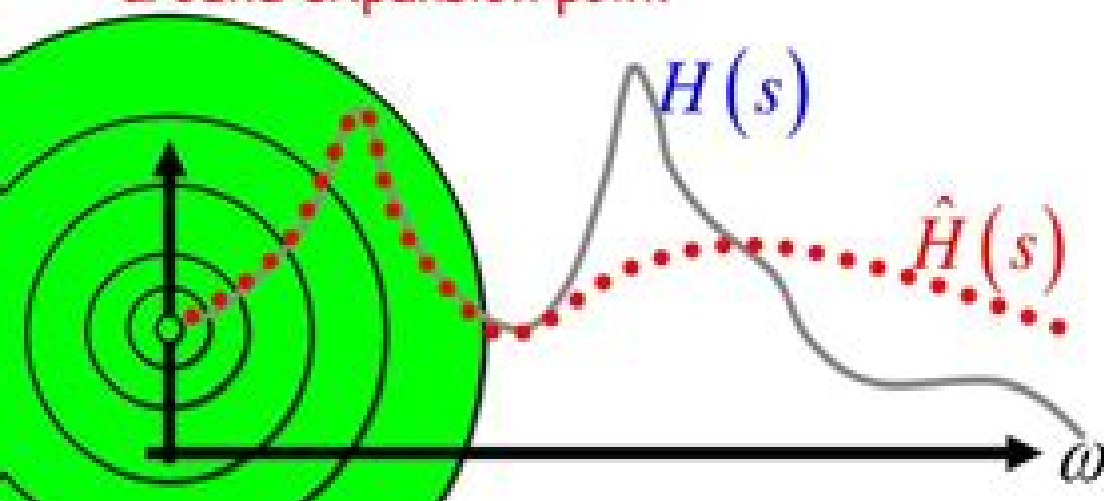# Intuitive view of Krylov subspace choice for U_q

$$(G + sC)x = Bu \quad \Longrightarrow \quad x = (G + sC)^{-1} Bu$$

Taylor series expansion: $A = -G^{-1}C$, $R = G^{-1}B$

$$x = (R + sAR + s^2A^2R + ...)u \quad \Longrightarrow \quad x \in \text{span}\{R, AR, A^2R, ...\}$$

- change base and use only the first few vectors of the Taylor series expansion: equivalent to match first derivatives around expansion point

$$\left| x \right| = \left| R \quad AR \quad A^2R \quad ... \right| \hat{x}$$

$H(s)$

$\hat{H}(s)$

ω

Krylov Subspace Techniques For Circuit And Interconnect Analysis

Yu Zhu,Andreas C. Cangellaris

Krylov Subspace Techniques For Circuit And Interconnect Analysis:

