Pitfall: The MIPS instruction add immediate unsigned `addiu` *sign-extends its 16-bit immediate field.*

Despite its name, add immediate unsigned (`addiu`) is used to add constants to signed integers when we don't care about overflow. MIPS has no subtract immediate instruction and negative numbers need sign extension, so the MIPS architects decided to sign-extend the immediate field.

Fallacy: Only theoretical mathematicians care about floating-point accuracy.

Newspaper headlines of November 1994 prove this statement is a fallacy (see Figure 3.23). The following is the inside story behind the headlines.

The Pentium uses a standard floating-point divide algorithm that generates multiple quotient bits per step, using the most significant bits of divisor and dividend to guess the next 2 bits of the quotient. The guess is taken from a lookup table containing –2, –1, 0, +1, or +2. The guess is multiplied by the divisor and

FIGURE 3.23 A sampling of newspaper and magazine articles from November 1994, including the *New York Times, San Jose Mercury News, San Francisco Chronicle,* and *Infoworld.* The Pentium floating-point divide bug even made the "Top 10 List" of the *David Letterman Late Show* on television. Intel eventually took a $300 million write-off to replace the buggy chips.

subtracted from the remainder to generate a new remainder. Like nonrestoring division (see Exercise 3.29), if a previous guess gets too large a remainder, the partial remainder is adjusted in a subsequent pass.

Evidently there were five elements of the table from the 80486 that Intel thought could never be accessed, and they optimized the PLA to return 0 instead of 2 in these situations on the Pentium. Intel was wrong: while the first 11 bits were always correct, errors would show up occasionally in bits 12 to 52, or the 4th to 15th decimal digits.

The following is a time line of the Pentium bug morality play:

- *July 1994:* Intel discovers the bug in the Pentium. The actual cost to fix the bug was several hundred thousand dollars. Following normal bug fix procedures, it will take months to make the change, reverify, and put the corrected chip into production. Intel planned to put good chips into production in January 1995, estimating that 3 to 5 million Pentiums would be produced with the bug.

- *September 1994:* A math professor at Lynchburg College in Virginia, Thomas Nicely, discovers the bug. After calling Intel technical support and getting no official reaction, he posts his discovery on the Internet. It quickly gained a following, and some pointed out that even small errors become big when multiplying by big numbers: the fraction of people with a rare disease times the population of Europe, for example, might lead to the wrong estimate of the number of sick people.

- *November 7, 1994: Electronic Engineering Times* puts the story on its front page, which is soon picked up by other newspapers.

- *November 22, 1994:* Intel issues a press release, calling it a "glitch." The Pentium "can make errors in the ninth digit. . . . Even most engineers and financial analysts require accuracy only to the fourth or fifth decimal point. Spreadsheet and word processor users need not worry. . . . There are maybe several dozen people that this would affect. So far, we've only heard from one. . . . [Only] theoretical mathematicians (with Pentium computers purchased before the summer) should be concerned." What irked many was that customers were told to describe their application to Intel, and then *Intel* would decide whether or not their application merited a new Pentium without the divide bug.

- *December 5, 1994:* Intel claims the flaw happens once in 27,000 years for the typical spreadsheet user. Intel assumes a user does 1000 divides per day and multiplies the error rate assuming floating-point numbers are random, which is one in 9 billion, and then gets 9 million days, or 27,000 years.

Things begin to calm down, despite Intel neglecting to explain why a typical customer would access floating-point numbers randomly.

- *December 12, 1994:* IBM Research Division disputes Intel's calculation of the rate of errors (you can access this article by visiting *www.mkp.com/books_catalog/cod/links.htm*). IBM claims that common spreadsheet programs, recalculating for 15 minutes a day, could produce Pentium-related errors as often as once every 24 days. IBM assumes 5000 divides per second, for 15 minutes, yielding 4.2 million divides per day, and does not assume random distribution of numbers, instead calculating the chances as one in 100 million. As a result, IBM immediately stops shipment of all IBM personal computers based on the Pentium. Things heat up again for Intel.
- *December 21, 1994:* Intel releases the following, signed by Intel's president, chief executive officer, chief operating officer, and chairman of the board: "We at Intel wish to sincerely apologize for our handling of the recently publicized Pentium processor flaw. The Intel Inside symbol means that your computer has a microprocessor second to none in quality and performance. Thousands of Intel employees work very hard to ensure that this is true. But no microprocessor is ever perfect. What Intel continues to believe is technically an extremely minor problem has taken on a life of its own. Although Intel firmly stands behind the quality of the current version of the Pentium processor, we recognize that many users have concerns. We want to resolve these concerns. Intel will exchange the current version of the Pentium processor for an updated version, in which this floating-point divide flaw is corrected, for any owner who requests it, free of charge anytime during the life of their computer."Analysts estimate that this recall cost Intel $500 million, and Intel employees did not get a Christmas bonus that year.

This story brings up a few points for everyone to ponder. How much cheaper would it have been to fix the bug in July 1994? What was the cost to repair the damage to Intel's reputation? And what is the corporate responsibility in disclosing bugs in a product so widely used and relied upon as a microprocessor?

In April 1997 another floating-point bug was revealed in the Pentium Pro and Pentium II microprocessors. When the floating-point-to-integer store instructions (`fist`, `fistp`) encounter a negative floating-point number that is too large to fit in a 16- or 32-bit word after being converted to integer, they set the wrong bit in the FPO status word (precision exception instead of invalid operation exception). To Intel's credit, this time they publicly acknowledged the bug and offered a software patch to get around it—quite a different reaction from what they did in 1994.