POSTER: Go Green Radio Astronomy

Approximate Computing Perspective: Opportunities and Challenges

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ABSTRACT

Modern radio telescopes require highly energy/power-efficient computing systems. Signal processing pipelines of such radio telescopes are dominated by accumulation based iterative processes. As the input signal received at a radio telescope is regarded as Gaussian noise, employing approximate computing looks promising. Therefore, we present opportunities and challenges offered by the approximate computing paradigm to achieve the required efficiency targets.

CCS CONCEPTS

• **Computing methodologies** → **Model development and analysis**; • **Hardware** → *Power and energy*; • **Computer systems organization** → Heterogeneous (hybrid) systems;

KEYWORDS

approximate computing, iterative workloads, power efficiency, energy efficiency, radio astronomy.

ACM Reference format:
G.A. Gillani, and A.B.J. Kokkeler. 2019. POSTER: Go Green Radio Astronomy. In *Proceedings of CF'19, Alghero, Italy, April 30-May 2, 2019,* 2 pages.
https://doi.org/10.1145/3310273.3323427

1 INTRODUCTION

Modern radio telescopes like the Square Kilometer Array (SKA) aim to increase our understanding of the universe like creation and evolution of galaxies, cosmic magnetism, and the possibility of life beyond earth [1]. To investigate such phenomena, a radio telescope has to offer very high sensitivity, resolution, and survey speed [2]. This brings terabytes of raw data per second to be processed. The consequence is a huge power consumption if the contemporary computing systems are utilized, e.g., 7.2MW is required for the fused multiply-add operations within the Science Data Processing (SDP) pipeline of SKA1-Mid [9].

The SDP pipeline of a radio telescope takes visibilities as input and provides a radio image of the sky as output. It is mainly comprised of instrument calibrator, gridder, and FFTs [6, 9, 11]. These are mainly accumulation based iterative processes that also utilize approximate algorithms like Least Squares (LS) [4, 8, 10, 11]. An example is the calibration processing signal-flow, shown in Fig. 1,

CF'19, April 30-May 2, 2019, Alghero, Italy

ACM ISBN 978-1-4503-6685-4/19/05.
https://doi.org/10.1145/3310273.3323427

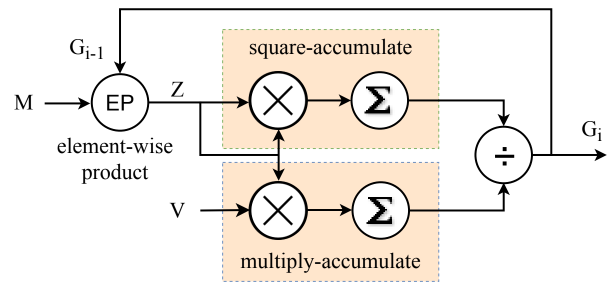

Figure 1: Radio Astronomy Calibration Processing [4].

where the antenna gains (G) of a radio telescope are iteratively estimated by processing the model (M) and the current (V) visibilities [4, 10]. The input signal that is received at a radio telescope can be regarded as gaussian noise [3]. The characteristic of radio astronomy processing is an excellent match with that of approximate computing promising candidates, namely: noisy data input and the signal processing based on iterative and approximate algorithms [5].

Contributions: Targeting energy/power-efficiency, this paper presents opportunities provided by approximate computing techniques for the accumulation based and iterative algorithms, which are the dominant part of processing in radio astronomy. Moreover, the challenges and future line-of-action are also discussed to embrace approximate computing principles.

2 APPROXIMATE COMPUTING OPPORTUNITIES

Keeping in view the SDP pipeline of radio astronomy processing, this section elaborates on approximate accelerator designs for accumulation based and iterative algorithms.

2.1 Accumulation Based Algorithms

Conventionally, the approximate designs for multipliers and adders were following the error-restricted methodologies such as fail-rare and fail-small techniques. These techniques restrict the approximate designs based on the error magnitudes and the error rates they introduce to avoid an unbearable quality loss during processing [5]. However, it also limits the hardware efficiency benefits that can be exploited within the error-resilient applications [4].

