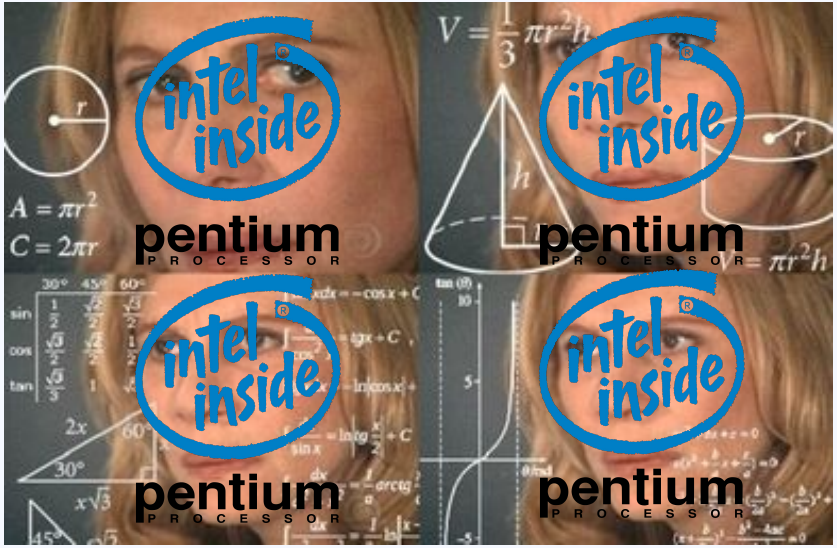
Warmup question: what is the point of floating point?



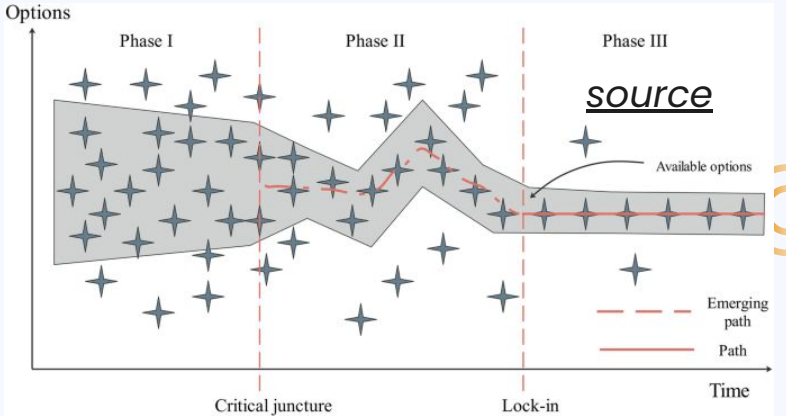
Story of the Intel Pentium fdiv bug

x86 was actually a mistake

(Literally… not editorializing)

- 1976: Intel 8800 (iAPX 432) development begins; with huge teams of PhDs; touted as the permanent future of Intel
- 8800 development ambitious and takes forever
- 1979: need stop-gap 16-bit competitor to Motorola et al; extends 8080 in three calendar weeks – called **8086**
- 1981: IBM goes with version of 8086 over Motorola; sells 100 million units

Moore's prediction was thus correct that the next ISA would last as long as Intel did, but the marketplace chose the emergency replacement 8086 rather than the anointed 432. As the architects of the Motorola 68000 and iAPX-432 both learned, the marketplace is rarely patient. *source*



