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PRESCOTT PUSHES PIPELINING LIMITS

Even With 31 Stages and 90nm Process, It's Only Slightly Faster

By Peter N. Glaskowsky {2/2/04-01}

Intel launches its new 90nm Pentium 4 processor today, but there's no party—no great cause for celebration. After two years of promises, hints, and rumors, the facts are somewhat disappointing. Prescott is being announced at speeds from 2.8GHz to 3.4GHz, but it simply isn't good enough to take a place at the top of Intel's x86 product line. Intel is also boosting the speeds of its 130nm chips, the Northwood Pentium 4 and Gallatin Pentium 4 Extreme Edition, to 3.4GHz. The latter product remains the highest-performance x86 processor Intel offers.

Consider the technology Intel put into Prescott. The core was completely redesigned, giving it 31 pipeline stages for simple integer operations—up from 20 in Northwood. Intel is using one of the industry's first 90nm processes, with strained-silicon transistors and seven layers of copper interconnect with low-*k* carbon-doped silicon oxide (CDO, also known as organosilicate glass, or OSG) dielectric. Prescott also has a larger, better L1 data cache (16K with eight-way set associativity compared with 8K and four sets); a larger L2 cache (1M vs. 512K); and more store buffers (32 vs. 24). Other microarchitectural improvements were made to the branch predictors, floating-point instruction scheduler, prefetch logic, integer multiplier, shift and rotate operations, and the Hyper-Threading logic.

Prescott also benefited from new layout tools. Northwood was designed with each functional block implemented in a separate region of the floor plan, with clearly distinct boundaries. In Prescott, functional units were designed independently but laid out together, with transistors located as needed to improve performance for the whole chip. Functional units overlap each other; there are few physical boundaries.

All these changes turn out to produce no net clock-speed increase at launch and only minor improvements in architectural performance. According to Intel, the 3.4GHz Prescott's SPECint2000 scores are only about 5.7% better than those of the 3.4GHz Northwood. SPECfp2000 scores go up about 11.5%. We attribute these increases mostly to the cache enhancements—not to the changes in the core.

Intel's customers will enjoy the performance improvement at no extra cost; Intel says Prescott will sell for the same price as an equal-frequency Northwood. That's good for the customers, but not so good for Intel, which is usually able to charge premium prices for premium performance.

The changes led to a dramatic increase in transistor count. Northwood has about 55 million transistors; Prescott has about 125 million. Intel attributes the increase to four factors: the larger caches, the deeper pipeline, the minor microarchitectural enhancements mentioned earlier, and features added to enhance manufacturability and yield. After accounting for the caches, we estimate the Prescott processor core has about 2.5 times as many transistors as Northwood's core.

Because of the increase in transistor count, Prescott is not much smaller or cheaper to make than Northwood. Northwood is 132mm^2 in size; Prescott is 112mm^2. Prescott is initially being made in Intel's D1C development fab and will be moved to the F11X production fab as quickly as possible. Intel will certainly obtain more die per wafer—about 16% more, based on die size alone—but we believe it will take time for yields on the 90nm process to match those on the more mature 130nm process.

AMD is already shipping a desktop Athlon 64 processor rated at "3400+" with 2.2GHz core frequency. This rating is officially a comparison with other AMD processors, but the foundation of the system is the Pentium 4's performance. We believe Prescott will put Intel into a better position vis-à-vis the 3400+, probably a little slower on most applications but with definite advantages for 3D gaming and video processing.

AMD plans to bring the 128-bit memory interface from its Opteron and Athlon 64 FX processors to mainstream desktops within the next few months, and we expect further clock-speed increases from AMD as well. These changes should put AMD solidly back into the lead over Prescott—unless Intel can quickly obtain more speed from the Prescott core.

Has x86 Finally Hit the Wall?

Clock-speed scaling hasn't been an Intel strength over the past few years. The Pentium 4 was introduced in late 2000 at 1.5GHz, manufactured in 180nm technology. Today, two process generations and more than three years later, it has just reached 3.4GHz. By Intel's own estimates, the Pentium 4 family has only doubled its performance during that time, despite more than doubling its core clock rate and the performance of other elements of its system architecture.

Joy's Law holds that CPU performance doubles every 18 months or so, yielding a four times gain in three years. Obviously Intel is well behind that curve. AMD is doing no better; Athlon 64 runs at 2.2GHz now, and the original Athlon ran at 1.1GHz when the Pentium 4 came out. AMD can point to its 64-bit architecture as an additional source of performance, but this does not provide a compelling argument for most users.

On more than one occasion in the past, the x86 architecture has appeared to run out of room to grow, only to break loose and obtain a little more headroom with the release of new implementations. Prescott does not appear to be such an implementation. Other companies have seen better results from 90nm technology, even without new microarchitectures. IBM's PowerPC 970FX, which we expect to gain about 25% in clock speed over its 130nm predecessor without having a redesigned core, is one example. This achievement puts PowerPC right on the Joy's Law pace, with about four times the performance of PowerPC chips available in early 2001. TI's 320C64x core is another example: it reached 720MHz in 130nm and is now running at 1GHz in 90nm. TI's 300MHz 320C55 DSP—with less than half the parallelism of the C64x—was state of the art in early 2001.

All these facts leave us wondering about the value proposition for Prescott. It's not much faster than Northwood, and most of that improvement could have been achieved without redesigning the core. Prescott is not much less costly to make, and it consumes considerably more power (103W vs. Northwood's 82W at 3.2GHz).

The ultimate question must be this: Why did Intel bother? The facts we have don't seem to justify the costs of the project, even given the 4GHz performance promised by the end of 2004. We believe the Northwood core, retargeted for a 90nm process and paired with new, larger caches, would have produced a smaller, faster chip.

There may be some other reason for Prescott's existence. We can only speculate, but the Prescott situation may be the result of a combination of factors—a redesign needed to integrate the rumored Yamhill 64-bit extensions, a process that doesn't yield the transistor or interconnect speeds Intel expected, plus the company's commitment to 90nm fabs, which must now be filled.

We'll learn more about Prescott at the International Solid-State Circuits Conference (ISSCC) and Intel Developer Forum (IDF) in February. Following those presentations, we'll be able to take a more detailed look at Prescott, and perhaps then it will make more sense. ◇