A Virtue Ethics Analysis of Intel's Response to Pentium FDIV Bug

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Spring 2023

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

In 1994, a mathematics professor found a bug in the recently released Intel's Pentium chip. The division algorithm embedded in the chip would make mistakes on some specific numbers, and the worst case would result in a mistake in the fourth significant digit (Edelman, 1997). Intel, initially convinced that the bug was minor and would only affect a small percentage of users, offered a conditional replacement policy to those who could prove that they were affected by the bug. However, Intel's response faced strong backlash from consumers, and Intel finally conceded to implement an on-request replacement policy. The whole event significantly harmed Intel's reputation.

Current academic works focus on Intel's mistake in inadequate testing and mishandling public relations (Price, 1995). However, few studies have been done in addressing the ethical issues in this case. A comprehensive understanding of the ethical implications of Intel's response would not only illustrate what went wrong in Intel's decisions, but also guide future practices if similar situations arise. The lack of systematic analysis, therefore, hinders understanding and prevents useful conclusions from being drawn.

I will apply virtue ethics to reason that Intel's initial response is unethical, that the unconditional replacement policy is moral, and that this case exemplifies how virtue can be learned. Virtue ethics determines the morality of actions based on if the actor possess certain desirable characteristics. Specifically, I will show that Intel initially lacked the virtue of clear communication but later demonstrated the virtue of making compromises. I will provide evidence, such as newspaper articles during the event and Intel's response and announcements, to justify my position.

Background

Intel's Pentium chip, released in 1993, used the newly developed SRT algorithm for floating-point division. The implementation required a prepopulated array of 1066 cells, among which five cells had their values mistakenly etched. As a result, divisions requiring these five cells would acquire errors. This bug was known as the Pentium FDIV bug due to the x86 assembly language mnemonic for floating-point division. Although the severity of the bug was debated, it was mathematically clear that only a small percentage of numbers would result in an error (Edelman, 1997). Intel claimed that an average Excel user would encounter the bug in 21000 years (Williams, 1997). Indeed, even after Intel implemented the on-request replacement policy, only about 10 percents of the users requested a replacement (Williams, 1997). In the end, Intel's replacement of chips costed about 475 million dollars pre-tax, which resulted in a significant decrease in revenue in 1994 for the company (Johnson, 1995).

Literature Review

While several scholars have examined the root cause of the Pentium FDIV bug, they focus on the technical aspects of the bug and offer ideas to improve the testing process to prevent future bugs. Another work partially addresses the need for ethical analysis by applying the framework of utilitarianism and Kant's duty ethics. However, the work evades the discussion using virtue ethics, which makes the scholar discourse incomplete.

In *The Mathematics of the Pentium Division Bug*, Alan Edelman illustrates the mathematical details of the bug (Edelman, 1997). Edelman describes the SRT algorithm in detail. Using rigorous mathematical reasoning, Edelman settles the debate of the severity of the bug and provides strict bound on how much error the division algorithm could acquire. Edelman, however, does not analyze the bug through either the lens of computer engineering or engineering ethics.

To further address the technical problems in Intel's design and manufacturing of the chips, Dick Price illustrates how Intel failed to comprehensively test the chip before its release (Price, 1997). Price first describes the different mistakes one could make when designing a computer chip, and then shows how Intel makes these mistakes in the Pentium case. Price calls for smarter and more comprehensive tests in chips design and offers specific advice for achieving that. Price also suggests slower product pace in the future. Although Price characterizes what caused the Pentium bug, and provides solutions to prevent future mistakes, his work does not mention the social and ethical aspects of the bug.

Addressing the need for ethical analysis of Intel's response to the Pentium crisis, Cindy Williams applies both the utilitarian and duty ethics frameworks to analyze Intel's behaviors (Williams, 1997). Williams first provides a timeline of Intel's response and then illustrates the need for ethical analysis. Williams further cites utilitarianism framework to reason how Intel mistakenly estimated the utility of other options. Williams notices that Intel failed to realize that its customers expected a chip that worked perfectly, so undermining that expectation lowered the customers' utility. Williams also shows that Intel misestimated two non-monetary costs. For example, Intel failed to recognize the external failure costs it incurred when handling complaints and improving public relations. After the analysis using utilitarian framework, Williams cites Kantian ethics to further show how Intel's actions violated important rights. Williams shows how withholding information regarding the chip violated the first Categorical Imperative, and how Intel's paternalistic attitude toward the customer violated the second Categorical Imperative.