   IC Interconnect Analysis Mustafa Celik,Larry Pileggi,Altan Odabasioglu,2007-05-08 As integrated circuit IC feature sizes scaled below a quarter of a micron thereby defining the deep submicron DSM era there began a gradual shift in the impact on performance due to the metal interconnections among the active circuit components Once viewed as merely parasitics in terms of their relevance to the overall circuit behavior the interconnect can now have a dominant impact on the IC area and performance Beginning in the late 1980 s there was significant research toward better modeling and characterization of the resistance capacitance and ultimately the inductance of on chip interconnect IC Interconnect Analysis covers the state of the art methods for modeling and analyzing IC interconnect based on the past fifteen years of research This is done at a level suitable for most practitioners who work in the semiconductor and electronic design automation fields but also includes significant depth for the research professionals who will ultimately extend this work into other areas and applications IC Interconnect Analysis begins with an in depth coverage of delay metrics including the ubiquitous Elmore delay and its many variations This is followed by an outline of moment matching methods calculating moments efficiently and Krylov subspace methods for model order reduction The final two chapters describe how to interface these reduced order models to circuit simulators and gate level timing analyzers respectively IC Interconnect Analysis is written for CAD tool developers IC designers and graduate students   *Novel Mathematics Inspired by Industrial Challenges* Michael Günther,Wil Schilders,2022-03-30 This contributed volume convenes a rich selection of works with a focus on innovative mathematical methods with applications in real world industrial problems Studies included in this book are all motivated by a relevant industrial challenge and demonstrate that mathematics for industry can be extremely rewarding leading to new mathematical methods and sometimes even to entirely new fields within mathematics The book is organized into two parts Computational Sciences and Engineering and Data Analysis and Finance In every chapter readers will find a brief description of why such work fits into this volume an explanation on which industrial challenges have been instrumental for their inspiration and which methods have been developed as a result All these contribute to a greater unity of the text benefiting not only practitioners and professionals seeking information on novel techniques but also graduate students in applied mathematics engineering and related fields   *Statistical Performance Analysis and Modeling Techniques for Nanometer VLSI Designs* Ruijing Shen,Sheldon X.-D. Tan,Hao Yu,2014-07-08 Since process variation and chip performance uncertainties have become more pronounced as technologies scale down into the nanometer regime accurate and efficient modeling or characterization of variations from the device to the architecture level have become imperative for the successful design of VLSI chips This book provides readers with tools for variation aware design methodologies and computer aided design CAD of VLSI systems in the presence of process variations at the nanometer scale It presents the latest developments for modeling and analysis with a focus on statistical interconnect modeling statistical parasitic extractions statistical full chip

leakage and dynamic power analysis considering spatial correlations statistical analysis and modeling for large global interconnects and analog mixed signal circuits Provides readers with timely systematic and comprehensive treatments of statistical modeling and analysis of VLSI systems with a focus on interconnects on chip power grids and clock networks and analog mixed signal circuits Helps chip designers understand the potential and limitations of their design tools improving their design productivity Presents analysis of each algorithm with practical applications in the context of real circuit design Includes numerical examples for the quantitative analysis and evaluation of algorithms presented Provides readers with timely systematic and comprehensive treatments of statistical modeling and analysis of VLSI systems with a focus on interconnects on chip power grids and clock networks and analog mixed signal circuits Helps chip designers understand the potential and limitations of their design tools improving their design productivity Presents analysis of each algorithm with practical applications in the context of real circuit design Includes numerical examples for the quantitative analysis and evaluation of algorithms presented **Multigrid Finite Element Methods for Electromagnetic Field Modeling** Yu Zhu,Andreas C. Cangellaris,2006-02-03 This is the first comprehensive monograph that features state of the art multigrid methods for enhancing the modeling versatility numerical robustness and computational efficiency of one of the most popular classes of numerical electromagnetic field modeling methods the method of finite elements The focus of the publication is the development of robust preconditioners for the iterative solution of electromagnetic field boundary value problems BVPs discretized by means of finite methods Specifically the authors set forth their own successful attempts to utilize concepts from multigrid and multilevel methods for the effective preconditioning of matrices resulting from the approximation of electromagnetic BVPs using finite methods Following the authors careful explanations and step by step instruction readers can duplicate the authors results and take advantage of today s state of the art multigrid multilevel preconditioners for finite element based iterative electromagnetic field solvers Among the highlights of coverage are Application of multigrid multilevel and hybrid multigrid multilevel preconditioners to electromagnetic scattering and radiation problems Broadband robust numerical modeling of passive microwave components and circuits Robust finite element based modal analysis of electromagnetic waveguides and cavities Application of Krylov subspace based methodologies for reduced order macromodeling of electromagnetic devices and systems Finite element modeling of electromagnetic waves in periodic structures The authors provide more than thirty detailed algorithms alongside pseudo codes to assist readers with practical computer implementation In addition each chapter includes an applications section with helpful numerical examples that validate the authors methodologies and demonstrate their computational efficiency and robustness This groundbreaking book with its coverage of an exciting new enabling computer aided design technology is an essential reference for computer programmers designers and engineers as well as graduate students in engineering and applied physics *The VLSI Handbook* Wai-Kai Chen,2019-07-17 Over the years the fundamentals of VLSI technology have evolved to include a wide

