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P6_3 Error 404

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Abstract

This paper presents an investigation into the probability of an error occurring given the amount of RAM usage and run time, due to cosmic ray induced soft errors. Using a model generated by IBM in the 1990s [1], the error probability was plotted as a function of both run-time and RAM usage in order to quantify the risk of program failures. It was found that the error probability increased exponentially to both increasing run time and rising RAM usage, indicating that these cosmic ray induced single event upsets will pose a potential threat to both terrestrial and space exploration electronic components.

Introduction

In 2003, the voting for an election in Belgium was taking place. Voting machines would take votes in two ways; one via entering it on the computer and one via saving the vote to a magnetic card which they dropped in a box. When tallying the votes from the computer, an error was found whereby one candidate had 4,096 more votes than was possible with the number of ballots cast. In the ensuing investigation, it was uncovered that the transistor responsible for signalling the 13th bit ($2^{12} = 4096$) was struck by a stray cosmic photon, with enough energy to flip the bit from a 0 to a 1. Before this however, due to the location of a computer chip manufacturing plant, a similar problem was found, but as the result of the trace amounts of uranium within the ceramic of the chips. It was this that resulted in IBM's investigation into these bit flips known as Single Event Upsets (SEUs), which are a type of 'soft-error'. During this investigation, the team modelled the soft-error rate [1] and found that '*a computer typically experiences one cosmic ray induced error per 256 megabytes of RAM per month*' [2]. The aim of this paper is to model and graph the risk increasing probability of a SEU occurring with increasing program system resource requirements.

Assumptions

In this paper, it is firstly assumed that the programs are run on computer chips that are not shielded from cosmic rays, nor is the computer placed within an environment that is protected from cosmic radiation, such as in a building. Secondly, whilst chip sizes have decreased since the time of IBM's analysis, it is assumed the reduction in probability of being struck by a comic ray is balanced by an increase in failure probability due to the increased sensitivity and susceptibility that results from using small chips [3]. This is because the voltages used to indicate a digital '1' or '0' are much lower, resulting in a cosmic ray being more likely to have energy to cause a bit to flip.

Method

Converting the rate given by IBM [1] into more basic units:

$$1SEU/256MB/month = 1.75 \times 10^{-16}/bit/s \quad (1)$$

Now calculating the probability of a SEU ***not*** occurring:

$$p = 1 - 1.75 \times 10^{-16} \quad (2)$$

The probability, P, that the program ***does not*** experience an error over a run-time, t, with a RAM usage, M, given that each SEU is an independent event takes the form:

$$P = p^{t*M*8*1024^2} \quad (3)$$

where the factor of 1024^2 converts M from megabytes to bytes and the factor of 8 converts from bytes to bits.

This leads us to the probability of an error ***occurring***, P_e, over run-time, t, and with RAM usage, M:

$$P_e = 1 - P \tag{4}$$

This function was inputted into R, and applied over a range of run-times and RAM usage to show their relationships. The range of run-times ran from 0 - 256 s (∼4 minutes) and RAM usage varied from 0 MB – 256 MB.

Results

The results of Eq.(4) applied over the range of inputs gives rise to the following plot:

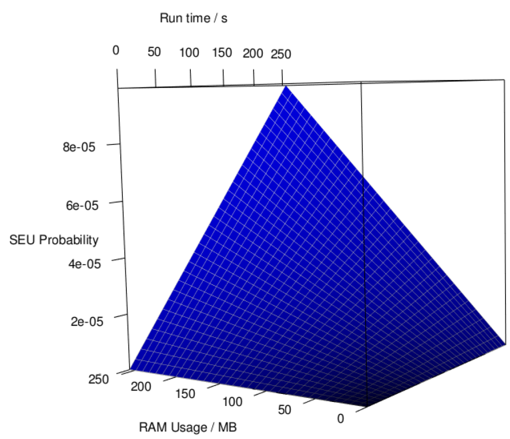

Figure 1: 3D plot showing a surface defined by the function in Eq.(4), which displays the error probability of a computer given a run-time and RAM requirement.

Discussion

The surface seen in Figure 1 shows that the error probability increases exponentially with run-time and RAM usage. Evidently, the probabilities we are dealing with, in the scope of Figure 1, are extremely small due to the rarity of a SEU occurring on any one chip. However, with the increase in complexity and capability of software programs over the past few decades, both the run-time and RAM usage have increased dramatically, running for days and/or using gigabytes of RAM respectively. The extent of Figure 1 does not capture these modern, more extreme cases, though one can clearly infer that scaling up of both the input variables leads to more considerable probabilities. For example, most modern computers require at least 8 GB of RAM [4], and are typically used for an average of 7.3 hours a day [5], resulting in a substantial error probability of $P_f = 0.278 = 27.8\%$. This poses a problem for modern electronics and requires the implementation of protective measures, particularly in the field of space technology in which the flux of radiation is significantly higher than on the Earth's surface. Examples of such measures for computers on Earth include *forward error correcting*; where integrating redundant data in each data word creates error correcting code or the use of *roll-back error detection* where parity bits can be used to rewrite incorrect data using another source. In space, a useful technique is *Triple Modular Redundancy* where a circuit is triplicated and processes the same data in parallel. The result is fed into a majority voting system as the probability of two circuits both experiencing the same error from such an event is incredibly small. Manufacturers typically don't use shielding for everyday computers, considering almost all are in buildings with thick layers of concrete, metal and other building materials that can shield from these rays. However, in space, manufacturers have taken to radiation hardening their processors and slower clocking speeds along with some of the aforementioned techniques to combat these risks.

Conclusion

The investigation featured in this paper demonstrates how the error probability of programs increases with increasing run-time and RAM usage. It implies that modern software, which typically have high resource requirements and are used over longer periods of time, can become increasingly likely to crash due to these cosmic ray induced SEUs. Measures, some of which discussed in the previous section, will need to be more frequently utilised to limit the risk posed by cosmic rays.

References

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