Although Williams's work fills the gap in understanding Intel's behavior ethically, it is not comprehensive in that it does not include a discussion using virtue ethics.

Building on the ethical understanding with utilitarian and duty ethics, I will apply virtue ethics to analyze Intel's response. While there are certainly similarities among the ethical frameworks, I argue that virtue ethics uniquely reveals some aspects of the ethical arguments. In addition, virtue ethics allows the ethical discussion to be expanded to include the industry, as Intel's change of attitude exemplifies how virtue is not innate but has to be learned.

Conceptual Framework

I argue that the framework of virtue ethics can be applied to analyze the extent Intel's behavior is ethical during the handling of Pentium bug. Virtue ethics, originally developed by Aristotle in Ancient Greece, states that the goal of human action is to strive for "the good life" (van de Poel & Royakkers, 2011). One achieves "the good life" by possessing various virtues that lie between extremes. For example, one is to exhibit courage instead of cowardice and recklessness. The possession of virtues not only requires reasoning and knowledge about them, but also constant practice of virtues in daily actions.

In the case of engineering ethics, Michael Pritchard provides a convenient list of virtues a morally responsible engineers should possess:

Therefore, one may determine if an engineer acts ethically or not based on whether they adhere

1. Competence.
2. Ability to communicate clearly and informatively.
3. Cooperativeness (being a good "team players").
4. Willingness to compromise.
5. Perseverance.
6. Habit of documenting work thoroughly and clearly.
7. Commitment to objectivity.
8. Openness to correction (admitting mistakes, acknowledging oversight).
9. Commitment to quality.
10. Being imaginative.
11. Seeing the "big picture" as well as the details of smaller domains.

Figure 1: Pritchard's Virtues for Morally Responsible Engineers

to these virtues or not (Pritchard, 2001). Pritchard argues that failing any one of the virtues would deem the engineer morally irresponsible, and that the lack of virtue can be shown by consistently failing to act in accordance with the virtue. On the contrary, an existence of virtues can be shown by the actions that exemplify the virtues.

An important theme that virtue ethics differs from other frameworks is that virtue ethics emphasizes that virtue can, and should be, learned and practiced. According to Aristotle, determining the moral actions to take is not easy, and often needs practice and experience to see. To this end, Aristotle emphasizes the need of "practical wisdom", the virtue that enables one to make the right choice (van de Poel & Royakkers, 2011). This view of virtues differs from other frameworks in that it does not dictate morally good actions to be a priori known, but individuals need possess the ability to learn from past experiences and develop the ability to act morally.

In this paper, I apply the framework of virtue ethics to comprehensively analyze what Intel did wrong or correct throughout the Pentium crisis. Since it is difficult to attribute Intel's behavior to individuals, I will treat the Intel corporation as a whole and study the ethics of its behavior. Since Intel is a firm consisting of skilled engineers, it should be judged in the same ways engineers are. By showing evidence of whether Intel acts in accordance with the virtues, I argue whether Intel possesses a certain virtue or not. I first reason that Intel's initial response lacked the virtue of clear communication and therefore was unethical. Then, I exhibit how Intel showed the virtue of willingness to compromise and openness to correction when Intel offered the unconditional replacement policy. Finally, I show that Intel's change during the event exemplified how virtue can be learned, and that this learned virtue changed the industry for good.

Analysis

Missing virtue: clear communication

I first argue that Intel's initial actions violate the virtue of clear communication by first not disclosing the bug after recognizing it inside the company, not acknowledging the bug, and finally using overly technical terms in communication with customers. As Pritchard argues, the ability to communicate clearly and informatively to customers is an important virtue for a morally responsible engineer (Pritchard, 2001). Communication is even more important when the product has a bug since consumers have relatively less information and power than engineers.

Before I describe how Intel failed to communicate the bug to customers, I first briefly exhibit the timeline of events from the discovery of the bugs to the implementation of unconditional replacement policy. In June 1994, Thomas Nicely, a mathematics professor at Lynchburg University, discovered the bug while working on a number theory problem (Williams, 1997). After reworking the numbers with other computers and confirming with friends, he called Intel in October to report his findings. Intel, initially not acknowledging existence of the bug, admitted only when the major newspapers reported the bug later in November that its engineers had also discovered the bug during the summer. Intel then announced to accept replacement requests if the user could prove that they are working on something that would be affected by the bug. However, facing strong customer backlash, Intel compromised and finally offered an unconditional replacement policy in December.