range of topics and a broad range of practices To encompass such a vast amount of knowledge The VLSI Handbook focuses on the key concepts models and equations that enable the electrical engineer to analyze design and predict the behavior of very large scale integrated circuits It provides the most up to date information on IC technology you can find Using frequent examples the Handbook stresses the fundamental theory behind professional applications Focusing not only on the traditional design methods it contains all relevant sources of information and tools to assist you in performing your job This includes software databases standards seminars conferences and more The VLSI Handbook answers all your needs in one comprehensive volume at a level that will enlighten and refresh the knowledge of experienced engineers and educate the novice This one source reference keeps you current on new techniques and procedures and serves as a review for standard practice It will be your first choice when looking for a solution *EDA for IC Implementation, Circuit Design, and Process Technology* Luciano Lavagno,Louis Scheffer,Grant Martin,2018-10-03 Presenting a comprehensive overview of the design automation algorithms tools and methodologies used to design integrated circuits the Electronic Design Automation for Integrated Circuits Handbook is available in two volumes The second volume EDA for IC Implementation Circuit Design and Process Technology thoroughly examines real time logic to GDSII a file format used to transfer data of semiconductor physical layout analog mixed signal design physical verification and technology CAD TCAD Chapters contributed by leading experts authoritatively discuss design for manufacturability at the nanoscale power supply network design and analysis design modeling and much more Save on the complete set Dimension Reduction of Large-Scale Systems Peter Benner,Volker Mehrmann,Danny C. Sorensen,2006-03-30 In the past decades model reduction has become an ubiquitous tool in analysis and simulation of dynamical systems control design circuit simulation structural dynamics CFD and many other disciplines dealing with complex physical models The aim of this book is to survey some of the most successful model reduction methods in tutorial style articles and to present benchmark problems from several application areas for testing and comparing existing and new algorithms As the discussed methods have often been developed in parallel in disconnected application areas the intention of the mini workshop in Oberwolfach and its proceedings is to make these ideas available to researchers and practitioners from all these different disciplines *Computational Acoustics of Noise Propagation in Fluids - Finite and Boundary Element Methods* Steffen Marburg,Bodo Nolte,2008-02-27 The book provides a survey of numerical methods for acoustics namely the finite element method FEM and the boundary element method BEM It is the first book summarizing FEM and BEM and optimization for acoustics The book shows that both methods can be effectively used for many other cases FEM even for open domains and BEM for closed ones Emphasis of the book is put on numerical aspects and on treatment of the exterior problem in acoustics i e noise radiation Design Automation, Languages, and Simulations Wai-Kai Chen,2003-03-26 As the complexity of electronic systems continues to increase the micro electronic industry depends upon automation and simulations to adapt quickly to market changes and new technologies Compiled from chapters

