considering they are all less than 1% of the average, it is hardly an issue.

SunGard ACR

The SunGard Adaptiv Credit Risk (ACR) benchmark, which was used in our analysis of Dempsey last year, has now been ported to 64 bits. This benchmark was provided by Intel and unfortunately, the binaries are still not publicly available.

ACR is an application from SunGard that uses a proprietary Monte Carlo engine to evaluate a hypothetical portfolio of assets. The benchmark portfolio consists of 1428 deals, primarily interest rate swaps and foreign exchange forwards; the portfolio is examined in conjunction with 29 price factors and 19 risk factors. Monte Carlo techniques are quite amenable to parallelization, since they usually partition problems into independent workloads. As a result, the benchmark should scale relatively well.

Unlike the rendering benchmarks, SunGard ACR has built in threading control. The user may set the number of threads, so that both performance and scaling can be observed. When a multithreading aware OS is used, preference will be giving towards physical processors. In this situation, we can very clearly see the performance gain from multithreading for Dempsey, as it is the speed up from 4 to 8 threads.

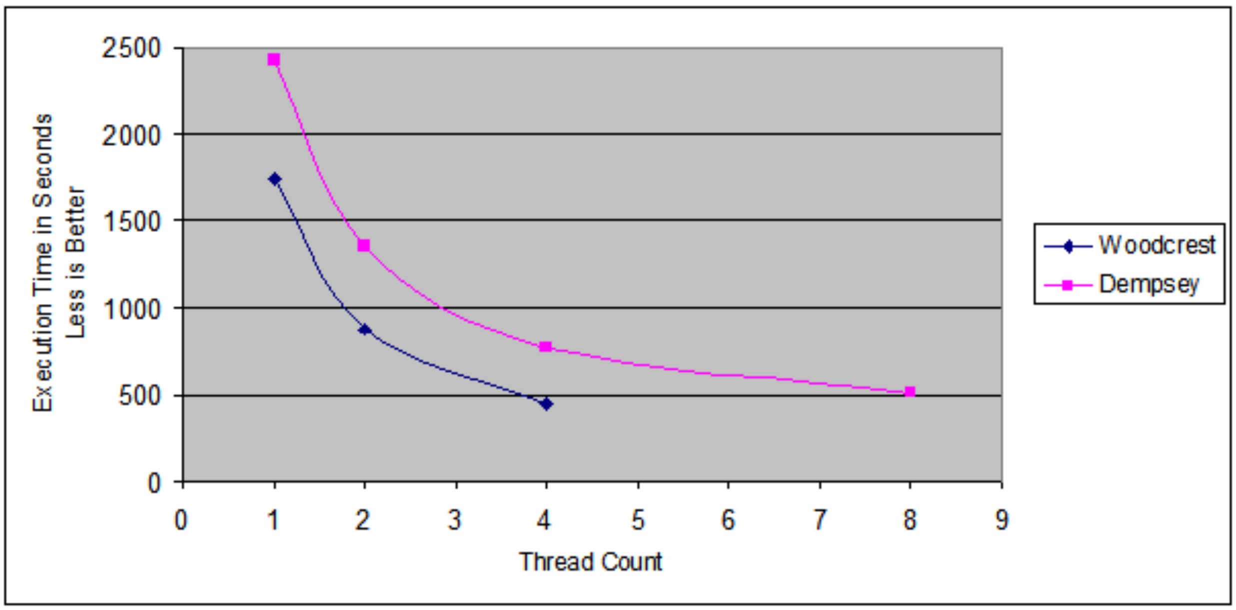

Figure 6 – SunGard ACR Performance

While some have objected that any benchmark provided by a vendor cannot possibly be unbiased, SunGard ACR is an application, not a toy benchmark. As a general rule of thumb, applications are somewhat less susceptible to tampering than other more artificial benchmarks. Perhaps the most ironic part of this review is that in the SunGard benchmark, which was provided by Intel, Dempsey is just a shade behind Woodcrest. This can almost certainly be chalked up to Dempsey's multithreading, which brings the execution time down from 763 seconds to a little over 500. Going from 1 to 8 threads reduces the execution time by 4.7x for Dempsey, another instance of super linear scaling. Despite that, Woodcrest is not far behind, with run times dropping by a factor of 3.9x, nearly perfect scaling.

The standard deviations for the Woodcrest system, going from 1 thread to 4 were 1.26, 1.65, and 4.77 seconds. The Dempsey system had standard deviations of 2.66, 8.89, 2.91 and 3.97 seconds. Most of these variations are small relative to the absolute scores, but the Woodcrest system running with 4 threads had roughly a 10% standard deviation, which could be improved. However, Woodcrest's performance lead was significant by any measure.

XML Test 1.1

It is our pleasure to introduce a new benchmark, XML Test 1.1, for this review (and all of our future server reviews). XML Test was designed by Sun Microsystems to evaluate the performance of XML document processing using Java and .Net. While this seems rather mundane and boring, XML processing is quite interesting because it is an essential element of many web services implementations. XML is a totally neutral document format that is an industry standard. XML processing is computationally taxing, and ubiquitous enough that some architects are considering incorporating hardware XML accelerators in the future. This benchmark models a Java server processing multiple XML documents in parallel. The documents are sample invoices for a company, of varying sizes.

