Fault-tolerant Iterative Solvers with Adaptive Reliability

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***Abstract*—Soft errors are increasing in modern computers. These faults can corrupt the results of scientific simulations. This work studies error propagation by a bit flip in conjugate gradient (CG) methods. We will also introduce adaptivity to selective reliable fault-tolerant (SRFT) solvers. Our study reduces the compute-intensive reliability steps in SRFT solvers.**

***Index Terms*—Fault-tolerance, iterative solvers, reliability.**

I. Introduction

The complexity of computations in scientific simulations from applications such as electromagnetics are increasing [1]. To meet these demands, semiconductor vendors are increasing transistor density per unit area in modern architecture. This transition has increased the rate of hardware errors on high-performance computing platforms. Failures from hardware errors are typically classified as hard faults and soft faults [2]. The former interrupts program execution and is easier to detect. However, soft faults, often caused by bit flips, can remain undetected and lead to wrong simulation results.

Recently, researchers have proposed selective reliable (SR) numerical methods [3], [2]. These methods guarantee convergence in the presence of faults, by making modest changes to the original algorithm. SR methods execute correction, i.e. reliability, steps that execute in a reliable computing mode. For example, the self-stabilizing conjugate gradient (SS-CG) method proposed in [3], runs a "reliable" iteration every F iterations of the CG algorithm. The reliable iterations in self-stabilizing CG are more compute-intensive than a standard iteration of the CG algorithm. Thus, F has to be carefully chosen to reduce the overhead of reliability in the solver. To our knowledge, we are the first to propose techniques to adaptively change F based on error prorogation proprieties and the algorithm. Our work reduces the number of required reliable iterations in SS-CG and reduces the cost of selective reliability in fault-tolerant iterative methods.

II. Error Propagation and Adaptive Reliability

The contributions of this work are two fold: 1- we first study the relation between a bit flip and error propagation on the iterative solver convergence rate, 2- from the aforementioned study, we propose techniques to adaptability change F, the frequency of running a reliable iteration, in SR iterative solvers. To demonstrate the effects of flipping bits and their significance in propagating errors, we flip different bits in the step length vector in CG. Figure 1 shows the bit flip pattern in our experiments. To allow the iterative solver to converge in reasonable time in the presence of faults, we use SS-CG. Because of space limitations, we only show results for the FEM_3D_thermal1 matrix from the UF matrix repository. As shown in figure 2, bit flips in the exponent have

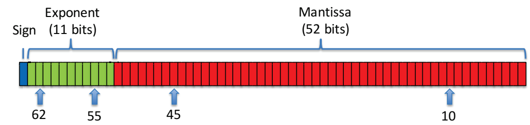

Fig. 1. The IEEE-754 Binary64 data layout and flipped bits.

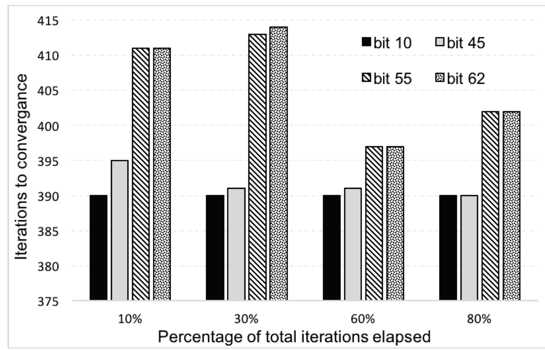

Fig. 2. The CG convergence rate in the presence of faults. X% shows a bit flip occurred in the first X% iterations, bit X shows the Xth bit was flipped.

a more noticeable effect on the iterative solver convergence rate. Also, if a bit flips occurs at the beginning of the execution it will have a more negative effect on the total of number of iterations. From this study, we propose to adaptively change the frequency of running reliable iterations in SS-CG. Although the SS-CG algorithm from [3] uses a fixed F, our proposed *Adaptive–F* method in Table I increases F by 5 every 100 iterations. Thus, while the *Adaptiv–F* method runs 4 times less reliable iterations, i.e. does less operations, it still shows a similar convergence behavior compared to the *Fixed–F* method. To conclude, this work proposes adaptive SR solvers that are able to tolerate faults and reduce the communication-cost of standard SRFT methods. Analytical study of the methods and other benchmark results will be presented in the long version of the paper.

TABLE I
Convergence Rate of Adaptive–F vs. Fixed–F, Flip-X% Shows a Bit Flip Occurred in The First X% Iterations

Method	Flip-10%	Flip-30%	Flip-60%	Flip-80%
Adaptive–F	407	409	399	401
Fixed–F = 5	411	413	397	402

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