contributed to CRC s best selling VLSI Handbook this volume of the Principles and Applications in Engineering series covers a broad rang *Advanced Symbolic Analysis for VLSI Systems* Guoyong Shi,Sheldon X.-D. Tan,Esteban Tlelo Cuautle,2014-06-19 This book provides comprehensive coverage of the recent advances in symbolic analysis techniques for design automation of nanometer VLSI systems The presentation is organized in parts of fundamentals basic implementation methods and applications for VLSI design Topics emphasized include statistical timing and crosstalk analysis statistical and parallel analysis performance bound analysis and behavioral modeling for analog integrated circuits Among the recent advances the Binary Decision Diagram BDD based approaches are studied in depth The BDD based hierarchical symbolic analysis approaches have essentially broken the analog circuit size barrier **Advanced Model Order Reduction Techniques in VLSI Design** Sheldon Tan,Lei He,2007-05-31 Model order reduction MOR techniques reduce the complexity of VLSI designs paving the way to higher operating speeds and smaller feature sizes This book presents a systematic introduction to and treatment of the key MOR methods employed in general linear circuits using real world examples to illustrate the advantages and disadvantages of each algorithm Following a review of traditional projection based techniques coverage progresses to more advanced MOR methods for VLSI design including HMOR passive truncated balanced realization TBR methods efficient inductance modeling via the VPEC model and structure preserving MOR techniques Where possible numerical methods are approached from the CAD engineer s perspective avoiding complex mathematics and allowing the reader to take on real design problems and develop more effective tools With practical examples and over 100 illustrations this book is suitable for researchers and graduate students of electrical and computer engineering as well as practitioners working in the VLSI design industry **Applied and Computational Control, Signals, and Circuits** Biswa N. Datta,2012-12-06 The purpose of this annual series Applied and Computational Control Signals and Circuits is to keep abreast of the fast paced developments in computational mathematics and scientific computing and their increasing use by researchers and engineers in control signals and circuits The series is dedicated to fostering effective communication between mathematicians computer scientists computational scientists software engineers theorists and practicing engineers This interdisciplinary scope is meant to blend areas of mathematics such as linear algebra operator theory and certain branches of analysis and computational mathematics numerical linear algebra numerical differential equations large scale and parallel matrix computations numerical optimization with control and systems theory signal and image processing and circuit analysis and design The disciplines mentioned above have long enjoyed a natural synergy There are distinguished journals in the fields of control and systems the ory as well as signal processing and circuit theory which publish high quality papers on mathematical and engineering aspects of these areas however articles on their computational and applications aspects appear only sporadically At the same time there has been tremendous recent growth and development of computational mathematics scientific comput ing and mathematical software and the resulting sophisticated techniques are

being gradually adapted by engineers software designers and other scientists to the needs of those applied disciplines

Symbolic Analysis and Reduction of VLSI Circuits Zhanhai Qin,Chung-Kuan Cheng,2009-03-13 Symbolic analysis is an intriguing topic in VLSI designs The analysis methods are crucial for the applications to the parasitic reduction and analog circuit evaluation However analyzing circuits symbolically remains a challenging research issue Therefore in this book we survey the recent results as the progress of on going works rather than as the solution of the field For parasitic reduction we approximate a huge amount of electrical parameters into a simplified RLC network This reduction allows us to handle very large integrated circuits with given memory capacity and CPU time A symbolic analysis approach reduces the circuit according to the network topology Thus the designer can maintain the meaning of the original network and perform the analysis hierarchically For analog circuit designs symbolic analysis provides the relation between the tunable parameters and the characteristics of the circuit The analysis allows us to optimize the circuit behavior The book is divided into three parts Part I touches on the basics of circuit analysis in time domain and in s domain For an s domain expression the Taylor s expansion with s approaching infinity is equivalent to the time domain solution after the inverse Laplace transform On the other hand the Taylor s expansion when s approaches zero derives the moments of the output responses in time domain Part II focuses on the techniques for parasitic reduction In Chapter 2 we present the approximation methods to match the first few moments with reduced circuit orders In Chapter 3 we apply the Y Delta transformation to reduce the dynamic linear network The method finds the exact values of the low order coefficients of the numerator and denominator of the transfer function and thus matches part of the moments In Chapter 4 we handle two major issues of the Y Delta transformation common factors in fractional expressions and round off errors Chapter 5 explains the stability of the reduced expression in particular the Ruth Hurwitz Criterion We make an effort to describe the proof of the Criterion because the details are omitted in most of the contemporary textbooks In Chapter 6 we present techniques to synthesize circuits to approximate the reduced expressions after the transformation In Part III we discuss symbolic generation of the determinants and cofactors for the application to analog designs In Chapter 7 we depict the classical topological analysis approach In Chapter 8 we describe a determinant decision diagram approach that exploits the sparsity of the matrix to accelerate the computation In Chapter 9 we take only significant terms when we search through determinant decision diagram to approximate the solution In Chapter 10 we extend the determinant decision diagram to a hierarchical model The construction of the modules through the hierarchy is similar to the Y Delta transformation in the sense that a byproduct of common factors appears in the numerator and denominator Therefore we describe the method to prune the common factors   **VLSI: Integrated Systems on Silicon** Ricardo A. Reis,Luc Claesen,2013-06-05 This book contains the papers that have been presented at the ninth Very Large Scale Integrated Systems conference VLSI 97 that is organized biannually by IFIP Working Group 10 5 It took place at Hotel Serra Azul in Gramado Brazil from 26 30 August 1997 Previous conferences have taken place in Edinburgh Trondheim

