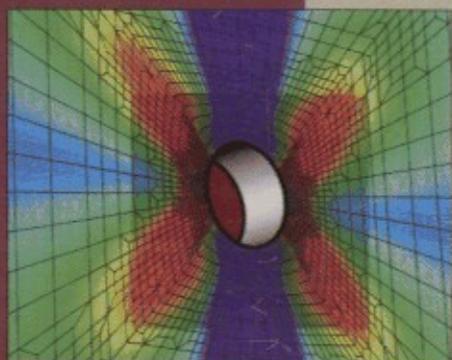


Editors: Erwin Stein | René de Borst | Thomas J.R. Hughes



# Encyclopedia of Computational Mechanics

Volume 1

Fundamentals

Volume 2

Solids and Structures

Volume 3

Fluids

 WILEY

# Contents

## VOLUME 1: FUNDAMENTALS

<b>Contributors to Volume 1</b>	<b>ix</b>		
<b>Preface</b>	<b>xi</b>		
<b>1 Fundamentals: Introduction and Survey</b>	<b>1</b>		
<i>Erwin Stein</i>			
1 Motivation and Scope	1		
2 Stages of Development and Features of Computational Mechanics	1		
3 Survey of the Chapters of Volume 1	2		
4 What We Do Expect	6		
<b>2 Finite Difference Methods</b>	<b>7</b>		
<i>Owe Axelsson</i>			
1 Introduction	7		
2 Two-point Boundary Value Problems	9		
3 Finite Difference Methods for Elliptic Problems	12		
4 Finite Difference Methods for Parabolic Problems	18		
5 Finite Difference Methods for Hyperbolic Problems	28		
6 Convection–Diffusion Problems	36		
7 A Summary of Difference Schemes	50		
References	52		
Further Reading	53		
<b>3 Interpolation in <math>h</math>-version Finite Element Spaces</b>	<b>55</b>		
<i>Thomas Apel</i>			
1 Introduction	55		
2 Finite Elements	56		
3 Definition of Interpolation Operators	58		
4 The Deny–Lions Lemma	60		
5 Local Error Estimates for the Nodal Interpolant	61		
6 Local Error Estimates for Quasi-Interpolants	66		
7 Example for a Global Interpolation Error Estimate	68		
8 Related Chapters	70		
References	70		
<b>4 Finite Element Methods</b>	<b>73</b>		
<i>Susanne C. Brenner/Carsten Carstensen</i>			
1 Introduction	73		
2 Ritz–Galerkin Methods for Linear Elliptic Boundary Value Problems	74		
3 Finite Element Spaces	77		
4 A Priori Error Estimates for Finite Element Methods	82		
5 A Posteriori Error Estimates and Analysis	85		
6 Local Mesh Refinement	98		
7 Other Aspects	104		
Acknowledgments	114		
References	114		
<b>5 The <math>p</math>-version of the Finite Element Method</b>	<b>119</b>		
<i>Barna Szabó/Alexander Düster/Ernst Rank</i>			
1 Introduction	119		
2 Implementation	120		
3 Convergence Characteristics	126		
4 Performance Characteristics	131		
5 Applications to Nonlinear Problems	133		
6 Outlook	136		
Acknowledgments	137		
Notes	137		
References	137		
Further Reading	139		
<b>6 Spectral Methods</b>	<b>141</b>		
<i>Claudio Canuto/Alfio Quarteroni</i>			
1 Introduction	141		
2 Fourier Methods	141		
3 Algebraic Polynomial Expansion	143		
4 Algebraic Expansions on Triangles	145		
5 Stokes and Navier–Stokes Equations	146		
6 Advection Equations and Conservation Laws	148		
7 The Spectral Element Method	150		
8 The Mortar Method	152		
References	154		
<b>7 Adaptive Wavelet Techniques in Numerical Simulation</b>	<b>157</b>		
<i>Albert Cohen/Wolfgang Dahmen/Ronald DeVore</i>			
1 Introduction	157		
2 Wavelets	160		
3 Evolution Problems – Compression of Flow Fields	169		
4 Boundary Integral Equations – Matrix Compression	175		
5 A New Adaptive Paradigm	181		

