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A novel model order reduction technique based on artificial intelligence

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ABSTRACT

Computer aided design (CAD) plays a vital role in modern VLSI design. Electronic simulation is widely used to verify the design and test the behavior of the circuit before fabrication. One of the major research areas in CAD is circuit simulation. Circuit simulation is to use mathematical models to predict the behavior of an electronic circuit. A circuit is usually represented by a set of partial differential equations (PDEs) or ordinary differential equations (ODEs). So, the circuit simulation actually involves solving large-scale ODEs which sometimes takes several days or even weeks. Therefore, fast and accurate circuit simulation algorithms are needed to accelerate the simulation cycle. One way to speed up the simulation is to approximate the original system with an appropriately simplified system which captures the main properties of the original one. This method is called model order reduction (MOR), which reduces the complexity of the original large system and generates a reduced-order model (ROM) to represent the original one. There are many existing MOR methods, but there is no method that gives the best results for all of the systems. So, each system uses the best method according to its application. So, there is still a need for novel MOR techniques. This paper presents a novel MOR technique based on artificial intelligence.

1. Introduction

Any physical system can be represented by a set of continuous Partial Differential Equations (PDEs) or discrete Ordinary Differential Equations (ODEs). At the same time, any set of PDEs should be transformed into a system of ODEs which can be linear ODEs or nonlinear ODEs. So, discretization is needed which approximates the behavior of the continuous systems [1]. Most CAD tools use the numerical Finite Element Method (FEM) approximation to accurately discretize in space, model and simulate these continuous structure-level VLSI systems.

Solving linear ODEs results in matrix form system that can be solved using direct method such as Gaussian elimination method or indirect method (iterative methods) such as Jacobi method, and solving non-linear ODEs can be done by newton's method. These methods are useful for moderately.

size problems (Fig. 1). But, solving high-order (system complexity is referred to as the order of the system) or high-degree of freedom of these discretized differential equations is a time consuming process. Model order reduction (MOR) technique is a compression method to reduce the order of the full-order ODEs for fast computations and less storage requirements and at the same time it keeps the same characteristics of the full system, unreduced model (URM), and it should be passivity-guaranteed and stability-guaranteed. There should be a global error bound between the transfer functions of the original and reduced/compact systems. MOR is developed after the FEM discretization or any other discretization method to reduce the matrix size. The MOR techniques are falling under two main categories, frequency-domain, time-domain, where frequency-domain category contains Eigen-mode Analysis, moment matching, and singular value decomposition (SVD). Eigen-mode Analysis MOR has three forms: Pole-Residue Form, Pole-Zero Form, and Rational form, it is simple but computationally inefficient. Moment Matching MOR is done by matching the Taylor series coefficients (Asymptotic waveform evaluation (AWE) moment matching), but this method had a low-accuracy. So, Padé approximations moment matching were later used to improve the accuracy, but due to the ill-conditioning of the matrices involved the approximate transfer function response was found to be narrow band, leading to inaccuracies at higher orders ODEs. Later, Krylov subspace-scheme moment matching is used to improve the ill-conditioning, it projects the problem onto a lower/smaller dimensional subspace that captures the vital aspects of the system behavior [2–4], and it is n iterative algorithm as depicted in Fig. 2 [5]. SVD is an approximation method based on the decomposition of the full-order system into a set of two orthogonal matrices and a diagonal matrix which contains the system's singular values.

Based on the magnitude of the singular values, a direct truncation method can be applied to achieve a reduced order model. SVD is computationally inefficient [6]. As stated earlier, MOR can be done either in frequency domain or in time domain. For frequency domain

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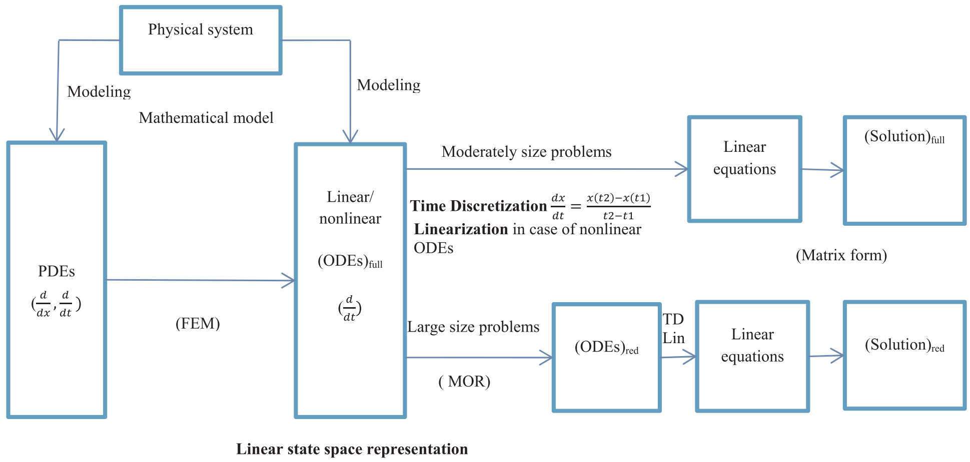