Vancouver Munich Grenoble and Tokyo The papers in this book report on all aspects of importance to the design of the current and future integrated systems The current trend towards the realization of versatile Systems on a Chip require attention of embedded hardware software systems dedicated ASIC hardware sensors and actuators mixed analog digital design video and image processing low power battery operation and wireless communication The papers as presented in Jhis book have been organized in two tracks where one is dealing with VLSI System Design and Applications and the other presents VLSI Design Methods and CAD The following topics are addressed VLSI System Design and Applications Track VLSI for Video and Image Processing Microsystem and Mixed mode design Communication And Memory System Design Cow voltage Low power Analog Circuits High Speed Circuit Techniques Application Specific DSP Architectures VLSI Design Methods and CAD Track Specification and Simulation at System Level Synthesis and Technology Mapping CAD Techniques for Low Power Design Physical Design Issues in Sub micron Technologies Architectural Design and Synthesis Testing in Complex Mixed Analog and Digital Systems   Domain-based Parallelism and Problem Decomposition Methods in Computational Science and Engineering David E. Keyes,Yousef Saad,Donald G. Truhlar,1995-01-01 This refereed volume arose from the editors recognition that physical scientists engineers and applied mathematicians are developing in parallel solutions to problems of parallelization The cross disciplinary field of scientific computation is bringing about better communication between heterogeneous computational groups as they face this common challenge This volume is one attempt to provide cross disciplinary communication Problem decomposition and the use of domain based parallelism in computational science and engineering was the subject addressed at a workshop held at the University of Minnesota Supercomputer Institute in April 1994 The authors were subsequently able to address the relationships between their individual applications and independently developed approaches This book is written for an interdisciplinary audience and concentrates on transferable algorithmic techniques rather than the scientific results themselves Cross disciplinary editing was employed to identify jargon that needed further explanation and to ensure provision of a brief scientific background for each chapter at a tutorial level so that the physical significance of the variables is clear and correspondences between fields are visible   *Fast Simulation of Electro-Thermal MEMS* Tamara Bechtold,Evgenii B. Rudnyi,Jan G. Korvink,2006-11-01 This book provides the reader with a complete methodology and software environment for creating efficient dynamic compact models for electro thermal MEMS devices It supplies the basic knowledge and understanding for using model order reduction at the engineering level This tutorial is written for MEMS engineers and is enriched with many case studies which equip readers with the know how to facilitate the simulation of a specific problem   *High Performance Integrated Circuit Design* Emre Salman,Eby Friedman,2012-08-21 The latest techniques for designing robust high performance integrated circuits in nanoscale technologies Focusing on a new technological paradigm this practical guide describes the interconnect centric design methodologies that are now the major focus of nanoscale integrated circuits ICs High Performance Integrated