There are many errors Intel made to communicate with customers during the event. First, Intel should have immediately disclosed the existence of the bug and advised the customers what to do with it. Instead, Intel discovered the bug in June but only acknowledged it later in November. According to an article in *InfoWorld*, a magazine in the information technology field, "Intel has a long-established tradition of meticulously listing errors for any chip it manufactures in errata sheets" (Crothers, 1994). However, Intel did not document the Pentium FDIV bug "for some perplexing reason" (Crothers, 1994). Being the engineers, Intel had more power than the customers to recognize bugs, and by not communicating to customers about the existence of the bug could cause the customers to lose trust in the company. In this case, Intel's action of not acknowledging the bug may have deeper intention, since it contradicted its tradition of listing errors in errata sheets. This further shows that Intel failed to show the virtue of clear communication.

Besides keeping the bug secret at the beginning, Intel's miscommunication is further exemplified by its initial attitude toward the bug. In a newspaper article featuring an interview with Nicely, the professor who discovered the bug, Nicely said that he was "brushed off" by Intel when he called (Baker, 1994). Intel did not recognize that the bug was a big problem, so even when customers like Nicely called to verify their findings, Intel still failed to acknowledge and report on the bug. By withholding information from the customers, Intel prevented the customers from truly understanding what is causing and the extent of the bug.

Besides not disclosing possible bugs to the public, Intel also failed to communicate clearly to customers after the bug was publicly known. According to a newspaper article in December, days after Intel announced the conditional replacement policy, Intel's president, Andrew Grove, had not given any press conferences on the Pentium problem (Corcoran, 1994). The lack of response from leadership made consumers feel left in the dark and hindered possible communication from happening. What made matters even worse was that Intel's "800" phone number that customers could talk to about possible replacement was staffed by technical specialists instead of consumer support specialists (Corcoran, 1994). The technical specialists did not help to ease the tension from the consumers since most of the users are nontechnical people who cared not about the probability of them encountering the bug but the assurance they could get from the company. By failing to provide any communication to the public effectively about the nature of the bugs, Intel lacked the virtue of clear communication, which deemed its actions morally irresponsible.

<u>Virtue: Openness to correction</u>

Contrary to Intel's initial response to the bug, Intel's final implementation of an unconditional replacement policy showed several desirable virtues, including openness to correction and willingness to make compromise. On December 19, 1994, Intel finally decided to offer replacement ships to anyone requesting one. In a *New York Times* article featuring an interview with Intel's president, the president admitted that they made a mistake: "I didn't know the scope of the problem. I didn't know until the end what the real objection was" (Markoff, 1994). By showing weakness on a major newspaper, Intel announced to the public that they had made a mistake. This action took significant courage since it could potentially harm the company's reputation further. As a result, Intel's decision was morally good because it exhibited the virtue of openness to correction, which is important in engineering practice.

In a latter ad that Intel posted on major newspapers, Intel further apologized publicly to the consumers and announced its replacement policy. A paragraph of the ad read:

> 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. (Intel Corp., 1994)

In the ad, Intel still made the point that the chip only had a minor problem and implied that most users should not worry about it. However, Intel was willing to recognize that users may have concerns, and to address these concerns, Intel offered an on-request replacement policy. Although Intel did not completely deny its position, Intel was willing to make compromises with the customers at the expense of the company. This showed that Intel possessed the virtue of willingness to make compromises, and the action was therefore more ethical.

Above I have argued that Intel admitted its earlier mistakes and thus was morally good. However, one could argue that Intel's change of attitude and policy was a result of pressure from customers and press, and thus Intel did not possess the virtue of willingness to make compromise and Intel's behavior should not be treated as morally good. However, this argument is flawed because it overestimates the public opinion over the case. Even though angry opinions could be seen on newspapers and magazines, there were also significant support for Intel's initial conditional return policy, especially those who felt that the bug was more trivial than reported.

According to an editor opinion from *InfoWorld* in January, looking back at the event, the editor conceded that there were “commentary that portray the Pentium flap as a rather overblown brouhaha caused by some troublemaking Internet surfers with nothing better to do and the irresponsible, overzealous, sensationalizing segment of the press” (Foster, 1995). The existence of these opinions showed that Intel had a choice but decided to make compromises and admitted their mistakes.