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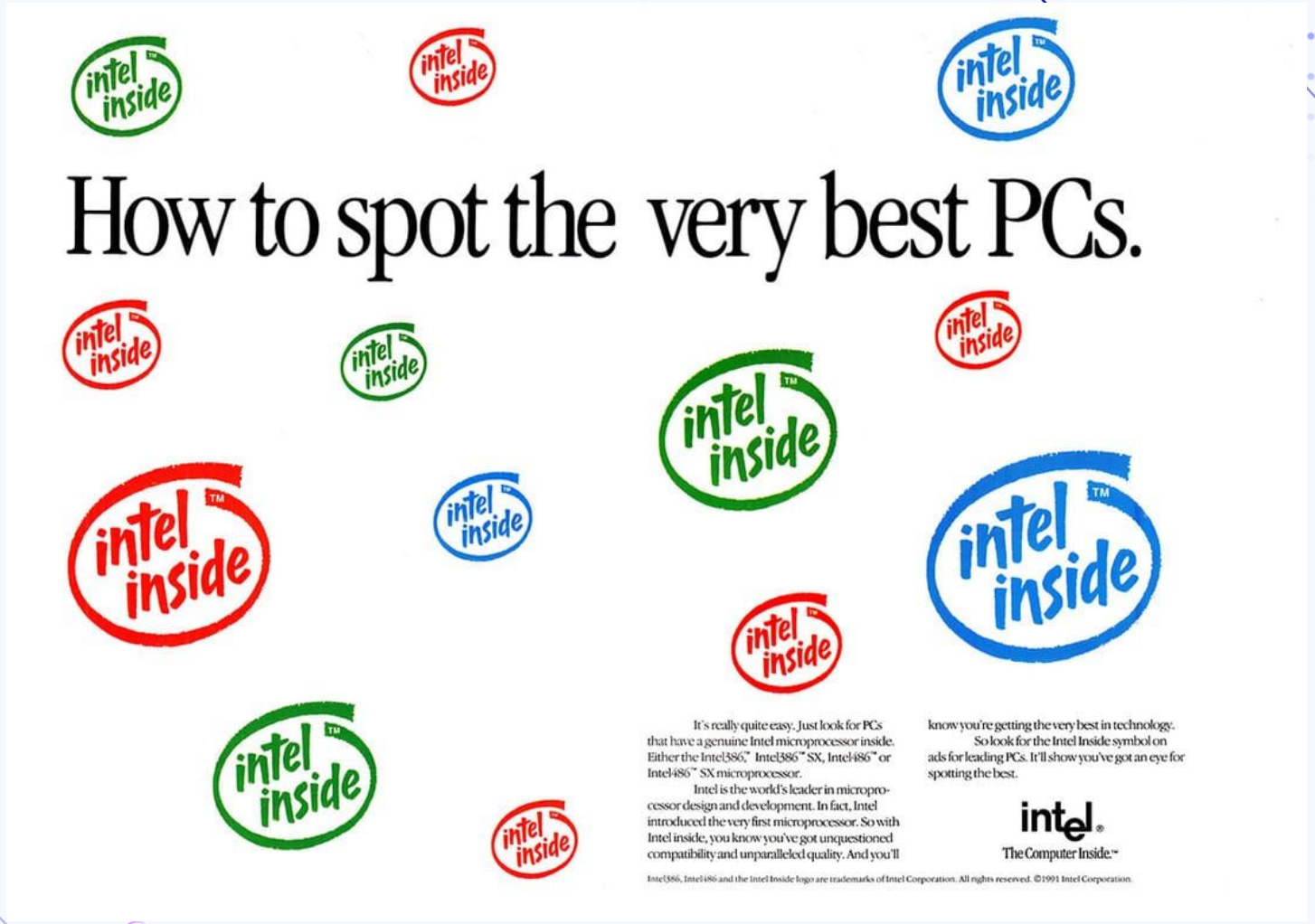
How to spot the very best PCs.
It's really quite easy. Just look for PCs that have a genuine Intel microprocessor inside. Either the Intel386,™ Intel386™ SX, Intel486™ or Intel486™ SX microprocessor.
Intel is the world's leader in microprocessor design and development. In fact, Intel introduced the very first microprocessor. So with Intel inside, you know you've got unquestioned compatibility and unparalleled quality. And you'll know you're getting the very best in technology.
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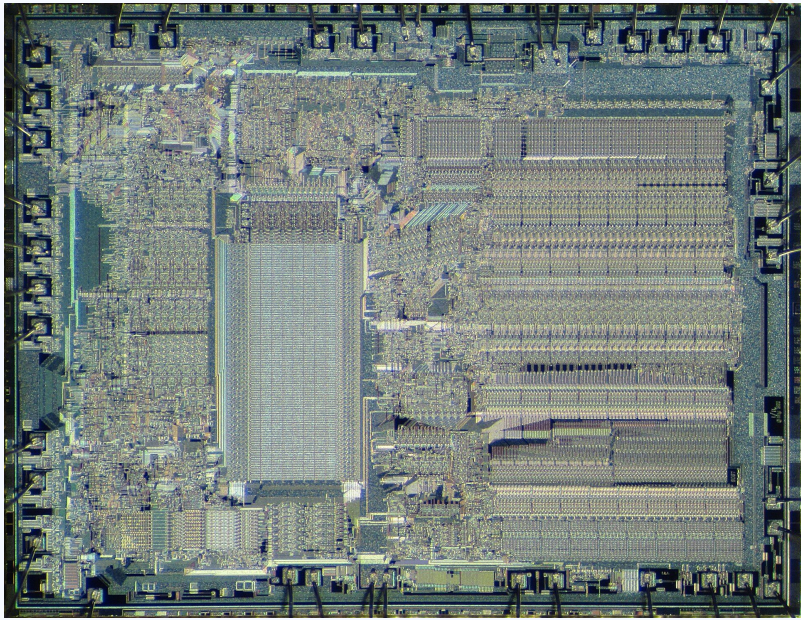
intel
The Computer Inside.™
Intel386, Intel486 and the Intel Inside logo are trademarks of Intel Corporation. All rights reserved. ©1991 Intel Corporation.