There are 9 sub tests, each using a different method, which are shown below in Figure 7. Every test consists of a warm-up time period, and then a steady state measurement period. The benchmark was run with all default settings, except that the heap size was set to 1024-2040MB. The 32 bit JRockit JVM cannot allocate more than 2040MB to heap, hence the somewhat odd range. Due to the run time of the benchmark, only peak performance measurements were made. Perhaps in future reviews, data for scaling will be collected. The Dempsey system ran with 8 threads, while the Woodcrest system used 4.

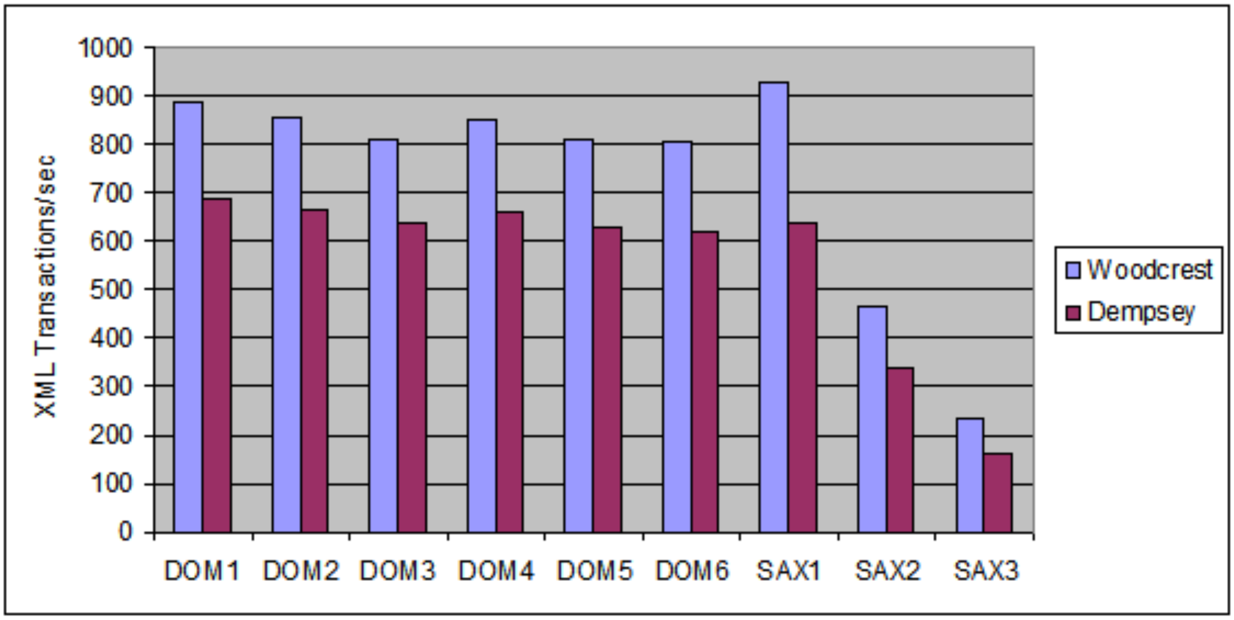

Figure 7 – XML Test 1.1 Performance

XML Test generally scales quite well according to the architects, and Woodcrest substantially improves over Dempsey. The performance increase is 25-45%, across all nine tests. The gains shown in XML Test are probably somewhat of an underestimate. Since the benchmark was designed for processing multiple documents in parallel, there should be little or no sharing between different threads and processes. As a result, the benefits of the shared cache in Woodcrest may not be readily apparent. Other commercial workloads may see more of a benefit from the shared cache (relative to shared package designs like Dempsey).

XML Test is very well designed, in terms of accuracy and repeatability. The standard deviations for each test were well under 3.5 transactions/sec. This is largely because the structure of the tests, using a warm-up period and a steady state measurement period, are superior to simple 'run once' benchmarks.

SPECjbb2005

Our last and unarguably most significant test is SPECjbb2005, which we have previously described. Out of our suite of benchmarks, SPECjbb2005 is the most directly correlated with commercial server performance. It is also an industry standard benchmark that is widely used by every vendor. Submissions for SPECjbb2005 range from small 1P systems, to massive 128P Itanium2 systems from SGI. The command line options used were:

-server –XXaggresive -XXtlasize64k –Xms2040M –Xmx2040M

Each warehouse independently spawns a thread in the benchmark, thus determining the level of concurrency in the benchmark. Each system has an expected peak number of warehouses (N), which corresponds to the total number of hardware threads supported. The score, measured in

Business OPerations per second (BOP/s) is actually an average of the throughputs for N, N+1, N+2…2N warehouses. Figure 8 below shows the results from SPECjbb2005, with the relevant scores circled in red.