Circuit Design begins by discussing the dominant role of on chip interconnects and provides an overview of technology scaling The book goes on to cover data signaling power management synchronization and substrate aware design Specific design constraints and methodologies unique to each type of interconnect are addressed This comprehensive volume also explains the design of specialized circuits such as tapered buffers and repeaters for data signaling voltage regulators for power management and phase locked loops for synchronization This is an invaluable resource for students researchers and engineers working in the area of high performance ICs Coverage includes Technology scaling Interconnect modeling and extraction Signal propagation and delay analysis Interconnect coupling noise Global signaling Power generation Power distribution networks CAD of power networks Techniques to reduce power supply noise Power dissipation Synchronization theory and tradeoffs Synchronous system characteristics On chip clock generation and distribution Substrate noise in mixed signal ICs Techniques to reduce substrate noise   Model Reduction for Circuit Simulation Peter Benner,Michael Hinze,E. Jan W. ter Maten,2011-03-25 Simulation based on mathematical models plays a major role in computer aided design of integrated circuits ICs Decreasing structure sizes increasing packing densities and driving frequencies require the use of refined mathematical models and to take into account secondary parasitic effects This leads to very high dimensional problems which nowadays require simulation times too large for the short time to market demands in industry Modern Model Order Reduction MOR techniques present a way out of this dilemma in providing surrogate models which keep the main characteristics of the device while requiring a significantly lower simulation time than the full model With Model Reduction for Circuit Simulation we survey the state of the art in the challenging research field of MOR for ICs and also address its future research directions Special emphasis is taken on aspects stemming from miniturisations to the nano scale Contributions cover complexity reduction using e g balanced truncation Krylov techniques or POD approaches For semiconductor applications a focus is on generalising current techniques to differential algebraic equations on including design parameters on preserving stability and on including nonlinearity by means of piecewise linearisations along solution trajectories TPWL and interpolation techniques for nonlinear parts Furthermore the influence of interconnects and power grids on the physical properties of the device is considered and also top down system design approaches in which detailed block descriptions are combined with behavioral models Further topics consider MOR and the combination of approaches from optimisation and statistics and the inclusion of PDE models with emphasis on MOR for the resulting partial differential algebraic systems The methods which currently are being developed have also relevance in other application areas such as mechanical multibody systems and systems arising in chemistry and to biology The current number of books in the area of MOR for ICs is very limited so that this volume helps to fill a gap in providing the state of the art material and to stimulate further research in this area of MOR Model Reduction for Circuit Simulation also reflects and documents the vivid interaction between three active research projects in this area namely the EU Marie Curie Action ToK project O MOORE NICE members

in Belgium The Netherlands and Germany the EU Marie Curie Action RTN project COMSON members in The Netherlands Italy Germany and Romania and the German federal project System reduction in nano electronics SyreNe *Coupled Multiscale Simulation and Optimization in Nanoelectronics* Michael Günther,2015-06-15 Designing complex integrated circuits relies heavily on mathematical methods and calls for suitable simulation and optimization tools The current design approach involves simulations and optimizations in different physical domains device circuit thermal electromagnetic and in a range of electrical engineering disciplines logic timing power crosstalk signal integrity system functionality COMSON was a Marie Curie Research Training Network created to meet these new scientific and training challenges by a developing new descriptive models that take these mutual dependencies into account b combining these models with existing circuit descriptions in new simulation strategies and c developing new optimization techniques that will accommodate new designs The book presents the main project results in the fields of PDAE modeling and simulation model order reduction techniques and optimization based on merging the know how of three major European semiconductor companies with the combined expertise of university groups specialized in developing suitable mathematical models numerical schemes and e learning facilities In addition a common Demonstrator Platform for testing mathematical methods and approaches was created to assess whether they are capable of addressing the industry s problems and to educate young researchers by providing hands on experience with state of the art problems **Scientific Computing in Electrical Engineering** Angelo Marcello Anile,Giuseppe Alì,G. Mascali,2007-01-10 This book is a collection of papers presented at the last Scientific Computing in Electrical Engineering SCEE Conference held in Sicily in 2004 The series of SCEE conferences aims at addressing mathematical problems which have a relevancy to industry The areas covered at SCEE 2004 were Electromagnetism Circuit Simulation Coupled Problems and General mathematical and computational methods

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