At the same time: Intel 8087

Floating-point **coprocessor** for 8086/8088

Heavily influenced the IEEE 754 FP standard



Before then: Wild West of FP

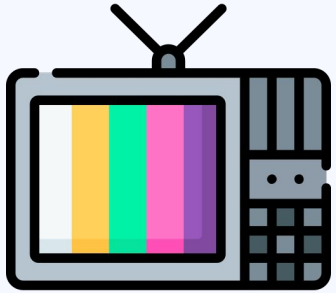
Representing approximate numbers was **not standardized**

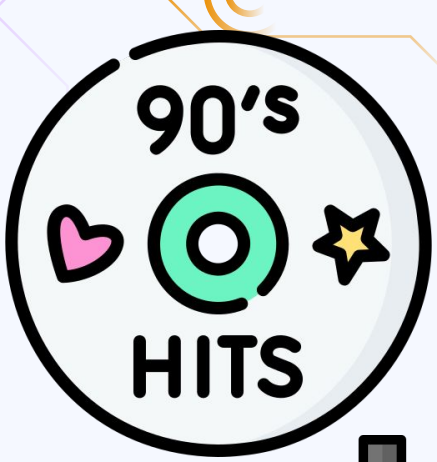
Same code produced different results on different computers … but rounding error is inevitable, so maybe this is OK

“Portable” software packages (Linpack, Eispack) cost a lot ($100/LOC) to develop

Led to issues when people upgraded their computers (IBM 7094 → System/360 meant doubles worked *worse* than single-precision)