Fig. 1. Typical development flow for complex systems: the big picture, MOR is needed for large size problems, given an ODE of order n, find another ODE of order r, where r « n with "essentially" the same "properties" and stability, passivity are preserved. We replace the set of ODEs by a smaller set of ODEs without sacrificing the accuracy of the system behavior.

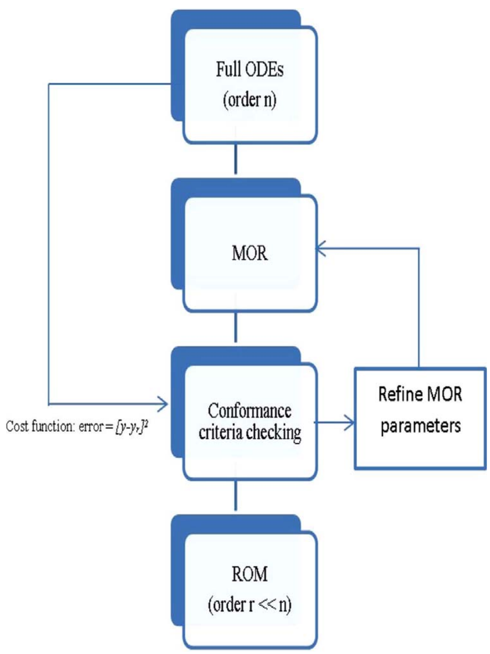

Fig. 2. MOR iterative method. The full order model and the reduced model are input to a Conformance Criteria Checking step that guarantees a conformance of their characteristics.

techniques such as AWE and Krylov subspace based methods which try to get a reduced order system by approximating a certain number of moments of the original system transfer function. But, the accuracy of the output response of this reduced system in time domain cannot always be guaranteed even if the reduced transfer function can be accurate in frequency domain. So, sometime time domain MOR is used such as Chebyshev [7,8]. Recently, wavelet based approach is proposed for the model order reduction of linear circuits in time-frequency. In this paper, artificial intelligence algorithms such genetic algorithm, neural network, fuzzy logic, particle swarm, and simulated annealing [9–11] are proposed as novel MOR techniques. The numerical comparisons will prove the advantage of our algorithms over the conventional algorithms in terms of the accuracy of frequency response.

This paper is organized as follows: In Section II, the proposed algorithms are presented. In Section III, Comparisons and results are discussed. In Section IV, Conclusions are given.

2. Background

2.1. Genetic algorithm

Genetic algorithm is based on iterative procedures of search for an optimal solution for a problem which have multiple local minima or maxima. The algorithm passes through steps of recombination including crossover, and mutation then selection which increase the probability of finding the most optimum solution, which is the reduced model with the least error compared to the original transfer model. The error is compared with the original transfer function in terms of fitness function. Before applying the genetic operators, a method of encoding should be chosen to represent the data either in float form which is the raw form of the data or binary representation or any other representation.

The crossover operator is a process of creating new individuals by selecting two or more parents and passing them through crossover procedures producing one or two or more individuals. Unlike real life, there is no obligation to be abided by nature rules, so the new individual can have more than two parents. There is more than one method for crossover process like simple crossover which includes exchange of genes between the two chromosomes according to a specified crossover rate.

Arithmetic crossover occurs by choosing two or more individuals randomly from the current generation and multiplying them by one random in the case of the Inevitability of the presence of a certain defined domain and more than one random if there is no physical need for a defined search domain [11–14].

The second process of genetic operators is mutation which is a process that occurs to prevent falling of all solutions of the population into a local optimum of the problem. The third genetic operator is selection which is the process of choosing a certain number of individuals for the next generation to be recombined generating new individuals aiming to find the most optimum solution. There is more than one technique to select individuals for the next generation.

The Elitism selection is simply selecting the fittest individuals from the current population for the next population. This method guarantees a high probability of getting closer to the most optimum solution due to passing of the fittest chromosomes to the crossover operator producing fitter individuals. Another technique is Roulette wheel selection. In this kind of selection, the parenthood probability is directly proportional to the fitness of the individuals where every individual is given a weight proportional to its fitness having a higher probability to be chosen as a parent for the next generation individuals and this technique is similar to rank selection where all individuals in the current population are