6	Construction of Residual Approximations and Complexity Analysis	187	12	<b>Boundary Element Methods: Foundation and Error Analysis</b>	<b>339</b>
	Acknowledgment	195		<i>G. C. Hsiao/W. L. Wendland</i>	
	Notes	195	1	Introduction	339
	References	195	2	Boundary Integral Equations	340
<b>8</b>	<b>Plates and Shells: Asymptotic Expansions and Hierarchic Models</b>	<b>199</b>	3	Variational Formulations	347
	<i>Monique Dauge/Erwan Faou/Zohar Yosibash</i>		4	The Galerkin-BEM	358
1	Introduction	199	5	The Role of Sobolev Index	366
2	Multiscale Expansions for Plates	202	6	Concluding Remarks	371
3	Hierarchical Models for Plates	207		Acknowledgments	371
4	Multiscale Expansions and Limiting Models for Shells	211		References	371
5	Hierarchical Models for Shells	218		Further Reading	373
6	Finite Element Methods in Thin Domains	219	<b>13</b>	<b>Coupling of Boundary Element Methods and Finite Element Methods</b>	<b>375</b>
	Acknowledgments	229		<i>Ernst P. Stephan</i>	
	Notes	229	1	Introduction	375
	References	229	2	Symmetric Coupling of Standard Finite Elements and Boundary Elements	377
	Further Reading	232	3	Fast Solvers for the hp-version of FE/BE Coupling	389
<b>9</b>	<b>Mixed Finite Element Methods</b>	<b>237</b>	4	Least Squares FE/BE Coupling Method	394
	<i>Ferdinando Auricchio/Franco Brezzi/Carlo Lovadina</i>		5	FE/BE Coupling for Interface Problems with Signorini Contact	396
1	Introduction	237	6	Applications	403
2	Formulations	238	7	Concluding Remarks	408
3	Stability of Saddle-Points in Finite Dimensions	246		References	409
4	Applications	257	<b>14</b>	<b>Arbitrary Lagrangian–Eulerian Methods</b>	<b>413</b>
5	Techniques for Proving the <i>Inf–Sup</i> Condition	269		<i>J. Donea/A. Huerta/J.-Ph. Ponthot/A. Rodríguez-Ferran</i>	
6	Related Chapters	276	1	Introduction	413
	References	276	2	Descriptions of Motion	415
<b>10</b>	<b>Meshfree Methods</b>	<b>279</b>	3	The Fundamental ALE Equation	417
	<i>Antonio Huerta/Ted Belytschko/Sonia Fernández-Méndez/Timon Rabczuk</i>		4	ALE Form of Conservation Equations	419
1	Introduction	279	5	Mesh-update Procedures	420
2	Approximation in Meshfree Methods	280	6	ALE Methods in Fluid Dynamics	422
3	Discretization of Partial Differential Equations	291	7	ALE Methods in Nonlinear Solid Mechanics	426
4	Radial Basis Functions	300		References	433
5	Discontinuities	300	<b>15</b>	<b>Finite Volume Methods: Foundation and Analysis</b>	<b>439</b>
6	Blending Meshfree Methods and Finite Elements	303		<i>Timothy Barth/Mario Ohlberger</i>	
	References	306	1	Introduction: Scalar Nonlinear Conservation Laws	439
<b>11</b>	<b>Discrete Element Methods</b>	<b>311</b>	2	Finite Volume (FV) Methods for Nonlinear Conservation Laws	442
	<i>Nenad Bićanić</i>		3	Higher-order Accurate FV Generalizations	450
1	Introduction	311	4	Further Advanced Topics	464
2	Basic Discrete Element Framework and Regularization of Nonsmooth Contact Conditions	314	5	Concluding Remarks	470
3	Characterization of Interacting Bodies and Contact Detection	317	6	Related Chapters	470
4	Imposition of Contact Constraints and Boundary Conditions	321		References	470
5	Modeling of Block Deformability	324	<b>16</b>	<b>Geometric Modeling of Complex Shapes and Engineering Artifacts</b>	<b>475</b>
6	Transition Continuum/Discontinuum, Fragmentation in Discrete Element Methods	329		<i>F.-E. Wolter/N. Peinecke/M. Reuter</i>	
7	Time Integration – Temporal Discretization, Energy Balance, and Discrete Element Implementation	331	1	Architecture of Modeling Systems	475
8	Associated Frameworks and Developments	333	2	Voxel Representation	476
	References	335	3	Surface Patches	477
	Further Reading	337	4	Boundary Representation	481
			5	Constructive Solid Geometry	483