See P&H 3.11 for more of the story





Intel doing very well, FP is standardized… Fast-forward to 1994

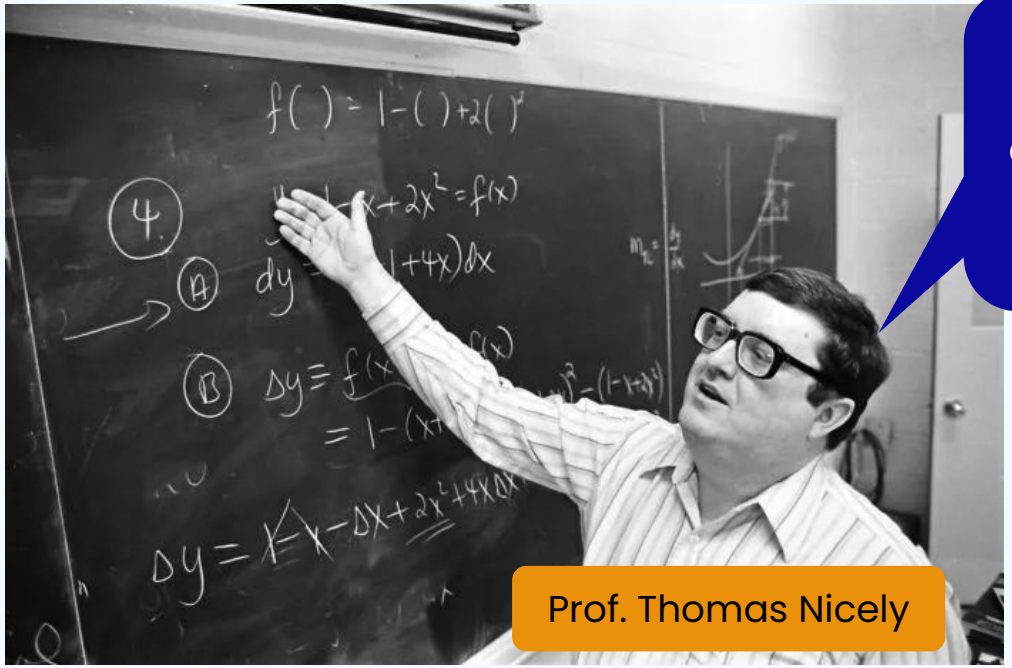


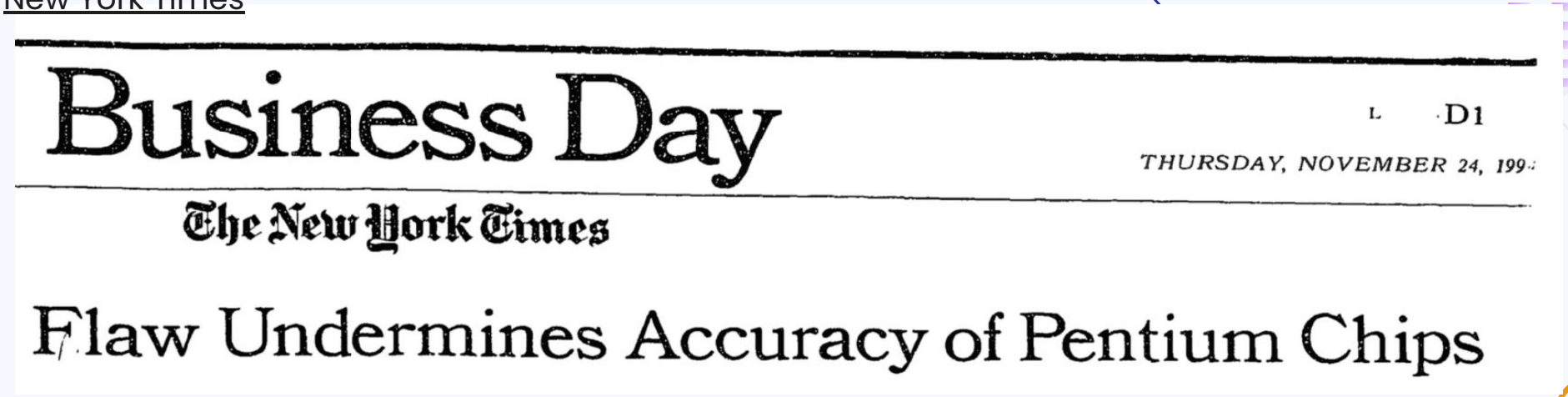
image source

yo why is my prime number program outputting weird results on my shiny new Pentium?!

