論文の内容の要旨

論文題目

Optimal Modeling for Circuit Simulation: Applications of Matroid Theory

（回路シミュレーションにおける最適モデリング：マトロイド理論の応用）

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Numerical simulation has established a position as a vital technique in the analysis of physical phenomena. Physical phenomena that arise in the real world are modeled by large-scale systems, whose simulation becomes possible with the recent development of computers. A further issue in numerical simulation is accuracy improvement.

In numerical simulation, we generate a mathematical model for the target phenomenon, and then apply numerical solution methods to it. In order to improve accuracy of numerical simulation, a great deal of research has been made on numerical solution methods. However, accuracy depends not only on "how to solve" but also on "what to solve." The same physical phenomenon admits a variety of mathematical models. Even if they are mathematically equivalent, they may differ in the ease of numerical solutions. Thus, it is important to adopt an "optimal mathematical model" in view of accuracy of numerical solutions. By applying efficient numerical solution methods to this optimal model, we anticipate achieving high accuracy in numerical simulation.

The aim of this thesis is to establish a systematic way of deriving an optimal model in circuit simulation. Lumped circuits in the time domain are described by differential-algebraic equations (DAEs), which consist of algebraic equations and differential operations. In the theory of DAEs, the inherent numerical difficulty of a DAE is measured by the index. The greater the index is, the more difficult it is to solve the DAE. In order to improve accuracy of numerical solution, we present algorithms for finding a DAE formulation with minimum index in the hybrid analysis, which is a circuit analysis method having a wide variety of variable selections. We further prove that the index of the DAE is determined only by the network structure of a circuit, that is, the index remains the same if we change physical characteristic values. This shows robustness of the obtained mathematical model, which is an important property for modeling.

The key tool in the analysis of DAEs is the degrees of subdeterminants in a polynomial matrix, which are known to form a valuated matroid. The polynomial matrix we deal with has two kinds of nonzero coefficients: fixed constants that account for conservation laws and independent parameters that represent physical characteristics. Such a matrix has been introduced as a mixed polynomial matrix. Our analysis on mixed polynomial matrices leads to improvement in efficiency of the index minimization/determination algorithms.

The viewpoint of matroids is helpful in grasping structure of the problem and capturing the essence. This enables us to make full use of structural information of the problem. Moreover, the effective application of matroid theory leads to efficient algorithms, which makes it possible to deal with large-scale systems. In large-scale systems analysis, selecting a smart mathematical model plays a more and more significant role. This thesis shows the utility of matroid theory in the optimal DAE modeling.