6	Medial Modeling	485	9	Applications to the Boundary Element Method (BEM)	593
7	Attributes	490		References	595
8	Outlook and Concluding Remarks	492		Further Reading	595
	Acknowledgments	494			
	Notes	494			
	References	494			
<b>17</b>	<b>Mesh Generation and Mesh Adaptivity</b>	<b>497</b>	<b>21</b>	<b>Panel Clustering Techniques and Hierarchical Matrices for BEM and FEM</b>	<b>597</b>
	<i>P. L. George/H. Borouchaki/P. J. Frey/P. Laug/E. Saltel</i>			<i>Wolfgang Hackbusch</i>	
1	Introduction	497	1	Introduction	597
2	A Brief History	498	2	The Panel Clustering Method (First Version)	600
3	Mesh-Generation Methods	499	3	The Panel Clustering Method (Second Version)	606
4	Quality Meshing and Adaptivity	502	4	Hierarchical Matrices	607
5	Adaptive FEM Computations	510		References	615
6	Large-size Problem, Parallelism and Adaptivity	516	<b>22</b>	<b>Domain Decomposition Methods and Preconditioning</b>	<b>617</b>
7	Meshing for Moving Boundary Problems	517		<i>V. G. Korneev/U. Langer</i>	
8	Application Examples	519	1	Introduction	617
9	Conclusions	520	2	Domain Decomposition History	619
	References	521	3	Fundamentals of Schwarz's Methods	621
	Further Reading	523	4	Overlapping Domain Decomposition Methods	630
<b>18</b>	<b>Computational Visualization</b>	<b>525</b>	5	Nonoverlapping Domain Decomposition Methods	633
	<i>William J. Schroeder/Mark S. Shephard</i>			Acknowledgments	644
1	Introduction	525		References	644
2	Data Forms	528		Further Reading	647
3	Visualization Algorithms	531	<b>23</b>	<b>Nonlinear Systems and Bifurcations</b>	<b>649</b>
4	Volume Rendering	541		<i>Werner C. Rheinboldt</i>	
5	Methods in Large Data Visualization	542	1	Introduction	649
6	Taxonomy for Data Visualization Systems	543	2	General Iterative Processes	650
7	Interfacing the Computational System with the Visualization System	546	3	Some Classes of Iterative Methods	657
	References	548	4	Parameterized Systems	661
<b>19</b>	<b>Linear Algebraic Solvers and Eigenvalue Analysis</b>	<b>551</b>	5	Bifurcation	669
	<i>Henk A. van der Vorst</i>			References	673
1	Introduction	551	<b>24</b>	<b>Adaptive Computational Methods for Parabolic Problems</b>	<b>675</b>
2	Mathematical Preliminaries	551		<i>K. Eriksson/C. Johnson/A. Logg</i>	
3	Direct Methods for Linear Systems	553	1	What is a Parabolic Problem?	675
4	Preconditioning	560	2	Outline	676
5	Incomplete LU Factorizations	562	3	References to the Literature	676
6	Methods for the Complete Eigenproblem	567	4	Introduction to Adaptive Methods for IVPs	677
7	Iterative Methods for the Eigenproblem	571	5	Examples of Stiff IVPs	680
	Notes	574	6	A Nonstiff IVP: The Lorenz System	680
	References	575	7	Explicit Time-stepping for Stiff IVPs	683
<b>20</b>	<b>Multigrid Methods for FEM and BEM Applications</b>	<b>577</b>	8	Strong Stability Estimates for an Abstract Parabolic Model Problem	686
	<i>Wolfgang Hackbusch</i>		9	Adaptive Space-Time Galerkin Methods for the Heat Equation	689
1	General Remarks on Multigrid Methods	577	10	A Priori and A Posteriori Error Estimates for the Heat Equation	690
2	Two-Grid Iteration	581	11	Adaptive Methods/Algorithms	691
3	Multigrid Method	584	12	Reliability and Efficiency	691
4	Application to Finite Element Equations	586	13	Strong Stability Estimates for the Heat Equation	691
5	Additive Variant	589	14	A Priori Error Estimates for the $L_2$ - and Elliptic Projections	692
6	Nested Iteration	590	15	Proof of the A Priori Error Estimates	693
7	Nonlinear Equations	592	16	Proof of the A Posteriori Error Estimates	695
8	Eigenvalue Problems	593	17	Extension to Systems of Convection-Diffusion-reaction Problems	696

18	Examples of Reaction–Diffusion Problems	696	<b>26</b>	<b>Finite Element Methods for Maxwell Equations</b>	<b>723</b>
19	Comparison with the Standard Approach to Time Step Control for ODEs	699		<i>Leszek Demkowicz</i>	
20	Software	702	1	Maxwell Equations	723
	References	702	2	Variational Formulation	725
	Further Reading	702	3	Exact Sequences	727
<b>25</b>	<b>Time-dependent Problems with the Boundary Integral Equation Method</b>	<b>703</b>	4	Projection-based Interpolation. De Rham Diagram	732
	<i>Martin Costabel</i>		5	Additional Comments	734
1	Introduction	703	6	Related Chapters	735
2	Space-time Integral Equations	705		Acknowledgment	735
3	Laplace Transform Methods	713		Notes	735
4	Time-stepping Methods	714		References	736
	References	719		Further Reading	737
				<b>Contents for Volumes 2 and 3</b>	<b>739</b>
				<b>Subject Index</b>	<b>745</b>