shut up nerd, weird of you to do obscure divisions

intel

New York Times



Business Day

D1

THURSDAY, NOVEMBER 24, 199

The New York Times

Flaw Undermines Accuracy of Pentium Chips

$$\frac{4,195,835}{3,145,727} = 1.333739068902037589$$

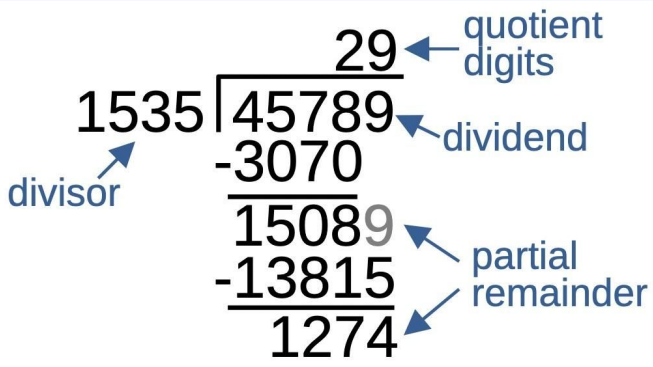
FP division algorithms

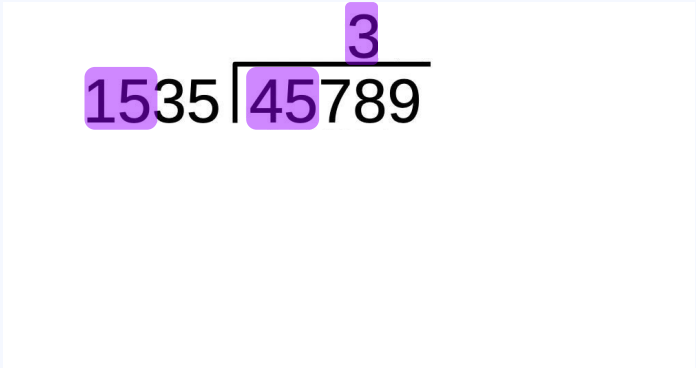
Naive algorithm: shift-and-subtract (mimics human mechanics)

Modern implementations: Sweeney, Robertson, Tocher (SRT)

- Approximation at each step
- Allow negative “digits” for adjusting
- Truncated approximation allows for lookup table

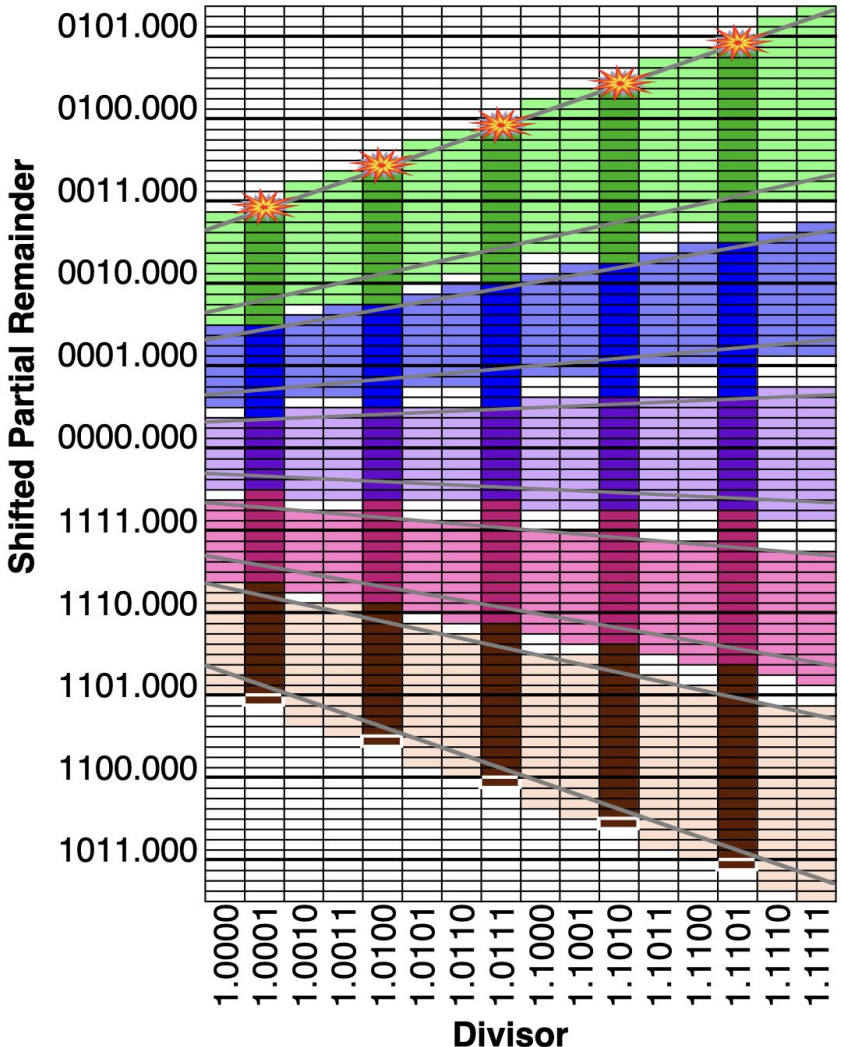
Image source and incredible blog post explainer