Figure 8 – SPECjbb2005 Performance

The Woodcrest system scored 56,804, 56,835 and 56,678 BOP/s for our three runs, while the Dempsey box managed 47,930, 47,449 and 47,707 BOP/s. In comparison, the best published two socket Opteron system, scores only 51,106 BOP/s, and that is with extensive tuning efforts. Considering that our JVM is tuned for Dempsey, but not for Woodcrest, a 20% performance lead is very respectable. Moreover, our test uses a 32b JVM, which does not perform as well as a fully configured and tweaked 64b JVM. It is quite likely that a fully tuned Woodcrest system would score in the 70-90K range, which would easily put Woodcrest ahead of all other competitors in the two socket space.

Conclusion

Up until today, with the release of the first Bensley platform, the server market was really a one horse race in terms of performance and power efficiency. Paxville, Intel's first dual core product, was a quick, dirty and ugly implementation that used up lots of power and gave little back in the way of performance. The combination of Dempsey and Blackford will significantly improve performance and should put Intel back on the map for servers. Dempsey may not beat the K8's performance, but it should be able to get within 10-20% on most benchmarks. Unfortunately, Dempsey does little to reduce power consumption. However, Intel's goal is not to achieve parity with AMD's existing products. At the end of the day, everyone wants to know whether Intel's vaunted Core microarchitecture is up to the task of reclaiming the server market from AMD. Can Woodcrest really live up to the hype?

Intel gave us some performance estimates for Woodcrest that seemed to answer in the affirmative. But what is the story in the real world?

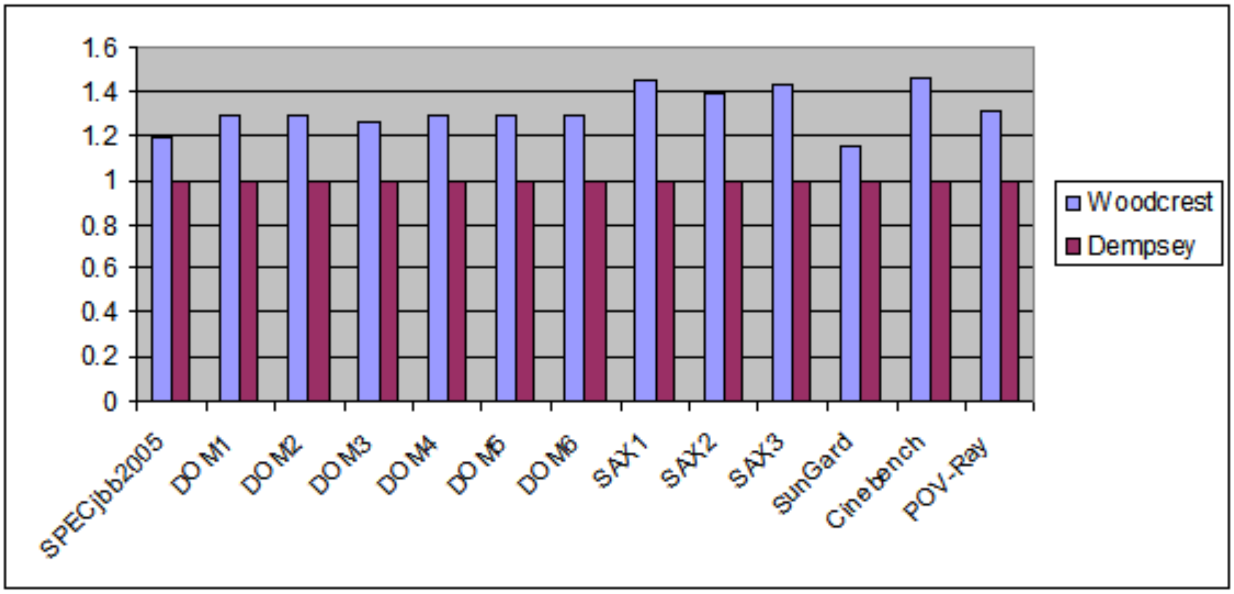

Figure 9 – Real World Relative Performance

Intel's performance estimates show an 11-50% increase in performance from Dempsey to Woodcrest. These numbers are a bit higher than ours, but they are not unreasonable. We measured 15-40% speed ups across a wide range of Windows applications, including ray tracing, Monte Carlo risk analysis, XML processing and Java based mid-tier OLTP workloads. While our numbers are lower than Intel's and our Dempsey system runs at a slightly lower clockspeed (3.4GHz versus 3.73GHz), there is still a lot of performance left on the table for Woodcrest. Current compilers, JVMs and applications have not been optimized for Woodcrest, and our system is using slower FBD-533 memory, rather than FBD-667. Furthermore, our performance is somewhat lower because we have 1 FB-DIMM per channel; two FB-DIMMs are needed for the best performance.

Given all this information, Woodcrest should outperform competing F-stepping Opterons (which should hit 2.8GHz, or maybe even 3.0GHz) by around 10-30% in most applications, when it arrives in June. The icing on the cake is a subject we have not even discussed: power and energy. Our anecdotal observation is that Woodcrest systems use half the power of Dempsey systems, while providing much better performance, but we will have some real data in the near future. The bottom line is that Intel is well positioned to regain control of the dual socket server market from June, till the start of 2007.