Virtues can be learned

Besides analyzing whether Intel’s actions were ethical or not, virtue ethics also offer the unique perspective that Intel’s change of response can be explained as learning the virtue. Since Intel, or other information technology companies, had probably never encountered a similar situation before, it was difficult to expect Intel to do everything right the first time. However, the experience would help the company and the whole industry to learn to practice the right thing to do. In January 1995, an article in a magazine stated that Intel “learned its lesson” and “boldly announced it would broadcast news of all its future chip imperfections over the Internet, leaving it up to the market to decide which flaws are worrisome and which are irrelevant” (Johnson, 1995). The change of policy, a “bold” move as the article called it, signified a change in Intel’s attitude toward chip imperfection and communication to customers. It showed the Intel learned from the experience and developed the virtue of active communication with customers. It also showed that Intel was further practicing the virtue of allowing criticism and letting the public decide what was a serious flaw and what was not. Intel’s change of policy could not only represent the company’s learning of virtue but also show a change in the industry. The same article notes that professionals “say Intel’s action will force smaller chip rivals, and possibly marketers of software and other computer products, to come clean on their flaws, too” (Johnson, 1995). By changing its policy, Intel, as one of the most influential IT companies, could force other companies to release their bugs too and thus make the chip industry more transparent. Thus, the Pentium crisis also makes the industry learn the virtues that Intel has learned. This shows that although virtues are not innate in individuals or companies alike, they can be learned through experience and practiced when situations arise.

Conclusion

I applied the framework of virtue ethics to analyze how Intel's initial response to the Pentium flaw was unethical, how Intel's final full replacement policy is ethical, and how the event can help Intel become a better company in handling ethical issues. I looked at specific evidence from newspaper articles and Intel's announcements to conclude that Intel failed to communicate with the customers at the beginning but showed courage and humility to concede to the customers later. By providing a virtue ethics framework, I add to the existing scholar discourse on whether Intel's actions were ethical or not. The virtue ethics framework offered unique perspectives in viewing Intel's change of attitude as learning the virtues. My analysis not only showed the power of the virtue ethics framework in studying ethical questions, but also helped to explain Intel's behavior using a formal framework. In addition, by showing what exactly Intel failed to do in its initial response, the analysis could help future companies better handle similar situations.

Reference

Baker, P. (1994, December 16). Hello, Mr. Chips: Va. teacher who found Intel's flaw. *Washington Post*. https://www.washingtonpost.com/archive/politics/1994/12/16/hello-mr-chips-va-teacher-who-found-intels-flaw/ced85f09-9d7e-4b45-9b6c-f4c1eca8debf/

Corcoran, E. (1994, December 19). The glitch that stole Intel Corp.'s Christmas. *Washington Post*. https://www.washingtonpost.com/archive/politics/1994/12/19/the-g litch-that-stole-intel-corps-christmas/5dbda034-c5be-4742-89e6-f499a11dcf0a/

Crothers, B. (1994, December 19). Vendors fail users' trust. *InfoWorld*, 16(51), 18.

Edelman, A. (1997). The mathematics of the Pentium division bug. *SIAM Review, 39(1), 54-67.*

Foster, E. (1995, January 16). Customers' victory over Intel gives rise to a new sense of hope. *InfoWorld*, 17(3), 52.

Intel Corp. (1994, December 21). Advertisement. *Wall Street Journal.*

Johnson, B. (1995, January 30). Will '94 be the year of the Pentium? *Advertising Age.*

Markoff, J. (1994, December 21). Intel's Crash Course on Consumers. *New York Times*. https://www.nytimes.com/1994/12/21/business/business-technology-intel-s-crash-course-on-consumers.html?

Price, D. (1995). Pentium FDIV flaw-lessons learned. *IEEE Micro*, 15(2), 86-88.

Pritchard, M. (2001). Responsible engineering: The importance of character and imagination.

Science and Engineering Ethics, 7(3), 391–402.

van de Poel, I., & Royakkers, L. (2011). *Ethics, technology, and engineering: An introduction*. Hoboken, NJ: Blackwell Publishing Ltd.

Williams, C. (1997). Intel's Pentium chip crisis: an ethical analysis. *IEEE Transactions on Professional Communication, 40(1), 13-19.*