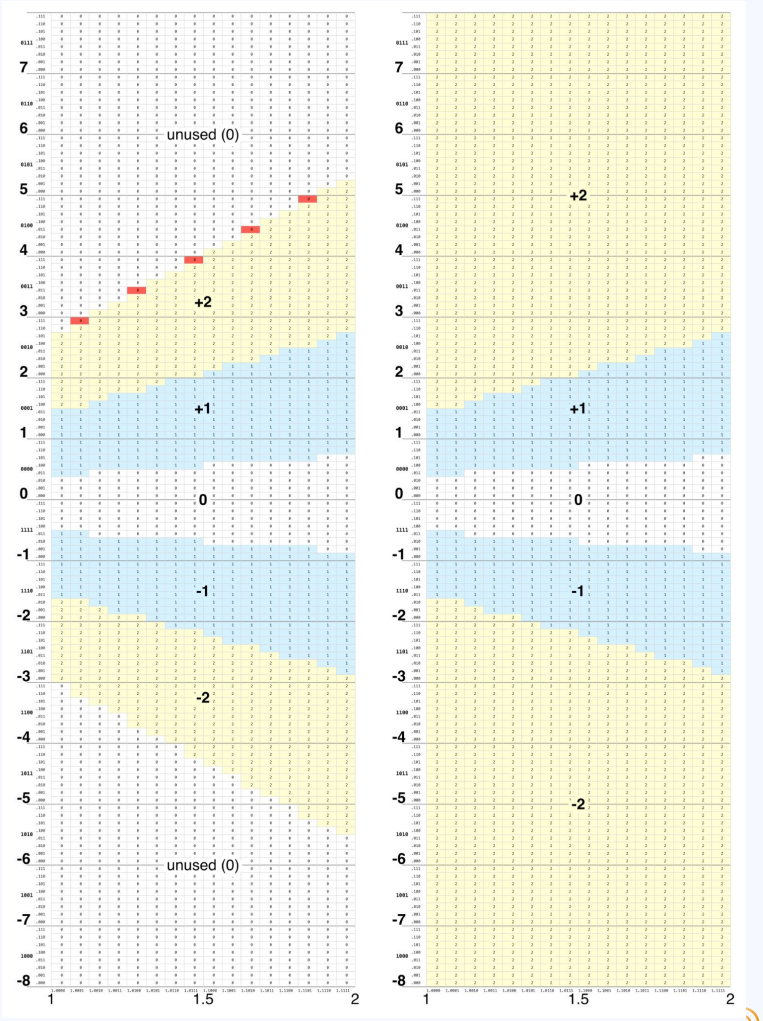




Pentium SRT table mistake

source/another explainer paper

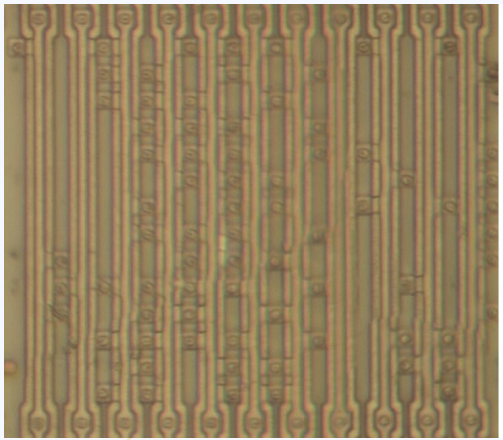




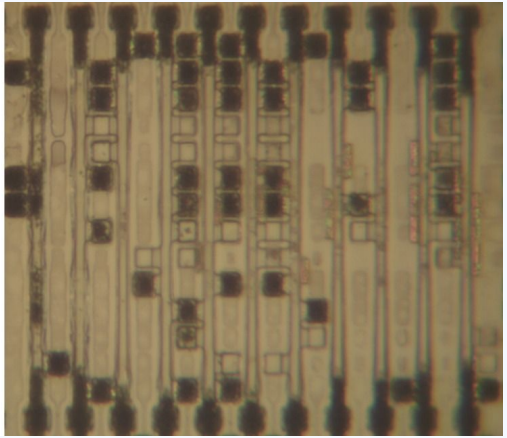
Lookup table fix

Programmable Logic Array – how combinational functions get synthesized to hardware (matrix of OR/AND gates)

Original



Fixed



Public backlash

Intel said yesterday that it did not believe the chip needed to be recalled, asserting that the typical user would have but one chance in more than nine billion of encountering an inaccurate result as a consequence of the error, and thus