Recently, a self-healing methodology has been introduced for accumulation based algorithms like a square-accumulate (SAC) unit [4], see Fig. 2. Wherein the approximations are not restricted by error metrics but are provided with an opportunity to cancel out the errors within the processing units. In Fig. 2, the P1 computing element can be regarded as a squarer or a multiplier in case of a SAC or multiply-accumulate (MAC) unit respectively, and the P2 computing element can be regarded as an accumulator. The approximations are applied to a pair of P1 in such a way that their corresponding errors have a potential to be canceled out in the P2 stage.

2.2 Iterative Algorithms

Error resilience analysis provides a means to assess an application if it is a promising candidate for approximate computing. The statistical approximation (error) models are applied to the application to quantify the intrinsic error-resilience and to identify the promising approximate computing techniques [5]. Targeting the iterative algorithms, adaptive approximation models have provided a way to quantify the number of iterations that can be processed using an approximate core while complying to the quality-criterion [7].

An approximate least squares (LS) accelerator design in [8] has shown how an iterative least squares (LS) algorithm can be processed using a hybrid architecture (a combination of accurate and approximate cores), see Fig. 3. Wherein a number of initial iterations are run in the approximate core and the rest in the accurate core to achieve a reduction in energy consumption.

2.3 Discussion: What's Green Here?

The term *Green* represents the computing architectures that are either low power or have low energy consumption. The self-healing methodology discussed in Section 2.1 provides promising solutions for low power SAC and MAC units required for the SDP pipeline. Moreover, the hybrid architecture discussed in Section 2.2 shows up to 28% of the reduction in energy consumption for radio astronomy calibration processing [8]. Therefore, the aforesaid techniques can be utilized to save power/energy in case of SDP pipeline.

3 CHALLENGES AND FUTURE DIRECTIONS

To embrace approximate computing principles discussed in Section 2, we first need to quantify the intrinsic error-resilience present in the SDP pipeline of radio astronomy processing. This requires to reason about a representative data-set of a radio telescope that can be analyzed for the introduction and propagation of errors within the SDP pipeline due to the employment of approximate computing techniques.

The self-healing methodology discussed in Section 2.1 has been demonstrated for a parallel square-accumulate operation, where a *pair of two* squarers are utilized to introduce opposite errors. However, investigating a methodology for a SAC/MAC unit that introduces self-healing within a single squarer/multiplier is important to relieve the *pair of two* restriction. Moreover, the approximate LS accelerator has shown the reduction in energy consumption based on a single time-slot of LOw-Frequency ARray (LOFAR) [6] data. As discussed, a well-reasoned representative data set can be utilized to further tune the approximate core in the hybrid architecture to quantify the overall energy-efficiency gains.

Also, *gridding* and *de-gridding* are compute-intensive parts of the SDP pipeline, which help to map the non-uniform visibilities to the Fourier Transform of the sky images [11]. These algorithms also require multiply-add operations that can be investigated for self-healing approximate computing techniques.

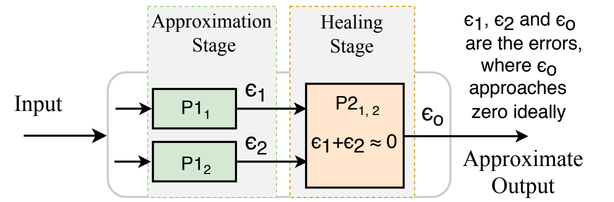

Figure 2: Self-healing technique for accumulation based algorithms [4].

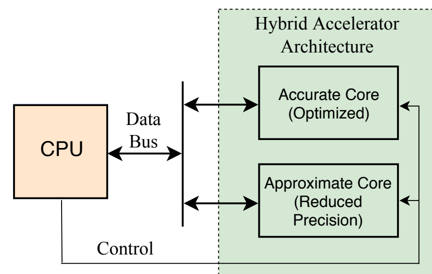

Figure 3: Approximate least squares accelerator design [8].

4 CONCLUSIONS

In this paper, it is discussed that approximate computing techniques can be utilized to achieve energy/power-efficiency for radio astronomy processing. Moreover, challenges and future directions are highlighted like quantifying the error-resilience intrinsic to Science Data Processing (SDP) pipeline, building a representative data set, and better self-healing techniques for accumulation based algorithms of the SDP.

ACKNOWLEDGMENTS

This work was conducted in the context of the ASTRON and IBM joint project, DOME, funded by the Netherlands Organization for Scientific Research (NWO), the Dutch Ministry of EL&I, and the Province of Drenthe.

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