there was no noticeable consequence to users of business or home computers. Indeed, the company said it was continuing to send computer makers Pentium chips built before the problem was detected.

New York Times, Nov 24 1994

Statistical Analysis of Floating Point Flaw in the Pentium™ Processor (1994)

Intel Corporation

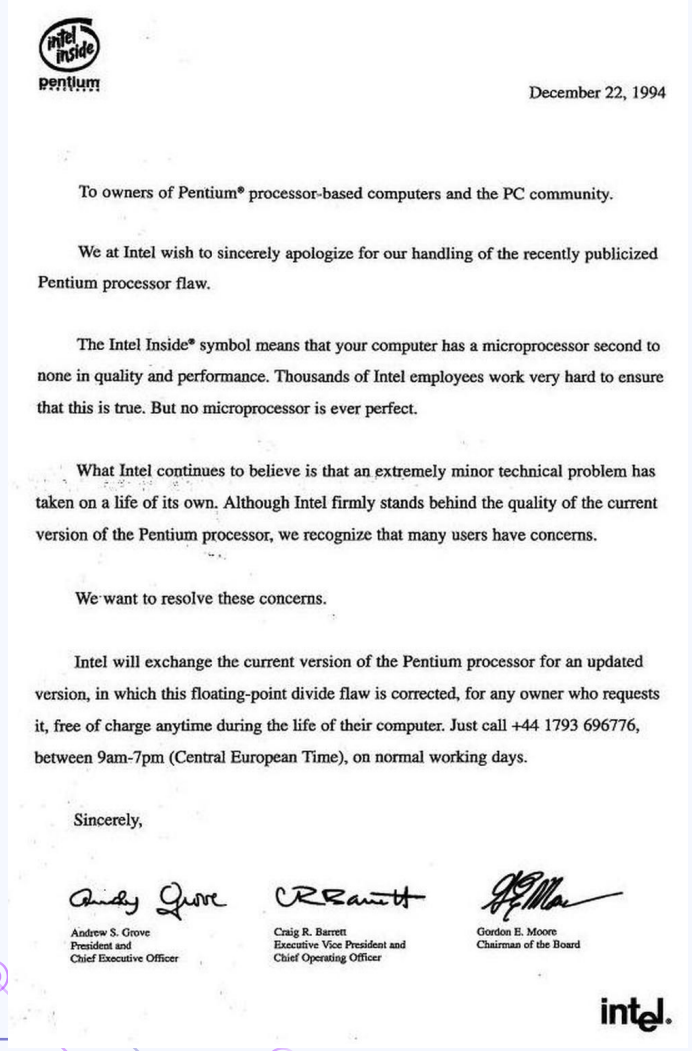
source

November 30th 1994

New York Times, Dec 13 1994

I.B.M. Deals Blow to a Rival As It Suspends Pentium Sales

By PETER H. LEWIS



December 22, 1994

To owners of Pentium® processor-based computers and the PC community.

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 that an extremely minor technical 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. Just call +44 1793 696776, between 9am-7pm (Central European Time), on normal working days.

Sincerely,

Andrew S. Grove
President and
Chief Executive Officer

Craig R. Barrett
Executive Vice President and
Chief Operating Officer

Gordon E. Moore
Chairman of the Board

intel.

17 Jan 1995 Intel announces a pre-tax charge of 475 million dollars against earnings, ostensibly the total cost associated with replacement of the flawed processors.

source

Lessons Learned: Pentium Flaws Aid Intel In Sandy Bridge Chipset Recall

BY ZEWDE YERASWORK
MARCH 30, 2011, 10:00 AM EDT

CRN ADD AS A PREFERRED GOOGLE SOURCE

Intel is receiving mostly positive feedback for its handling of the Sandy Bridge chipset recall, and a big reason for that may be the chip maker's past missteps in dealing with high-profile design errors and recalls.

The world's largest chip maker was once known for making critical mistakes related to product flaws, and one episode in particular 17 years ago proved to be a crucial learning experience for Intel that helped it avoid a potentially embarrassing repeat.

source

A delightfully snarky article from the time

But shouldn’t they have tested?

Retrospective with nicely presented opinions on hardware testing

Consequently, Intel's proof checked only half of the programmable lookup array (PLA), assuming that the other half was the mirror image. But that's where the bugs were. "These two mistakes—one to have a mistake in the proof, the other to have a sort of typo that caused a flaw in the design—need not have been fatal." What was actually fatal was failing to think about whether a different design than what was in the corporate legacy should have different testing. "They were blinded by their proof, so they didn't think of what kind of tests they should use."

source (Pentium 4 came out in 2000)

Formal Verification in Intel CPU Design

John O'Leary
Strategic CAD Labs, Intel Corporation
john.w.oleary@intel.com

Abstract

This talk will relate a success story: formal verification of floating-point operations implemented in hardware, using a combination of model checking (symbolic trajectory evaluation) and higher-order logic theorem proving. Our tools and methods have been applied to a number of design projects, including the Pentium (R) 4 processor. In designing the Pentium 4 formal verification was indispensable, capturing several extremely subtle bugs that eluded simulation. Any of these could have resulted in an FDIV-like recall. The talk will explain the tools and technologies we used, the lessons we learned, and next challenges we face.

source (Nehalem came out in 2008)

Replacing Testing with Formal Verification in Intel® Core™ i7 Processor Execution Engine Validation

Roope Kaivola, Rajnish Ghughal, Naren Narasimhan, Amber Telfer, Jesse Whittemore, Sudhindra Pandav, Anna Slobodová, Christopher Taylor, Vladimir Frolov, Erik Reeber, and Armaghan Naik

Intel Corporation, JF4-451, 2111 NE 25th Avenue, Hillsboro, OR 97124, USA

RE:RE:FWD:FWD:RE:FWD:

TOP TEN NEW INTEL SLOGANS FOR THE PENTIUM (*source*)

9.9999973251 It's a *FLAW*, not a Bug
8.9999163362 It's Close Enough, We Say So
7.9999414610 Nearly 300 Correct Opcodes
6.9999831538 You Don't Need to Know What's Inside
5.9999835137 Redefining the PC -- and Mathematics As Well
4.9999999021 We Fixed It, Really
3.9998245917 Division Considered Harmful
2.9991523619 Why Do You Think They Call It *Floating* Point?
1.9999103517 We're Looking for a Few Good Flaws
0.9999999998 The Errata Inside